PAPERmaking!

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PAPERmaking!

FROM THE PUBLISHERS OF PAPER TECHNOLOGY

Volume 2, Number 2, 2016

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The Paper Industry Technical Association (PITA) is an independent organisation which operates for the general benefit of its members – both individual and corporate – dedicated to promoting and improving the technical and scientific knowledge of those working in the UK pulp and paper industry. Formed in 1960, it serves the Industry, both manufacturers and suppliers, by providing a forum for members to meet and network; it organises visits, conferences and training seminars that cover all aspects of papermaking science. It also publishes the prestigious journal *Paper Technology* and the *PITA Annual Review*, both sent free to members, and a range of other technical publications which include conference proceedings and the acclaimed *Essential Guide to Aqueous Coating*.

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Initial wet web strength of paper

Jürgen Belle & Jürgen Odermatt

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REVIEW PAPER

Initial wet web strength of paper

Jürgen Belle · Jürgen Odermatt

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Abstract Despite much research into and development within the complex area of the initial wet web strength of paper, no complete model has yet been developed to describe this property. This type of paper strength is the most important property to ensure an effective paper machine run. Furthermore, the process of strength development in the sheet forming and pressing portion of the process is the basis of the final paper strength. Recent investigations have focused on the surface interactions of fibers on the molecular level. There have also been several innovative findings about fiber swelling and the impact of swelling on the mechanical characteristics of fibers in wet conditions. Overall, progress obtained using new methodologies enables a deeper understanding of the mechanism of strength development. This review discusses these important areas by examining the literature and the authors' own work to obtain a better understanding of the strength development in wet paper webs. This paper highlights that the fiber morphology and the dryness of the wet web have the greatest impact on the strength of the wet web. As fiber sources and machinery are fixed, the fiber water gel is one of the easiest factors to adjust via the process water quality and the use of chemical additives.

Keywords Capillary force · Dryness · Fiber water gel · Frictional connection · Measurement technique · Van der Waals force

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Introduction

There is a clear trend in the paper industry towards lower grammages and higher machine speeds to increase productivity while conserving resources and energy. Especially in packaging papers, there is a trend to decrease base weight from 110 to 130 g/m^2 down to 70 to 90 g/m^2 with machine speed up to 1900 m/min (Guldenberg and Schwarz 2004; Müller 2010). Most papers are manufactured on machinery with an open draw downstream of the forming and/or pressing section (Berger and Schramm 2011; Erhard and Kretschmer 2007; Schwarz and Bechtel 2003). Thus, the initial wet web strength (IWWS) is the utmost important factor for setting the paper in the first open draw, where the paper web is transferred without external support in the paper machine. As a result, the IWWS is the central parameter that controls the number of breaks at this point of the production process (Clark 1978c; Edvardsson and Uesaka 2009; Guldenberg and Schwarz 2004; Lindqvist et al. 2012;

Miettinen et al. 2009; Salminen 2010), thus determining productivity.

Against this background, it is critical for both scientists and practitioners to understand the effects of forces and conditions that can be influenced, leading to increased IWWS. This understanding is a prerequisite to be able to draw the correct conclusions regarding the development of new processes and additives.

Definition

The IWWS identifies the tensile energy absorption of a wet paper web during the production process. Generally, the designation "initial wet" spans a dryness level from approximately 10 % during web formation up to approx. 60 % in the first dryer. Until approximately 1960, research papers noted dryness levels of approximately 10 %. These values were measured downstream in the forming section or by laboratory web forming equipment. Today, depending on the construction of the forming section and the fibrous material, dryness levels of 18 % up to a maximum of 25 % are achieved.

In this context, it is important to consider the different interactions among interfaces during sheet formation (Fig. 1). Solids are dispersed in water at the headbox and on the wire in stage 1. At the end of the wire and in the pressing section, the water contains both, solids and air, with the air presenting another surface interaction to be considered in stage 2. Stage 3 starts in the press section. From here on, solids and water are in air. Due to these different interfaces and the interactions among solids, water and air, the relationships among these components have a critical impact on paper strength.

In accordance with ISO 3781, the wet strength of a specific paper type indicates the strength of a manufactured paper after remoistening, not to be confused with IWWS. In addition to the IWWS, the dry strength of paper has been extensively studied. As a rule, the term "dry strength" indicates the strength of paper after manufacturing with a dryness level of >85 %. The wet and dry strength of paper follow different rules and principles compared to the IWWS.

This literature review considers the IWWS of paper at dryness levels from approx. 10 to 60 %. This review explains the different behaviors of fibers and additives on paper strength properties, with a focus on the IWWS.

Calculation of IWWS

Page developed a specific function for IWWS based on his equation for the tensile strength of a dry sheet by including the effects of fiber length and coarseness (Page 1969, 1993). Shallhorn enhanced this equation by considering the effect of pressing load (Shallhorn 2002). This incorporates the fiber length and coarseness as fiber morphology parameters, as well as the surface tension of the solvent water. Shallhorn showed that this function is limited to the large-fiber fraction of softwood kraft pulps. When using this Eq. 1, it is important to bear in mind that fines and short fibers are not considered. But those fiber fractions have a great impact on the IWWS and are widely used in papermaking.

In addition, surfactants and web temperature clearly have a significant impact on the surface tension of the water and thus on the IWWS of the paper web.

Calculation of IWWS (Page 1993; Shallhorn 2002).

$$T_{IWWS} = \frac{0.37 * \pi\eta\gamma LW\left(RBA_{dry}\right)}{(Ct)} \tag{1}$$

T_{IWWS}: initial wet web tensile strength; η: friction coefficient between two wet fibers; γ: surface tension of water; L: fiber length; W: fiber width at moisture contents between 20 and 60 %; $RBA_{(dry)}$: Relatively Bonded Area (proportion of the fiber surface contained within a water meniscus); C: fiber coarseness; t: minor axis of the elliptical cross-section of the fiber.

Explanatory levels

To explain the IWWS, results from the reviewed literature is divided by scale and considered systematically at the molecular level (nanometer range), the fiber morphology (micrometer range) and the paper level (macro range). Figure 2 emphasizes the fact that these levels of explanation overlap. This figure shows that although the individual levels are studied separately, it is important to consider that they occur concomitantly, interacting with and influencing each other. These interactions are addressed in papers referenced in the individual chapters and in the section "Integral explanatory models".

As described in the previous paragraph, the strength properties of paper strongly depend on the dryness

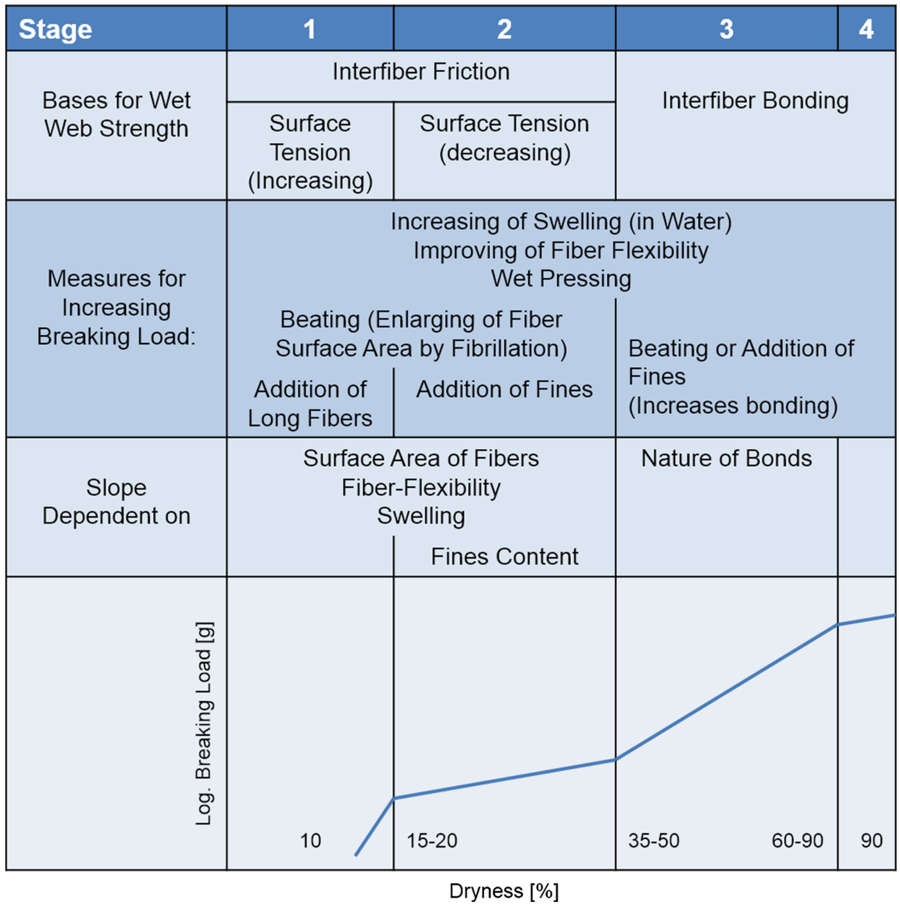


Fig. 1 Factors influencing the breaking load of paper according to Brecht and Erfurt (1959a, b)

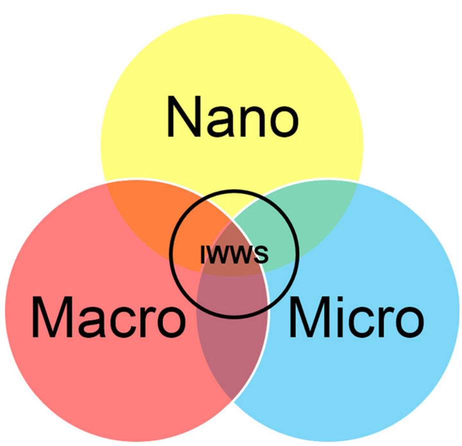


Fig. 2 Explanatory levels

level, and the IWWS is not an exception. Even in early papers from the last century, several authors noted that certain conditions are responsible for the strength within a sheet of paper at different dryness levels, such as flexible and smooth fibers that enable contact points between fibers (Brecht and Erfurt 1959a, b; Lyne and Gallay 1954a, b). After many years, various authors have begun working on these correlations again, addressing the factors affecting these forces such as capillary forces, van der Waals forces, and entanglement that leads to frictional connections (Hubbe 2006; Tejado and van de Ven 2010; Wågberg 2010; Wågberg and Annergren 1997).

It is well known that the dependence of strength on the dryness level is not linear, but over a certain range exponential. In addition, different forces of different magnitudes such as capillary and frictional forces do overlap at specific dryness levels, resulting in a force responsible for the paper strength in the first open draw.

Given this background, it is necessary to evaluate the measured strength values in relation to their respective dryness levels. The web dryness is influenced by the type of raw material, its composition, and additive usage during sheet formation, even though all mechanical settings for sheet formation and press operation are kept constant. For this reason, the evaluation of IWWS should be done at constant sheet dryness. The effect of changing sheet dryness should be evaluated separately.

Nanometer level (molecular scale)

The nanometer level describes the bonding forces such as electrostatic forces e.g. van der Waals forces. At this level, the approximation of the contacts and bonding forces between fibers and fibrils is the decisive factor. The following paragraphs present the forces and conditions affecting this bonding type according to their mechanistic priority.

If the distances between the solid particles are sufficiently small, electrostatic and van der Waals forces can develop (Israelachvili 2006b; Pelton 1993; Wågberg et al. 1987). Second, the theory of molecular fibrillation and partial solubility has been described (Campbell 1930, 1933; Casey 1960; Clark 1978a). To achieve the most accurate possible fiber and fibril approach, a high degree of fiber flexibility is required, which is significantly influenced by internal hydrogen bonds (Hubbe 2006; McKenzie 1984). External hydrogen bonds between fibers will only form during drying (Forgacs et al. 1957; Lobben 1976; Robertson 1959; Williams 1983). For this reason, external hydrogen bonds are not studied in detail in this paper.

Fiber water gel on the fiber surface

In 1963, Voyutskii proposed the formation of a hydrogel on macromolecules in "Autohesion and Adhesion of High Polymers" (Voyutskij 1963b). In additional papers, the bonds in wet sheets were explained based on a gel-like surface of the fiber (de Oliveira et al. 2008; Lindqvist et al. 2013; McKenzie 1984; Myllytie 2009).

In principle, the swelling of a gel can be determined by the energies summarized in Eq. 2 (Flory 1953; Katchalsky 1954; Yin et al. 1992):

ΔG_{elast}. elastic free energy of the gel; ΔG_{mix} free energy of mixing of the gel components and the swelling medium; $\Delta G_{electr.}$ electrostatic free energy

In equilibrium the total free energy is 0 and so the following equation is valid:

Total free energy in a gel: ΔG

$$\Delta G = G_{elast} + G_{mix} + G_{electr} = 0 \tag{2}$$

ΔG_{elast} counteracts the osmotic forces described by ΔG_{mix} and $\Delta G_{electr.}$. In the case of papermaking fibers it is determined by the constituents of the fiber wall and the arrangement of the different fiber wall layers. ΔG_{mix} is defined by the molecules in the network of the gel, molecular cellulose fibrils, and the solvent water. These mobile molecules form a mix with the polymer and the solvent. $\Delta G_{electr.}$ is specified by the charges within the gel that gives rise to the osmotic pressure. The status $\Delta G = 0$ might be valid before sheet forming and is therefore strongly depending of process water quality and used additives. Dewatering and the corresponding approach of the fibers and fibrils is responsible for interfering the fiber water gel and for the intermediate fiber–fiber bonds (Kibblewhite 1973; Wågberg and Annergren 1997).

Van der Waals forces

If fibers are in sufficient close proximity, van der Waals forces will occur between fibers and fibrils (Eriksson 2006; Hubbe 2006; McKenzie 1984; Pelton 2004; Wågberg and Annergren 1997; Williams 1983) . Figure 3 describes different forces on the surface of cellulose I, II and amorphous cellulose that may act also between the fiber and fibril surfaces.

However, this may not be applicable for initially wet paper due to the high water content and the greater distances between the single fibers (Linhart 2005). For interactions to occur, the distances between the fibers and/or fibrils must be very small. The distances described in the literature are between 0.15 and 0.35 nm (Gardner et al. 2008; Linhart 2005). Remarkably, these distances are considerably smaller than the fiber roughness, which ranges between 10 and 10,000 nm (Heinemann et al. 2011). Figure 4 shows an example of an uneven fiber surface of a common never dried softwood fiber.

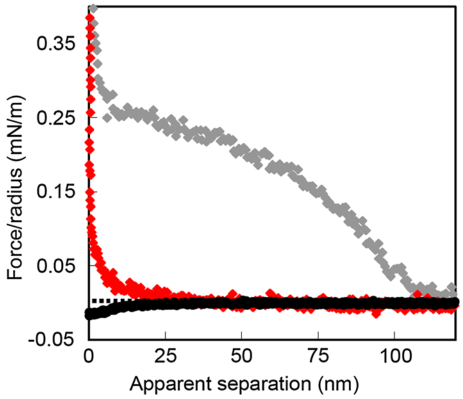


Fig. 3 "Comparison of the interaction force-distance curves between a cellulose sphere and the cellulose I, II and amorphous cellulose surfaces at pH 3.5 and in 0.1 mM aqueous NaCl solution. The interaction with the cellulose I sample (*red*) is characterized by an electrostatic repulsion, while van der Waals forces and steric interactions predominate with the cellulose II sample (*black*) and amorphous cellulose sample (*grey*), respectively" [Reprinted with permission of Eriksson (2006)]

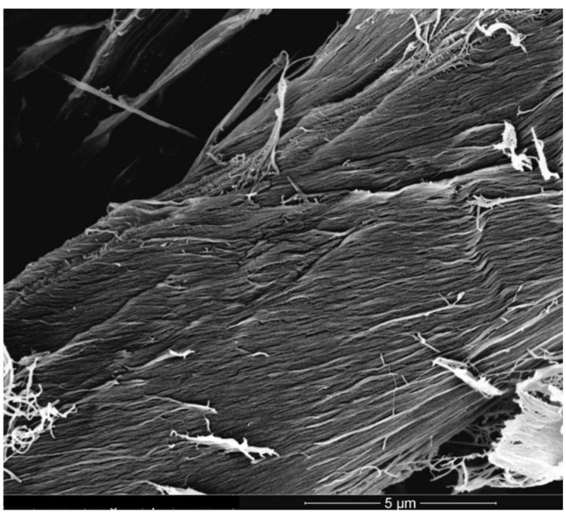


Fig. 4 Uneven fiber surface of a never dried unrefined Nordic bleached softwood kraft (NBSK) fiber in a paper sheet at 20 % dryness

However, if instead of considering the fiber as a smooth, well-formed unit, its actual shape is considered with numerous micro and macro fibrils, especially if it is refined, the formation of van der Waals forces is quite conceivable. In the middle of the image in Fig. 5, two beaten fibers arranged in parallel are bound via fibril bundles from the S1 layer. These fibrils bridge the gap due to interactions between fibers and fibrils.

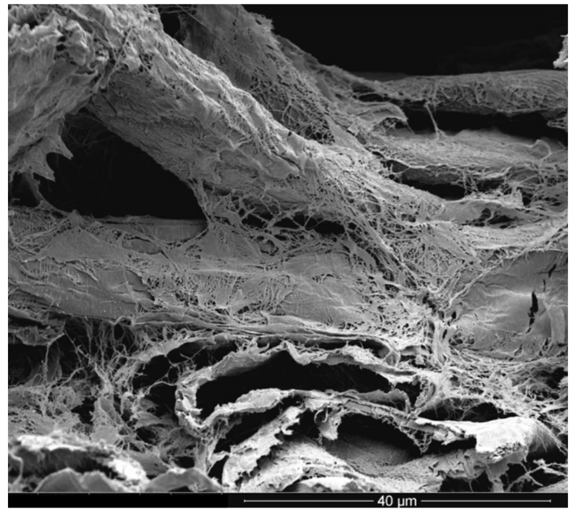


Fig. 5 Fiber–fiber interactions of refined NBSK (SR 30) fibers in a paper sheet at 45 % dryness

Electrostatic forces

A share of the strength developed at low dryness levels may be attributed to acid/base interactions (Gardner et al. 2008; Lindström 1980; Wågberg and Annergren 1997; Williams 1983). As a general rule, carboxyl groups and/or sulfonic acid groups are fixed at lignocellulosic fibers (Sjöström 1989). Therefore, the influence of metallic ions in aqueous solutions must be taken into account. The micro and macro fibrils of the fibers react similarly to polyelectrolytes (Caseri 2009). In water with low conductivity, dispersed fines and fibrils stretch into the surrounding water. High conductivity levels force the fibrils to retract from the surrounding suspension onto the attachment points on the fibers. Both parameters, pH and salt content, have a direct influence on the electrostatic potential and swelling behavior of the fibers. Because of that, these parameters have an indirect effect on the strength formation in both, wet and dry paper (Grignon and Scallan 1980; Nelson and Kalkipsakis 1964a, b; Scallan 1983; Scallan and Grignon 1979). These phenomena can be explained with DLVO theory, named after Derjaguin, Landau, Vervey and Overbeek (Derjaguin 1954; Derjaguin and Landau 1941; Israelachvili 2006b; Pelton 1993; Vervey and Overbeek

1948). The type and amount of salt added to the solvent water has a negative impact on IWWS, similar to the findings of Grignon for dry paper (Belle et al. 2014a; Grignon and Scallan 1980).

Fiber surface

The hypothesis of "dissolved fiber surfaces" was developed in the middle of the twentieth century. This hypothesis assumes that the surfaces of the cellulose fibers partially solute in water and diffuse into each other during sheet formation (Campbell 1930; Casey 1960; Clark 1978a). This approach was later expanded with the explanation that the reduced end groups of the cellulose form a kind of molecular fibrillations that are solvated or partially soluted in water. As a result, the molecular fibrillation rise up, leading to improved availability for bond formation (Clark 1978a). The assumption is that the wetted fiber is surrounded by water and the fibers and fibrils approaching each other during dewatering to such an extent that at first van der Walls bonds and with further drying hydrogen bonds can form. In this regard, Clarks' theory emphasizes the high bonding capacity of hemicelluloses. For materials with a high percentage of hemicelluloses, there is a relatively high proportion of short molecules, which are more active in bond formation than large molecules when present in an easily accessible, upright state (Clark 1978b). McKenzie developed an additional model based on the adhesion between two plasticized surfaces in respect to Voyutskij's theory about autohesion and adhesion for high polymers (McKenzie 1984; Voyutskij 1963a). It is assumed that in the intermediate area of two fibers in a plastic state, the micro and macro fibrils are close enough to form molecular alignments (Pelton et al. 2000). Neumans surface force measurements are consistent to these hypothesis and lead to the schematic representation of "dangling tails" on the fiber surface in Fig. 6 that have a length about 60–80 nm (Neuman 1993).

Internal hydrogen bonds

Internal hydrogen bonds (H-bonds) play a key role with regard to the intermolecular forces within the cellulose. On the one hand the intermolecular H-bonds bind the cellulose chains together and contributes to the lateral strength of the fiber, on the other hand the intramolecular H-bonds contributes to the axial stiffness of the cellulose molecules. These bonds are weakened by the adsorption of water and results in swelling of the fibers (Linhart 2005). The correlation between the Young's modulus of the fibers and their internal hydrogen bonds is described in detail in the literature (Nissan and Batten 1990; Zauscher et al. 1996, 1997). However, these papers mainly focus on correlations to dry paper. Furthermore, the strong influence of water on the fiber–fiber bonds in paper (Hubbe 2006; McKenzie 1984) has led to a thermodynamic examination of fiber–fiber bond formation (Wågberg 2010).

Measurement techniques

Various technologies have been used to characterize surfaces and measure surface forces at the nanometer level, such as atomic force microscopy (AFM) (Gustafsson et al. 2003; Huang et al. 2009; Koljonen et al. 2003; Leporatti et al. 2005; Paananen 2007; Stenius and Koljonen 2008) and scanning electron microscopy (SEM) (Belle et al. 2015a, 2016; Heinemann et al. 2011; Pye et al. 1965; Tejado and van de Ven 2010; Washburn and Buchanan 1964). These results must be evaluated taking into account the fact that the AFM is in contact with the scanned surface. As a result, AFM can disturb the sensitive fiber surface. In contrast, the SEM has limited resolution when imaging wet samples due to the vacuum required for

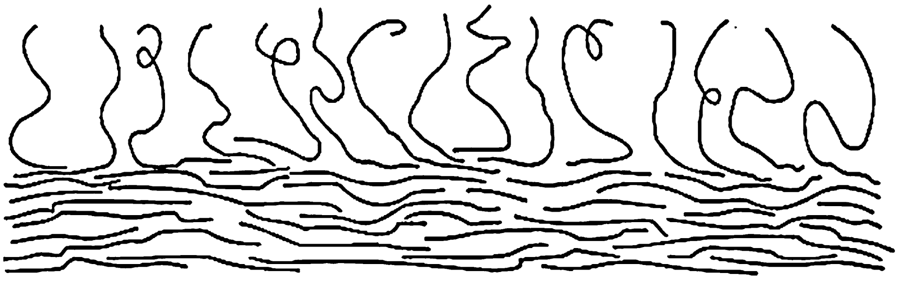


Fig. 6 Outline of Neuman's dangling tail model (Neuman 1993); (Reprinted with permission of The Pulp and Paper Fundamental Research Society)

operation. Sample preparation by freeze-drying and freeze fracturing can remedy this problem for certain resolutions (Belle et al. 2015a, 2016; Pye et al. 1965; Washburn and Buchanan 1964). Thomson used the fluorescence resonance energy transfer method to examine cellulose surfaces (Thomson 2007), which in future may be an additional option for the determination of phenomena occurring on the fiber surface.

These methods enable the visualization of even the smallest changes on fiber surfaces. Whether and to what extent the nanometer scale fiber surfaces have a direct and verifiable influence on the IWWS will only become evident when the two other size ranges are considered, the micrometer and macro scale because of the strong interactions among all three levels.

Micrometer level (fiber morphology)

At the micrometer level, processes between fibers, fillers and additives are studied more closely. First, the interaction between fibers and water is explained by capillary forces and the processes of swelling, gel formation in the proximity of fibers, and hornification. Subsequently, the influence of the fiber characteristics on the IWWS is discussed, including the surface roughness and the complex fiber morphology comprising fiber fractures, fibrils and fines particles. This discussion includes both, the beating and blending of fibrous materials and the measurement techniques used to assess the fiber characteristics.

Capillary forces

Besides drainage pressure and suction in the wire section the capillary forces are acting for the fiber and fibril approach, and as a result are a major factor affecting the IWWS in the early stages of paper dewatering (Campbell 1933; Israelachvili 2006a; Kendall 2001b; Page 1993; Persson et al. 2013; Rance 1980; Schubert 1982; van de Ven 2008; Williams 1983). The capillarity describes the properties of liquids in narrow spaces. Equation 3 shows the formula for the capillarity:

Capillarity

$$h = \frac{2\gamma \cos\theta}{\rho g r} \tag{3}$$

h: height of a liquid column; γ: surface tension liquid-fiber surface; θ: contact angle of water with fiber surface; ρ: density of liquid; g: gravity; r: radius of capillary

The formula shows that as "r" decreases, the capillarity increases. In practice, this relationship can be simplified as displayed in Eq. 4, highlighting the fact that capillary forces are mainly controlled by the thickness of the water film (Lyne and Gallay 1954a, b).

Simplified calculation of capillary forces

$$F_C \sim \frac{1}{D} \tag{4}$$

F_C: capillary force; D: water film thickness between two fibers

The applicability of this theory can be observed during sheet forming. As during the dewatering process the gross of the sheet volume is removed in terms of water, the distances between the fibers decrease, resulting in lower water film thickness, and thus in increasing capillary forces. The resulting capillary force increases. The idealistic model representation of fibers as two cylinders that approach each other during the dewatering process states that the greater the amount of water removed, the closer the fibers come to each other, increasing capillary forces and holding the fibers together (Wågberg and Annergren 1997). Lyne and Gallay showed this in trials with glass fibers (Lyne and Gallay 1954b). However, this model assumes rigid, smooth bodies, and therefore is only a rough approximation of the true phenomenon (Wågberg 2010). This is because fibers have a certain morphology, are flexible, present in various deformed or swollen states, and are very coarse, especially in wet conditions (Belle et al. 2015a; Feiler et al. 2007; Heinemann et al. 2011).

Calculations based on the capillary theory showed lower values than one order of magnitude compared to measured values (Miettinen et al. 2007; Tejado and van de Ven 2010). This shows that besides the capillary force other forces interact and contribute to the IWWS. It is proposed that especially the conformability of the fibers in the network leads to frictional connection that contributes significantly to the IWWS.

Fiber swelling

The "fiber saturation point" (FSP) has been used to characterize the water adsorption and swelling properties (Christensen and Giertz 1965; Scallan and Tigerström 1992; Scallan 1977; Stone and Scallan 1967; Tejado and van de Ven 2010; van de Ven 2008). An additional method of determining the swelling state is to measure the water retention value (Höpner et al. 1955; Thode et al. 1960; Zellcheming 1957). Scallan and Tigerström used the van't Hoff equation to calculate the bulk modulus of the fiber wall shown in Eq. 5 supposing "that the hydrogen form of the charged groups of the fibers can be taken as a reference state" (Wågberg and Annergren 1997).

Bulk modulus "K" of the fiber wall (Scallan and Tigerström 1992)

$$K = \frac{RT\left(\frac{n}{V}\right)}{\frac{(V-V_0)}{(V_C+V_0)}} \quad (5)$$

In this equation the $RT\left(\frac{n}{V}\right)$ is the osmotic pressure in the fiber wall.

R: gas constant; T: absolute temperature; n: mole of charged groups per kg oven dried pulp; V: Volume of water in the swollen fiber wall; V_0: Volume of water in the fiber wall when the charged groups are in their hydrogen form; V_C: specific volume of the material in the fiber wall assuming the density to be 1.5×10^3 kg/m^3.

The swelling contributes to the fibers' flexibility, resulting in considerably better entanglement (Barzyk et al. 1997; Brecht 1947; Brecht and Erfurt 1959b; Erhard et al. 2010; Linhart 2005; Lyne and Gallay 1954a, b; Scallan 1983; Weise et al. 1998). The degree of beating enhances or lessens this effect (Brecht and Erfurt 1959b; Kibblewhite 1973; Lindqvist et al. 2011; Salminen 2010). All authors cited above conclude that proper swelling increases the dry strength of the paper. This means that conditions such as beating, alkaline pH and low conductivity contribute to a strong dry paper. There has been done only few research in case of IWWS.

Hornification

Drying and pressing introduces an irreversible change in lignocellulosic fibers resulting in a loss of swelling ability of fibers that is also named hornification (Fernandes Diniz et al. 2004; Pönni et al. 2012; Reeves 1991; Weise 1998; Young 1986). The process of hornification has been divided by Weise (1998) into two different phenomena, called wet and dry hornification. The wet hornification process is defined in a range of 40–70 % dryness and describes the removal of free water from fiber lumen and fiber surface without or with pressing of the wet web. This causes cell wall collapse and pore closure. Thanks to morphological restrains of the fiber cell wall this process stops at a certain point. This kind of hornification is mostly reversible if the fibers are rewetted. Further drying of the wet web results in dry hornification (Bawden and Kibblewhite 1997; De Ruvo and Htun 1981; Laivins and Scallan 1993; Weise 1998), the type of hornification this paper refers to. Depending on the drying temperature this hornification is only partly reversible by mechanical energy or chemical use. The reaction of hydroxyl and carboxyl groups to H-bonds and/or lactone bridge formation in closed pores and collapsed fibers is still under discussion (Fernandes Diniz et al. 2004; Lindström 1986; Lindström and Carlsson 1982; Wang 2006).

The degree of hornification can be measured as the reduction in the water retention value (WRV) (Jayme 1944, 1958). Jayme suggested to calculate the degree of hornification in Eq. 6:

Degree of hornification according to Jayme (1944)

$$Hornification = \frac{WRV_0 - WRV_1}{WRV_0} \times 100\,[\%] \quad (6)$$

WRV_0: initial WRV; WRV_1: WRV of hornificated sample

Hornification as a result of drying leads to better dewatering, decreased fiber flexibility and stiffer fibers as well as to a decrease in the dry strength of paper (Lindström and Carlsson 1982; Röder and Sixta 2004; Weise 1998).

Experiments comparing never-dried with dried unbleached, unbeaten spruce sulfite pulp show that hornification leads to a decrease in strength at any dryness level (Brecht and Erfurt 1959b). Own studies with commercial bleached softwood sulfite pulp demonstrate that hornification has a significant negative impact on the strength values at dryness levels greater than 25 % (Belle et al. 2014a). Below 25 % dryness there is a slightly positive effect. The differences in the results can be explained by the higher accuracy of the DIN 54514 method (see also "Macro level—Measurement techniques").

In experiments about the effect of freezing on pulp properties, Kibblewhite determined that the IWWS decreases as the drying rate increases (Kibblewhite 1980). Similar to other research work, this study argues that the increased fiber rigidity/hornification leads to a reduction in bonding intensity. Adapting the sample preparation process enables the investigation of fiber surface effects and the hornification, characterized by comparing the fiber collapse of conventionally dried samples with freeze-dried samples by means of SEM imaging (Belle et al. 2015a). This study shows that in comparison to conventional drying, freeze-drying leads to significantly reduced fiber, fibril and surface hornification.

Dependent on dryness, hornification affects the IWWS in several ways. Below 25 % dryness, hornificated fibers are stiffer with a lower young-modulus (Scallan and Tigerström 1992), higher friction coefficients and flatter shapes. This leads to denser sheets with better conditions for capillary forces and frictional connection. From 25 % dryness onwards a non-hornificated fiber is needed for better IWWS. Higher young-modulus and a flexible fiber results in better conformability and more initial contact points as well as a better entanglement.

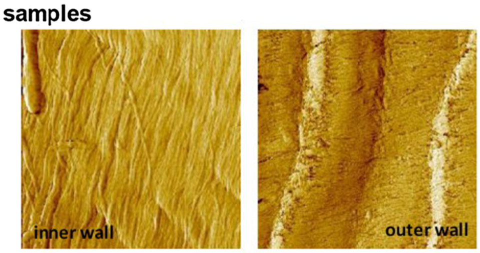
Surface roughness of the fibers

The surface roughness of the fibers is given by the type of wood and is modulated to a significant degree by the pulping process (Fengel and Wegener 1989). Additionally, the fiber surface roughness is specifically influenced by pulp beating and the associated generation of fiber fragments and suspended fibrils. The surface roughness of the individual fibers and the associated fiber–fiber adhesion play an important role in regard to the strength in the wet paper web because they affect the capillary forces during dewatering (Alince et al. 2006; Hubbe 2006; Thomson 2007). Fiber pore sizes also play an important role (Erhard et al. 2010; Scallan and Tigerström 1992; Scallan 1977). However, only a few values for fiber surface structure and roughness were available. Additional values can now be generated by the AFM method published in 2011 describing the scanning of fiber surfaces, including the calculation of the surface roughness and fibril angle of fibers shown in Fig. 7 (Heinemann et al. 2011).

A REF samples

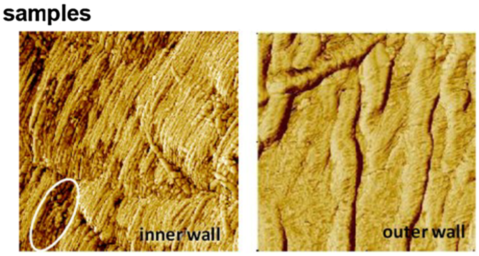
Fibril angle, °	20	87
S_q, nm	14.2	45.3
S_{ku}	4.49	2.28
S_{sk}	0.26	0.10

B OX samples



Fibril angle, °	12	69
S_q, nm	21.6	54.4
S_{ku}	3.96	2.69
S_{sk}	-0.41	-0.07

C AC samples



Fibril angle, °	25	76
S_q, nm	23.6	26.7
S_{ku}	4.38	2.91
S_{sk}	-0.78	0.13

Fig. 7 "AFM phase images and corresponding fibril angle and surface roughness parameters for each individual image representing the inner (S2) and outer (ML/P) fiber wall layers… The images are 3 μm × 3 μm". [Reprinted with permission of Heinemann et al. (2011)]

S_q: RSM (root-mean-squared) roughness; S_{ku}: kurtosis; S_{sk}: skewness; REF: Reference; OX: chemical treatment of the sample with buffered oxalic acid dihydrate; AC: chemical treatment of the sample with hydrochloric acid

SEM studies by the author show a very large irregularity of the fiber surface of industrially manufactured pulp, caused by fragments of the S1 and S2 fiber wall (Belle et al. 2015a).

Fiber morphology

The fiber morphology is related to the fiber structure. These are primarily given by the wood and pulping type, as well as by beating. In addition to the fiber length, additional fiber characteristics can be calculated by means of image analysis procedures. Generally, when describing fibrous suspensions, the following terminology is used: fiber length, fiber width, kink, curl, coarseness, fibrils, fines and broken fibers (Page et al. 1985; Saren et al. 2013; Weihs and Wätzig 2007).

Studies of unbleached pine sulfate pulp have shown that an increase in fiber length contributes to the IWWS (Seth 1995). This paper further demonstrates that an increase in fiber coarseness will decrease the IWWS. Another investigation on various recovered paper fibers about the influence of beating show that the strength index can be increased from 2.5 to 3.3 Nm/g at a dryness level of 50 % (Klein 2007). After the fiber analysis, Klein attributes the increase in strength to the larger specific surface of the fiber material after the beating process. Thus, a certain extent of beating can increase the IWWS due to the higher portion of fines and the creation of additional surface area on the fibers.

The curl determines the maximum elongation of the paper up to breakage, and can therefore be a direct indicator of the stability of the paper web in the first open draw (Brecht and Erfurt 1959a; Rance 1954). The more pronounced the curl is, the more the fibers can be elongated under tensile load before the fiber structure breaks (Seth et al. 1984; Tejado and van de Ven 2010).

Beating

Many publications have studied the development of paper strength by beating, but only a small number of these studies have focused on the influence of beating on the IWWS (Belle et al. 2016; Bhardwaj et al. 2000; Brecht and Erfurt 1959a; da Silva et al. 1982; Gurnagul and Seth 1997; Kibblewhite and Brookes 1975; Koskenhely et al. 2011; Lindqvist et al. 2011; Robertson 1959). In general, the beating of fibers is a non-specific process during which both the fiber morphology and the particle size distribution are modified in many respects (Banavath et al. 2011; Laitinen et al. 2014). Beating is partly able to reverse hornification and results in better fiber swelling, even with virgin fibers, with all the positive effects on IWWS. The mechanical energy put into the process affects the internal and external fibrillation and enables more contact points for van der Waals bonds in the wet state and more H-bonds in dry state. The change in fiber morphology can be measured as fiber length, coarseness, fines and some other values. For calculation the IWWS as shown by Page (1993) and Shallhorn (2002) only fiber length and coarseness are significant values.

In summary, beating has a strong influence on the fibrous material blend and the fiber morphology, which in turn have a decisive impact on the IWWS.

Fibrils and fines

Fines are in general defined as particle that passes the 100 or 200 mesh wire of e.g. a Bauer McNett fiber classifier and consist of cellulose, hemicelluloses, lignin and extractives (Retulainen et al. 1999). As a rule 0.2 mm is the size that is considered as fines in optical fiber analyzers. Several scientist, amongst others, worked on the topic of using or generating fibrils and fines to enhance the IWWS of paper (Brecht and Erfurt 1959b; Corson and Lobben 1980; Lindqvist 2013; Myllytie et al. 2009; Pye et al. 1965; Retulainen and Salminen 2009; Salminen 2010; Washburn and Buchanan 1964). Fibrils and fibrillar fines are supposed to increase the IWWS by better conformability that leads to improved frictional connection. Salminen (2010) reported that wet web tensile is dependent on quality and amount of fines. An "addition of heavily refined kraft pulp with a high amount of fines to wood containing paper grades could increase the residual tension of wet web significantly…" (Salminen 2010). Lindqvist worked with a harsh and a gently refining strategies (Lindqvist 2013). Pulp that was gently refined generated fines without decreasing the fiber length. The resulting fibers were more flexible and lead to increased wet tensile strength and residual tension. It is concluded that the internal and external fibrillation are critical for the residual tension. The movement of the fibrils and fines during sheet forming

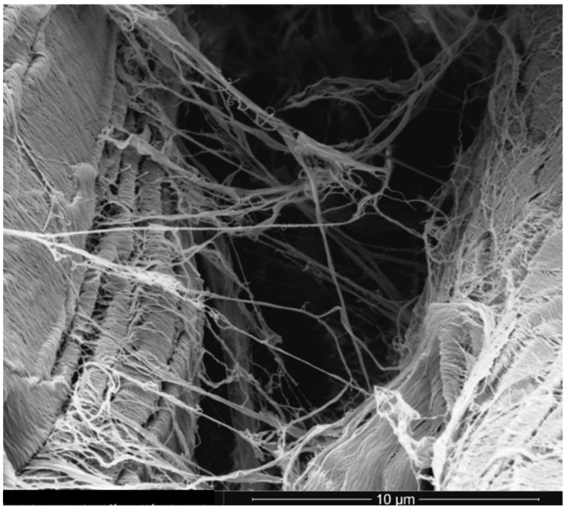


Fig. 8 Fibrils between two unrefined fibers at 20 % dryness

is determined by the amount of water in the proximity of the fiber and by the elastic modulus that is in the range of 2–15 MPa for fibers (Myllytie 2009; Nilsson et al. 2001; Scallan and Tigerström 1992). The SEM image performed by the authors in Fig. 8 shows the space between two fibers that is bridged by fibrils (Belle et al. 2015a). The conductivity of the solvent water was below 1 µS/cm, with the result that the fibrils of the fibers were able to move freely in the surrounding water, making contact and bonding with the next fibrils.

To facilitate the scientific study of the influence of individual fibrous material components on strength development, a selective approach of using enzymes to reduce the presence of micro and macro fibrils could be useful (Teeri 1997).

Fibrous material blends

The blending of fibrous material components is another possible approach to increase the IWWS. Several authors have shown that a fiber component blend of long fiber, short fiber, flour and mucilaginous substances from groundwood pulp production mainly leads to a higher IWWS compared to the values of the individual components (Back and Andersson 1993; Brecht and Erfurt 1961; Brecht and Klemm 1952). Towards the end of the 1950s, trials have shown (Brecht and Erfurt 1959a) that blending different softwood pulp fractions has an impact on IWWS. These trials show, that the addition of up to 70 % of a beaten pulp fraction results in higher IWWS values. Similar experiments show that a specific blend of refined softwood and ground wood pulp results in a higher IWWS compared with the individual components (Schwarz and Bechtel 2003). This results show that different fiber components have complementary properties that are needed for a good IWWS. The studies reviewed here demonstrate that in each individual case, an optimal fibrous material blend can be found based on chemical and physical principles.

Measurement techniques

The sheet strength comprises the strength values of the individual components of the sheet as well as the strength of the interactions between those components. A variety of methods are available to measure the strengths of individual fibers and of the interactions between fibers. One method involves sample preparation with drops of resin to fix the fibers (Groom et al. 2002; Yu et al. 2010) followed by measurement with special equipment. However, this method is very time consuming. A variety of other approaches have been developed to investigate fiber properties, including the "Zero Span Method" (Burgert et al. 2003; Derbyshire et al. 1996; Futo 1969; Malhaire et al. 2009; Michon et al. 1994; Saketi and Kallio 2011; Saketi et al. 2013). Until now, these measurements have mainly been used in wood research. Meanwhile, the latest measurement techniques enable fibers to be pulled from the fiber network to determine the strength with which it is anchored to the sheet structure (Saketi and Kallio 2011). Another possibility to get a deeper look inside the paper structure is the X-ray synchrotron radiation tomography (Latil et al. 2010; Marulier et al. 2012, 2015; Wernersson et al. 2014). This technique enables researcher to get a 3D-image from the fiber network that might help in the future to get more valid information about fiber contact points and their bonding mechanism.

Macro level (sheet level)

The macro level analysis below addresses a number of aspects. First, an overview of the optimization options including chemical additives and adjustments in the forming and press section of a paper machine will be presented. This is followed by an overview of computer simulations to predict IWWS. This section concludes with a summary of the measurement techniques to determine the strength of wet paper webs.

Chemical additives

Many paper additives derived from renewable and conventional resources have been developed and tested in recent years. The most popular additive for strength enhancement is starch. The cationic starch manly used for dry strength improvement is not able to increase IWWS of paper, it works quite contrary. This results in a decreased residual tension of about 10 to 15 % at 50 % dryness (Hamzeh et al. 2013; Laleg et al. 1991; Retulainen and Salminen 2009; Salminen 2010). Figure 9 shows this strength loss described in a paper from Retulainen and Salminen 2009. The decrease is explained by steric and electrosteric repulsion that reduces the friction force between the fibers.

As Fig. 9 also shows, with cationic aldehyde starch there is a strength improvement possible at dryness above 45 %. Laleg and Pikulik came some years before to a similar result (Laleg and Pikulik 1991, 1993a). In contrast to the cationic starch, the cationic aldehyde starch is proposed to form a kind of cross linking in the fiber network "with hemiacetal bonds formed between the aldehyde groups of starch and the hydroxyl groups of cellulose" (Pikulik 1997).

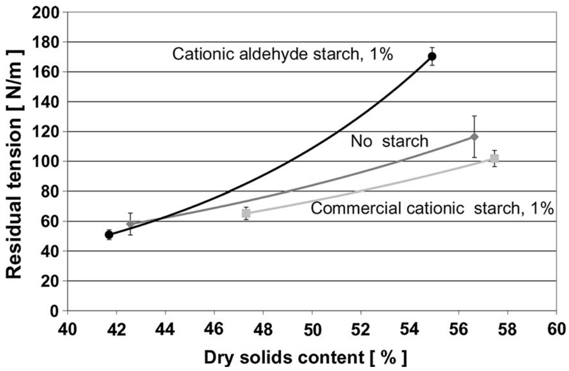


Fig. 9 The effect of two different starches on residual tension of wet web at 2 % strain (Retulainen and Salminen 2009); (Reprinted with permission of The Pulp and Paper Fundamental Research Society)

CMC is also an additive that is used for strength improvement. Even for wet web it improves the strength in a range of 20–25 % at 50 % dryness (Klein 2007; Myllytie 2009). This might be explained with the more uniform paper by reduced flocculation tendency that results in stronger wet webs (Linhart et al. 1987; Nazhad et al. 2000).

Even a very expensive resource like chitosan is an object of research to improve IWWS. Different researchers got strength improvements > 30 % at dryness between 30 and 55 % (Hamzeh et al. 2013; Klein 2007; Laleg and Pikulik 1992, 1993b; Myllytie 2009; Pikulik 1997; Salminen 2010). The structural similarity with the 1,4-glycosidic bonds are responsible for the adsorption capacity of Chitosan onto Cellulose (Klein 2007). Especially for mechanical pulp the strength improvement is attributed to crosslinking "the fibrous network via imino bonds formed between the primary amino groups of the polymer and the aldehyde groups present in mechanical pulp" (Pikulik 1997).

Guar gum has also been used to improve the IWWS (Myllytie 2009; Weigl et al. 2004). Weigl et al. (2004) were able to improve the strength of about 20 % at a dryness of 30 % with 0,5 % dosage of cationic guar to a pulp for LWC paper production. The effect of guar is attributed to the hydrophilic character, the cationically and uniform charge of the polymer.

Galactoglucomannan (GGM) as a by-product of softwood pulping was recently tested by Lindqvist in 2013. She was able to increase the strength with 3,5 % GGM of about 10 % at 45 % dryness. She used bleached kraft pulp for the laboratory sheets. The GGM is supposed to disperse the fibrils on the fiber that they are more outstretched. In this way, they are able to interact with other fibrils and develop the contact points for web strength (Lindqvist 2013; Lindqvist et al. 2013).

Besides these renewable additives, there exist several conventional chemicals that are used in paper making. One kind of these are surface active chemicals. They are mainly used for stabilizing the paper making process but they influence also the paper strength. For an optimal dosage it has been found that the dewatering of the sheet was improved and the dryness and thereby the IWWS at same process conditions increased (Lindqvist 2013; Retulainen and Salminen 2009). By using oleic acid and defoamer a slight decrease of IWWS was observed (Retulainen and Salminen 2009). These chemicals might interfere the fiber water gel and this results in less contact points between the fibrils.

Another research group developed vinylformamide copolymers to increase the IWWS (Esser et al. 2008; Gels et al. 2012). The presented results are from paper machines and it is proposed that less breaks in the first open draw are a reference for better IWWS.

Various cationic polyacylamides are used to improve dry strength of paper. Despite good results in dry paper, a decrease in IWWS is observed (Alince et al. 2006). The explanation for these phenomena is the steric and electrostatic repulsion of fully polyacrylamide coated fibers. This results in increased distances between fibers with less friction force in the wet web. If the dosage is "below full coverage, fiber flocculation occurs resulting in weak spots in the wet sheet" (Alince et al. 2006).

A selective addition of different additives is a good option for improving IWWS. Salminen added a cationic polyacrylamide (C-PAM) to the short fiber fraction and a cationic starch to the long fiber before mixing them. He observed good results in dewatering and IWWS. The positive effects are explained by the prevented flocculation of the long fibers due to adding the C-PAM to the short fibers including better retention of fines and better sheet formation. In addition it is supposed that "selective addition of chemicals generated pulp with both cationic and anionic surfaces, thus leading to a greater quantity of molecular level interactions" (Salminen 2010). Several other authors got also good results with selective addition of anionic and cationic polyacrylamides (Sutman 2011), microfibrillated cellulose together with anionic and cationic polyethyleneimine (Szeiffova and Alince 2003), as well as chitosan, cationic starch and polyvinyl alcohol (Hamzeh et al. 2013).

Furthermore the spraying technique in the wet end of the paper machine is rediscovered in several recent publications (Oksanen et al. 2011, 2012; Retulainen and Salminen 2009; Salminen 2010). This technology has the advantage that there are almost no interactions between water contaminants and the used additives as well as a very good chemical retention on the web. The dryness of the web is usually >45 % and good results were achieved with CMC (Salminen 2010), Chitosan (Salminen 2010), Guar (Oksanen et al. 2011), Xyloglucan (Oksanen et al. 2011, 2012) and polyvinyl alcohol (Retulainen and Salminen 2009; Salminen 2010). One disadvantage might be the contamination of the felts in the press section with residues of these additives.

In general, while chemical additives can improve the IWWS, their effects are minor compared to those of fiber morphology and dryness. Additionally, most of these additives are hydrophilic (Pelton 2004), with the result that the achievable dryness under given process conditions will be lower, thus limiting the IWWS.

Sheet forming

Studies performed on paper machine forming sections usually emphasize the dewatering speed, retention and web formation. In addition to studies that describe the influence of beating on dewatering and strength (Berger and Schramm 2011; da Silva et al. 1982; Kibblewhite 1973; Lindqvist 2013; Lindqvist et al. 2011, 2012; Lindström and Kolman 1982; Pikulik 1997), there is an extensive body of research papers on dewatering chemicals and the use of mineral fillers (Alince et al. 2006; de Oliveira et al. 2009; Esser et al. 2008; Gärdlund et al. 2003; Hua et al. 2011; Lindqvist et al. 2009; Pikulik 2000; Sutman 2011; Szeiffova and Alince 2003).

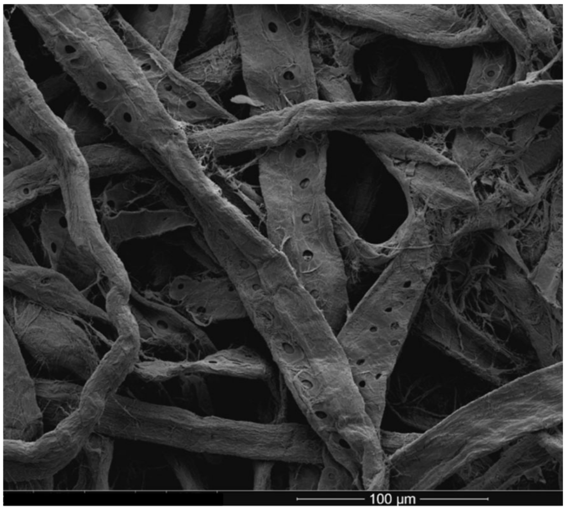


Fig. 10 Sheet structure of unbeaten softwood pulp at SR 12 and 20 % dryness

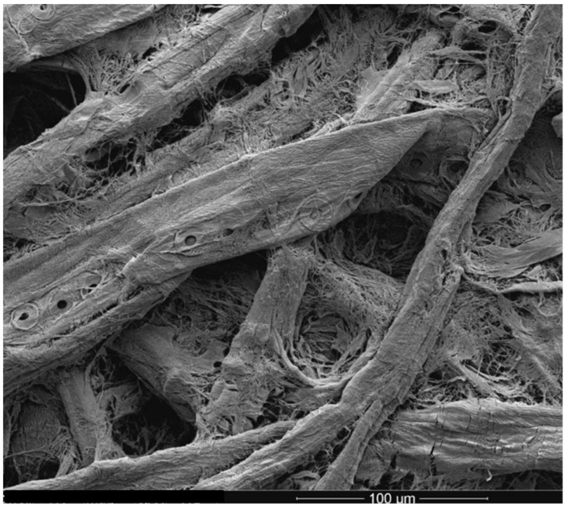


Fig. 11 Sheet structure of beaten softwood pulp at SR 30 and 20 % dryness

Furthermore, the sheet structure and the fiber orientation is largely determined by the condition in the headbox and forming section. The structure in the three dimensions x, y, and z have a major impact on the size of bonds, their distribution in the network and the conformability. This develops frictional connections and entanglement (Ora 2012; Ora and Maloney 2013; Salminen 2010). Figures 10 and 11 show the sheet structure at 20 % dryness for unbeaten and beaten softwood pulp, respectively. Even these laboratory sheets show the entanglement of the fibers at this stage of dewatering that leads to the frictional connections and entanglement.

Sheet forming is a crucial step in the papermaking process. In this regard the jet to wire ratio has also an important effect on IWWS, because with this parameter the fiber orientation in-or cross machine direction (MD/CD) is adjusted. Increased fiber orientation results in higher MD tensile in wet webs (Kouko et al. 2007; Ora 2012; Salminen 2010).

In recent years for many paper mills the problem area of the first open draw has moved from web transfer to press to web transfer to the drying section. Only for some specialty paper machines the open draw after the forming section is still existent. Especially for their machines, the most important factor to obtain high strength is to achieve the highest possible dryness level at the end of the forming section. Chemical additives and plant adjustments can be used to increase dryness at this point.

Wet pressing

Several authors have addressed the subject of pressing work and compacting in relationship to the development of strength (Brecht 1947; Clos et al. 1994; Edvardsson and Uesaka 2009; Guldenberg and Schwarz 2004; Hua et al. 2011; Kurki et al. 1997; Lobosco 2004; Mardon 1961; Paulapuro 2001; Pye et al. 1965; Stephens and Pearson 1970; Washburn and Buchanan 1964). To summarize the results of these studies, the press work is an external force that causes elastic and plastic flow of the fibers. It can be assumed it supports the already formed capillary and surface forces and it overcomes possible steric or electrostatic repulsive forces. This leads to more closed pores, closer fiber to fiber proximity, a denser web and increased tensile strength of the sheet (Maloney et al. 1997).

Additionally, the press dewatering increases the dryness of the paper. This inspired Shallhorn to improve Page's method of calculating the tensile strength of wet webs. The increased dryness after the press enhances the ability to separate the paper web from the press felt or press roll into the first open draw. One possibility to increase the dryness after press is to increase the temperature of the sheet during pressing (Back and Andersson 1993; Jantunen 1985). But the higher temperature leads to less "work of straining and both elastically and plastically adsorbed energy" of the wet paper web at constant dryness (Kouko et al. 2014). It is explained by softening of the wet fibers via heating.

A number of studies have investigated the separation of the web from the press roll into a free open draw, attempting to support this process using chemical additives (Edvardsson and Uesaka 2009; Hättich 2000; Mardon 1961, 1976; Oliver 1982; Pikulik 1997; Sutman 2011). All of these optimizations lead indirectly to an increase in the IWWS by increasing the dryness.

Figure 12 shows what happens in the z-direction of paper during dewatering, pressing and drying. At 20 % dryness there is much space between the fibers and especially at fiber crossings a water film with resulting capillary forces are imaginable. Further dewatering and pressing leads to a compacted sheet at 45 % dryness. This results in elastic and plastic flow and to force induced conformability. Some fibers are wet hornificated. The mechanic force leads to more contact points and a higher proportion of fiber surfaces

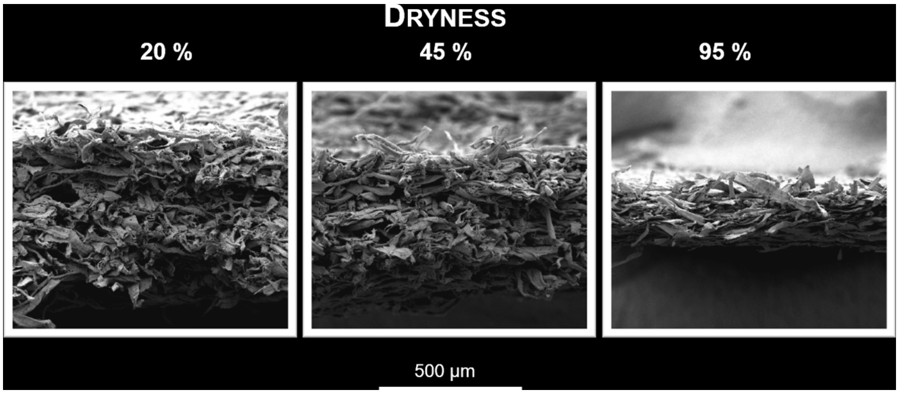


Fig. 12 Decreasing distance between fibers effected by dewatering, pressing and drying; handsheets of unrefined bleached kraft pulp (Belle et al. 2015b)

contained within a water meniscus increases. The drying of the sheet up to a dryness of 95 %, see Fig. 12, results in dry hornification of the fibers. They look like completely flattened ribbons. The sheet is dense and the distance between the fibers is small. Fiber crossings reach a maximum contact area and bonding capability.

Simulation

As it is complex and expensive to perform experiments, particularly in recent years a significant amount of research work has been carried out using simulations of paper machines, with the focus on the effects of various process parameter on the IWWS (Edvardsson and Uesaka 2009; Jantunen 1985; Kulachenko and Uesaka 2010; Lappalainen and Kouko 2011; Lobosco 2004; Matheas et al. 2011; Salminen 2010; Zimmermann 2012). These studies have mainly focused on wire and press dewatering and on the behavior of paper in the paper machine at increasing machine speed. Experiments indicate the effects of variables like press impulse, densification, dryness, papers' elastic modulus and release from press roll to the first open draw. Among others these have been incorporated into more or less extensive simulation calculations and black box models.

In this manner, it is currently possible to predict the IWWS within certain limits and for certain machine parts. These simulations significantly simplify both the configuration of the paper machine during planning and construction based on the raw material properties as well as the determination of the guaranteed IWWS values (Schwarz and Bechtel 2003). In spite of these shortcomings, the number of breaks caused by insufficient IWWS can be estimated and minimized.

Measurement techniques

IWWS can be measured using a variety of methods. Brecht described an early method (Brecht and Volk 1954; Zellcheming 1966) using a force elongation device that permits the testing of wet or dry paper in accordance with the possibilities available at that time. He used this method in a variety of studies. The disadvantage of this measurement is that the sample is fixed horizontally by two weights. These weights are pressing the wet sample and this eventually results in pressing water into the testing area. This leads to a high variance of measurements. Additional methods have been developed (Alince et al. 2006; Andrews et al. 1945; Jantunen 1985; McCallum 1957; SCAN 1981, 2005; Stephens and Pearson 1970; TAPPI 1997).

The German DIN standard "Testing of paper and board—Determination of the IWWS by tensile test" DIN 54514 2008 was issued in 2008 for the measurement of the IWWS. This method is suitable for the measurement of the entirety of forces that act on the sensitive paper web. However, the determination of the dryness of each sample is essential for the correct assignment of the measured forces. A prerequisite to ensure appropriate conclusions for practical applications. As shown, the result of the IWWS depends strongly not only on the dryness level but also on the speed of the tensile test. The higher the drawing speed, the higher the tensile strength is. This indicates that the measured IWWS may depend on the conditions in the paper machine to a significant degree. High machine speeds result in different loads compared to slower running equipment. Therefore, the visco-elastic properties of the paper play an important role (Andersson and Sjöberg 1953; Hardacker 1970; Retulainen and Salminen 2009; Skowronski and Robertson 1986). For this reason, recent studies have used a speed of 1000 mm/s (Kouko et al. 2007; Kurki et al. 2004). However, the DIN 54514 standard refers to the straining rate from DIN ISO 1924-3:2007-06. This standard specifies a strain rate of only 100 mm/min (1.667 mm/s). This significantly lower speed was chosen to avoid an influence of the inertia of the measurement equipment during testing (Schwarz and Bechtel 2003). Nevertheless, Kurki and others did comprehensive research on wet web tensile and relaxation characteristics with extensive findings as shown above.

Recent developments in pilot plant scale are able to measure additional parameters. Tanaka et al. (2009) reported about wet web rheology by means of "a wet web winder installed on a pilot paper machine" . This enables the measurement of dynamic stress–strain relationship considering the strain of unrolling. Ora did a similar investigation but used rewetted reels (Ora 2012).

In addition to the measurement technique itself, the assessment and correlation to the boundary conditions is of particular importance. The "failure envelope method" evaluates the strength and elongation values in relation with the dryness (Seth et al. 1982). This enables an assessment of the applied forces and the resulting elongation at different dryness levels on the runability of wet webs. Additionally, statistical experimental planning enables the calculation of the importance of the used factors. Thus, it is possible to make significantly more precise statements to explain observed phenomena and to optimize the paper production process in a better way (Belle et al. 2014b).

Integral explanatory models

As described in the sections on the nanometer, micrometer and macro levels, different chemical, physical and mechanical forces are involved in the development of paper strength during the processes of dewatering and drying. These may be complementary to each other, overlap each other or counteract one another. In the late 1950s, Brecht defined different stages of strength development (Fig. 1), which depend

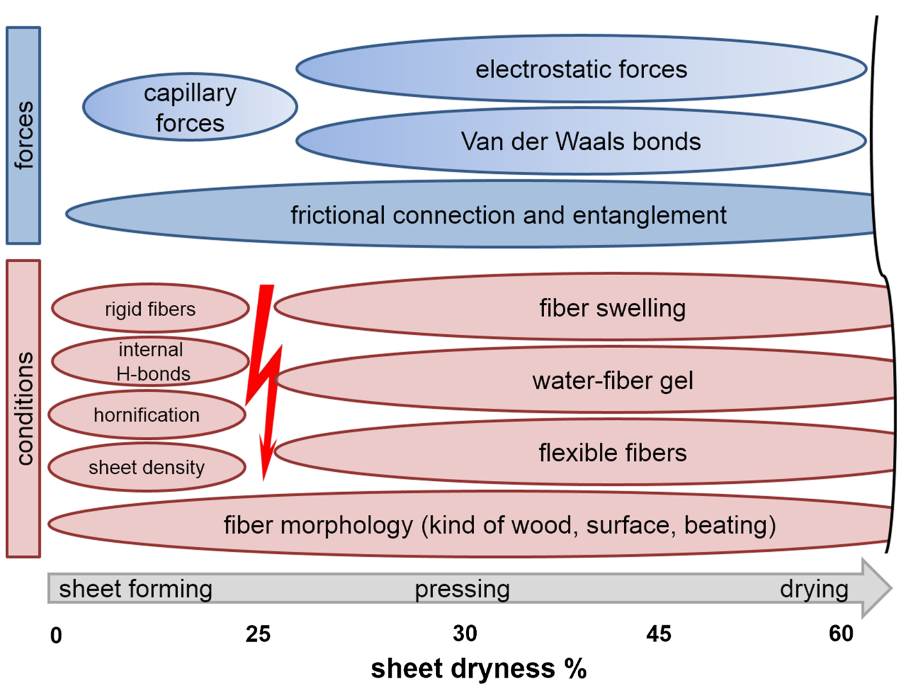


Fig. 13 Overview about the initial strength development of the wet web

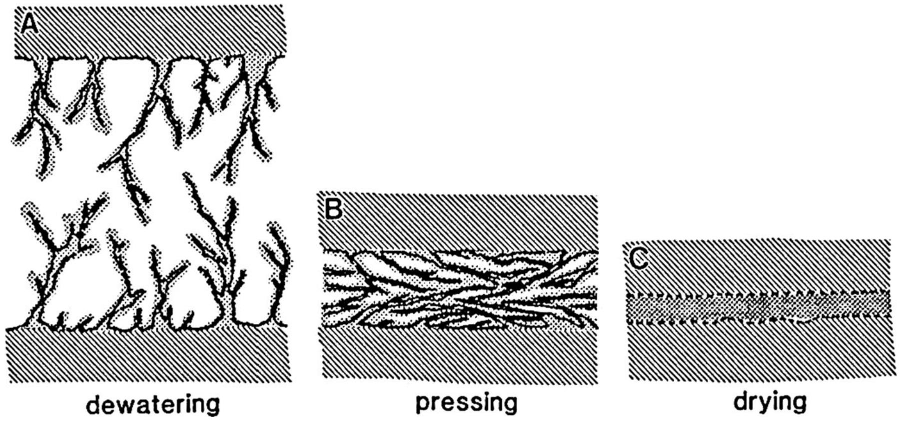


Fig. 14 Schematic illustration of bonding layer formation process; (Reprinted with permission of The Pulp and Paper Fundamental Research Society)

to a considerable degree on the dryness of the paper web (Brecht and Erfurt 1959a, b). In 2010, two explanatory models with three different phases of strength development were published by Tejado and Erhard (Erhard et al. 2010; Tejado and van de Ven 2010). These are expanded upon in the following paragraph based on own observations and experiments summarized in Fig. 13. At the top of the diagram the involved forces are shown. The bottom part illustrates the conditions to get the best IWWS. The arrow shows the contrariness of the needed conditions between the two phases of strength development.

During the first phase, up to a dryness level of ~25 %, capillary forces can be assumed to be prevalent. These forces develop in the structure due to progressive dewatering and result in frictional connection and entanglement (Belle et al. 2014a; Kallmes et al. 1977; Kendall 2001a; Williams 1983). With further dewatering, the fibers progressively collapse (Belle et al. 2015a; Paavilainen 1993a, b; Weise et al. 1996; Weise and Paulapuro 1996), with the result that the macroscopic and mechanical interlocking and felting of fibers increases the entanglement and frictional connections (de Oliveira et al. 2008; Tejado and van de Ven 2009; Williams 1983). Rigid, smooth fibers are best suited for this phase of strength development, as they support the capillary forces and interlocking at large distances between fibers (Belle et al. 2014a).

In the second phase, at dryness levels of >~25 % up to ~60 %, attractive van der Waals and repulsive forces occur in accordance with the DLVO theory (Derjaguin 1954; Derjaguin and Landau 1941; Israelachvili 2006b; Pelton 1993; Wågberg and Annergren 1997). In contrast to the first phase of strength development, in this second phase a flexible, viscoelastic, soft and coarse fiber surface is required, which stimulates the formation of larger contact areas between fibers (Kendall 2001b; Lindström et al. 2005; Nanko and Ohsawa 1989; Nilsson et al. 2000; Pelton 1993; Persson et al. 2013). Figure 14 shows the schematic illustration of bonding formation (Nanko and Ohsawa 1989).

In this phase, the gel formation in the proximity of the fibers is an important parameter affecting the formation of contact points (Kibblewhite 1973; McKenzie 1984; Voyutskij 1963b; Wågberg and Annergren 1997). These forces are supported by the diffusion of polymer chains of dissolved cellulose on the fiber surface and by wood polysaccharides, particularly xylan (Casey 1960; Clark 1978a; McKenzie 1984; Pelton 1993). In this phase, the distances between the fiber surfaces and fibrils are already so small that self-assembly take place. This enables the fibrils to form bonds between fibers (Belle et al. 2015a; Persson et al. 2013; Pönni et al. 2012; Yan and Li 2013).

The dry content in the first open draw of modern paper machines is >40 %, even 60 % is possible if it is in the first drying section.

During the third and final phase until the final dried paper is obtained, hydrogen bonds are established and reinforced by the increasing dryness level (McKenzie 1984; Nissan and Batten 1990; Wågberg and Annergren 1997).

Conclusions

This paper discusses the knowledge obtained from several decades of research on IWWS; summarizes the newest insights about the surface interactions of fibers, fiber swelling and new methodologies; and interpret these findings. Various forces and factors influencing the IWWS are presented and placed in context. The effects were separated into the size ranges of nanometer, micrometer and macro scale. The corresponding forces and phenomena from the literature and from own work are assigned to the appropriate ranges.

While summarizing the complex field of IWWS it might be reduced to a three-dimensional system: dryness, forces and conditions.

On one hand the maximum level of dryness should be reached to get the utmost strength values and best pick up from wires, rolls and felts used. On the other hand, the dryness level indicates, which forces are acting while holding the wet web together. For each certain dryness level the best conditions have to be chosen to get highest tensile strength and best relaxation characteristics.

For older, mainly specialty paper machines the dryness below 25 % is still relevant. In this range the conformability of the fiber network has big influence on the frictional connection of the wet web. The friction coefficient between two wet fibers and the coarseness are important parameters. Besides this, the capillary force is acting. This involves the conditions of water quality like surface tension at water-fiber surface, contact angle, density of the water and particularly the water film thickness between adjacent fibers. Thanks to the progressive dewatering this is a highly dynamic system with e.g. starting of fiber collapse and increasing sheet density.

State of the art paper machines have dryness levels between 25 and 60 % at the first open draw. Based on mechanical pressure in the press section the steric repulsive force might be overcome and the number of contact points increases rapidly. At this stage a flexible, viscoelastic and smooth fiber is needed. Fines and fibrils are creating van der Waals bonds backed by the fiber water gel and beyond of this. The fiber water gel is important for wooden polysaccharides like xylan and other hemicelluloses to interdiffuse and to build up another kind of bonding via attraction and repulsive force according to the DLVO theory. Strong H-bonds and chemical bonds between fibers, fibrils and fines are unlikely because of too much remained water in the wet web and other mild reaction conditions like relatively low temperature.

At the end, there is no doubt that two factors are particularly important: the dryness level of the wet web and the fiber morphology. Chemical additives can improve the IWWS at intermediate dryness levels of approximately 30–60 %. In practice, the fiber water gel is the easiest factor to adjust by controlling the process water quality and the use of chemical additives.

Furthermore, developments in measurement techniques, micro robotics and computed tomography promise to improve our ability to measure the existing forces and to describe the mechanisms of strength formation.

Remark

All samples and SEM images were prepared as described in "Demonstration of Strength Development in Initial Wet Paper Web using Field Emission-Scanning Electron Microscopy (FE_SEM)" (Belle et al. 2015a).

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Detailed life cycle assessment of Bounty® paper towel operations in the United States

Wesley Ingwersen, Maria Gausman, Annie Weisbrod, Debalina Sengupta, Seung-Jin Lee, Jane Bare, Ed Zanoli, Gurbakash S. Bhander, Manuel Ceja

Life Cycle Assessment (LCA) is a well-established and informative method of understanding the environmental impacts of consumer products across the entire value chain. However, companies committed to sustainability are interested in more methods that examine their products and activities' impacts. Methods that build on LCA strengths and illuminate other connected but less understood facets, related to social and economic impacts, would provide greater value to decision-makers. This study is a LCA that calculates the potential impacts associated with Bounty® paper towels from two facilities with different production lines, an older one (Albany, Georgia) representing established technology and the other (Box Elder, Utah), a newer state-of-the-art platform. This is unique in that it includes use of Industrial Process Systems Assessment (IPSA), new electricity and pulp data, modeled in open source software, and is the basis for the development of new integrated sustainability metrics (published separately). The new metrics can guide supply chain and manufacturing enhancements, and product design related to environmental protection and resource sustainability. Results of the LCA indicate Box Elder had improvements on environmental impact scores related to air emission indicators, except for particulate matter. Albany had lower water use impacts. After normalization of the results, fossil fuel depletion is the most critical environmental indicator. Pulp production, electricity, and fuels for product production drive fossil fuel depletion. Climate change, land occupation, and particulate matter are also relevant. Greenhouse gas (GHG) emissions by pulp, electricity, papermaking, and landfill methane from the disposed product, drive climate change impacts. Pulp provides significant offsets to balance climate change impacts due to sequestration of atmospheric carbon dioxide. 99% of land occupation is for the growth of the trees for pulp production. Papermaking, electricity, and pulp production cause the most potential particular matter formation.

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Detailed life cycle assessment of Bounty® paper towel operations in the United States

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ABSTRACT

Life Cycle Assessment (LCA) is a well-established and informative method of understanding the environmental impacts of consumer products across the entire value chain. However, companies committed to sustainability are interested in more methods that examine their products and activities' impacts. Methods that build on LCA strengths and illuminate other connected but less understood facets, related to social and economic impacts, would provide greater value to decision-makers. This study is a LCA that calculates the potential impacts associated with Bounty® paper towels from two facilities with different production lines, an older one (Albany, Georgia) representing established technology and the other (Box Elder, Utah), a newer state-of-the-art platform. This is unique in that it includes use of Industrial Process Systems Assessment (IPSA), new electricity and pulp data, modeled in open source software, and is the basis for the development of new integrated sustainability metrics (published separately). The new metrics can guide supply chain and manufacturing enhancements, and product design related to environmental protection and resource sustainability. Results of the LCA indicate Box Elder had improvements on environmental impact scores related to air emission indicators, except for particulate matter. Albany had lower water use impacts. After normalization of the results, fossil fuel depletion is the most critical environmental indicator. Pulp production, electricity, and fuels for product production drive fossil fuel depletion. Climate change, land occupation, and particulate matter are also relevant. Greenhouse gas (GHG) emissions by pulp, electricity, papermaking, and landfill methane from the disposed product, drive climate change impacts. Pulp provides significant offsets to balance climate change impacts due to sequestration of atmospheric carbon dioxide. Ninety-nine percent of land occupation is for the growth of the trees for pulp production. Papermaking, electricity, and pulp production cause the most potential particular matter formation.

1. Introduction

Procter & Gamble is a multi-billion dollar consumer products company that incorporates sustainability in its purpose (Procter and Gamble, 2015a, 2015b). P&G's sustainability vision includes powering its plants with 100% renewable energy, using 100% renewable and/or recycled materials in products and packaging, having 0% consumer and manufacturing waste go to landfill, and designing delightful consumer products while maximizing the conservation of resources. The company employs many tools, innovations, and experts to make progress toward this vision.

For example, in January 2012, the US EPA's Office of Research and Development's National Risk Management Research Laboratory (NRMRL) and P&G signed a 5-year Cooperative Research and Development Agreement (CRADA) to support the development of methods and tools for sustainability assessment within consumer product life cycles. An initial result has been a sustainability assessment approach that incorporates LCA with the use of novel integrated metrics (Ingwersen et al., 2014; Young et al., 2012). This work builds on two decades of LCA experience with US EPA and

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P&G scientists in research, method development, application, and collaboration through the professional society, “Society of Environmental Toxicology and Chemistry (SETAC)” and local projects (Curran, 2000; Fava et al., 1991; Jolliet et al., 2004, 2014; Margni et al., 2007); while providing EPA's researchers the opportunity to develop and apply tools, including newly developed LCA software (Gooch and Mack, 2012).

This collaborative effort addresses the following questions:

1) What product assessment approaches provide accurate and actionable information about social, economic, *and* environmental pillars of sustainability?
2) Can these approaches inform how changes in product design and manufacturing influence these pillars up and down the supply chain?
3) Is there an assessment framework that puts it all together practically, efficiently, and is actionable in any function and for any product?

P&G selected paper family products, and in particular paper towels, as the subject of an initial targeted effort to address these questions.

This paper towel LCA study is a key objective of the effort, where its results serve as the basis for the integrated sustainability metrics (Ingwersen et al., 2016). P&G has a history of using LCA to assess products and guide innovation (Saouter et al., 2002; McDougall et al., 2008; Weisbrod and Loftus, 2012; Weisbrod and Van Hoof, 2012; Van Hoof et al., 2014). The above questions stem from that experience.

For the EPA, this is an opportunity to work with a leading global manufacturer to advance sustainability science with real application to consumer products with global supply chains (Ingwersen et al., 2014; Weisbrod and Loftus, 2012; Weisbrod and Van Hoof, 2012; Young et al., 2012). One example of the CRADA results, incorporated and further tested in this LCA, is the Industrial Process System Assessment (IPSA) methodology (Sengupta et al., 2015a). IPSA is a multiple step allocation approach for connecting information from the production line level up to the facility level, and vice versa, using a multiscale model of process systems (Sengupta et al., 2015a). The method helps resolve challenges in assessing multi-product or multi-production line systems (Bousquin et al., 2012).

While this LCA model is foundational to exploring new integrated sustainability metrics, it is also designed to stand-alone. It thoroughly evaluates different supply chains and production processes used by two lines making paper towels at two facilities in the U.S. in 2012. The lines differ by age, location (Albany, Georgia vs. Box Elder, Utah), and technology. Other studies published on paper products do not have the resolution of assessing product impacts to the level of a single production line in a multi-line/product manufacturing facility (Madsen, 2007; Montalbo et al., 2011; Joseph et al., 2015; Boguski, 2010). It incorporates detailed data from the IPSA allocation method, updated data on regional US electricity grids and pulp production, and a normalization procedure to identify key processes and materials that contribute most to potential environmental impacts in the life cycle of a consumer good. P&G benefits from the LCA results for having the most accurate and recent model of Bounty to use as a benchmark to compare innovations to. It also serves to compare the value of conducting a complex LCA relative to other more simple methods, such as tracking energy use and waste generation (i.e., would the same priorities to improve processes or materials be identified by a cost and resource analysis as by an LCA?).

For the average LCA practitioner, this study demonstrates a number of important advances that can improve the quality of LCA studies. These include the benefits of using the IPSA method in comparison with conventional facility-level allocation approaches, the benefits of using newly-developed US regionalized electricity life cycle inventory, the use of an openLCA version of the EPA Waste Reduction Model (WARM), and the use of new functionality for advanced scenario modeling in openLCA software, all of which are not described elsewhere. It also provides a cradle-to-grave paper towel life cycle inventory of high data quality from a major global manufacturer with detailed contribution analysis describing the results from life cycle impact assessment.

2. Materials and methods

The scope of this analysis is cradle-to-grave. Foreground data account for forestry and wood chip production, pulp production, papermaking and converting, multiple transportation steps, and end-of life of all wastes. The Life Cycle Inventory (LCI) data are aggregated at the following levels: forestry and pulp production, pulp transport, paper towel production, fuels for each paper towel facility, electricity for each facility, product distribution, and end-of-life. Product use by a consumer is assumed not to lead to any measureable impact.

The study is conducted on one roll of Bounty regular towels. The unit is not based on function, because there are many ways that people commonly use paper towels. The two lines being compared make the same formulation of towel, so using one unit of the product for comparing processes and equipment function is more useful.

An iterative approach was taken where a preliminary screening-level LCA was performed in order to anticipate important sources of impact and direct subsequent work. The analysis was performed according to the same methods described here, using preliminary inventory data representing a single limited supply chain with primarily secondary data from the US Life Cycle Inventory (USLCI) (NREL, 2013) and Ecoinvent 2.2 (ecoinvent Centre, 2010). Preliminary results indicated the potential importance of pulp and direct energy consumption (particularly electricity) at the papermaking facility to many impact categories, and the importance of allocation choices/assumptions (Ingwersen et al., 2013). Therefore, additional efforts were made to improve the data quality of the pulp and electricity LCI, and to develop a more accurate method for allocating impacts from the papermaking facility to the Bounty product of interest.

The LCA was conducted by both EPA and P&G researchers working with EXCEL® spreadsheets and openLCA framework 1.4 (© 2007–2015 GreenDelta). ISO 14040 standards are followed and the highest level of data quality is utilized whenever available (ISO, 2006).

2.1. Inventory modeling

Original LCI data from suppliers and P&G for pulp production and transport, paper towel production, and product distribution are used in the study.

2.1.1. Pulp production and transport

Pulp production is represented by a set of unit processes for Kraft pulp (almost pure cellulose) used for paper towels, referred to henceforth as Pulp. Fig. 1 shows the basic steps in pulp production from harvest through arrival at the paper facility. Transportation between the processes is not pictured, but is included in data for forestry, sawmill, pulp mill, and paper facilities.

The original pulp data were secured from multiple suppliers in several countries from 2010 to 2014. These confidential LCIs cover material sourcing and production beginning with forestry

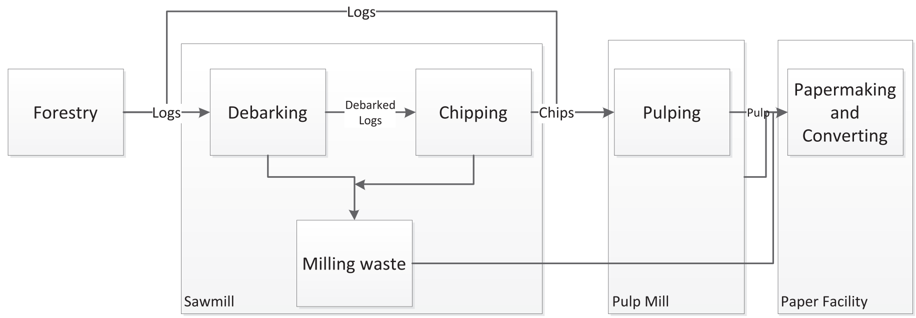

Fig. 1. Generic processes are shown for pulp production, papermaking, and converting. Each box represents a separate unit process for the pulp LCIs used in this study.

operations through pulp production. Not included in LCIs, but an important consideration for data reliability and appropriateness for environmental indices, is that independent third-party verification systems (e.g., auditing by Price Waterhouse Coopers for Forest Stewardship Council standards) are used to ensure sustainable forest management and wood traceability. P&G works with global multi-stakeholder organizations (e.g. World Wildlife Fund) on the development of tools and scientific methods to protect both the commercial value and services that forests provide, such as biodiversity, watershed protection, and climate moderation (Procter and Gamble, 2015a, 2015b).

Pulp mills commonly acquire a large fraction of their non-electricity energy needs from combustion of biomass fuels like wood chips and recovered fuels like black liquor that are of biogenic origin. Emissions of carbon dioxide from biogenic sources are typically excluded from facility reporting in systems such as EPA's GHG eGRET tool (US EPA, 2015a, 2015b, 2015c). This study includes biogenic CO_2 emissions in the inventory, as recommended by a recently developed product category rule for market pulp (FP Innovation, 2015). Therefore, CO_2 emissions were determined by calculations based on standard methods using the carbon content of the reported fuels used (US EPA, 2015a, 2015b, 2015c).

Forestry and sawmills are represented with data generated by the Consortium for Research on Renewable Industrial Materials (CORRIM) (Puettmann et al., 2010; Wagner et al., 2009), except for data on land occupation/conversion and carbon uptake. The CORRIM data include processes to grow, fell, delimb, skid, load timber onto a truck, and replant following harvest. The wood chips and forest residues for pulp production for the paper towels come from multiple sources and co-product generation processes, such as lumber and mill scrap and on-site chipping. Data from CORRIM do not separately identify the different sources of wood chips that become the pulp. A very conservative approach is used for this model and the trees are assumed to be grown exclusively for pulp production with no allocation for other uses. Under confidentiality disclosure agreements, land occupation and conversion data were collected and averaged from multiple growers as primary sources used by the pulp mills. Carbon uptake was calculated using standard IPCC methods based on forest species harvested, harvest density, wood density; assuming 0.5103 kg C/kg oven dry wood (IPCC, 2007). Age of trees at harvest ranged from 6 to 68 years and harvest volume 40–219 dry m^3/hectare (Binkley, 2014; Cochran and Dahms, 2000; USFS, 1983). Wood densities ranged from 445 to 574 kg/m^3 at 12% moisture. The burning of plantation residue following harvest is assumed to not occur, as consistent with the third party verification standards. In accordance with product carbon foot printing standards (BSI, 2011; EC, 2013; GHG Protocol, 2011), only the carbon sequestered in the trees that were harvested was accounted for in carbon uptake; other carbon uptake associated with forest land was excluded. For the portion of carbon uptake that was included, emissions of CO_2 from combustion and decay of biogenic sources were included across all phases of the life cycle. With this method for developing inventory, all inputs and outputs to processes are tracked to achieve a carbon balance.

Wood residuals from debarking and chipping are assumed to be collected for use as fuel for pulp production, and allocation was performed on a mass-basis for these processes. For Albany, sawmills provide some waste residues as fuels, but not at Box Elder.

The pulp is made in mills via a thermo-chemical process from wood chips. Inputs to pulping include various fuel sources, purchased electricity, processing chemicals, and water. To represent the pulping process, data were solicited from 2010 to 2014 from seven pulp mills. Transportation distances from harvest location to pulp mill were estimated based on data from the Commodity Flow Survey (BTS, 2009), and mode was assumed to be heavy-duty tractor trailer.

2.1.2. Paper towel production

Paper towel production includes both papermaking and paper converting, including embossing, rolling paper on cores and putting rolls in primary packaging. The papermaking and converting lines operate independently. Towels are tracked by a specific pair of making and converting lines (a line pair). Two line pairs, each from a different North American facility, were thus chosen based on their operation for producing the same paper substrate, i.e. Bounty regular, over the same time period, differences in papermaking and converting technologies, and differences in facility characteristics. Table 1 summarizes some of the key differences between the selected lines.

Conventional facility level product allocation by mass or value did not provide the needed accuracy to obtain accurate inventories representative of the line pairs. Totally avoiding allocation was impossible because of confidentiality, lack of line level monitoring of some inputs and outputs, and because of the need to attribute some of the processes serving multiple lines (e.g. utilities) to a roll from a specific line pair. IPSA is a structured method for assessing the inputs and outputs related to a product of interest when the intention is to compare products from specific production lines in one or more complex industrial facilities (Fig. 2). It uses sub-process modeling to avoid allocation when data are available at a sub-process level, and provide clear allocation when not available, within the context of a structured approach. In Step 1, a full list of flows into and out of the facility including material, energy, products, and releases were obtained from the facilities. Information was obtained on equipment and throughput to model capacities. In Step 2, flows were assigned to direct process (papermaking and converting); ancillary (e.g., boilers) and non-process (e.g., storage space) based on equipment usage data. In Step 3, flows further split among the direct processes to papermaking and converting line pairs, and among the ancillary processes based on equipment type.

Table 1
Characteristics of Bounty® lines selected for case study.

Aspect	Albany facility/Line A	Box Elder facility/Line B
Line Technology	Older traditional platform	Newest state-of-the-art platform
Primary Fuel & Energy Sources	Natural gas, biomass, grid electricity	Natural gas, grid electricity
Comparative Facility Size	Large	Small
Facility Age	>30 years old	<10 years old
Primary Emission Control Technology	BACT combustion, Separators & scrubbers, Wet ESP, Bag & Drum filtration	Low-NO_x combustion, Separators & scrubbers, Drum filtration

BACT = Best Available Control Technology; ESP = Electrostatic Precipitator; NO_x = nitrogen oxides.

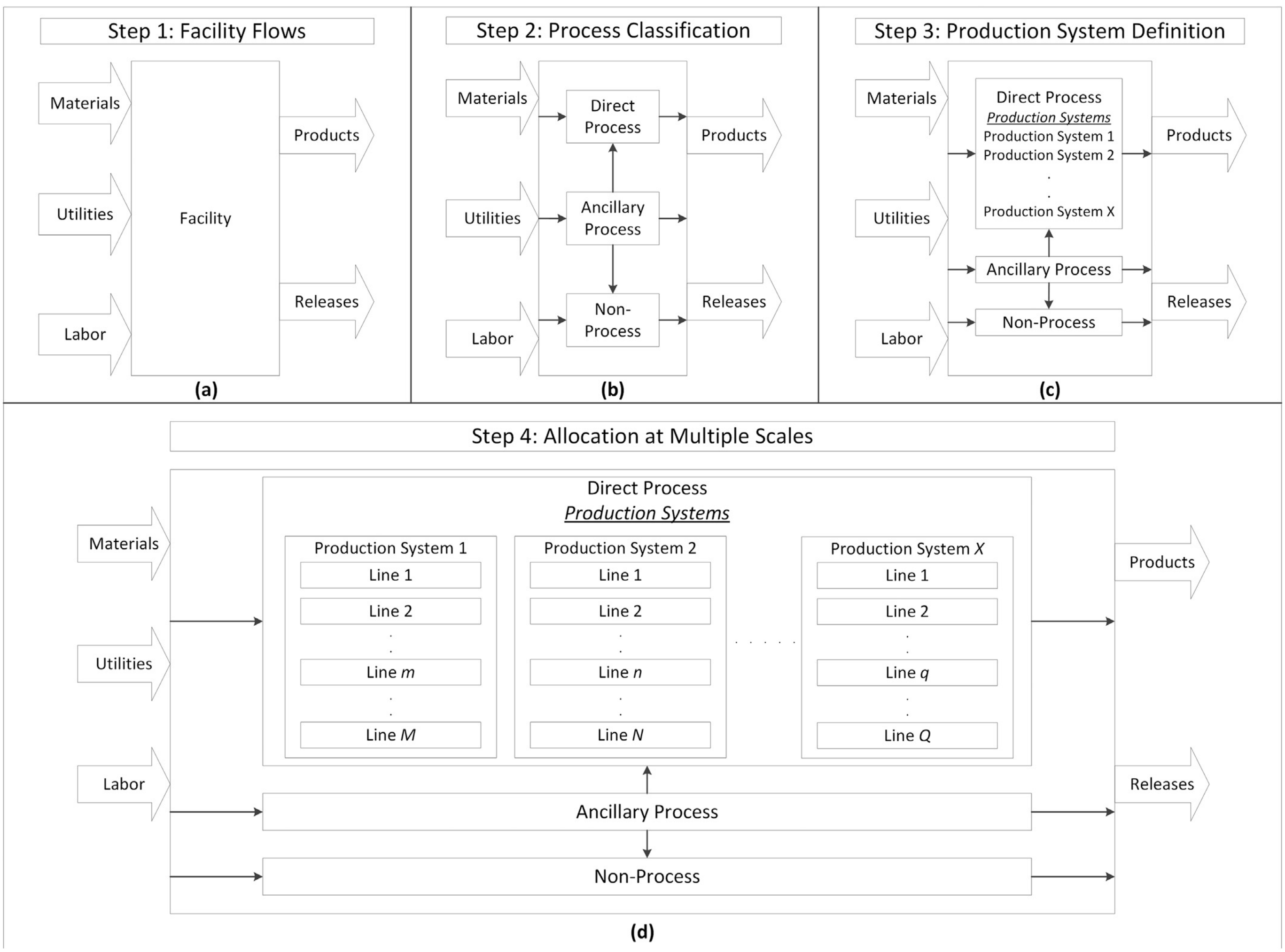

Fig. 2. IPSA four-step analysis method from Sengupta et al. (2015a).

In Step 4, flows are assigned to specific papermaking or converting lines. Finally, flow amounts assigned to each component of the system including those for the line pair, the line pairs use of ancillary equipment, and the non-process activities are aggregated and divided across the total mass of product of interest produced by the line pair.

2.1.3. *Fuels and electricity for paper towel facilities*

For modeling electricity production for the US-based facilities for pulp and paper towel production, new LCI was developed for US eGRID (multi-state) regions (Lee et al., 2015). There is relatively high-energy demand for pulp and paper production (EPA, 2010), and electricity production is a potentially significant source of impacts (Boguski, 2010; Ingwersen et al., 2012) in this sector. Known regional differences in electricity-related impacts are influential (Mutel et al., 2011). For pulp production overseas, comparable inventories based on national mixes were developed. When the region for a supply chain was unknown, the US average electricity production model was used.

For developing fuel-specific electricity processes (e.g., electricity from coal), electricity unit processes were aggregated by fuel source from Ecoinvent 2.2 data, maintained their inputs, and replaced the emissions associated with combustion for electricity production with fuel source-specific emission factors based on US electricity. Fuel-source specific emissions factors for three GHGs (CO_2, CH_4, N_2O) and the criteria air pollutants (CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, VOCs) were adopted from Cai et al. (2012), which are the same used in the GREET model. Fuel source-specific water loss estimates were included based on Macknick et al. (2012). Electricity processes by fuel source were then included as inputs into regional and/or national level electricity generation mix processes. Regional US electricity mixes by fuel source came from the EPA eGRID year 2010 data (EPA, 2014). Outside the US, national level mixes came from international energy statistics available from the Energy Information Administration (EIA, 2015). Table A1 in the Appendix summarizes the power mixes assumed for the facilities.

Electricity generation mix processes were then connected to 'electricity, at industrial user' processes for modeling distribution to point of use. National level losses associated with distribution were estimated based on Schmidt et al. (2015). No emissions or infrastructure demands were modeled for distribution, assuming the insignificance of impacts associated with distribution (aside from losses) relative to production and other upstream processes.

2.1.4. Packaging

Materials and processes used to model packaging for a roll of paper towels comes from Ecoinvent v2.2 (ecoinvent Centre, 2010). This includes folding boxboard for the paper towel core and polyethylene (LLDPE) for the plastic wrapper of the roll. P&G provided the mass of the core and wrapper. No secondary and transport packaging materials included. The contribution of packaging to the results is low (<1%) it is not included in the tables and graphs of the analysis.

2.1.5. Distribution, use, and end-of-life

The Bounty towels made at the two production facilities are distributed by tractor-trailer truck to a mix of distribution centers, clubs stores, and retailers across North America. Average distances range from 300 to 500 miles one-way and a load factor of 0.85 (representing trucks at 50% load capacity to pick up goods and at 100% capacity delivering goods) was assumed. No burdens were allocated to the retailer or the consumer to store, display, or use the product. The product does not contain chemicals that volatilize or leach, so there were no emissions to report during the use phase.

The roll of paper towels was assumed to be used for common household purposes, disposed, and hauled off with other household garbage to either a Municipal Solid Waste (MSW) landfill or incineration facility. US national average end of life treatment for the 2011 study year (US EPA, 2014a, 2014b) statistics provided the mix of landfill and incineration. Since used towels cannot be recycled because the fibers are two short to be commercially viable as a paper stock, the following equation estimates the percentage of towel waste to landfill:

$$l = \frac{l_a}{1 - r_a} \quad (1)$$

where l_a is the reported average percentage of US MSW to landfill and r_a is the reported average percentage recovered via recycling. The remaining percentage was assumed to be incinerated. GHG emissions and energy use related to end-of-life treatment were modeled with the EPA Waste Reduction Model (WARM) (US EPA, 2015a, 2015b, 2015c). The openLCA database of WARM (Ingwersen et al., 2015) was used instead of the EXCEL® version of WARM to align WARM modeling choices of biogenic carbon with the approach taken in this study. In the model, each material was treated independently (towel, core, and wrapper). As the specific materials are not available in WARM, proxy materials were chosen for modeling. 'Mixed paper (primarily residential)' represented the towel, 'corrugated cardboard' represented the core, and 'LDPE' the plastic film wrapping. WARM by default accounts for "carbon storage" in the landfill, which is the total amount of carbon in the product remaining after partial decay. The total C stored is then converted to CO_2-equivalents and subtracted from the total CO_2-eq emissions to report GHG emissions, which is equivalent to the CO_2 originally sequestered from the atmosphere by the biogenic source minus the C-equivalent that decays in the landfill. Since the CO_2 originally sequestered was accounted for the forestry stage of the LCA model, the carbon storage in CO_2 equivalents was not subtracted from the total CO_2 emissions, to avoid double-counting. WARM by default does not track biogenic CO_2 emissions from landfilling or combustion processes. These were then added in the model. The C content of the final product was assumed to be the same as C content of biomass. The percent of material combusted to CO_2 was 98%, the same percentage used in combustion of other materials in WARM. Because landfill gas is on average 50% CO_2 and 50% CH_4 (Ingwersen et al., 2015), the amount of CO_2 emission was set to match the amount of CH_4 emissions. National average conditions and other default choices for WARM were used for model parameters.

2.1.6. Background data

For all processes, production of generic chemicals, industrial water and wastewater treatment, and fuels other than petroleum are represented by data from Ecoinvent v2.2 (ecoinvent Centre, 2010). Data for petroleum fuels was taken from the inventories described in Sengupta et al. (2015b). Data on crude oil and natural gas extraction as well as data from general forestry operations were taken from the USLCI Database (NREL, 2013).

2.1.7. Data quality

Data used in this study scores high for quality based on indicators like completeness, representativeness, consistency, reproducibility, data sources, technology coverage, precision, geographical coverage, time-related coverage, and uncertainty (ISO, 2006). The scoring approach is based on Weidema and Wesnaes (1996); a semi-qualitative matrix pedigree method. The indicators of completeness, time-related coverage (temporal correlation), geographical coverage (geographical correlation), and technology coverage (technical correlation) match the indicators in ISO 14044. Sample size compliments the completeness indicator. Temporal, geographical, and technical correlation describes representativeness. Consistency, reproducibility, and data sources are discussed throughout this section, Materials and methods. Uncertainty is addressed with a sensitivity analysis. See Table A3 for the various data quality scores.

2.1.8. Sensitivity analysis

Four types of scenarios were analyzed to understand the importance of new methods and datasets, as well as to evaluate inherent data uncertainties.

One scenario was developed to understand the life cycle result differences brought about by the new IPSA approach. In this scenario, a facility-level mass allocation approach was used to estimate the paper facility inventory to contrast with the new IPSA line level estimations.

Two scenarios were created explicitly to test how the specific datasets for pulp and regional electricity compared with national average data. In the first of these scenarios, US national average pulp data from 2011 was used to create a modified pulp LCI reflective of national conditions. Data from this scenario were taken from a dataset developed by the US EPA and others to support the Universal Industrial Sectors Integrated Solutions Model for the pulp and paper sector (US EPA, 2014a, 2014b; Modak et al., 2015). The national average energy inputs, and GHG and criteria pollutant emissions developed from these data, are presented in the Appendix Table A5. Other input process names and inputs were set to be identical to the existing pulp datasets to hold other factors constant. In the second scenario, the use of the new regionalized electricity LCI in the paper facility was replaced with the equivalent Ecoinvent 2.2 process for average US electricity at an industrial facility, which is 'electricity, medium voltage, at grid/US'.

Additional scenarios were developed to understand the importance of specific data accuracy on results; we systematically altered one or more of the key data points. Following initial model runs, key data points with inherent uncertainty were identified of particular potential importance to model results. Primary data provided by papermaking facilities were of high quality in all aspects (ISO, 2006). Data of lesser quality and therefore with less certainty included data representing forestry and pulp operations (e.g. forestry yield, water use), product distribution, and end-of-life. For these points, values were doubled or halved. Ten scenarios were developed and applied to each line for a total of 20 scenarios run in the sensitivity analysis. New functionality was developed in openLCA 1.4 in collaboration with GreenDelta in order to conduct the sensitivity analyses. Within an openLCA 1.4 "Project," which is where different product systems can be compared, functionality to track variants of one or more systems were added. "Variants" were created with many variations of the baseline product system with a single change in one of the aforementioned key variables. Additional "variants" were created that used different product systems (or models) where unique unit processes have been substituted in the process network. This approach was taken to model the alternative facility allocation approach, and the scenarios with the substitution of the datasets, including the use of national average pulp and national average electricity datasets in place of the specific datasets used in the baseline case. The LCA results were then calculated simultaneously for each of these system variants.

2.2. Impact assessment

Impact categories were chosen based on known impacts of concern, ability to contextualize impacts, availability of data to accurately represent potential impacts, and appropriateness of available impact methodologies. The selected categories are presented in Table 2 along with indicators to represent them. Impact indicators at the inventory analysis, midpoint, and endpoint are chosen along with normalization factors when available. Indicators from TRACI 2.1 (Bare, 2012) and ReCiPe 1.08 (Goedkoop et al., 2012) were chosen to represent potential environmental and human health effects at the midpoint level. TRACI models for these impacts are based on US conditions, where the majority of life cycle activities occur. ReCiPe was used to provide endpoint indicators for the same and additional impact categories and provide external normalization using global normalization factors (Sleeswijk et al., 2008; Van Hoof et al., 2013). Normalization is an optional approach in the ISO 14044 standards (ISO, 2006) that can be used to view indicator scores in respect to a comparable reference point to aid in interpretation. P&G uses this approach to prioritize impact indicators without using additional subjective weighting values; this interpretation implicitly implies an equal weighting value for all impact categories in the study. As a global consumer products company serving consumers with the variety of perspectives on which environmental issues are most critical, this approach is used as a way to narrow the indicators that are considered for further analysis, but not used as a reason for suggesting that other indicators are not important (Van Hoof et al., 2013). Where midpoint factors for resource depletion are not well developed in TRACI, methods were adopted from ReCiPe as well. The ReCiPe methodology is used in application to other P&G products and provides consistency across applications of LCA to different P&G products. The use of similar impact indicators from multiple LCIA methodologies provides a sensitivity check to help understand how results might differ across impact methods. Neither TRACI nor ReCiPe include indicators of energy use or solid waste generation. The Swiss Center for Life Cycle Inventories method for non-renewable energy demand was used (Frischknecht et al., 2007). To track water consumption, all evaporative losses as defined by the Water Footprint Network as blue water were tracked and aggregated by volume (WFN, 2009). Human health and ecotoxicity indicators were not used in this study due to lack of high quality data on toxics release to air and water across the entire life cycle, and due to manufacturing and consumer related releases that undergo detailed risk assessment, which is separate from LCA modeling.

Table 2
Impact indicators used in this study, organized according to Bare and Gloria (2008). Impact categories names are those described in TRACI 2.1, except for categories which did not exist there, in which case names from ReCiPe or the other referenced methods are used.

Area of protection	Impact category	Material flux Indicator units	Midpoint indicator units	Endpoint indicators, units[b]	Normalized?[c]
Human health effects	Particulate matter		kg $PM_{2.5}$eq[a], kg PM_{10}eq[b]	DALY	Yes
	Ozone depletion		kg CFC11-eq[a,b]	DALY	Yes
	Smog formation		kg O_3-eq[a], kg NMVOC-eq[b]	DALY	Yes
	Global climate		kg CO_2-eq[a,b]	DALY, species yr[g]	Yes
	Ionizing radiation		kg U_{235}-eq[b]	DALY	Yes
Natural resources	Fossil fuel depletion		kg oil-eq[b]	$	Yes
	Metal depletion		kg Fe-eq[b]	$	Yes
	Water consumption/depletion	m^3[d]			No
	Cumulative energy demand, non-renewable	MJ[e]			No
	Land occupation/transformation	m^2 yr[f]	Agricultural land, m^2 yr[b]	Agricultural land, species yr	Yes
			Urban land, m^2 yr[b]	Urban land, species yr	Yes
			Land transformation, m^2[b]	Land transformation, species yr	Yes
Environmental quality	Freshwater eutrophication		kg N-eq[a], kg P-eq[b]	species yr	Yes
	Marine eutrophication		kg N-eq[b]	species yr	Yes
	Acidification		kg SO_2-eq[a,b]	species yr	Yes

[a] TRACI 2.1 (Bare, 2012).
[b] ReCiPe 1.08 with Hierarchist Perspective (Goedkoop et al., 2012).
[c] Normalization factor used were for Endpoint normalization factors in world per person impact.
[d] Water consumption is non-rainwater (bluewater) evaporative losses.
[e] Frischknecht et al. (2007).
[f] Total land occupation.
[g] Global climate is normalized to both human health and environmental quality endpoints.

In the climate change category for both TRACI and RECIPE methods, CO_2 uptake was assigned a CO_2-eq. value and −1 and biogenic CO_2 emissions were assigned a CO_2-eq of 1 so that both biogenic uptake and emissions were characterized to be consistent with the adjustments to the life cycle inventory. This results in the calculation of net global warming potential which can be represented in the following equation:

$$GWP_{net} = GWP_{gross} + GWP_{uptake} \quad (2)$$

where GWP_{gross} is the global warming potential of all greenhouse gas emissions regardless of fossil or biogenic origin, and GWP_{uptake} is the global warming potential of plant uptake, which is always a negative value.

3. Results

Fig. 3 shows results of the LCA for 1 roll of paper towels made at Albany and Box Elder as a fraction of average global person consumption estimates using the ReCiPe endpoint normalization values. Fossil fuel depletion across the full paper towel life cycle is the largest potential indicator of environmental impact. The fossil fuel depletion score is one order of magnitude (~10×) greater than the next significant indicators, human health effects of climate change, agricultural land occupation, and human health effects of particulate matter formation, which in turn are an order of magnitude greater than the remaining indicator scores. Although use of normalization factors adds additional uncertainty to results (Van Hoof et al., 2013; Benini and Sala, 2015; Weidema, 2015), the profound differences increase the likelihood that these are the impact categories with relatively higher contributions to average per person global impacts. It should also be noted that the differences between indicators are more substantial than the differences between Albany and Box Elder in the context of a global average consumer.

Fig. 4 is a comparison of results for the most significant impact categories for the production of Bounty at Albany and Box Elder based on the endpoint normalization, along with water consumption. The impact scores are internally normalized to reflect 100% of the highest score. Water consumption is an additional indicator not available for normalizing to annual world emissions, but is relevant for products that are made with pulp, as their processing requires

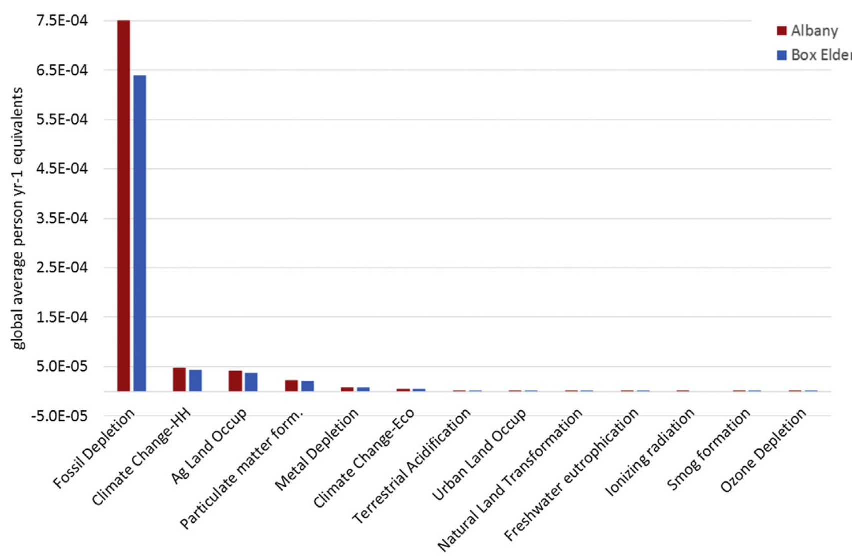

Fig. 3. Normalized results of producing 1 roll of Bounty® paper towels at Albany and Box Elder.

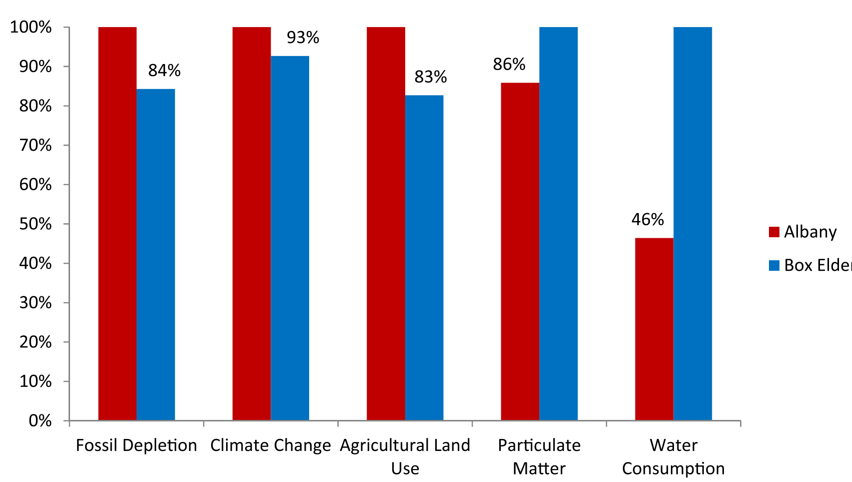

Fig. 4. Comparison of results for selected indicators calculated for the production of Bounty® at Albany and Box Elder. The impact scores are internally normalized to reflect 100% of the highest score.

significant amounts of water. Box Elder has lesser impacts for fossil fuel depletion, climate change, and land occupation, whereas Albany has a lesser impact on particulate matter formation and water consumption. The differences range from 7% for fossil fuel depletion to 54% for water consumption. These differences are explained in the contribution analysis.

A contribution analysis enables a better understanding of the most significant life cycle stages and drivers for each impact category, and provides a "hotspot analysis" to focus future research and development. Based on early analysis, life cycle groupings that showed distribution of impacts by upstream contributors and downstream stages were identified. Upstream impacts were largely distributed across the electricity, fuel, and pulp supply chains for Bounty production. Direct impacts of the Bounty production facility were important to distinguish, as well as impacts related to the downstream stages of distribution and end-of-life.

Fig. 5A shows the contribution analysis for fossil fuel depletion, the indicator most significant from the normalized comparison, for the paper towels made at each facility. Pulp purchased to make the paper towels is the largest contributor (49%). Some of the energy for making pulp is derived from non-fossil resources (~5%). The pulp combinations used at Albany contribute slightly more than the pulp materials at Box Elder (0.19 kg oil eq vs. 0.16, respectively). The residual wood from debarking and chipping are used as fuel for the pulp production. However, the wood milling process (making of logs, debarking, and chipping) uses residual fuel oil boilers (Wagner et al., 2009), which drives the fossil fuel depletion indicator in this case. Facility electricity and fuels are the next leading contributors to fossil fuel depletion following pulp production. A larger share of electricity purchased by the older Albany comes from fossil fuel sources because of the local electricity grid. The newer Box Elder has an overall smaller fuel energy requirement, for which it uses natural gas. Although Albany uses biomass from milling wastes (a non-fossil fuel source) for a percentage of its energy needs, the residues from debarking and chipping required fossil fuels for their harvesting and processing. Distribution of the product to wholesale and retailers requires long-distance trucking, which contributes approximately 6% to fossil fuel depletion.

Global climate change was modeled to include both emissions of GHGs as well as sequestration of atmospheric CO_2 by trees used for pulp and fuel production. Significant contributors to emissions include pulp production, facility electricity, facility production lines, and end-of-life consumer disposal (Fig. 5B). Pulp production contributed the greatest share to GHG emissions. Pulp production, however, results in significant reductions due to carbon sequestration during tree production. The net global warming potential from pulp is slightly negative (-0.15 to -0.25 kg CO_2-eq), as the sequestration slightly outweigh the emissions from the supply chains. The mix of tree species was different at each facility. Tree species production for pulp purchased by Box Elder provided more carbon sequestration, but Albany showed more carbon sequestration overall when the biomass fuels at the facility were included. Facility electricity is the next most contributing life cycle stage, dominated by electricity from coal. Production Line and disposal emissions are relatively small as the third contributor, and Box Elder has reduced its lines' emissions more than Albany (0.16 kg CO_2-eq vs. 0.22 kg CO_2-eq). Disposed Bounty is assumed to degrade anaerobically in landfills, contributing to some landfill methane emissions.

Agricultural land occupation is dominated by the Pulp life cycle stage (Fig. 5C). The Pulp combination used at the older Albany has slightly greater land occupation than Pulp used at Box Elder (2.3 m^2 yr vs. 2.2 m^2 yr, respectively). This life cycle indicator is influenced by the differences in pulp suppliers; which include differing tree species, climate, time to yield, and operations. Details on pulp supply and mix purchased by the facilities cannot be disclosed due to legal agreements on data confidentiality.

The particulate matter health effects indicator results were different between facilities, as shown in Fig. 5D. Particulate emissions <2.5 μm for the newer facility are associated with the production line and other activities, while the older facility had sulfur dioxide and particulate emissions <2.5 μm related to pulp production and electricity purchased for the manufacturing. A portion of both facilities' electricity came from coal and biomass, which contributes most to respiratory effects. The pulp purchased by Albany is responsible for more potential respiratory effect than that purchased by Box Elder.

Other indicators that have no normalization factors, but are relevant for product systems like paper towels, are analyzed. Those indicators include Cumulative Energy Demand and Water Consumption. Cumulative Energy Demand (Fig. 5E) reflects a nearly identical contribution analysis profile as the Fossil Fuel Depletion chart (Fig. 5A), in that the largest contributing phases are pulp followed by electricity and facility fuel.

For water consumption (Fig. 5F) the dominant contributor varies by facility. The newer Box Elder facility is more water efficient during production; however, electricity purchases by the facility dominate water consumption for Box Elder by 64%. Box Elder purchases electricity with a high contribution of hydropower in the grid, resulting in large evaporative water loss in reservoirs used to generate hydropower, which dominated the facility's life cycle water consumption. This water consumption is three times greater than direct water consumption at the production stage, which contributed 19% of total water consumption, just 3% greater than the contribution of pulp for this facility. For the older Albany facility, the production line requires more water compared to all other life cycle stages (47% of total), followed by pulp (29%) and electricity (24%). Pulp production is the next most contributing component. The pulp mix used at Box Elder is slightly more water intensive than the pulp mix used at Albany.

4. Sensitivity analysis

4.1. IPSA vs traditional facility level allocations

Results of the scenario to understand if/which differences are brought about by using the new IPSA approach vs. a more traditional facility-level mass allocation approach are shown in Table 3. Results show that the IPSA method produces line-specific input and emissions estimates that differ from facility averages. For Albany, the IPSA-based quantities are less than the traditional mass allocation approach by 14% for most inputs, and vary from 6 to 61% less for the emissions. This can be interpreted that the Albany production system for producing the paper towel during the time period of interest was less input-intensive and emitted less than the average line in the facility. On the other hand, the IPSA-based quantities for Box Elder are about the same as the average for the facility (0–2%+). There is less variation in Box Elder from the facility average because there was a single papermaking production line online during the sampling period, so the variation is only explained by the differences in the paper conversion line.

4.2. Pulp and regional electricity scenarios

Using national average pulp data on energy use and emissions resulted in the largest differences of any scenario. The input data for national average pulp is more energy and criteria pollutant emission-intensive than the pulps used by the facilities, but emits less GHGs. Due to this apparent inconsistency in these results, a consistency check was performed to compare the GHG emissions

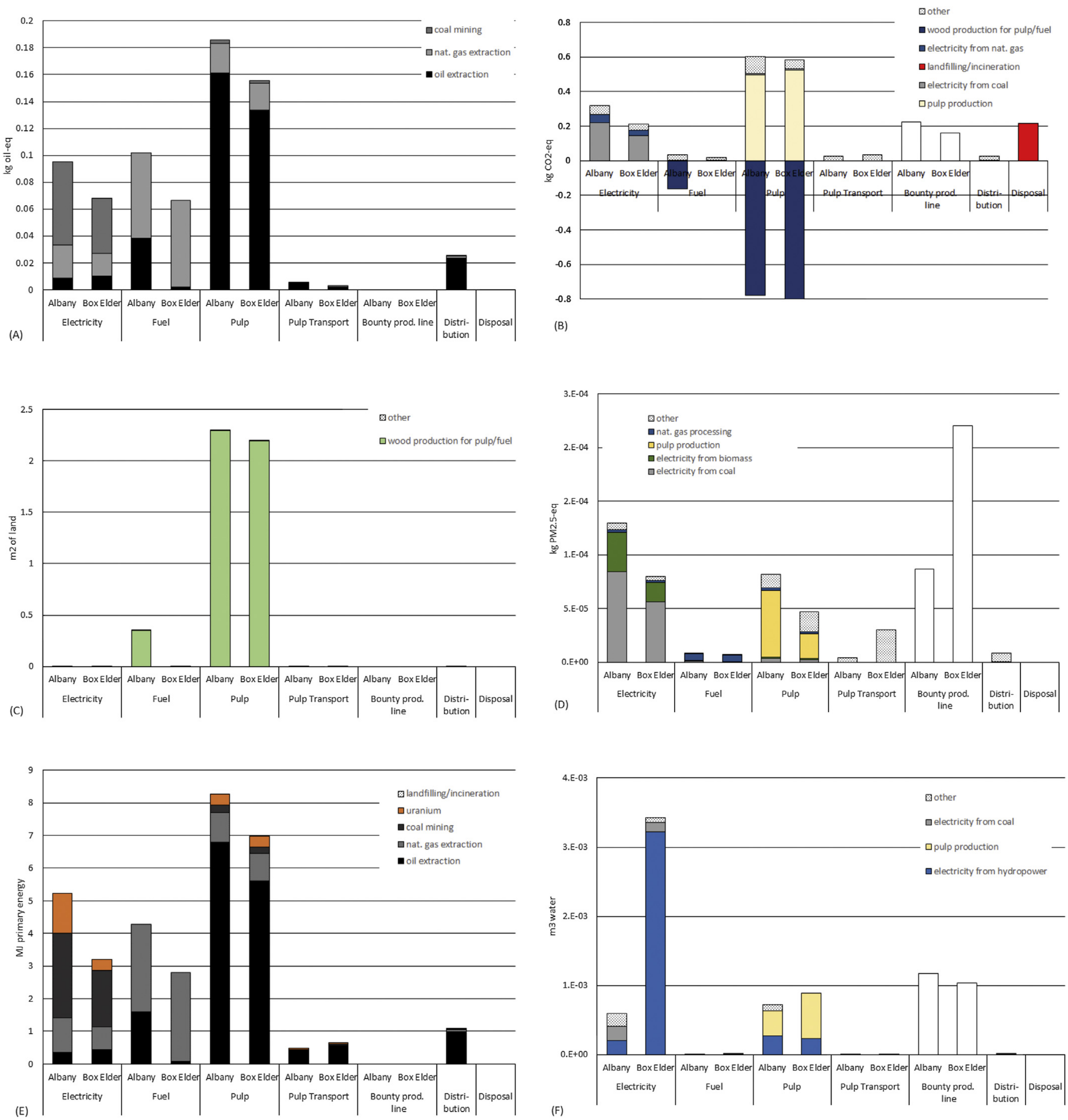

Fig. 5. Comparison of contributors to (A) fossil fuel depletion (kg oil-eq), (B) climate change (kg CO_2-eq), (C) agricultural land occupation (m^2), (D) particulate matter formation (kg $PM_{2.5}$-eq), E) cumulative energy demand (MJ primary energy), and (F) water consumption (m^3 of water). Contributions are presented by process and further broken down by key life cycle stage components. 'Electricity' represents electricity for Bounty production; 'Fuel' is fuel for Bounty production; 'Pulp' is pulp production; 'Distribution' is distribution of Bounty to retailers; and 'disposal' is disposal of Bounty by the consumer. For these latter two stages, impacts apply equally to both lines, otherwise they are independent.

from these two datasets. Pulp mills use a number of energy sources including many internally recycled biogenic sources, and there might be differences in accounting procedures for GHGs as a result that could not be reconciled. The use of an alternate proxy material for paper towels in the WARM model resulted in a significant decrease in disposal phase and full life cycle emissions.

4.3. Key data scenarios

The other data points that could have significant influence on results include the water loss in pulp production and the distribution distance; neither had much influence over the life cycle results. The forest yield changes do impact land use since it is dominated by the forestry, but otherwise yield does not affect life cycle impacts.

Table 3
Relative paper facility flow amounts from IPSA procedure as % of facility level mass allocation.

	Albany	Box Elder
Inputs		
Pulp	86%	102%
Chemicals (average)	86%	102%
Fuels (average)	86%	100%
Water	86%	100%
Electricity	89%	100%
Outputs		
PM_{10}	94%	102%
$PM_{2.5}$	93%	102%
SO_2	86%	102%
NO_X	39%	102%
VOC	84%	102%
CO	61%	102%
Lead	86%	102%
NH_3	87%	102%
CO_2	68%	102%
Wastewater	86%	102%
Water loss	86%	102%

Tables 4 and 5 show the results of the sensitivity analyses for Albany and Box Elder, respectively, for the impact categories of most significance. For Albany, the IPSA procedure had a significant impact on results, since the line showed different performance than other lines in that facility when compared to the facility-level mass allocation. Having accurate numbers for forest yield and supply chain specific pulp data would also influence results for that facility. Results for Box Elder were similar, except the IPSA method was not as significant; this is due to only having the one line running so the facility level data already reflected just that line, not a line average.

5. Discussion and conclusions

LCA studies can vary in quality due to data, methodologies, allocations, assumptions, modeling choices, etc. (Bousquin et al., 2012; Subramanian et al., 2011). Extra care is needed to use the best data and methodologies possible so that sustainability goals and strategies are based on robust science. This study used innovative and technically strong approaches to fortifying data (pulp, manufacturing, electricity), allocation (IPSA), and modeling (openLCA, WARM). The iterative nature of the LCA resulted in a recognition of the need to improve the quality of pulp and electricity LCI, making the results for these important contributors more accurate. Pulp production LCI specific to the most important pulp sources for Bounty production were developed, providing results that appear to differ significantly from use of average US pulp data. New electricity LCI data were developed, which better reflects the technologies currently in use in the US. This is important in the paper towel life cycle, particularly for facilities that draw from a regional electricity grid with a much different mix than the national average. The data allocation at the complex, multi-line manufacturing facility is superior to previous methods of simple mass or economic allocation, since actual line metrics were utilized in the new IPSA methodology to avoid arbitrary allocation. This is particularly important in providing line-level inventory and distinguishing many lines of varying performance at a facility. Additional functionality was added to openLCA software that provided a more straightforward and consistent means of performing sensitivity analysis for LCA that will be of

Table 4
Relative changes to full life cycle impact indicator results for Albany from the sensitivity analyses of allocation method, distribution distance, pulp, electricity, forest yield and water used in forestry.

Scenario	Fossil fuel depletion	Climate change	Ag. land occupation	Particulate matter	Energy demand	Water consumption
High forest yield	100%	100%	**67%**	100%	100%	100%
Low forest yield	100%	100%	**133%**	100%	100%	100%
High water loss for pulp	NA	NA	NA	NA	NA	99%
Low water loss for pulp	NA	NA	NA	NA	NA	101%
National average pulp vs supply chain specific data	**166%**	**84%**	NA	**113%**	**160%**	NA
National average electricity vs regional	98%	103%	100%	99%	99%	**76%**
Mass allocation vs IPSA	**114%**	**120%**	**116%**	**114%**	**115%**	**115%**
Long distribution distance	104%	104%	100%	102%	104%	100%
Short distribution distance	98%	98%	100%	99%	98%	100%
Alternate material for WARM	NA	**82%**	NA	NA	100%	NA

Note: Bolded values indicate sensitivities of 10% or higher.

Table 5
Relative changes to full life cycle results for Box Elder from sensitivity analysis of allocation method, distribution distance, pulp, electricity, forest yield and water used in forestry.

Scenario	Fossil fuel depletion	Climate change	Ag. land occupation	Particulate matter	Energy demand	Water consumption
High forest yield	100%	100%	**67%**	100%	100%	100%
Low forest yield	100%	100%	**133%**	100%	100%	100%
High water loss for pulp	NA	NA	NA	NA	NA	92%
Low water loss for pulp	NA	NA	NA	NA	NA	104%
National average pulp vs supply chain specific data	**211%**	**85%**	NA	**127%**	**201%**	NA
National average electricity vs regional	105%	**125%**	100%	**111%**	107%	**36%**
Mass allocation vs IPSA	99%	100%	98%	98%	99%	99%
Long distribution distance	107%	106%	100%	103%	107%	100%
Short distribution distance	96%	97%	100%	99%	97%	100%
Alternate material for WARM	NA	**80%**	NA	NA	100%	NA

Note: Bolded values indicate sensitivities of 10% or higher.

benefit to the global LCA community of practitioners. OpenLCA 1.4 proved to be effective for performing and managing a detailed LCA study of a product from a major manufacturer. This study is foundational to the exploration of other integrated sustainability metrics that incorporate the environmental estimates from this study, with financial and social data.

The conclusions of this study are clear, based on this work and other LCAs on paper towels (Montalbo et al., 2011; Madsen, 2007; Joseph et al., 2015), that making the product drives much of the relevant impacts on the environment. Energy requirements at the plants are high and draw from fuels and electricity grids that are predominantly fossil-based. However, this study also revealed that use of facility-level metrics alone to drive facility-level changes is insufficient to address all significant life cycle impacts. Analyzing beyond the papermaking and converting plants, pulp supply contributes greatly to the life cycle impact of paper towels as well. Other life cycle stages, including disposal, are not insignificant and therefore metrics that capture the full life cycle context are indeed needed to provide the proper context to inform sustainability-related decisions and identify potential changes that might be made beyond the facility.

In this study, both the manufacturing facility's life cycle impacts are based on the same unit, 1 roll of Bounty paper towels; yet the analysis still identified differences in environmental impacts driven by different technological processes and locations. Box Elder is a newer plant with a state of the art platform, and incorporates design features to improve efficiency. Bounty produced at Box Elder has potentially a lesser impact on global warming potential (−9%) and fossil fuel depletion (−8%). Agricultural land occupation is lower for Box Elder (−16%), which is more a reflection of pulp supply mix than Box Elder's processing and operations. Box Elder results in more life cycle water consumption (+54%), due not to plant operations but electricity production in the region of the facility, and more potential health effects of particulate matter emissions (+14%) than Albany, which is an older site.

Within the scope of this study, fossil fuel depletion is the most relevant impact indicator, and looking at both direct and indirect means of reducing fossil fuel usage should be the highest priority for reducing overall impacts. Electricity production is identified as being significant for many of the impact categories including fossil fuel depletion. Both facilities use nearly identical electricity amounts per unit output paper towel. Differences in the specific energy mix in each region were significant. The electricity mix supporting Albany, utilizes a grid powered by more than 50% coal, which drove the calculated impacts (Appendix Table A1). Subsequently, both facilities, especially Albany, would benefit from less dependency on coal power or through otherwise acquiring more electricity from less fossil-fuel intensive sources. Reductions in the dependency of grid electricity would reduce impacts in fossil fuel depletion, respiratory effects, and global warming potential. However, increasing the use of wood residues, which reduces the need for grid electricity, will increase agricultural land occupation. The Albany plant recently announced development of an up to 50-MW biomass plant on-site. Because Albany is one of P&G's largest U.S. facilities, the project will significantly increase P&G's use of renewable energy, helping move the company closer to its 2020 goal of obtaining 30% of its total energy from renewable sources (Procter and Gamble, 2015a, 2015b). P&G will need to stay diligent in its commitment to sustainable sourcing so that expanding the land area needed to support energy needs at the facilities will not impair forest value and services. P&G's wood procurement policy (Procter and Gamble, 2014) addresses sustainable forest management, certifications, conversions, and its efficient use of resources. This is designed to ensure responsible long-term supply, enabling reliable quality and availability of paper products.

The fossil fuel energy use information, along with the global climate change estimates, could be used to encourage pulp suppliers to continue to reduce their energy use and greenhouse gas emissions during production. The results showed the pulp combination used at Box Elder can provide more carbon sequestration, although the pulp types used at Albany had higher carbon sequestration overall when the biomass fuels at the facility were included in the modeling scenarios. When including the potential for carbon sequestration as criteria for product design, pulp production processes could deliver the most significant reductions in the climate change indicator, along with fuel purchasing (of biomass for energy) at the Albany.

For water consumption, this study helps to recognize that electricity sources, even those from renewables, can lead to impacts that dominate the life cycle; such as the hydropower-associated water losses that dominate water use for Box Elder. Hydropower is an important contributor to the power mix in that region. Operational water consumption factors for aggregate US in-stream and reservoir hydropower for a median of 4491 gallons/MWh. Other renewable electricity sources have water consumption factors ranging from 0 to 1000 gallons/MWh (Macknick et al., 2012; Mekonnen and Hoekstra, 2012). Continuous improvement programs designed to use less water and recycle more can yield life cycle benefits, provided that burden-shifting is avoided. Further this study illustrates that technology improvements at the older Albany can reduce water consumption enough to match the newer lines at Box Elder, which would result in less water impacts from product production. Water reduction or recycling strategies at the pulp and papermaking facilities would make the most meaningful improvements to this indicator.

P&G has a long history of developing LCA methods and studies, and using the results to set practical and meaningful sustainability goals. Previous studies identified the importance of reducing resources and emissions from paper plant operations. This more detailed study has four main findings with practical application to paper products and other company product families. First, although the IPSA method has more steps than the traditional facility-level allocation method, it is not difficult to use and delivers more accurate input data for LCA. P&G will apply the IPSA method for inputs to other product LCAs in the future. Other manufacturers and LCA practitioners may be persuaded to use IPSA as well, as the algorithms are published and described. Secondly, by applying a normalization step, the study identifies the most important impact indicators that P&G should track for this product to enable more sustainable production. The top 6 indicators will continue to be monitored and improved, but focusing on energy types and use are critical. Third, defining the meaningful differences between plants, driven by established vs. new technologies and/or location, is also important. For example, Figs. 4 and 5 show the importance of understanding particulate emissions at Box Elder, and determining whether the higher water consumption due to reservoir evaporation at hydroelectric dams is something that P&G deems of relevant or minimal concern. Fourth, by conducting a series of sensitivity analysis coupled with detailed contribution analysis, P&G can understand where better data and methods will improve model accuracy, as well as estimate how changes in facility operations, supplier activities, or otherwise product characteristics can change life cycle impacts.

Disclaimer

This article does not reflect the endorsement or opinion of the US Environmental Protection Agency.

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Appendix A. Supplementary material

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2016.04.149.

Appendix

Table A1
Electricity power mix for the regions in which the facilities were located in comparison with the US average in 2011.

	US-Avg	Albany region (US SE)	Box Elder region (US NW)
Electricity, coal	**45%**	**52%**	31%
Electricity, oil	1%	0%	0%
Electricity, gas	24%	25%	14%
Electricity, nuclear	20%	17%	3%
Electricity, hydro	6%	3%	**44%**
Electricity, biomass	1%	3%	1%
Electricity, wind	2%	0%	5%
Electricity, solar	0%	0%	0%
Electricity, geothermal	0%	0%	1%
Electricity, other fossil fuel	0%	0%	0%

Note. Predominant fuel sources for each region are bolded.

Table A2
Scenarios for sensitivity analysis.

Scenario	Life cycle stage affected	Description of model change
High forest yield (m^3 wood/hec)	Forestry stage (for pulp)	Increase yield in forestry process by 25%
Low forest yield (m^3 wood/hec)	Forestry stage (for pulp)	Reduce yield in forestry process by 25%
High water loss for pulp	Pulp production	Increase water lost to evaporation during pulp production by 100%
Low water loss for pulp	Pulp production	Reduce water lost to evaporation during pulp production by 50%
Use national average pulp energy and emissions data	Pulp production	Modify the pulp production data to use a national average energy and air emissions data in place of existing supplier data
National average electricity LCI	Paper towel production	Use the Ecoinvent 'electricity, medium voltage, at grid' process in place of the region-specific electricity LCI
Facility-level mass allocation	Paper towel production	Use a facility-level mass allocation approach in place of the IPSA procedure for determining inputs and output quantities per unit towel
Long distribution distance	Distribution	Increase distribution distance of paper towel to retailers by 100%
Short distribution distance	Distribution	Decrease distribution distance of paper towel to retailers by 50%
Alternate material selection for WARM	Disposal	Use 'Newspaper' as the proxy material for paper towel in the WARM model for estimating disposal stage emissions and energy use

Table A3
Data quality scores.

Process	Data quality Indicators				
	Source reliability	Completeness	Temporal correlation	Geographical correlation	Technical correlation
Electricity	1	1	1	1	1
Fuel	1	1	1	1	1
Pulp	2	1	1	1	1
Pulp transport	2	1	1	1	1
Other facility purchases	1	1	1	1	1
Distribution	1	2	1	2	4
Disposal	2	1	1	2	4

Table A4
Life cycle inventory data on WARM landfilling model for materials used as a proxy.

WARM material	Amount modeled in WARM per roll (kg)	Biogenic C content (%)[a]	Landfill CH_4 generation (CO_2-eq/dry MT)[a]
Mixed paper (used in baseline scenario)	0.17856	44%	3.18
Newspaper (used in alternative scenario)	0.17856	49%	1.33
Corrugated cardboard	0.0134	49%	3.48
LDPE	0.0032	0%	0

[a] Source: ICF International (2015).

Table A5
Life cycle inventory data for national average pulp – energy inputs and emissions for 1 metric tonne pulp.

Name	Amount	Unit
Inputs		
Electricity, at industrial user	163	kWh
Coal	40	kg
Residual fuel oil	0.0382	m^3
Petroleum coke	0.0175	m^3
Biomass	90	kg
Natural gas	159	m^3
Black liquor – internal recycle	1145	kg
Lime mud – internal recycle	204	kg
Sludge – internal recycle	0.89	kg
Outputs		
National avg pulp, at pulp and paper plant	1	tonne
Nitrogen oxides	1.77	kg
Sulfur dioxide	2.03	kg
Carbon dioxide, fossil	726	kg
Carbon dioxide, biogenic	1832	kg
Particulate matter <2.5 μg	0.30	kg
Particulate matter >2.5 μg, <10 μg	0.30	kg
Volatile organic compounds, unspecified	0.20	kg
Hydrogen chloride	0.139	kg

Source: US EPA (2014a, 2014b).

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Pulsed laser processing of paper materials

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At present the trends in paper and packaging industries are the personalisation of products and the use of novel high-tech materials. Laser processes as non-contact and flexible techniques seem to be the obvious choice to address those developments. In this paper we present a basic understanding of the occurring mechanisms of laser based engraving of different paper and paperboard materials, using a picosecond laser source at 1064nm. The influences on the beam-paper-interaction of grammage, the composition of the paper matrix, as well as the paper inherent cellulose fibres were investigated. Here the ablation threshold of commercially available paper was determined and a matrix ablation effect under the 1064nm radiation observed. These results were characterised and qualified mainly by means of laser scanning microscope (LSM) micrographs in combination with colour-space analytics.

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Pulsed laser processing of paper materials

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Abstract

At present the trends in paper and packaging industries are the personalization of products and the use of novel high-tech materials. Laser processes as non-contact and flexible techniques seem to be the obvious choice to address those developments. In this paper we present a basic understanding of the occurring mechanisms of laser based engraving of different paper and paperboard materials, using a picosecond laser source at 1064 nm. The influences on the beam-paper-interaction of grammage, the composition of the paper matrix, as well as the paper inherent cellulose fibers were investigated. Here the ablation threshold of commercially available paper was determined and a matrix ablation effect under the 1064 nm radiation observed. These results were characterized and qualified mainly by means of laser scanning microscope (LSM) micrographs in combination with color-space analytics.

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH

Keywords: laser-based paper processing; IR-wavelength; ultra-short-pulses

1. Introduction

Nowadays paper as oldest fiber composite material is a functionalized high-tech material. Laser machining allows the production of finely and delicate design elements by cutting, scoring, perforating and engraving.

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Especially at small charge numbers or individual demands, common processes reach their limits and the laser process is advantageous (H. Pilii et al. 2009). The currently used laser systems are cw-CO2 lasers. These systems may affect unwanted material changes like bleaching or changing of colors e.g. at the cutting edges during the laser process by thermal decomposition of the material (A. Stepanov et al. 2010).

On the other hand also material inherent properties hamper the processing of paper materials. These are its manifold of thickness, different ingredients and finishing for example. Either a broad process window or specialized systems are needed to achieve a high quality laser processing.

In this study we utilize a 1064 nm picosecond pulsed laser system and show basic results of machining commercially available, standard paper substrates. These materials received no property enhancing treatments like absorption enhancing additives or a smoothening finish and thus can display the very basic laser-matter-interaction at short pulsed laser processing of paper.

2. Experimental Details

The chosen laser for this study was an ultra short pulsed system with a pulse duration of 12 picoseconds at a variable repetition rate (single pulse up to 8.2 MHz), a spot diameter of 30 µm and a maximum average power of 50 W at a wavelength of 1064 nm. In our experiments, repetition rate was fixed at 200 kHz and the pulse overlap Ω was set to be equally spaced in x- and y-direction. The parameters to vary were therefore the average power (3.1 W, 6.4 W, 9.5 W), number of transitions n (1 to 20), and overlap Ω (10 % to 90 %). The used average powers result in peak fluences F_0 of 4.39 J/cm², 9.05 J/cm², and 13.44 J/cm².

The thickness and basic optical properties, as a result of spectroscopic measurements, of the two used paper materials P1 and P2 are shown in Table 1. These are standard commercially available paper without any special coating or filler material. The used materials P1 and P2 are of similar composition, have therefore comparable optical properties, and differ in their overall thickness. The paper consists mainly of cellulose fibers, calcium carbonate as filler material, and a small fraction of binders. The optical properties are only measured for the overall paper and not for the single components.

Table 1. Thickness and optical properties of used papers.

Name	Grammage	Thickness	Reflectance (at 1064 nm)	Transmittance (at 1064 nm)	Absorptivity (at 1064 nm)
P1	220 g/m²	290 ± 8,2 µm	73,4 %	9,3 %	17,3 %
P2	300 g/m²	370 ± 2,1 µm	74,2 %	7,5 %	18,3 %

Next to the optical properties, the composition of the paper material causes a quite inhomogeneous structure (K. Niskanen et al. 1998) as seen in Fig. 1(a). Here especially the voids within the structure are visible. In Addition to the rough surface, the structure of the paper influences the laser processing and cause special obstacles like local change of absorptivity.

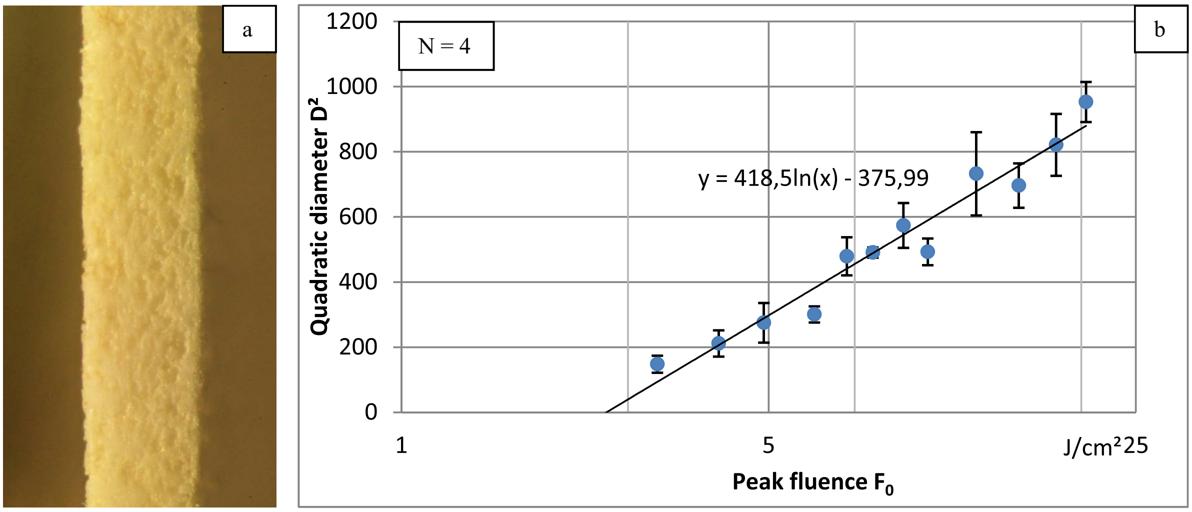

Fig. 1. (a) Photograph of ps laser cut of paper P2 at F_0 = 15 J/cm², Ω = 90 %, n = 15; (b) Damage threshold determination for P2.

A laser damage threshold determination was conducted according to J. M. Liu (1984). Here a gaussian beam shape is anticipated and the peak fluence connected to the resulting diameter of the damaged area on a certain material. The result is shown in Fig. 1(b) and yields a damage threshold for P2 with the used laser system of 2.5 J/cm². This threshold was determined by placing 500 pulses at one spot for each pulse energy tested. It holds true for the whole paper, not for the single components. Single pulses were not measurable due to the general optical properties of the paper and its inhomogenious composition

Table 2. Classification of ΔE.

ΔE	Impression
0 - 2	Imperceptible difference
2 - 4	Detection threshold
> 4	Recognized as different color

One possibility to classify the laser processed materials is to measure the discolouration caused by thermal decomposition. This effect is quantified by a colourimetric measurement instrument (SpectroDens; Techkon). It assignes, according to EN ISO 11664-4 „Colorimetry - Part 4: CIE 1976 L*a*b* Colour space“, every measured colour a distinct point in the three dimensional L*a*b* colour-space as seen in Fig. 2. Subsequently these points are used to define a ΔE value, which is the length of the vector of the distance of two colour-points in this system. Table 2 shows a classification of these values as percepted by the human eye. Here the unprocessed paper is used as reference to discolouration after a certain treatment, for this includes any colour pigments already existing beforehand. Measuring the colour value is a strong indicator at which parameters cold ablation takes place.

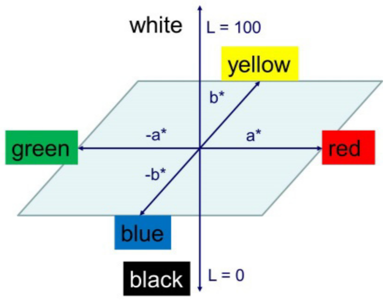

Fig. 2. L*a*b* Colour space.

For a detailed look onto the ablation of the laser processed paper, an Laser-Scanning-Microscope was used. Here especially the topography was depicted as well as micrographs of the machined materials for the usage of depths measurements, which are shown in the next chapter.

3. Experimental Results

Fig. shows exemplary a full matrix of ablation of paper P2, whereas the y-axis indicates the number of transitions and the x-axis the overlap of pulses Ω (here named UE) in percent. As can be seen, the highest overlap of 90 % caused the material to burn, making further analysis impossible at these parameters. As expected, higher transitions and higher Ω leads to a stronger ablation of paper.

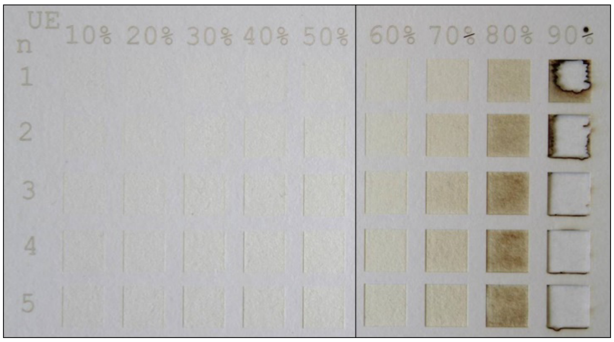

Fig. 3. Ablation of paper P2 using a peak fluence of 9.05 J/cm². Different Ω (here named UE) are shown on the x-axis, on the y-axis the number of transitions are increased.

Fig. 4 shows the topography of certain ablation configuration (varying Ω from 10 % to 70 %) after five transitions. A roughening of the surface can be observed, exceeding even the base level of the untreated material as seen in the micrographs from 10 % up to 50 % pulse overlap. This roughening decreases with an increasing Ω as the energy density brought onto the processed area rises.

This roughening is a result of a selective ablation of the fiber-containing matrix and leads to a lawn-like structure of an enlarged, compared to the state before processing, and rough surface of mostly fibre material. During fabrication of the paper the fibres are pressed and dried within the ambient matrix, consisting filler material and a small fraction of additives. By only ablating those matrix elements, the fibers are released from their former stress and can form this lawn-like surface structure. At higher energy densities this structure is destroyed again, as seen in the micrographs of 60 % and 70 % pulse overlap in Fig. 5. First Experiments at a nanosecond laser system with a wavelength of 1064 nm show a clear enhancement of this effect. Here the lawn-like structure is clearly visible without a microscope.

The attempt to quantify the roughness by R_a for example, resulted in no clear trend and does not resemble the visual impression of Fig. 4. Here other ways of defining the surface and its process formed surface properties had to be found like in-depth 3D-surface analytics, as the complex structure with its undercuts seems to be the problem. Also this matrix ablation complicated the ablation threshold determination. Here no clear ablated circles could be measured, as the fibres are not fully ablated by the 1064 nm picosecond radiation. Because of this the ablation threshold study has to be performed with several pulses on the same spot, rather than with single spots.

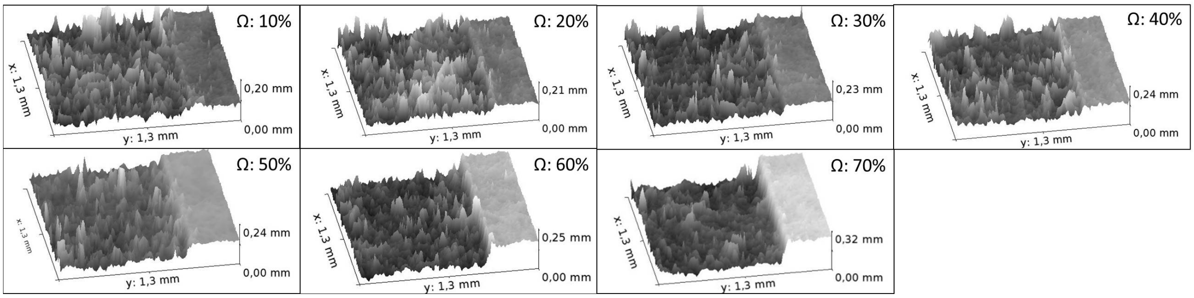

Fig. 4. Topographic micrographs of seven different pulse overlaps are shown after five times of ablation at 9.05 J/cm².

The measured ablation depths are depicted in Fig. 5 (left scale) as well as the measured discoloration ΔE on the right scale. The blue bar marks the regime of no noticeable colour difference for the human eye below the value of 4 for ΔE, as seen in Table 2. As can be seen, even for ablation at 10 % pulse overlap, the value already exceeds this mark. Hence thermal degradation of the paper plays a crucial role and no cold process is possible at these laser parameters of 12 ps, 200 kHz and 9.05 J/cm². Beyond 50 % of pulse overlap the ablated depths as well as ΔE increase significantly.

Fig. 6 shows different peak fluences and their corresponding different ablation depths at processing paper P2. At 4.39 J/cm² up to a value of Ω = 50 % the ablation is not measurable. Here only the matrix ablation takes place and the fibers outreach the former substrate level. At 9.05 J/cm² and 13.44 J/cm² the difference in ablation depth excessively starts to differentiate beyond 50 % pulse overlap.

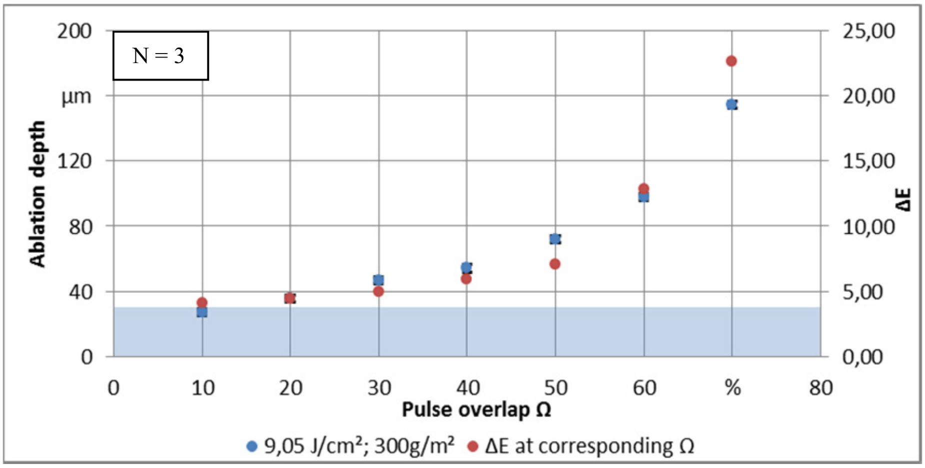

Fig. 5. Comparison of ablated depth at different Ω after five transits and its corresponding change in colour, given in calculated ΔE. Blue region marks ΔE below 4.

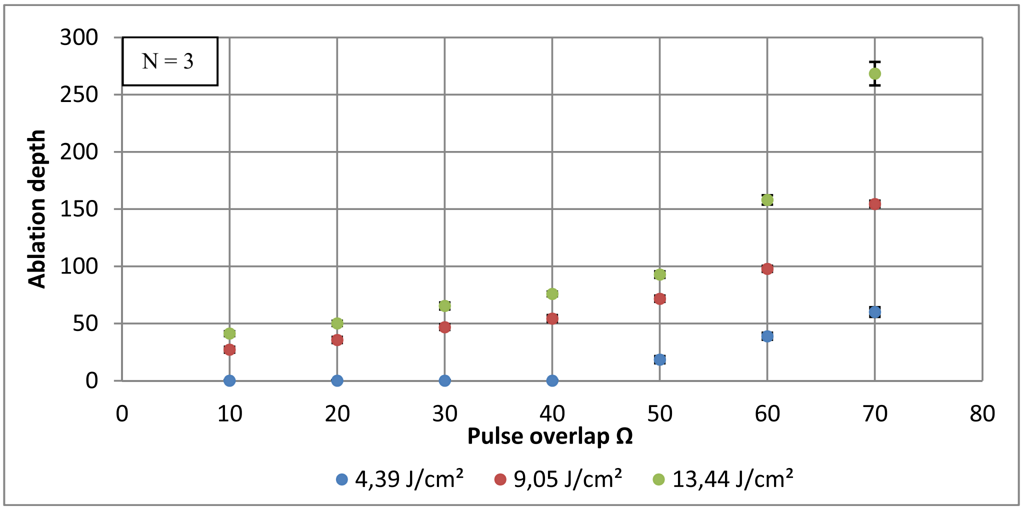

Fig. 6. Comparison of three different average power used for ablation at different Ω after five transits on material P2.

The comparison of processing the paper P1 and P2 at the same peak fluence of 9.05 J/cm² at different Ω is shown in Fig. 7. Here, no difference in the ablation behavior between the two materials can be observed. The main difference between the two materials is the thickness; this means that no heat conduction into the remaining bulk material assists the ablation. This also allows transferring the results from the ablation threshold determination to material P1.

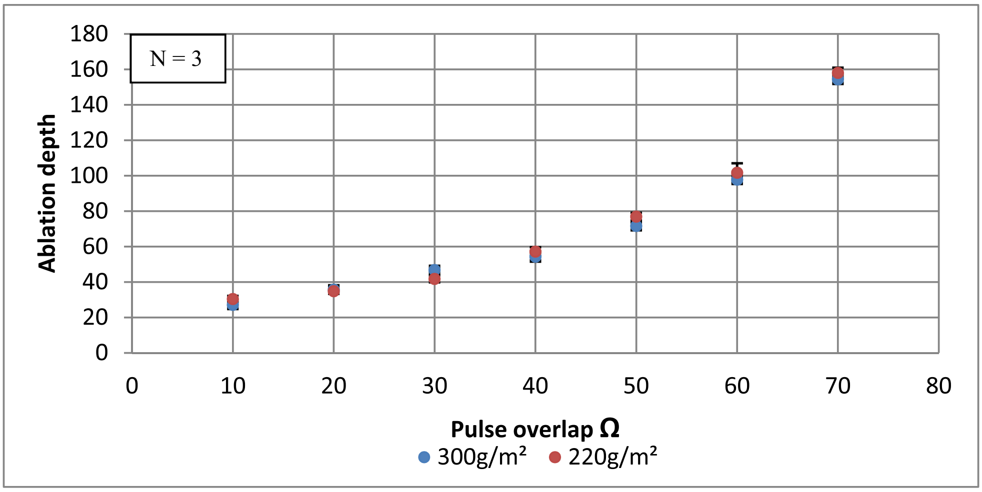

Fig. 7. Comparison of the two used materials P1 and P2 at a peak fluence of 9.05 J/cm².

4. Conclusion

We have shown the ablation of paper at 1064 nm at 200 kHz and 12 ps pulse duration in dependence of peak fluence F_0. Depending on the energy density, ablation can change its behavior from a more cold process at a low pace, meaning low pulse overlap, to a quite thermal and material-burning process. This switching happens at an overlap of about 50 %. Also a strong discoloration at higher overlap can be noticed after this point, stating a thermal process. Here the colour-space determination quantified the resulting colour change after processing the paper. Falling below the stated mark ΔE =4 for this change, was not achieved. Here the decrease of the repetition rate below 200 kHz can possibly change this drawback, the induced heat has more time to distribute in the ambient material and is not accumulated, and enhance the process to a pure cold ablation without any colour change.

A selective matrix ablation was observed after processing with picosecond laser pulses creating a lawn-like surface structure, because of the cellulose fibers were not ablated by the 1064 nm ps radiation. Here the wavelength of 1064 nm is the determining factor caring for a selective ablation, as first experiments with longer pulses of the same wavelength suggest. These pulses were in the range of nanoseconds and clearly enhance the overall effect of creating this lawn-like structure. Here new applications are possible with this kind surface treatment, for example in the fields of filter technologies. On the other hand, this effect hardened the conduction of determining the ablation threshold. Further studies have to distinguish between a threshold for the matrix and the fibers separately.

The thickness of material does to this point not influence the ablation of paper material at all, which diminishes the importance of the thickness from the vast matrix of the influencing factors on laser processes on paper material.

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An Evaluation of Biological Approach for the Effluent Treatment of Paper Boards Industry - An Economic Perspective

K Rajkumar.

The environmental problems of paper board industry are not limited by the high water consumption, generate wastewaters and solid wastes. This paper presents the paper board industry effluent treatment plant components performance and physio-chemical characteristics of wastewater and sludge. In ETP operation most important factors is effluent characterization, flow rate, aeration tank dissolved oxygen (DO) level, mixed liquid suspended solids (MLSS), food to micro-organism ratio (F/M), sludge volume and chemical addition for nutrients and coagulant. The wastewater is characterized by extreme quantities of pH, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and the solid waste from ETP sludge is characterized by SEM –EDX and ICP. The wastewater samples were collected from the partied of one month influent and treated effluent. An influent consist pH of 7.1-7.7, TSS of 1160-1380 mg/L, TDS of 1500-2000 mg/L, BOD and COD varies 200-250 mg/L and 2010-1286 mg/L respectively. The treated effluent of pH varies 7.1-7.3, TSS 10-20 mg/L, TDS ranges from 1500-1900 mg/L, BOD and COD ranges from 7-16 mg/L and 54-145 mg/L, respectively. Further solid waste in the form of sludge handled through mechanical dewatering devise (belt press). The result shows that the performance of effluent treatment plant based on the permissible limits prescribed by regulatory agencies and can be recycle an entire treated effluent into the board manufacturing process. The fixed capital cost was 700 lakhs- Indian Rupees (Rs.) and annual operation and maintenance cost was estimated Rs. 180 lakhs (without RO plant). Reuse of treated effluent in pulp process and sludge in sun dry board manufacturing and composting were adopted to achieve the target of sustainable development for ecological and economical gains.

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An Evaluation of Biological Approach for the Effluent Treatment of Paper Boards Industry - An Economic Perspective

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Abstract

The environmental problems of paper board industry are not limited by the high water consumption, generate wastewaters and solid wastes. This paper presents the paper board industry effluent treatment plant components performance and physio-chemical characteristics of wastewater and sludge. In ETP operation most important factors is effluent characterization, flow rate, aeration tank dissolved oxygen (DO) level, mixed liquid suspended solids (MLSS), food to micro-organism ratio (F/M), sludge volume and chemical addition for nutrients and coagulant. The wastewater is characterized by extreme quantities of pH, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and the solid waste from ETP sludge is characterized by SEM –EDX and ICP. The wastewater samples were collected from the partied of one month influent and treated effluent. An influent consist pH of 7.1-7.7, TSS of 1160-1380 mg/L, TDS of 1500-2000 mg/L, BOD and COD varies 200-250 mg/L and 2010-1286 mg/L respectively. The treated effluent of pH varies 7.1-7.3, TSS 10-20 mg/L, TDS ranges from 1500-1900 mg/L, BOD and COD ranges from 7-16 mg/L and 54-145 mg/L, respectively. Further solid waste in the form of sludge handled through mechanical dewatering devise (belt press). The result shows that the performance of effluent treatment plant based on the permissible limits prescribed by regulatory agencies and can be recycle an entire treated effluent into the board manufacturing process. The fixed capital cost was 700 lakhs- Indian Rupees (Rs.) and annual operation and maintenance cost was estimated Rs. 180 lakhs (without RO plant). Reuse of treated effluent in pulp process and sludge in sun dry board manufacturing and composting were adopted to achieve the target of sustainable development for ecological and economical gains.

Keywords: Paper board industry; Effluent treatment plant; Zero liquid discharge; Scanning electron microscopy; Reuse and recycling; Sludge

Introduction

Water is an essential raw material for manufacturing of paper boards, and effluent treatment is critical part of this process. The paper boards industry is highly evaluated for effective reuse of the waste paper and for its attitude toward effective use of precious resources on earth. The waste paper once used only as paperboard has come to be used as newspaper, writing paper. The produced wastewater has detrimental impacts on the environment and poses a serious threat to the wild and human life [1]. The pulp and paper industry is ranked as the third world's largest consumer of water and is consequently producing high amounts of wastewaters [2]. The environmental impact of pulp and paper industry is a particular concern since these units generate 150-200 m^3 effluent/ton paper with a high pollution loading of 90-240 kg suspended solids /ton paper, 85-370 kg biochemical oxygen demand (BOD)/ton paper and 500-1100 kg chemical oxygen demand (COD)/ ton paper [3] and it is sixth largest polluter in the world (after the oil, cement, leather, textile, and steel industries) and emits a variety of gaseous, liquid, and solid wastes to the surroundings [4]. As per the Ministry of Environment and Forest (MoEF), Government of India, the pulp and paper sector is in the "Red Category" list of 85 industries having a high polluting potential CPCB (2016). Pulp and paper industry play a vital role in socio-economic development, while it is associated with significant environmental concerns due to its large footprints on environmental resources.

The researchers are more focused on environmental friendly technologies for the treatment of wastewater. Therefore they use biological approach for the removal of contaminants from the effluent. There are numerous aerobic biological treatment systems available, but the most common is the activated sludge process, which can achieve high removal efficiencies for BOD and COD [5,6]. The biological treatment process able to reduce COD, BOD, and toxic low molecular weight derivatives. Pulp and paper industry uses conventional activated sludge treatment process in which they are using nonspecific micro-organisms and they kept food/microbe (F/M) ratio low in the aeration tank. They are maintaining the effluent treatment plant with high MLSS in order to buffer the BOD, pH, wastewater composition or temperature. The manufacturing process depends upon the demand therefore the raw material changes accordingly, which in turn changes the ultimate pollution load in the wastewater.

Study Area

This study carried out from the M/s Senthil Papers and Boards (P) Limited, Tamil Nadu, India (Latitude- 11°29'54.13"N and Longitude -77° 9'32.50"E), a capacity of paper board manufacturing was 15,125 TPA (Ton/annual). A schematic overview covering the processes of main interest within this project is provided in Figure 1. The streams of wastewater originate primarily after several processes *viz.* secondary fiber treatment (SFT), board machines (BM) and coating chemical kitchen (CCK) is discharged as a wastewater to biological wastewater treatment plant.

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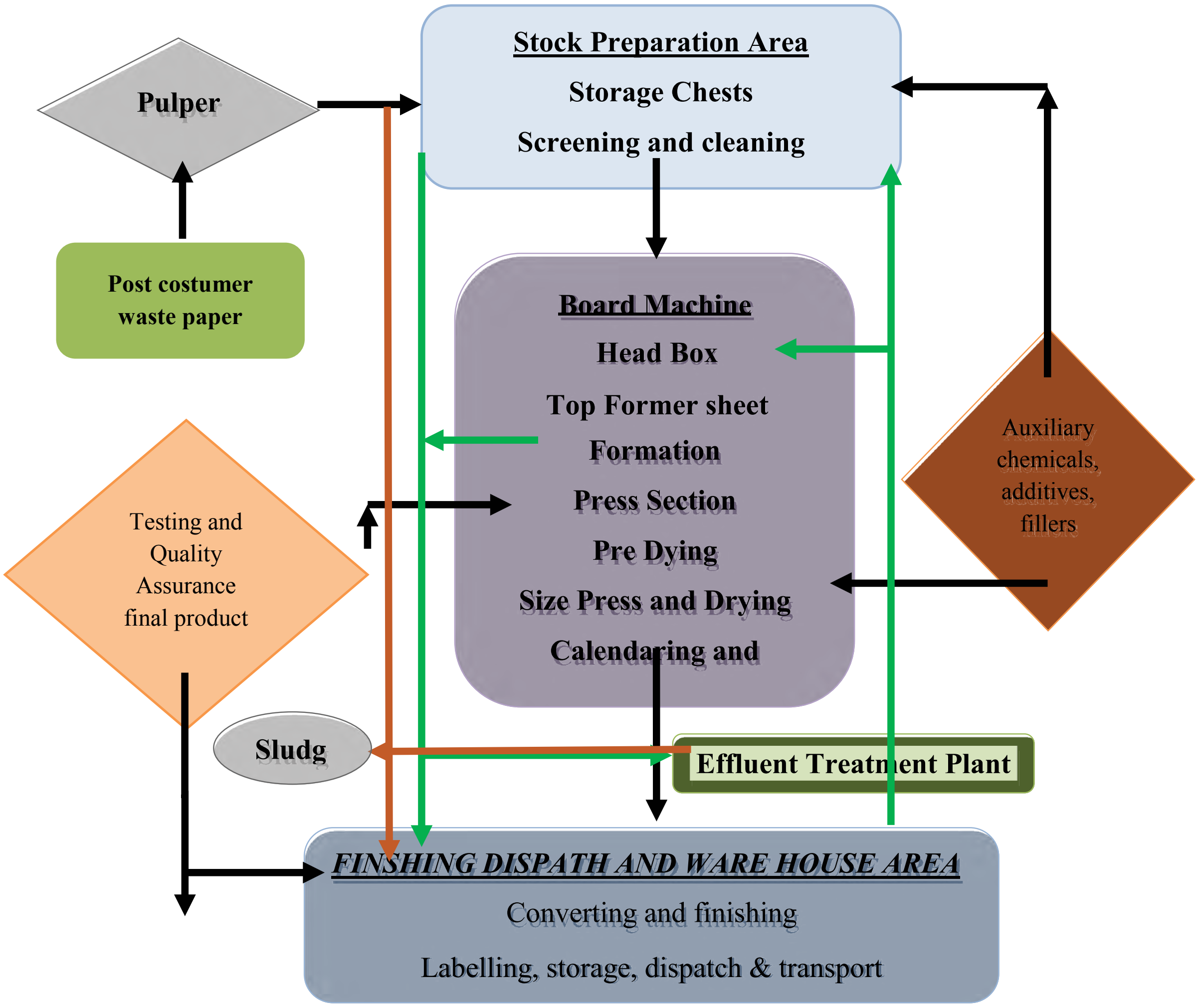


Figure 1: Simplified schematic diagram of paper board manufacturing processes.

Effluent treatment plant components

The wastewater generated from pulping process contains high concentration of BOD, COD and TSS, which subsequently undergo activated sludge process for the treatment. The ETP comprises of the following units, viz. drum screen, sedicell, equalization tank, primary clarifier, conventional Aeration, secondary clarifier – A, extended aeration, secondary clarifier – B, tertiary clarifier, chlorination, milt grad sand filter and mechanical dewatering devise (MDD). The activated sludge plant treats an average of 4000 m^3 wastewater per day. Other technical information, wastewater characteristics and operation condition can be found in Tables 1-3 and the schematics of the ETP depicted in Figure 2. The effluent is first passed through screened with coarse filters (bar screen), and followed by dram screen for removal, of plastic and other floating materials in the pre-treatment stage. The effluent pumped into sedicell fiber recover system with addition of flocculent (4 kg/d) to remove the bottom and top of flotation pulp with 6-7 par presser of air dissolving tube (ADT) system and output of effluent less than 50 ppm of TSS and effluent collect an equalization basin and after fiber/pulp recovery the raw effluent will be neutralized in equalization tank with coarse bubble aeration system with air blowers are provided for equalization of raw effluent and surge control and will be taken to primary treatment where flocculants and coagulants are used to remove suspended solids.

In convention aeration tank added nutrient for microbial activation purpose and surface aerators are provided in aeration basins for oxygen transfer and mixing of biomass with wastewater. This is aerobic biological treatment process where the bacteria decompose the organic matter in presence of oxygen. The extended aeration system works in the lag growth phase of the bacterial growth curve i.e., endogenous phase. To maintain requisite MLSS and food to micro-organism ratio (F/M), part of settled sludge from Secondary Clarifier will be re-circulated back to the aeration tank. In addition diffused aeration arrangement also provided at the periphery of aeration tank which will ensure mixing of sludge once in a while. The clarifier is a hopper bottom circular tank with centrally driven clarifier mechanism. In clarifier solids get settled at the hopper bottom. The supernatant from the clarifier overflows uniformly over the peripheral launder. A part of sludge from clarifier re-circulated back to aeration tank while balanced is sent to thickener through sludge pump. Effluent from secondary clarifier-B shall be entering into the accelerated gravity separator. AGS is high rate treating clarifier, which produces treated water of highest quality with minimum time, space and chemicals. The supernatant from AGS overflows uniformly over the peripheral launder. It will

S No	Parameters	Hydraulic Retention Time (Hrs)	Volume (m³)
1	Mechanical Drum Screen	0.4	12
2	Sedicell	1.9	350
3	Equalisation Tank	15	2500
4	Primary Clarifier	4.2	700
5	Aeration Tank - I	36	6000
6	Secondary Clarifier -A	5.4	900
7	Aeration Tank - II	15	2500
8	Secondary Clarifier -B	6	1000
9	Tertiary Clarifier	4.2	700
10	Hypo Contact Tank	2.4	400
11	Treated Effluent Tank	2.4	400
12	Fiber Sludge Thickener	2.6	80
13	Biological Sludge Thickener	0.5	14

Table 1: Technical information of the wastewater treatment plant at SPBPL.

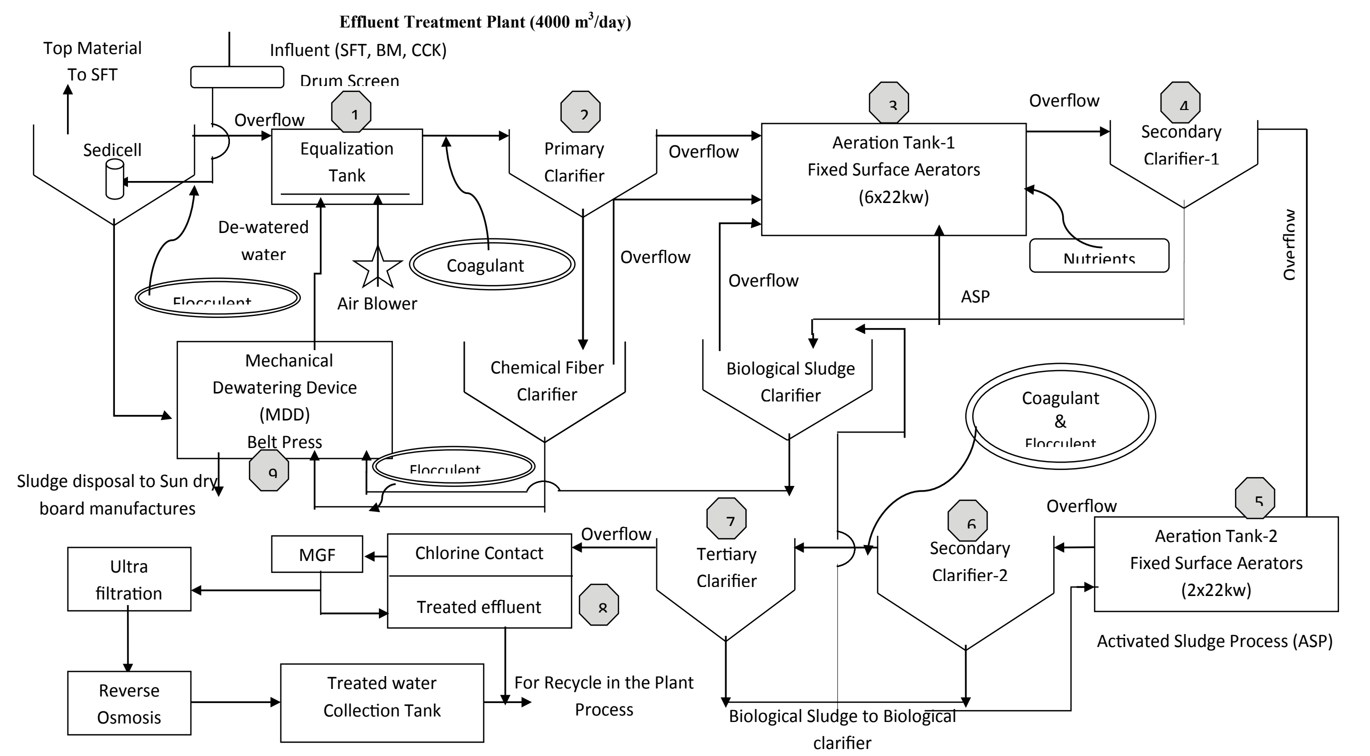


Figure 2: The schematic diagram of paper board industry effluent treatment plant at SPBPL (ZLD).

enter in Hypo contact tank then Multi Grade Filter (MGF) feed tank. Treated effluent will then be pumped to an entire treated effluent recycles to board manufacturing process. The sludge generated from primary treatment and biological system taken sludge produced in the process is taken to the belt press dewater well be routed back to the treatment system.

The high costs associated with the plant and their operations require a wise optimization of the process. In recent years various systematic design approaches to wastewater reuse across complex manufacturing operations have been developed [7-11]. Because economic benefits are undoubtedly a major driver for industry to implement wastewater reuse programs, recent research in this area has focused on the economic optimization of wastewater reuse systems [12-15].

In the present research is to treat the paper board industry wastewater in biological oxidation in the meaning of environmental friendly manner and also to know the influences of Temperature, pH, F/M ratio and DO concentration on the microorganism's growth and pollutant removal and to assess the biodegradability of the wastewater and also to recycle and reuse the waste for economic profits and suitability of a zero discharge system to paper board industry.

Materials and Methods

Samples collection and analytical methods

Wastewater from different streams was collected together as received finally by the ETP through a single drain. For the present study, effluent samples were collected from over flow of sedicell, primary clarifier, aeration tank-A, secondary clarifier -A, aeration tank –B, secondary clarifier –B, Tertiary clarifier and MGF. The liquid waste parameters such as pH, Temperature, TDS, TSS, COD, BOD, Cl and SO_4 were monitored at influent and treated effluent. All the samples were analyzed using analytical grade chemicals and all the parameters were analyzed using the Standard Methods for the Examination of Water and Wastewater of the American Public Health Association (APHA, 1995) and are approved by the U.S. Environmental Protection Agency (USEPA). In solid waste sample analyses were performed in Scanning Electron Microscopy (SEM) quanta FEG 250 FEI Company, Czech Republic and Perkin Elmer optima 5300DV ICP-OES.

Results and Discussion

Wastewater characteristics

Pollution loading of the paper board industrial wastewater depends significantly on the raw material used. Wastewater characteristics were analyzed in order to see the fluctuations in loadings during board machine production process. The effluent was characterized for various physicochemical parameters like: pH, Temperature, TSS, TDS, Chloride, Sulphate, BOD, COD and Oil and Grease in a process step wise showed in Table 2.

ETP performance

This analysis will give us a brief idea of ETP performance and efficiency of process to pollution load handle daily by the industrial persons. The wastewater was collected over a period of study and the results were depicted in Figures 3-11.

Temperature: Temperature was greatly affects the activity of

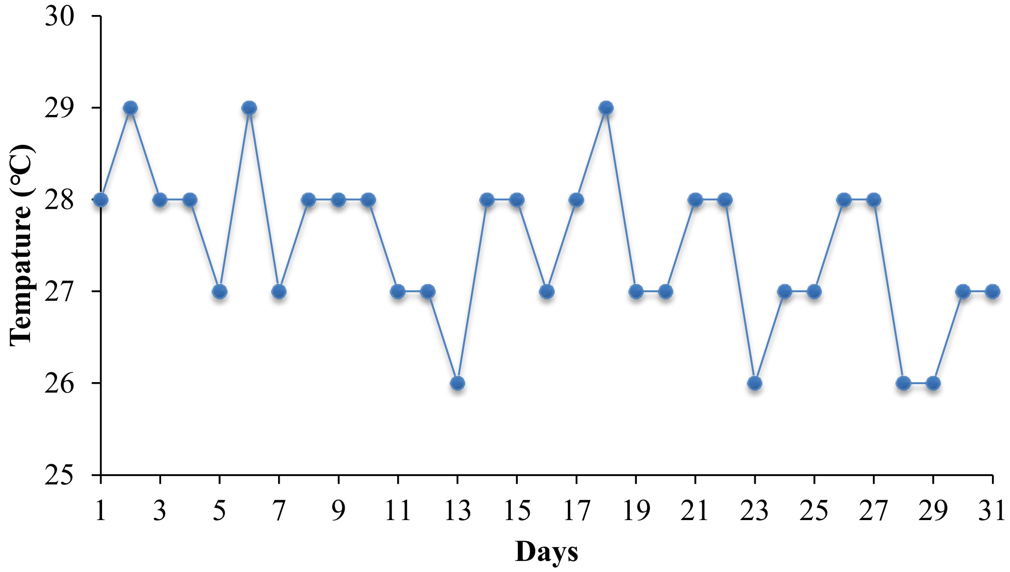


Figure 3: Variation in the process temperature for the period of study.

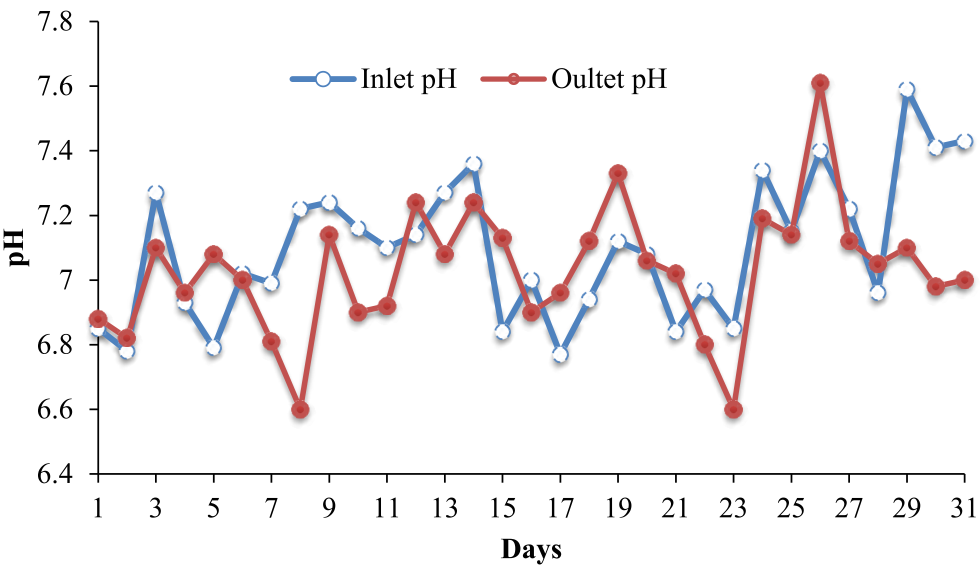


Figure 4: Variation in the pH profile in influent and treated effluent for the period of study.

microbes [16]. There are different types of bacteria (Psychrophiles exist at 5°C-35°C, Mesophile at 25°C-40°C and Thermophiles at 25°C-75°C) depending on the temperature range. Figure 3 shows that the range of temperature observed during the one month study of wastewater characteristics fall between 25°C - 30°C.

pH: pH of wastewater is very important to be monitored as it determines the feasibility of a particular sample to be biologically treated [17,18]. Biological treatment can be suitably applied to wastewater only if pH values are near neutral. Acidic and basic character of the wastewater has negative effect on the microorganisms and thus leads to inefficient treatment [19]. The normal pH in wastewater for bacterial survival is 5 to 9. But, neutral pH i.e., about 6.5-7.5 is required for the optimum activity of the bacteria. If the pH is in acidic range fungi can become predominant than the bacteria which will results in poor settling. If the pH is too high it will affect the metabolic activity of the microbes which directly affects the treatment process [20]. For bacteria there is an orderly increase in growth rate between the minimum and maximum pH. Figure 4 showed that the levels of pH in the conversional treatment process influent and treated effluent range between 6.6 to 7.6 and 6.8 to 7.5 respectively. The additions of coagulants (non-ferric alum) depress the wastewater pH to a lower or higher value. The decrease in pH after the addition of coagulant may be due to the several hydrolytic reactions, which are taking place during coagulation, forming multivalent charged hydrous oxide species and generating H_3O^+ ion during each step, thus reducing the pH value [21]. It has also been reported that the coagulant addition depresses pH to highly acidic levels, as the coagulant dose is highly correlated with pH [22]. It is supposed that improvement of flocculation pH may reduce the alum dose needs for the optimization of the process. It can be said that the highest range of pH exists between 6.0 and 8.0, beyond which the effluent quality deteriorates.

Effluent flow rate: The effluent flow rater and hydraulic react time is induced the performances of the process and the desired degree of treatment. It is an important parameter because industrial persons cannot hold their wastewater within their premises for longer period. Figure 5 clearly shows that the flow rate of the influent 4396 m^3/d (Max) and 1816 m^3/d (Min) and treated effluent 3232 m^3/d (Max) and 1456 m^3/d (Min), respectively. The maximum and minimum input of influent not affects the treatment process. Wastewater aeration time, usually expressed in hours, is based on the time required by the micro-organisms to degrade the organic load present therein. Table 3 shows that the hydraulic react time of each system.

Dissolved Oxygen (DO): Dissolved oxygen supplying with 22 kw surface fixed aerators in conventional aeration take (6 Nos) and extended aeration tank (2 Nos). DO is required by the microorganisms to respire properly in aeration tank (Figure 6). Too much oxygen adds unnecessary cost due to increased power consumption and too little

System Condition	Levels
Effective volume	4000 m^3
Influent flow rate	165 m^3/Hr
HRT	36 Hr
pH	06 Jul
Dissolved Oxygen	2-4 mg/L
Influent BOD	200-300 mg/L
Influent COD	1000-2500 mg/L
MLSS	5000 mg/L
MLVSS	3000 mg/L

Table 2: Operation condition of the conventional treatment process.

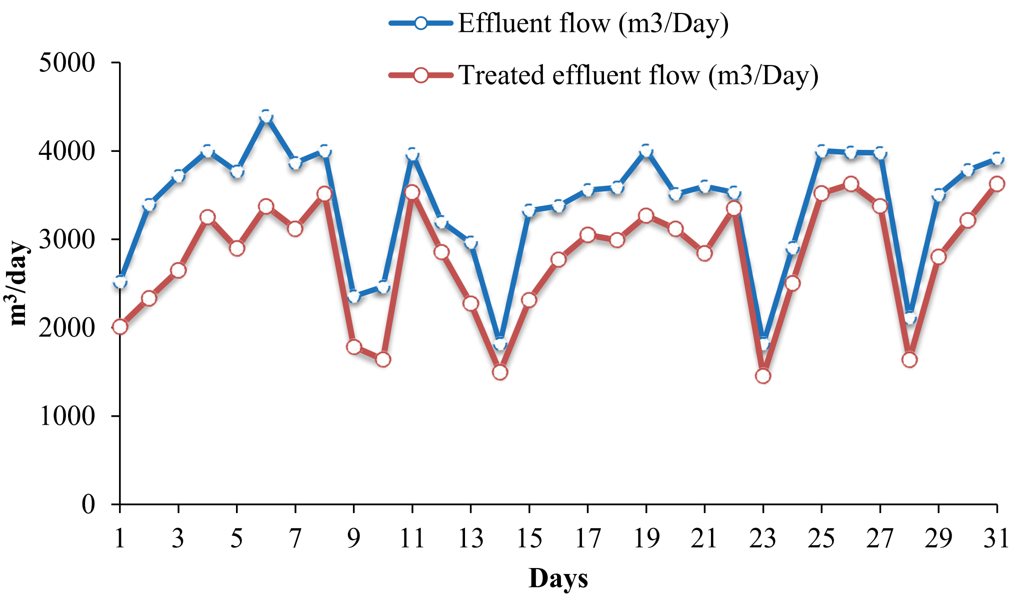


Figure 5: Variation in the influent and treated effluent flow rate for the period of study.

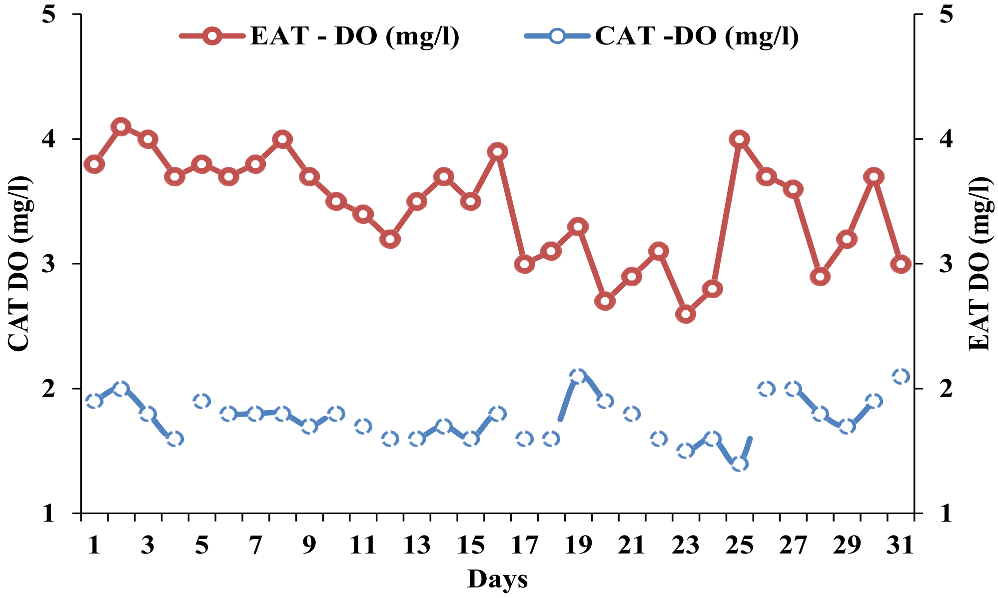


Figure 6: Variation in the aeration tank DO level for the period of study.

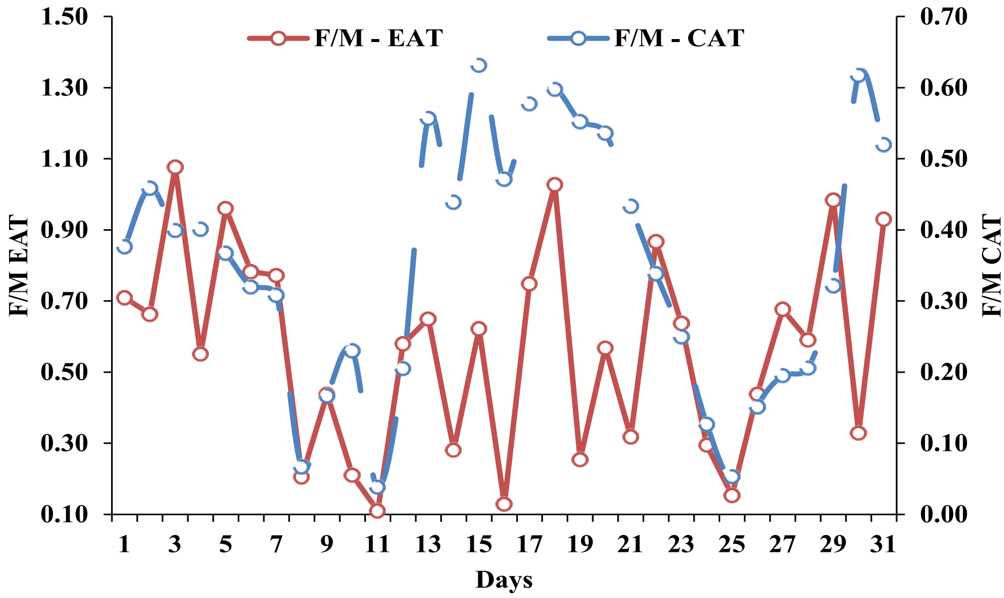


Figure 7: The F/M ratio in effluent treatment plant process for the period of study.

can decrease the metabolism of the micro-organisms and the efficiency of the process. The optimum range for the DO in the treatment plants were in between 2-3.5 mg/L.

F/M ratio: The food to microorganism ratio is defined as the ratio between the amount of food (organic matter) entering the treatment plant and the mass of micro-organisms (MLSS) in the aeration tank [23]. The F/M ratio is an important control parameter as the quantity of biomass present will influence the removal efficiency. The F/M ratio is indirectly proportional to the MLSS. If F/M ratio is low, then MLSS is high with low dissolve oxygen concentration. Due to which filamentous bulking occurs that cause poor settling problems. Figure 7 shows that the conversional and extended aeration tank F/M ratio effective to treat the wastewater. If F/M ratio is high then, MLSS is low which will affect the treatment process. If any fluctuation occurs in the production process and the wastewater entering the treatment system with high organic load than at that time the entire system fails because this will not be encountered properly by the low MLSS treatment system. This treatment results in effective BOD removal but face several problems. Low F/M ratio leads inadequate food for the population of microorganisms and problem arises in maintaining the sufficient dissolved oxygen concentration [24].

Nutrient dosing: Levels of nitrogen and phosphorus in paper board industry effluents are usually low compared to municipal sewage. Nitrogen and Phosphorus are the essential elements other than the carbon for the proper growth and activity of the microorganism present in the aeration chamber [25]. Pulp and paper industrial effluent is rich in carbon source due the raw material used but, wastewater is deficient in N and P [26]. For effective treatment of wastewater, significant quantity of N and P must be added because micro-organisms present in the effluent require N and P to produce enzymes for the degradation of organic matter present. These observations are in close agreement with other's findings [27,28]. Insufficient N can result in filamentous and dispersed growth of microbial population which settles poorly. As a general rule the ratio of N and P required with respect to BOD load is 100 BOD :5 N :1 P. Although nitrogen limitation has been reported as an important factor in inducing ligninolytic activity and ligninase production in several white rot fungi [29,30].

Sludge Volume Index (SVI): The sludge produced in physical–chemical treatments is due to the organic matter and total solids in suspension that are removed and the compounds formed with the coagulants used, since practically all of the latter become part of the sludge solids. In general, the amount and characteristics of the sludge produced during the coagulation process depend on the coagulants used and on the operating conditions. Sludge settleability was determined by measuring the SVI, which is the volume of MLSS after 30 min of settling. The SVI in coagulation process is generally governed by three factors: high polymer effect, osmotic pressure effect and hydration effect [31]. The SVIs measured throughout the study and its important parameter for the treatment of wastewater. SVI is used to assess the settling qualities of sludge and minimum and maximum values were 52 and 109 respectively (Figure 8). It is reported in literature that SVI can vary from 30-400 mL/L [32]. But it is also mentioned that if the value increased from 150 mL/L the plant operator should face the problem of sludge bulking [33].

BOD and COD removal: Aerobic treatment currently use on site biological treatment. There are numerous biological treatment systems available, the most common being the activated sludge process. BOD and COD the pulping process plays a central role in the pollution load and composition of the wastewater produced by the pulp and paper mills [4]. SFT house liquors contain high amounts of chemicals, lignin, residual fibres, etc., which result in increased levels of BOD and COD as high as 400 and 2500 mg/L, respectively. The BOD and COD levels of influent wastewater varied from 80-240 mg/L and 545-1817 mg/L respectively. Whereas the BOD and COD levels of effluent varied from 16.5-6.4 mg/L and 54.1-156 mg/L respectively. Figures 9 and 10 clearly shows that the levels of BOD and COD values show that the removal percentage is 91.27- 95.60% and 77.04 - 94.05% respectively. These show that very high removal efficiency can be obtained both for BOD and COD removal. These reduced to certain extent due to biological treatment process for which the effluent is treated which consists of equalization, primary clarifier, aeration tank, secondary clarifier, tertiary clariflocculator and MGF. Biological treatment process results in oxidation of organic matter, which provides energy for microbial metabolic process. It could be argued that there are two critical operational aspects of an activated sludge plant; maintaining a proper control of the dissolved oxygen (DO) concentration in the aeration tank and maintaining a good settling sludge. After observing the results the reduction obtained in case of BOD, and COD, were 93.7 and 88.3% respectively with 79 Sludge Volume Index (SVI).

Total dissolved solids and total suspended solids: High amounts of dissolved solids that are commonly known as TDS. The biological treatment process cannot reduce TDS to any significant extent and the efficiency of the system can be greatly affected by high TDS [34]. The major portions of such solids are inorganic and present mostly in ionic form. Nowadays, removal of dissolved solids from industrial wastewater is a challenging job for the environmental engineers. Inorganic components of dissolved solids are more difficult to remove by biological processes. Membrane separation (ultra-filtration) [35,36] or reverse-osmosis [37] are the treatment technologies that can be employed for TDS removal. Total Dissolved Solids were also alarmingly high in treated effluent, crossing the 2,100 mg/L limit set by the Indian regulatory authorities (Table 2). Table 2 shows the total dissolved solids concentration from inlet 1599 mg/L whereas from treated effluent 1946 mg/L respectively. TDS is also one of the often-neglected parameters, even though it can have tremendous effects on the overall quality of water. In this site especially TDS control purpose installed tertiary treatment for ultra-filtration (UF) followed by reverse-osmosis (RO). Membrane treatment in paper board industry serves to optimize loop closure and therefore helps to reduce fresh water intake as well as wastewater treatment.

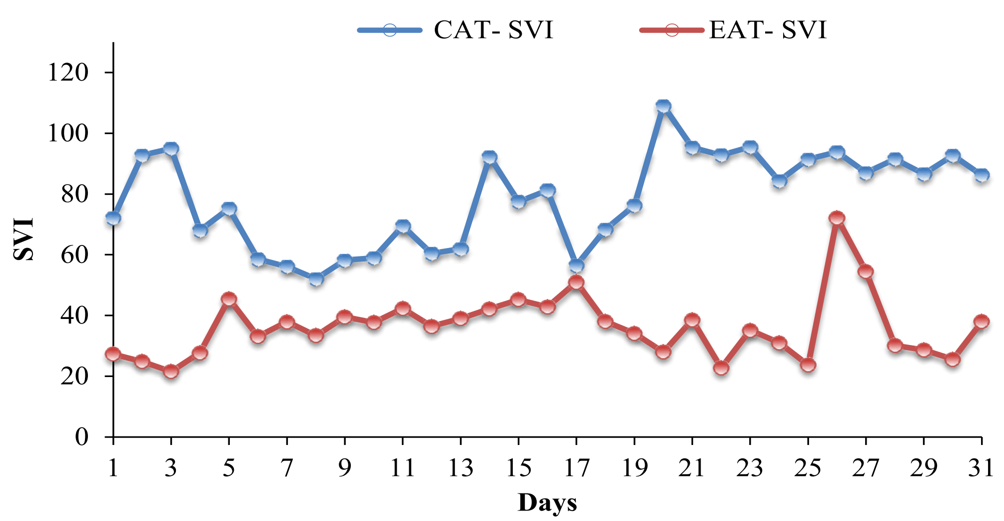


Figure 8: Variation in the SVI characteristics of the activated sludge produced in the treatment of paper board industry wastewater for the period of study.

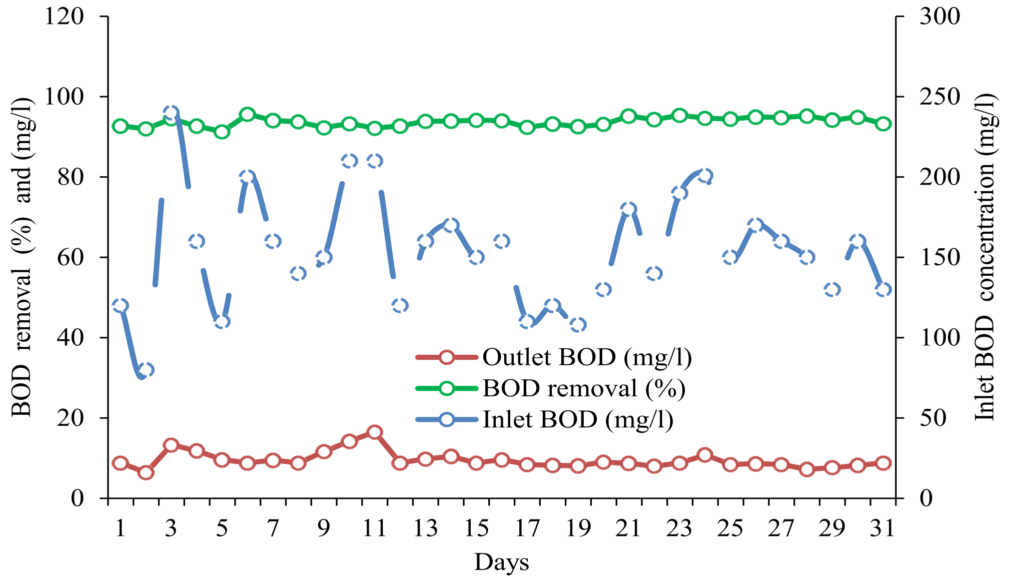


Figure 9: Effluent BOD concentrations and removal efficiency for biological oxidation treatment of paper board industry wastewater for the period of study.

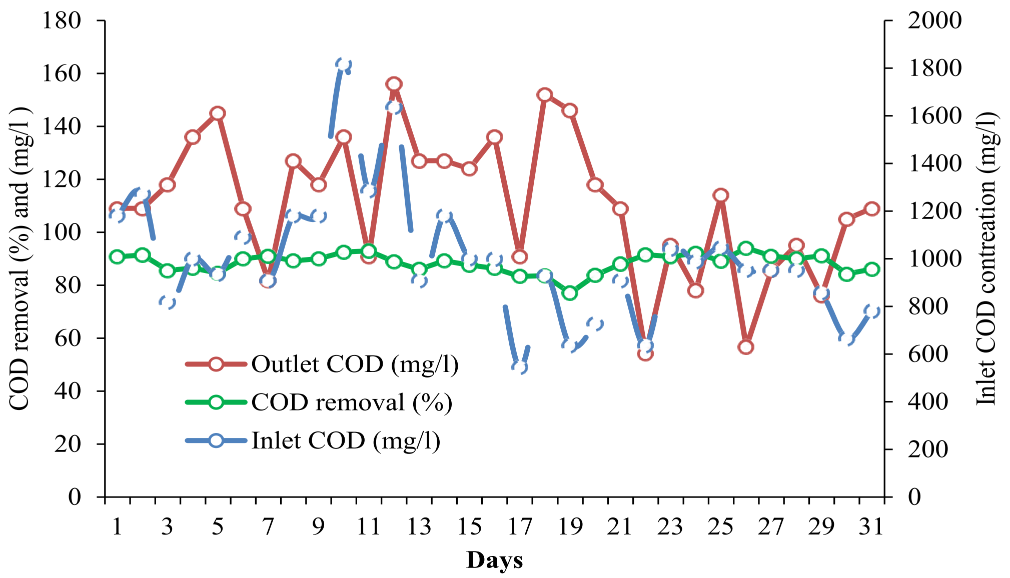


Figure 10: Effluent COD concentration and removal efficiency for biological oxidation treatment of paper board industry wastewater for the period of study.

Table 2 shows the concentration of suspended solids measured from influent 756 mg/L after treatment the concentration of suspended solids measured from treated effluent 12 mg/L respectively. ETP operation performance to total suspended solids reduced 74% due to the presence of sedicell recover fibres system in ETP. A sedicell removes solids by means of dissolved air flotation and sedimentation simultaneously. Floatation of solids occurs because of air bubbles introduced into the feed water. Clarified water from the outlet of the sedicell is pumped under pressure through an air dissolving tube where air under pressure is dissolved in the water. This air stays in solution as long as the water is at pressure. The pressure is released by a special globe valve, just before this water is injected into the feed line. This pressure reduction causes the air to come out of solution and form millions of tiny air bubbles, which then attach themselves to the solid particles in the feed water. These bubbles cause the solids to float to the surface of the sedicell where they can be removed by the spiral scoop. The recover fibres send back the stock preparation plant tower. The sedicell overflow wastewater less the 50 mg/L of TSS directly raw effluent reused in SFT plant, so that reduced the wastewater treatment cost and sludge production less in ETP primary clarifier. An economic perspective the sedicell recovered fiber again used in paper board manufacturing process and indirectly raw material wastage avoided and also raw material procurement cost saved.

Energy consumption of aeration system: The biological treatment system has eight surface aerators (each 30 hp, 1 horsepower hour=0.746 kWh^{-1}). The energy consumption of aerators 179.04 kWh^{-1}, the activated sludge process most efficient technology for the removal of pollutants depends on the nature of the pollutant. However, the cost of the treatment terms of electrical units ($kWhm^{-3}$). In the case of ETP, the estimation of the price per unit (oxygen added), as the aeration is directly related to the specific energy consumption of aerators ($kWhm^{-3}$), tank volume 8500 m^3 and the energy consumption can be obtained from this value by using Eq. (1), Once the energy consumption has been calculated, the price of the power unit permits the price of the oxygen transfer dose to be calculated:

$$\text{Power (W)} = \frac{(\text{HP})(0.746\,\text{kW/ hp})(\text{Day})}{\text{Motor efficiency}(0.9)} = 4774.4\,\text{kWhm}^{-3}/\text{day} \quad (1)$$

Solid waste

Generally, the paper and board manufacturing units practice recycle and reuse the treated effluent for the secondary fiber treatment process and by-products from ETP Primary sludge is generated in the clarification of process water by kidney treatments, e.g., dissolved air flotation. The sludge consists of mostly fines and fillers depending on the recovered paper being processed and it is relatively easy to dewater. Secondary sludge are often difficult to handle (due to a high microbial protein content), and such solids need to be mixed with primary sludge to permit adequate dewatering [38]. The paper and board manufacturing units about 300 kg of sludge is produced for each 1 ton of recycled paper [39]. The mechanical dewatering of paper board industry sludge is usually performed using a series of process units, such as gravity table or rotary thickener followed by a belt press or a screw press, as each process unit operates in different ranges of the total solids content. Primary and secondary sludge it is either recycled to the product: Sun dry board and composting respectively.

Sludge physical and chemical properties: Sludge showed a wide range of humidity 65 ± 15. Variability depended on the method used to clarify and dewater sludge, and the presence of chemicals (polyelectrolytes) used to aid. The Proximate analysis of paper board industry sludge shown in Table 4. The main organic components of the sludge are cellulose fibers, hemicellulose, lignin and, to some extent, also organic binders and process chemicals which are all residues from the processes and enter the biological wastewater treatment plant via the process water flows circulating in the process. The chemical compositions in the form of oxides are showed in Figure 12. Sludge ash concentrates heavy metals, however, and if their concentration arises hazardous levels, the ash requires special handling [40,41]. Every tone of recovered fiber generates up to 200 kg (dry weight) of sludge of different types and up to 400 kg (dry weight) of rejects and sludge.

Sludge structure analyses: The sludge generated by the biological wastewater treatment process at pH=7 and the fractured concrete specimens were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray microanalysis (EDS). The sludge is flocculating suspension liquid, which is made up of living or dead microorganism in network structure of extracellular polymeric substance, mixing some organic and inorganic. Sludge present in the form of complex floc structure. There are a lot of pore holding too much water in those floc structure. SEM image can be shown that Figure 12a, the shape of sludge is irregular loose body, which has much pore on surface filling with a number of small grains and holding a lot of floc, forming irregular structure. The sludge shows a heterogeneous morphology, as shown in Figure 12b. Its elemental composition as determined by EDS results show that the amount of carbon (12%), oxygen (25%), calcium (47.28%), chloride (1.85%) silica (4.52%) and aluminum (8.35%). The counts referred to the lowest energy 0.25 -0.5 keV. The peak at 1.5, 1.8 2.7 and 3.7 keV was assigned to Al, Si, Cl and Ca respectively. The sludge contained more silica and calcium than that of the other inorganic elements. This may be the reason for calcium and oxygen is mainly present in calcium carbonate, which is used as filler and coatings in paper board making process.

Sludge macro and micro nutrient: The macro and micro elements contents of paper board industry sludge change dramatically based on the sludge source. Metals occur in sludge in various physicochemical forms, such as soluble, adsorbed, exchangeable, precipitated, organically, complexed, and residual phases. They used it to fractionate metals into the following fractions: (1) Exchangeable fraction, representing the most easily available metals, (2) Acid-soluble (carbonate bound) fraction, (3) Reducible (Fe – Mn oxide bound) fraction, (4) Oxidizable (organically+sulphide bound) fraction, and (5) Residual fraction, that is tightly bound to the silicate matrix of the sample. If heavy metals exist as loosely bound fractions, such as the

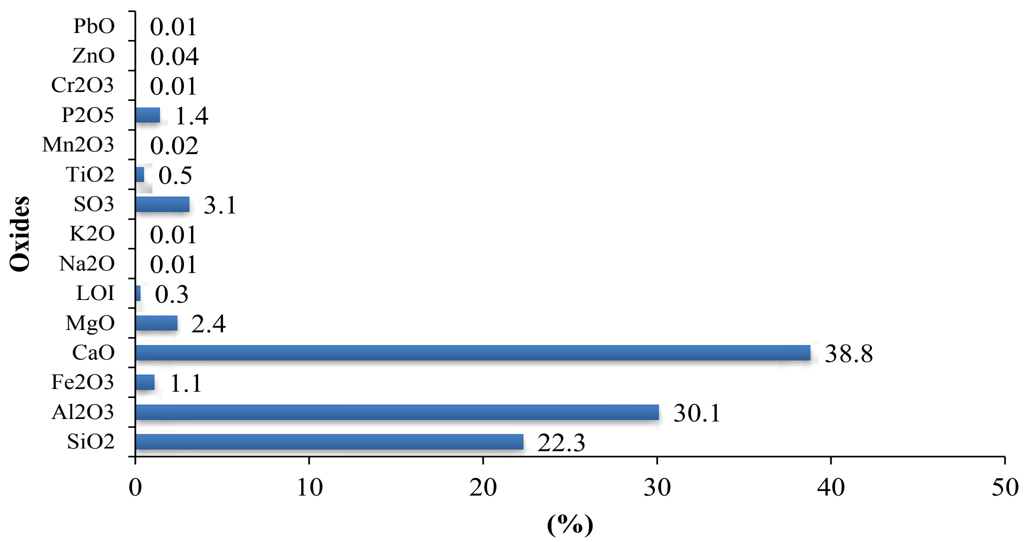


Figure 11: A chemical composition of paper board industry ETP sludge ash.

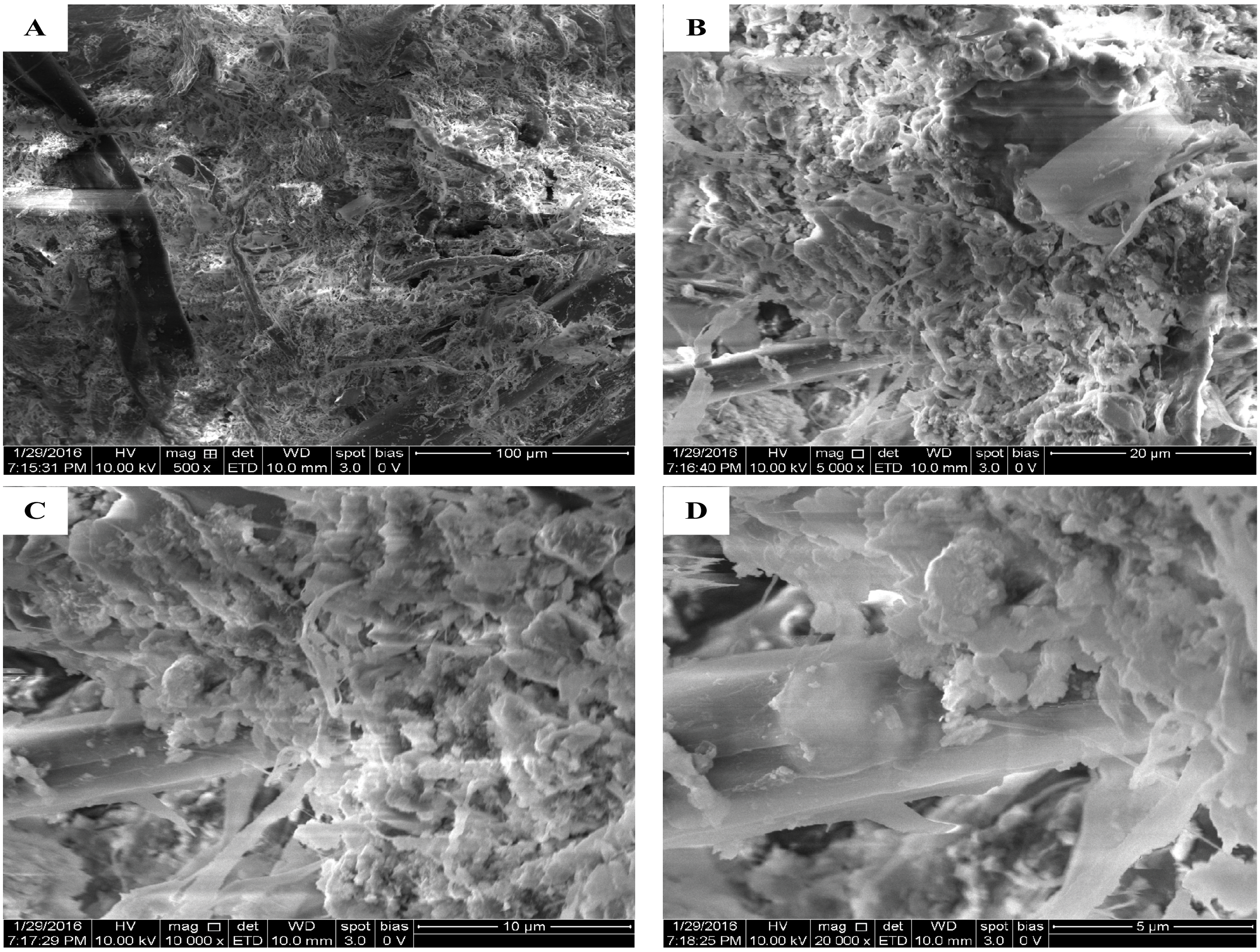


Figure 12a: Scanning electron micrograph of ETP sludge: (a) 500X magnification, (b) 5000X magnification, (c) 10000X magnification and (d) 20000X magnification.

soluble or exchangeable faction, then they tend to be easily moved and dispersed, whereas metals associated with the silicate matrix are not easily separated or mobilized [42-44]. Table 5 also shows that the high amount of K, Al, Fe, Mg and Na with a very small amount of Be, As, Se, Cd and Mo. The high organic matter content and low trace metal and organic pollutants in paper board industry sludge suggest that these residuals may provide a valuable resource for soil amendments.

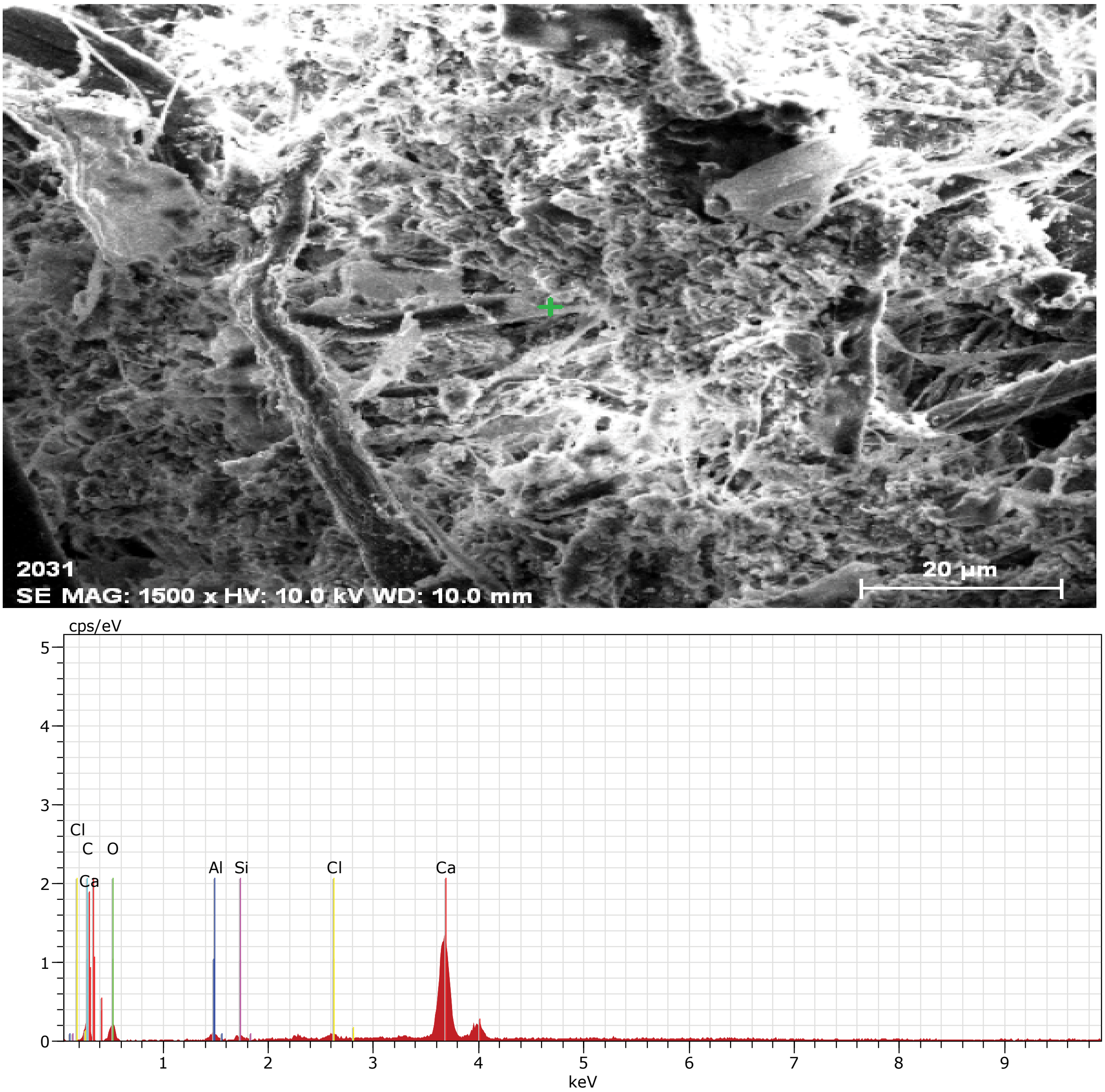
Economic study

Based on the above results, effluent treatment plant economic study for 4000 m^3/d wastewater treatment plant for the paper board industry was conducted. The maximum design parameters of wastewater are illustrated in Table 3. Figure 2 shows the schematic block flow diagram of the effluent treatment system. The fixed capital cost was Rs. 700 lakhs and operation cost (not added RO plant) such as chemicals, energy and maintenance was Rs. 180 lakhs/Annual. The total operation costs were chemical 8%, energy 80% and maintenance 12% respectively.

Conclusions

This study has demonstrated the practical feasibility of biological oxidation during treatment of a paper board wastewater and the conclusions can be summarized as follows:

- The result obtained indicated that biological oxidation has a great potential in treating paper board industry wastewater stable operation and removal performance at where, conventional aeration treatment provided a high reduction of TSS 92.10%, BOD 93.70%, COD 88.33% respectively.
- The paper board industry is adopting zero liquid effluent technologies to reduce freshwater consumption. This implies closure of water circuits and the progressive accumulation of pollutants that must be removed before water reuse. Based on the result biological wastewater treatment plant pollutants removal too high and zero liquid effluent technologies without RO operation. But the TDS concentration increased due to the entire treated effluent recirculation in the process. The TDS concentration reducing purpose using RO plant.
- Solid waste from ETP sludge contains significant amount of inorganic compounds, calcium and aluminium is the highest one, silicon and magnesium also present in measurable amount and other macro and micro elements are observed. This sludge disposed in a safe manner in the way of primary sludge sun dry board manufacturing and secondary biological one of the raw material for composting materials.
- The total operation cost played a very important role in determining



El	AN	Series	Coun. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
Ca	20	K-series	41.03	66.06	47.28	1.50
O	8	K-series	8.68	13.97	25.05	2.26
Al	13	K-series	4.88	7.85	8.35	0.43
C	6	K-series	3.38	5.44	12.98	0.93
Si	14	K-series	2.75	4.42	4.52	0.28
Cl	17	K-series	1.40	2.25	1.82	0.13
		Total:	62.11	100.00	100.00	

Figure 12b: SEM- energy dispersive X-ray microanalysis for paper board industry sludge.

S No	Parameters	Units	Equalization	Primary Clarifier	Aeration Tank - I	Secondary Clarifier -A	Aeration Tank - II	Secondary Clarifier -B	Tertiary Clarifier	Treated Effluent	SPCB stranded
			1	2	3	4	5	6	7	8	
1	pH		7.19	7.11	7.22	7.38	7.23	7.56	7.42	7.5	6.5-8.0
2	TSS	mg/L	756	152	5036	16	3980	12	16	12	100
3	TDS	mg/L	1599	1612	1708	1843	1893	1878	1891	1946	2100
4	Chloride	mg/L	734	783	910	881	861	812	822	812	1000
5	Sulphate	mg/L	469	490	585	656	624	651	611	626	1000
6	BOD	mg/L	225	80	1800	4	1100	10	9	9	30
7	COD	mg/L	932	264	4480	88	3200	56	56	56	250
8	Oil and Grease	mg/L	18	12	24	4*	22	4*	4*	4*	10

*Below detectable limit

Table 3: Characteristics of paper board industry wastewater and ETP stage wise pollutants reduction.

Sludge	Proximate analysis				Sodium (%) ODB*	Chloride (%) ODB*	Calorific Value (kCal/kg)
	Moisture (%)	Volatile Mater (%)	Ash (%)	Fixed Carbon (%)			
Primary and secondary clarifier	61.7	31.7	6.4	0.2	0.9	0.3	1879

*On dry base

Table 4: Proximate analysis of paper board industry ETP sludge.

S No	Metals	Mass	Concentration (mg/kg)
1	Be	9	0.0002
2	Na	23	8.7333
3	Mg	24	9.7866
4	Al	27	61.8084
5	K	39	1.2967
6	Cr	52	0.1594
7	Mn	55	0.4242
8	Fe	57	11.5066
9	Ni	60	0.1526
10	Cu	63	0.3272
11	Zn	66	0.4698
12	As	75	0.0032
13	Se	82	0.0003
14	Mo	98	0.0408
15	Cd	111	0.0048
16	Pd	208	0.1118

Table 5: Macro and micro elements of paper board industry ETP sludge.

the treatment cost. The observed result indicate that further reduction in the operation cost for energy can contribute strongly to reduced the total treatment cost.

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Measurement of Dynamic Viscoelasticity of Full-Size Wood Composite Panels Using a Vibration Testing Method

Cheng Guan, Houjiang Zhang, John F. Hunt, Lujing Zhou, and Dan Feng

The dynamic viscoelasticity of full-size wood composite panels (WCPs) under the free-free vibrational state were determined by a vibration testing method. Vibration detection tests were performed on 194 pieces of three types of full-size WCPs (particleboard, medium density fibreboard, and plywood (PW)). The dynamic viscoelasticity from smaller specimens cut from the panels was measured using a cantilever beam vibration test apparatus, and the two data sets were compared. A strong linear relationship was discovered between the dynamic viscoelasticity values measured by the vibration detection test and the cantilever beam vibration test. The storage modulus values of the panels were far higher than their loss modulus values, and PW panels had the smallest value of loss modulus. For the panels tested, density had a good linear impact on storage modulus. In comparison with density, logarithmic decrement had a greater linear impact on loss modulus. This study demonstrated that the vibration test method is a valid approach for determining the dynamic viscoelasticity of full-size WCPs.

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Cheng Guan,[a] Houjiang Zhang,[a,]* John F. Hunt,[b] Lujing Zhou,[a] and Dan Feng [a]

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Key words: Full-size wood composite panel; Dynamic viscoelasticity; Storage modulus; Loss modulus; Vibration testing

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INTRODUCTION

Engineered wood composite panels (WCPs) are widely used in furniture production, construction, packaging, transportation, musical instruments, and other sectors. Full-size WCPs refer to panels with a nominal size (length × width) of 2440 mm × 1220 mm, which are the most common in production and sales. To make use of full-size WCPs reasonably and effectively, accurate measurements of their mechanical properties are essential; thus, these measurements have been the focus of research for many years.

Modulus of elasticity (MOE) and shear modulus are two key indexes for evaluating the mechanical performance of WCPs. Conventionally, non-destructive techniques have been used to determine these performance parameters in WCPs. Most studies conduct non-destructive testing of MOE and shear modulus of small wood composites specimens and full-size WCPs, with remarkable results (McNatt *et al.* 1990; Shyamasunder *et al.* 1993; Larsson 1996; Yoshihara 2011; Wang *et al.* 2012; Hunt *et al.* 2013; Guan *et al.* 2015). However, similar to wood material, WCPs also exhibit dynamic viscoelastic effects. Dynamic viscoelasticity mainly refers to hysteresis phenomena and mechanical losses under the action of cyclic stress and strain. Its main parameter indicators include storage modulus and loss modulus. Storage modulus reflects the material's elastic stiffness, and loss modulus reflects the damping properties of the material. Both moduli are important reference indicators for determining the mechanical properties of the material itself that affects the use of WCPs. Reports on the dynamic viscoelasticity on full-size WCPs are relatively rare. Current test equipment, such as dynamic mechanical analyzers (DMA), are generally limited to smaller samples with a thickness of no more than 10 mm. For thinner materials, the dynamic viscoelasticity of two types of hardboard have been tested using the vibrating reed method by means of non-destructive dynamic vibrations (Moslemi 1967). A cantilever beam apparatus was developed for determining dynamic viscoelasticity of wood or composite materials, and it quickly and accurately determines the dynamic viscoelasticity of small specimens of wood or WCPs (Yan 2010; Zhou *et al.* 2014b). Currently, there are no test methods or equipment that have been useful for determining the dynamic viscoelasticity for full-size WCPs.

Based on "free-free" vibration theory and support conditions, a laboratory test apparatus was developed to determine the dynamic MOE for full-size WCPs (Guan *et al.* 2015). This work is a continuation of initial research to determine the dynamic viscoelasticity of full-size WCPs using this apparatus. The objective of this paper is to examine the feasibility and validity of the vibration testing method for assessing dynamic viscoelasticity for full-size WCPs. Vibration detection tests were performed on 194 pieces of full-size WCPs. The panels tested included particleboard (PB), medium density fiberboard (MDF), and plywood (PW), over a range of thicknesses and densities. To examine the validity of this method, the data was compared with dynamic viscoelasticity measurements obtained from cantilever beam vibration tests performed on specimens cut from the sample panels.

EXPERIMENTAL

Theoretical Basis

The dynamic viscoelasticity (E^*) of the full-size WCP was determined using Eq. 1,

$$E^* = E' + iE'' \tag{1}$$

where E' is the storage modulus and E'' is the loss modulus.

"Free-free" support refers to the panel being supported on its two nodal lines, which are located at 22.4% and 77.6% of its length. A panel's free vibration under this support state is called "free-free" support vibration (Guan *et al*. 2015). Both calculated modal analysis and experimental modal analysis show that the first vibration mode of a full-size panel under this support state is the first-order bending along the length direction of the panel, which is the same as the vibration mode of a beam supported at the same locations (Guan *et al*. 2014; Zhou *et al.* 2014a). Therefore, the related equation for storage modulus and loss modulus of the beam in this support state can be used to derive the equation for storage modulus, Eq. 2, and loss modulus, Eq. 3, of the panel (Guo and Liu 1985). The derived E' and E'' correspond to the storage modulus and loss modulus along the length direction of the panel, respectively,

$$E' = E_{\mathrm{d}} \left[1 - \left(\frac{-\pi + \sqrt{\pi^2 + \Delta^2}}{\Delta} \right)^2 \right] \tag{2}$$

$$E'' = E_{\mathrm{d}}\left[1-\left(\frac{-\pi+\sqrt{\pi^2+\Delta^2}}{\Delta}\right)^2\right]\frac{\Delta}{\pi} \tag{3}$$

where E_d is the dynamic MOE of the panel (Pa) and Δ is the logarithmic decrement of the panel.

According to the transverse vibration of a rectangular orthotropic plate, neglecting shear deformation and rotary inertia, the E_d of the panel can be calculated using Eq. 4 (Zhou and Chui 2015),

$$E_{\mathrm{d}} = \frac{48\pi^2 ML^3 f^2 (1-\upsilon_1\upsilon_2)}{500.6bh^2} \tag{4}$$

where f is the natural first-order vibration frequency in bending along the length direction of the panel (Hz) without damping for this "free-free" support state, M is the weight of the panel (kg), v_1 and v_2 are the Poisson ratios of the panel, and L, b, h are the length, width, and thickness of the panel (m), respectively.

The Poisson's ratios of the panel have a very small influence on the first resonant frequency (Sobue and Kitazumi 1991; Schulte *et al.* 1996). Hence, substituting a constant value for the Poisson ratios will have a small influence on the calculated properties. Here v_1v_2 was assumed to be 0.01 as used for most wood materials (Hearmon 1946).

Free vibration of the panel in this support state appears as a damped sine wave. According to the damped sine wave vibration amplitude, the logarithmic decrement Δ is shown using Eq. 5 (Hunt *et al.* 2013),

$$\Delta = \ln\frac{A_n}{A_{n+1}} = \frac{1}{n+1}\ln\frac{A_1}{A_n} = \frac{2\pi\zeta}{\sqrt{1-\xi^2}} = 2\pi\zeta\frac{f}{f_r} \tag{5}$$

where A_1 is the first amplitude of the damped sine wave selected, A_n is the nth amplitude of the damped sine wave selected, A_{n+1} is the (n+1)th amplitude of the damped sine wave selected, f is first natural frequency of the panel vibration without damping, f_r is first natural frequency of the panel vibration tested, and ζ is the damping ratio.

In Eq. 5, ζ can be calculated using the logarithmic decrement of vibrational decay (Δ) in Eq. 6:

$$\zeta = \frac{\Delta}{\sqrt{4\pi^2+\Delta^2}} \tag{6}$$

According to Eq. 5 and Eq. 6, first natural frequency of the panel vibration (f) can then be calculated using the measured first frequency (f_r), as shown in Eq. 7.

$$f = \frac{f_{\mathrm{r}}}{\sqrt{1-\zeta^2}} \tag{7}$$

When the panel geometry size (L, b, h) is given, the dynamic viscoelasticity values (storage modulus E' and loss modulus E'') for the full-size WCP are obtained by substituting these parameters into Eq. 2 and Eq. 3. This was the theoretical basis for determining dynamic viscoelasticity for the full-size WCP.

Materials

A total of 194 pieces of full-size WCPs were used in this study. There were 67 pieces of PB panels with different nominal thicknesses of 9, 16, 18, and 25 mm; 69 pieces of MDF panels with nominal thicknesses of 9, 12, 15, and 18 mm; and 58 pieces of PW panels with nominal thicknesses of 9, 15, 18, and 25 mm. The MDF panels were provided by a local MDF manufacturer (Krono, Beijing, China). These panels were manufactured from mixed species of both softwood and hardwood using urea-formaldehyde resin. The PB and PW panels were purchased from the local supplier (Beijing, China). So the resin types or other manufacturing characteristics were not available for this test. The PW panels were made from poplar veneer. Table 1 shows the specifications of the full-size WCP samples. The length (L), width (b), and thickness (h) of the panels were measured prior to testing. Average density of the panels was calculated based on the weight and volume. The moisture contents of the panels were determined using the National Standards of the People's Republic of China GB/T 17657-2013 (2013).

Table 1. Dimensions and Physical Characteristics for the Full-size Wood Composite Panels Tested

Panel Code	Quantity (Panels)	Average Panel Sizes (mm)			Average Density (kg/m^3)	Average Moisture Content (%)
		Thickness	Width	Length		
PB9	13	9.01	1222.9	2442.2	658	4.5
PB16	25	16.04	1223.1	2441.0	699	4.3
PB18	24	18.03	1220.2	2437.0	655	5.7
PB25	5	25.19	1219.8	2439.2	672	6.8
MDF9	5	9.01	1222.0	2446.6	771	4.5
MDF12	20	12.03	1221.6	2444.2	827	3.9
MDF15	20	15.07	1222.0	2445.8	882	4.0
MDF18	24	18.03	1221.4	2443.8	773	3.9
PW9	15	9.42	1219.1	2438.1	505	9.4
PW15	15	14.48	1220.9	2439.4	503	10.5
PW18	15	17.01	1221.0	2438.5	522	8.6
PW25	13	24.37	1219.2	2439.5	528	9.8

After conducting the full size vibration test (described below), the measured panels were cut into smaller specimens for the cantilever beam vibration test. One specimen was cut from each full-size WCP along the length of the panel. As for the dimensions of the specimen, to ensure the effects of shear force and rotary motion in the specimen could be neglected, the ratio of free length to thickness were greater than 14.5 (Hunt *et al.* 2013). Detailed dimensions are shown in Table 2. The moisture content has a strong influence on material properties. Unfortunately, a laboratory with constant climate could not be used for the tests. To limit the influence of moisture content on comparison test results, there was a minimal time difference between the full-size tests and cantilever beam tests. The interval between the two tests was a maximum of 2 h for cutting specimens for the cantilever beam vibration test from the panel immediately after testing the full-size panel. The two tests, the full-size panel and the smaller cantilever beam test, were conducted in a room with a relative humidity of 30±5% and a temperature of 20±2 °C.

Table 2. Dimensions for the Smaller Cantilever Beam Specimens Cut from the Full-size Panels

Thickness *h* (mm)	Length *l* (mm)	Width *b* (mm)	Number of Specimens
9	600	50	33
12	600	50	20
15	900	50	35
16	900	50	25
18	1000	50	63
25	1200	50	18

Vibration Detection Test

The vibration detection test was conducted using the same laboratory testing apparatus for a previous study (Guan *et al*. 2015). Two load sensors were used to measure the weight of the full-size WCP being tested, and a laser sensor located at the middle of the panel was used to measure the vibrational displacement. LabVIEW software (Beijing, China) was written and used to collect and process both load and vibration signals and to calculate storage modulus and loss modulus based on Eq. 2 and Eq. 3 (Xu *et al*. 2009).

The full size panel was placed on the laboratory testing apparatus and was supported on bars at the locations, 22.4% and the 77.6% along its length direction. The testing software collected the load sensor signal and calculated the panel weight. An initial displacement was applied with both hands at one end of the panel away from the load sensor, and the hands were released from the end of the panel allowing the panel to vibrate at its free vibration state (first mode). The laser sensor recorded the vibration displacement signal used to calculate the first natural frequency (f) of the panel vibration and logarithmic decrement (Δ) of the vibrational decay. The software calculated the storage modulus (E') and loss modulus (E'') of the panel. Through R language modeling, these test data were analyzed with regression analysis using one variant linear regression analysis method, analysis of variance, and t-test (Wang 2014).

Cantilever Beam Vibration Test

To examine the validity of the panel vibration testing method, the cantilever beam vibration test was conducted (Yan 2010; Zhou *et al.* 2014b). One end of each small specimen was clamped at a length of 50 mm. The free end of the specimen was displaced an initial distance and then released, resulting in re-vibration in the first mode of the cantilever beam. The cantilever vibration displacement signal was recorded. Storage modulus and loss modulus were calculated for each cantilever specimen.

RESULTS AND DISCUSSION

Dynamic Viscoelasticity for the Full-size WCPs

The average values and standard deviations (SD) for the storage modulus and loss modulus for all the panels are given in Table 3. The coefficient of variation (COV) and ratio of E' to E'' of the three types of panels are also given in Table 3. The values for E' were greater than the values for E'' for all panels tested, which was similar to previous studies of small specimens of hardboard, particleboard, and fiberboard (Moslemi 1967;

Yan 2010; Zhou *et al*. 2014b). The ratios of their values were in the range of 24.94 to 77.61; the ratios of E' and E'' of PB panels were in the range of 24.94 to 48.77. The ratios of E' and E'' of MDF panels were in the range of 33.29 to 47.22, and the ratios of E' and E'' of PW panels were in the range of 44.43 to 77.61. The ratios of E' and E'' for the PW panels were higher than the PB and MDF panels. Furthermore, the COV values of E'' were greater than those of E' among the panels tested, which revealed that the variability of loss modulus was higher than that of the storage modulus for these three types of panels.

Table 3. Storage Modulus and Loss Modulus of Full-size Wood Composite Panels Tested Using Vibration Test Method

Panel Code	Storage Modulus (MPa)			Loss Modulus (MPa)			Ratio of Storage Modulus to Loss Modulus
	Average	SD	COV	Average	SD	COV	
PB9	2834.97	142.32	5.02%	113.65	13.55	11.92%	24.94
PB16	3631.88	141.47	3.90%	80.55	5.88	7.30%	45.09
PB18	2327.62	158.35	6.80%	70.01	5.50	7.85%	33.25
PB25	2637.88	119.71	4.54%	54.09	6.72	12.43%	48.77
MDF9	3358.80	89.13	2.65%	100.90	15.31	15.17%	33.29
MDF12	4405.44	66.19	1.50%	124.90	17.89	14.32%	35.27
MDF15	5297.37	138.89	2.62%	112.19	7.69	6.85%	47.22
MDF18	3871.71	130.03	3.36%	83.59	7.25	8.67%	46.32
PW9	3568.06	301.23	8.44%	80.31	14.37	17.89%	44.43
PW15	3256.64	201.86	6.20%	48.68	4.63	9.51%	66.90
PW18	4584.77	242.91	5.30%	59.07	7.30	12.37%	77.61
PW25	4758.05	354.76	7.46%	64.48	9.32	14.46%	73.79
Note: SD, standard deviation; COV, coefficient of variation.							

Furthermore, PW panels had the lowest E'' values, indicating that PW panels exhibit lower dampening properties. This result is expected due to the cross-laminated veneer and higher stiffness properties or PW in general. Both PB and MDF panels have higher loss modulus values and are generally considered to have better damping properties for absorbing vibration energy. For example, PW panels are used to construct components in guitars and pianos that require improved resonance properties that have low loss modulus characteristics, whereas low-density MDF panels are used as room dividers to adsorb sound energy.

Density and Logarithmic Decrement Relationship with Dynamic Viscoelasticity

Relationship of storage modulus (E') with density

Figure 1 shows the relationship between E' and density (ρ) for PB, MDF, and PW panels. The linear regression equations and the related parameters are listed in Table 4. There was a good linear relationship between E' and ρ for the three types of panels, and their relationships were highly significant at the 0.001 level. Moreover, the correlation coefficients between E' and ρ of PB panels, MDF panels, and PW panels were 0.883, 0.898, and 0.735, respectively.

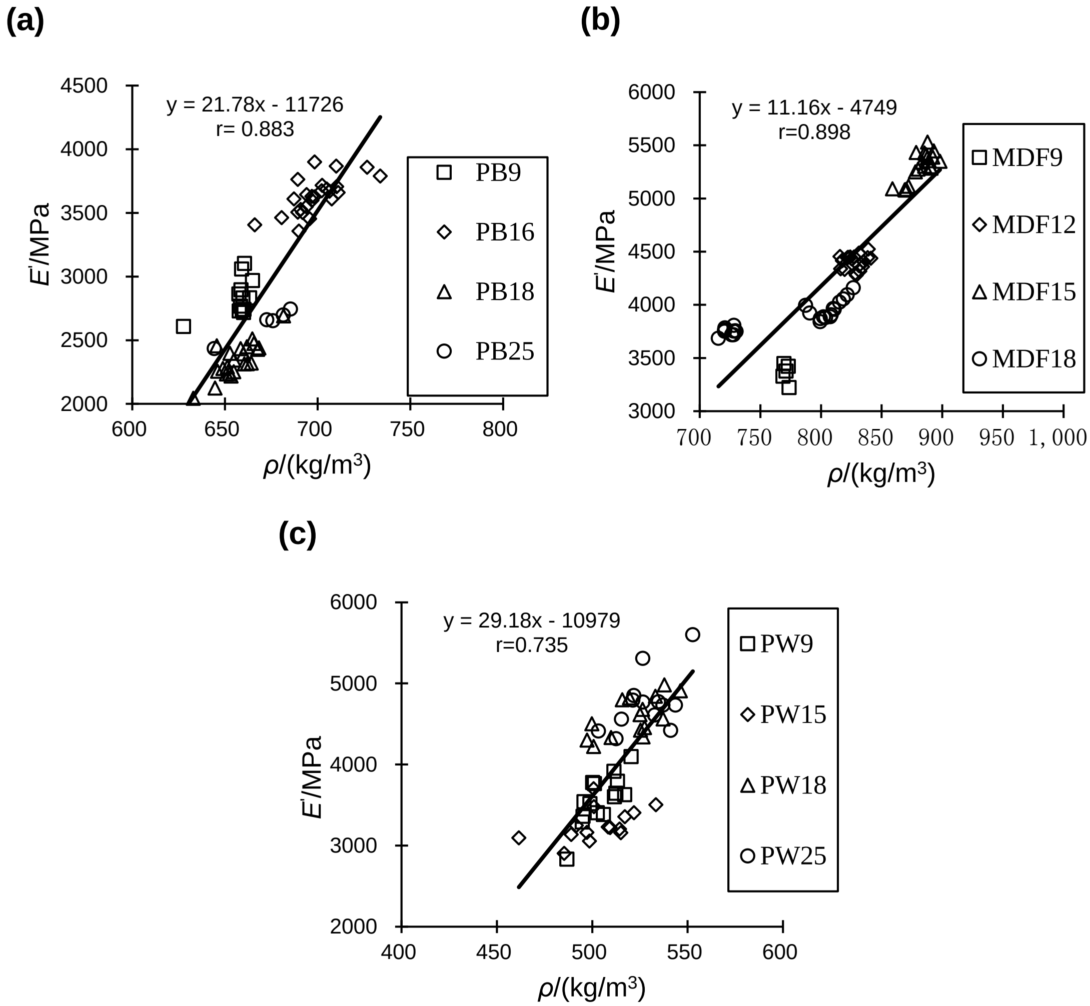

Fig. 1. Relationship between storage modulus and density for full-size panels for (a) particleboard (PB), (b) medium density fiberboard (MDF), and (c) plywood (PW)

Table 4. Linear Regression Equations and Parameters Relating Storage Modulus with Density between Three Types of Panels

Panel	No. of Panels	*y = ax+b*		Correlation Coefficient (*r*)	F-statistic	Level of Significance
		a	*b*			
PB	69	21.78	-11726	0.883	230	0.001
MDF	67	11.16	-4749	0.898	279	0.001
PW	58	29.18	-10979	0.735	65.8	0.001
Note: PB, particleboard; MDF, medium density fiberboard; PW, plywood						

Relationship of loss modulus (E'') with logarithmic decrement

In the process of vibration, logarithmic decrement (Δ) is an important index for measuring material damping ratio. Figure 2 shows the relationship between E'' and Δ among the three types of panels tested. Through the R language modeling, the test data was also analyzed in the same way as the E' values. The linear regression equations and the related parameters are listed in Table 5. Figure 2 and Table 5 show that there was a positive linear relationship between E'' and Δ for these panels, which was highly significant at the 0.001 level. The correlation coefficients between E'' and Δ of PB, MDF, and PW panels were 0.720, 0.718, and 0.800, respectively.

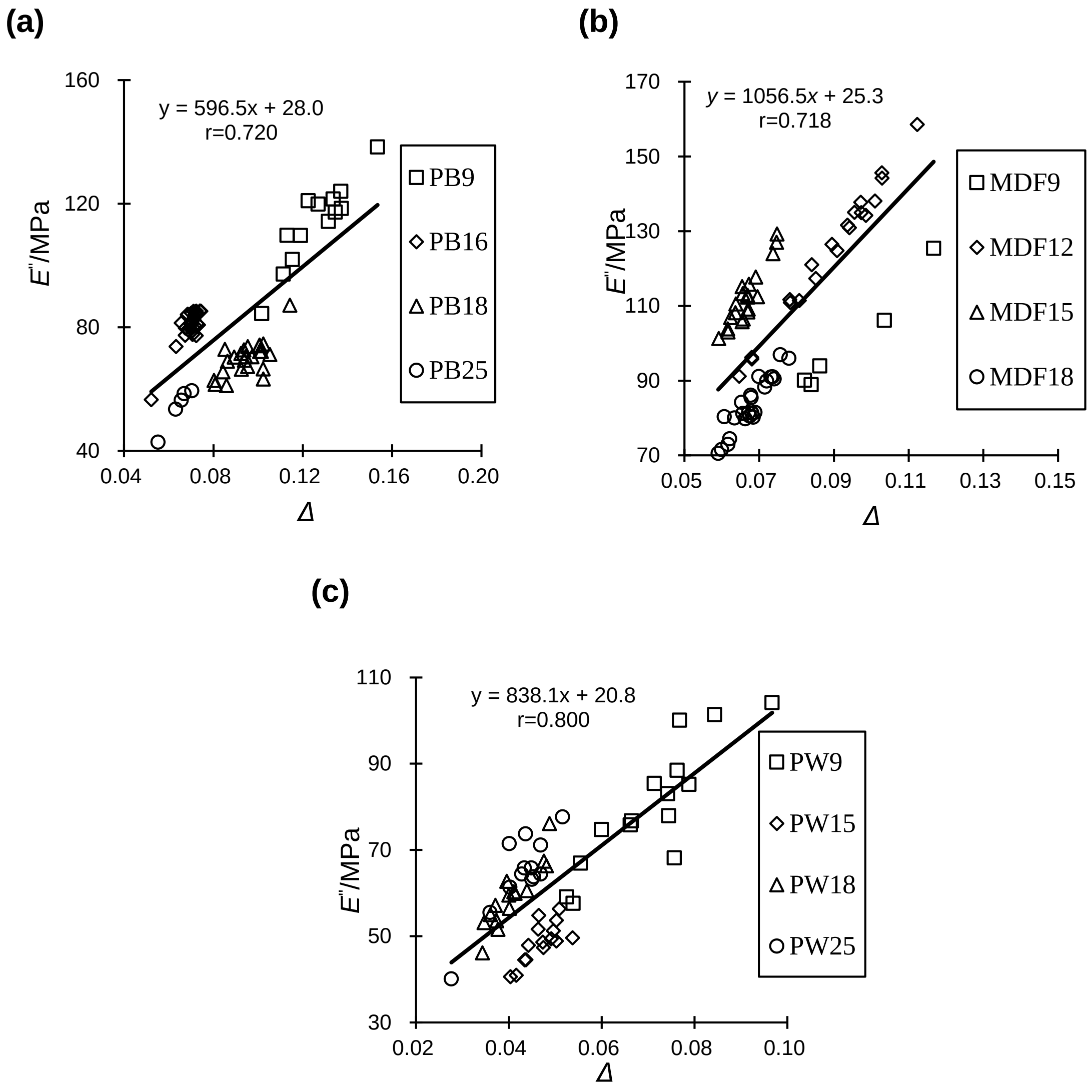

Fig. 2. Relationship between loss modulus and logarithmic decrement for the three full-size WCPs (a) particleboard (PB), (b) medium density fiberboard (MDF), and (c) plywood (PW)

Table 5. Linear Regression Equations and Parameters Relating Loss Modulus with Logarithmic Decrement for the Three Types of Panels

Panel	Number of Panels	*y = ax+b*		Correlation Coefficient (*r*)	F-statistic	Level of Significance
		a	*b*			
PB	69	596.5	28.0	0.720	70.8	0.001
MDF	67	1056.5	25.3	0.718	71.8	0.001
PW	58	838.1	20.8	0.800	101	0.001

Relationship of logarithmic decrement and density with loss modulus

In one variant linear regression analysis above, although there was a highly significant linear relationship between E' and ρ as well as between E'' and Δ for the three types of panels tested, the correlation coefficient between E'' and Δ was not particularly high. Thus, a modified regression model was generated where Δ and ρ of the panels were selected as the independent variables x_1 and x_2, and E'' was selected as the dependent variable y. Their linear regression equations and related parameters are listed in Table 6.

Table 6. Linear Regression Equations and Parameters Relating Loss Modulus with Logarithmic Decrement and Density between Three Types of Panels

Panel	Number of Panels	$y=ax_1+bx_2+c$			Correlation Coefficient (r)	F-statistic	Variable	Standard Regression Coefficient*
		a	b	c				
PB	69	949.2	0.57	-389	0.922	182.5	x_1	1.1455
							x_2	0.7132
MDF	67	1091	0.243	-177	0.946	282.6	x_1	0.7425
							x_2	0.6153
PW	58	983.8	0.385	-184	0.911	133.8	x_1	0.9385
							x_2	0.4519

*Level of significance = 0.001

The correlation coefficients between E'', Δ, and ρ among the types of panels tested were significantly higher than those between E'' and ρ in the one variant linear regression analysis discussed previously, which illustrated that a multiple regression model is meaningful for an automatic testing device. Moreover, the linear relationship between ρ and E'' as well as between Δ and E'' were both highly significant at the 0.001 level; as observed from the standard regression coefficients, Δ had a greater effect than ρ on E''.

Results Analysis of Dynamic Viscoelasticity in the Two Kinds of Methods

Comparisons with the cantilever beam vibration test were from only one small specimen cut from each panel. Due to possible poor uniformity of the panels tested, there were differences between the density of the panel and density of the small cantilever specimen. In terms of the analysis above, a good linear relationship was still found between E' and ρ. However, to minimize the impact of a density difference between the small specimen and full-size WCP on the E'_s values of small specimens, the impact of density on E'_s was accounted for by Eq. 8 (Moslemi 1967),

$$E'_b = \frac{\rho}{\rho_s} E'_s \tag{8}$$

where E'_s is the unadjusted storage modulus for the small specimen, E'_b is the adjusted storage modulus of small specimen, and ρ and ρ_s are the average densities of full-size WCP and small specimen, respectively. The density ratio between full-size WCPs and corresponding small specimens ranged from 0.91 to 1.09.

A density difference between small specimen and full-size WCP can also lead to a damping ratio difference between the samples (Wang *et al.* 2012; Hunt *et al.* 2013). To eliminate the impact of a damping ratio difference between small specimen and full-size WCP on the E''_s of a small specimen, the impact of density and logarithmic decrement on E''_s was accounted for by Eq. 9,

$$E''_b = \frac{\Delta}{\Delta_s} E'_b \frac{\Delta_s}{\pi} \quad (9)$$

where E''_s is the unadjusted loss modulus of small specimen, E''_b is the adjusted loss modulus of small specimen, and Δ and Δ_s are the logarithmic decrements of full-size WCP and small specimen, respectively.

After adjusting the dynamic viscoelasticity for the small specimen, the dynamic viscoelasticity of full-size WCPs and small specimens were compared (Fig. 3). There was a statistically significant, highly correlated linear relationship between storage modulus of all the panels tested and their small specimen. Similarly, the loss modulus was highly correlated with the small cantilever specimens. The linear correlations of storage modulus and loss modulus were 1.033 and 1.012, with the coefficients of correlation of 0.951 and 0.968, respectively, revealing that determining dynamic viscoelasticity of full-size WCPs by the vibration testing method was very effective and feasible.

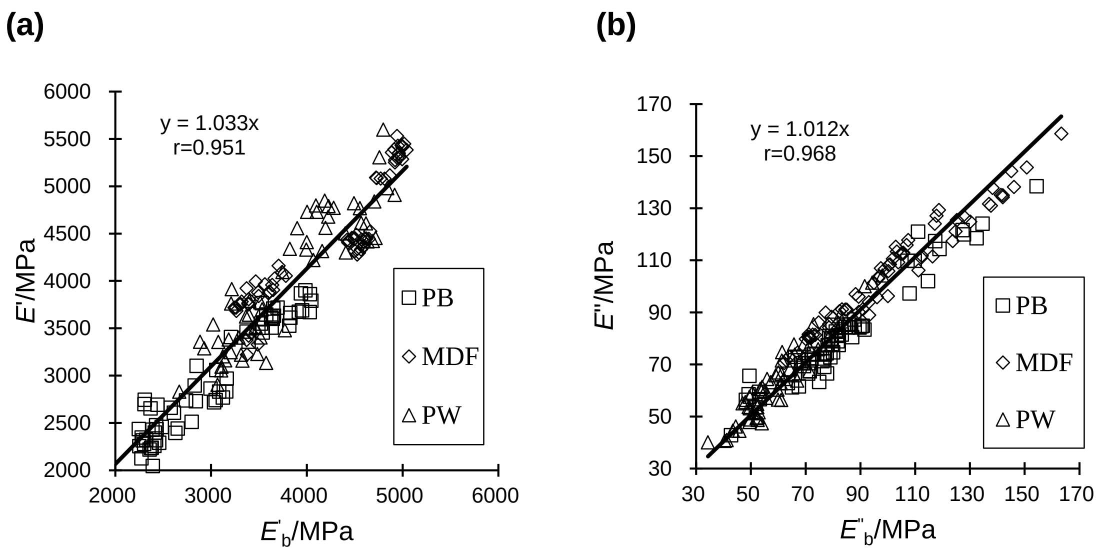

Fig. 3. Relationship of dynamic viscoelastic properties between full-size panels (y-axis) and smaller cantilever beam specimen (x-axis) (a) storage modulus, and (b) loss modulus

CONCLUSIONS

1. The laboratory testing apparatus provides an easy method to determine dynamic viscoelasticity of full-size WCPs fast and accurately.
2. A statistically significant and highly correlated linear relationship existed between the dynamic viscoelasticity of the panels tested in the vibration detection test and small specimens tested using the cantilever beam vibration test.

3. Storage modulus values of PB, MDF, and PW panels were far higher than their loss modulus values, and PW panels had the smallest value of loss modulus.
4. For the panels tested, density had a good linear impact on storage modulus and logarithmic decrement had a greater linear effect on loss modulus compared with density.

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Corrosion, cracking, and downtime

The failure of heat transfer in industrial applications: A problem-solution approach

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Corrosion, cracking, and downtime

The failure of heat transfer in industrial applications: A problem-solution approach

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Contents

> "The finned tube heat exchanger of a chemical plant I have just visited suffers from a dew point corrosion problem. What's the best way of dealing with such a situation?"
>
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1. Introduction

The sentence above was posted on a chemical engineering forum in the past 12 months, and highlights the problems that British industry is having with its conventional design heat transfer equipment.

Whether the heat transfer equipment is located in a waste processing incinerator, a cooking oven in a food processing plant or a furnace in a metal processing application, all too often it's prone to failure, which means that it is unable to provide the valuable energy savings and CO_2 reductions that were promised when it was first installed.

The result? Unplanned downtime, increased maintenance charges and spiralling production costs. It is not uncommon, in fact, for exasperated engineers to completely bypass the malfunctioning heat transfer equipment, thus foregoing any of the potential benefits.

This white paper takes a problem-solution approach to this issue. First, we will identify a number of specific problems associated with traditional heat transfer equipment, and then introduce a new technology that has the potential to revolutionise the way this equipment is designed and utilised within UK industry.

Effective energy transfer is a basic prerequisite for the success of many industrial processes. When heat transfer equipment fails, entire processes fail along with it, costs increase and emissions targets are missed.

Modern technology has the capability to make heat transfer equipment work more efficiently, productively and with minimal disruption. This white paper sets out the case.

Mike Griffin
Emerging & Innovative Technology Manager Northern Europe at Spirax Sarco

2. Problems with conventional heat transfer design

There are multiple problems associated with the design of conventional heat transfer equipment that will be very familiar to engineers and maintenance teams working in a wide variety of industries.

Dirt and corrosion

Industrial exhaust gases can be dirty and corrosive, and can also contain particulates that are abrasive or will build up and coat the surfaces of an exhaust gas system. In this type of application, traditional heat transfer designs can easily become clogged or damaged due to the high thermal stresses generated.

Thermal stress and thin metal surfaces

Thermal stress and cold spots which cause gas condensation and, in turn, corrosion are very common problems for conventional heat transfer designs. They are often equipped with thin metal surfaces that, whilst aiding heat transfer, leave them vulnerable to corrosion and fouling.

Preventing dew point corrosion

Conventional heat transfer designs, which often use long lengths of tube, are vulnerable to cold spots and variations in temperature along their length. This can cause thermal and dew point corrosion.

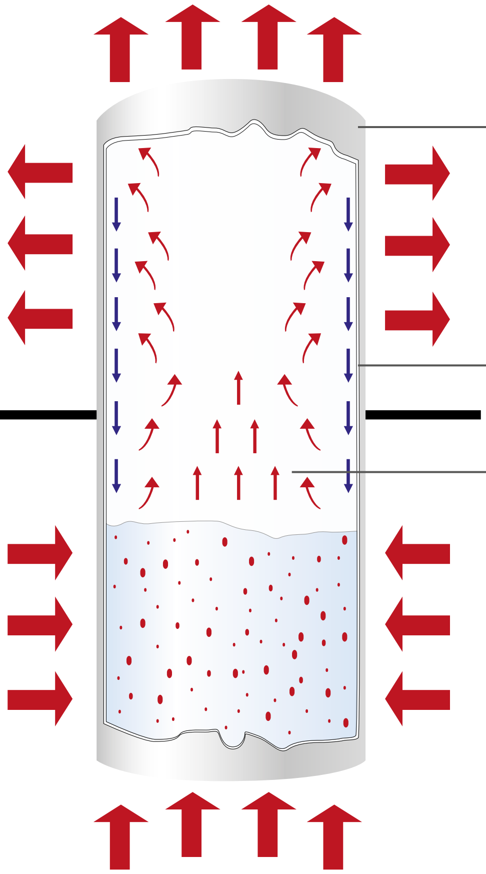
Single tube failure

Single tube failure is a particular problem for conventional heat transfer designs, which often results in catastrophic failure and the complete write-off of the equipment. When a single tube fails, the overall efficiency of the heat exchanger is significantly impacted, and often the only resort is to completely replace the entire unit.

Maintenance and reliability

Conventional heat transfer design is also susceptible to fouling from industrial processes, such as milk spray drying, waste incinerators and tablet spray drying in the pharmaceuticals sector. Often, the design is difficult to clean and requires de-installation, which impacts productivity and efficiency.

3. The solution



Heat pipe operation

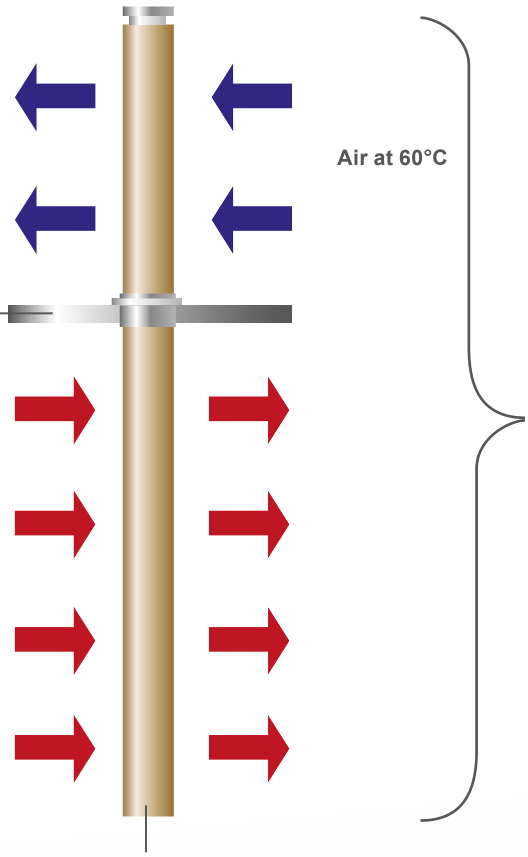
A heat pipe is a metal tube, sealed at both ends with a vacuum inside, filled with a small quantity of fluid. The fluid used depends upon the required working temperature range of the heat pipe. For example, a water-filled heat pipe has a working temperature range of 80°C to 320°C, enough to meet over 90% of application requirements.

The metal used for the heat pipe construction depends upon the application needs. In industrial applications the most common materials used are copper, carbon steel, stainless steel (AISI 304 and AISI 316) and aluminium, although other materials are available to meet the needs of specific applications.

The part of the heat pipe that is immersed in the hot stream absorbs heat, causing the liquid inside the pipe to evaporate. The evaporated liquid (steam) then travels to the top of the heat pipe. When this steam reaches the top, it heats up the cold stream, causing it to condense back into a liquid. The liquid then flows back to the bottom of the heat pipe, and the cycle will continue as long as there is a temperature difference between the hot stream and the cold stream.

Due to the difference in density of the working fluid in its liquid and vapour phases, a natural circulation cycle operates inside the heat pipe. It is not necessary for the heat pipe to be mounted vertically for this cycle to operate effectively. It will operate perfectly, even when the heat pipe is installed as little as 4º from the horizontal.

4. Thermal features of heat pipe

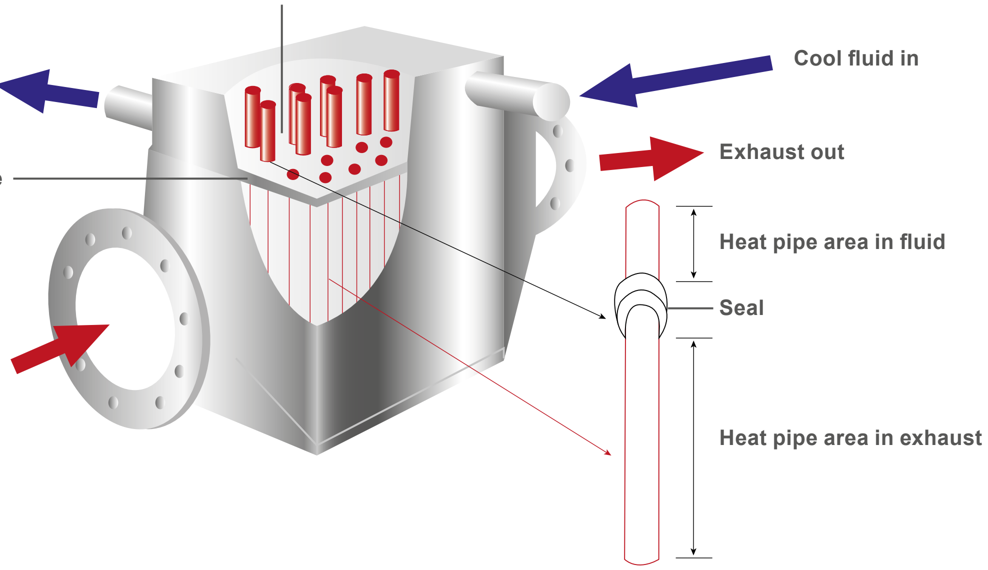


As a result of the high quality construction of the heat pipe and in particular its high integrity vacuum, heat transfer between the hot stream and the cold stream is virtually instantaneous.

Another very important thermal characteristic of the heat pipe is its isothermal operation, which allows it to operate with a uniform temperature along its whole length.

The result is that there is very little thermal stress along the length of the pipe, and no cold spots occur where condensation could take place, which, in turn, reduces the potential for corrosion.

5. Heat Pipe Heat Exchangers



Heat pipe heat exchanger construction

The mechanical and thermal properties of heat pipes, with their many advantages, make them particularly suitable for use as the heat conductors in heat exchangers, particularly for energy recovery applications that cannot be addressed by traditional designs. Specifically, heat pipe is exceptionally well suited for energy recovery from high temperature, corrosive or contaminated exhaust streams.

Heat pipe heat exchangers can be designed for most heating applications, with the majority addressing one of the following:

Exhaust Gas → Air Heating

Exhaust Gas → Water Heating

Exhaust Gas → Diathermic Oil Heating

Exhaust Gas → Steam Generation

Many application demands can be met from a modularised standard range of heat pipe heat exchangers, where standard 'cartridges' of heat pipes are installed into a standard heat exchanger casing, suitable for a particular application. Where it is necessary, individual designs can be made to suit the individual needs of a particular application. Exhaust gas energy recovery installations will usually include one or more of three elements:

1. Heat exchanger to extract the energy from the hot exhaust gas and transfer to the cold stream (water, air etc.) to heat it up.

2. Diverter system composed of by-pass duct work around the heat exchanger together with diverter valves to facilitate maintenance or cleaning of the heat pipe heat exchanger.

3. Control systems to ensure the heated fluid or gas is heated to the required temperature, operates safely and can be safely shut down if there is a problem. The control system can also incorporate alarms, communications, self-diagnostics and reporting.

6. Advantages of heat pipe heat exchangers

The problems associated with conventional heat transfer designs, which were outlined earlier in this white paper, can be alleviated by using heat pipe technology. The advantages of using a heat pipe heat exchanger are:

1: Energy and carbon reduction savings

The single greatest advantage of heat pipe heat exchangers is their ability to contribute to energy and carbon reduction measures, in line with a site's decarbonisation strategy. Heat pipe heat exchangers generate hot water or steam from existing waste streams, thereby reducing utility supply consumption and costs by circa 3-7% and carbon by circa 4%.

2: Multiple redundancy

Each pipe operates independently, which ensures that the unit is not vulnerable to a single pipe failure. This prevents cross contamination, as each heat pipe acts as an additional buffer between the two fluids. Within the heat exchanger, each heat pipe is an individual heat exchange unit. The heat pipes are very robust, and designed to operate in aggressive industrial environments. However, even if one or two heat pipes fail, this will have a very small effect on the overall performance of the heat exchanger. For example, with a heat exchanger composed of 100 heat pipes, failure of a single pipe will still result in 99% effectiveness of the entire system.

3: Low fouling and ease of maintenance

The use of smooth pipes allows heat pipe heat exchangers to be used in high particulate or oily applications, which can have a severely detrimental effect on conventional heat exchangers, for example those found in food processing waste incinerator applications. This low fouling capability ensures that heat pipe heat exchangers can be easily maintained in situ, with no requirement to uninstall.

4: Isothermal operation – no hot or cold spots

Heat pipe heat exchangers eliminate cold corners, which are common in heat exchangers designed with a complex multi-tubular structure. This, in turn, significantly reduces dew point corrosion issues, and improves overall thermal performance of the heat exchanger.

5: Robust materials and long life

Heat pipes do not rely on thin metal surfaces for effective heat transfer, and therefore can be constructed from robust materials that offer increased resistance to corrosion. What's more, heat exchangers designed with heat pipe enable the pipes to freely expand and contract within the heat exchanger casing, which eliminates thermal stress on the structure.

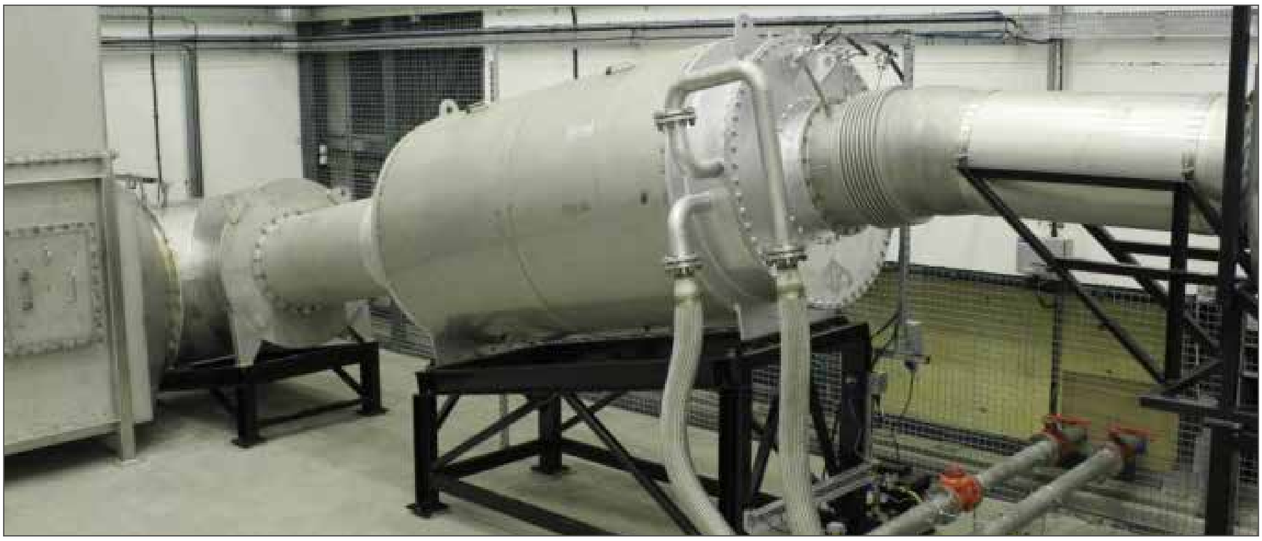
6: Low pressure drop

Compared to other heat recovery solutions currently available on the market, heat pipe based solutions have extremely low pressure drops. This is particularly significant in situations in which size or weight are a consideration, as this low pressure drop is achieved with systems that are also much smaller and lighter than traditional systems.

7. Payback & ROI

The potential payback periods for heat pipe heat exchangers are very much dependent upon a number of different variables, including hours of operation, exhaust temperatures, and price per kWh. However, payback periods of as little as 2-3 years are common.

Case study 1: Gas to oil unit fitted in a waste processing plant



A smooth / finned hybrid pipe 'through-flow' heat exchanger of the gas to oil type was installed in a waste processing plant based in the UK.

The application had particularly high inlet exhaust temperatures of 1000°C, which were catered for by the use of the 'through-flow' model.

The application also had to cope with a very high particulate matter exhaust from the furnace, which was dealt with by removable panels, incorporated for cleaning.

Overall, the installation provided a low fouling, easy cleaning, low maintenance and high reliability solution with a payback period of less than six months.

Exhaust temperature in / out	1,000°C / 250°C
Water temperature in / out	135°C / 280°C
Exhaust / water mass flow	4,150kg/h / 9,200kg/h
Weight of unit	1,800kg
Exhaust pressure drop	650Pa
Energy recovered	940kW
Recovered energy value	£150k p/a

Case study 2: Biofuel plant gensets

A biofuel plant, based in the UK, installed a double water vessel heat exchanger to recover energy from its gensets.

The Spirax Sarco solution was a bespoke design of an irregular shape, to take account of the large duct diameter, which necessitated a large cross sectional area on the unit.

The application recovered 750 KW of energy with a value of £175,000 per annum.

The payback on this application for the customer was less than six months.

Exhaust temperature in / out	440°C / 371°C
Water temperature in / out	75°C / 98°C
Exhaust / water mass flow	46,500kg/h / 36,210kg/h
Weight of unit	1,556kg
Exhaust pressure drop	850Pa
Energy recovered	750kW
Recovered energy value	£175k p/a

Case study 3: Gas to water food processing boiler

Smooth pipe heat exchanger fitted to a food processing boiler. The application suffered from high particulate matter exhaust from the furnace.

The Spirax Sarco solution was to install a gas-to-water heat pipe heat exchanger, with a soot trap and removable panels for easy cleaning.

The company now has a low fouling, low maintenance, high reliability heat exchanger capable of recovering £82,000 of energy per annum for a capital investment of £40,000, offering a payback period of less than a year.

Exhaust temperature in / out	236°C / 158°C
Water temperature in / out	105°C / 131°C
Exhaust / water mass flow	18,675kg/h / 6,374kg/h
Weight of unit	3,600kg
Exhaust pressure drop	650Pa
Energy recovered	440kW
Recovered energy value	£82k p/a

8. Conclusion

As I stated at the outset, effective energy transfer is a basic prerequisite for the success of many industrial processes. And yet, all too often, heat transfer equipment appears to be letting industry down by failing to deliver the promised efficiencies, either in terms of energy reduction or CO_2 emissions.

Worse still, the equipment is prone to downtime and malfunction, which consumes engineering and maintenance time that could be better spent on other tasks. Applications in the ceramics or food processing sectors are more likely to suffer the consequences of heat exchangers and therefore have a much shorter life lifespan.

Fortunately, technology is providing a solution that is both innovative and has the potential to pay for itself in double quick time. The payback periods for heat pipe heat exchanger applications can be as little as three months, and this is before potential savings on engineering and maintenance time are factored in.

The truth of the matter is that British industry has been rightly frustrated with its conventional heat transfer equipment, often choosing to shut it down or bypass it, rather than waste any more time trying to get it to work efficiently.

The good news is that help is at hand with a new generation of heat transfer technology, which promises to finally deliver.

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Germany
Ireland
* Italy
Middle East
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Netherlands
Poland
Portugal
Russia
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Sweden
Switzerland
Turkey
* UK

Americas

* Argentina
* Brazil
Canada
Chile
Colombia
* Mexico
Peru
* USA

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* China
* India
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Solenis Combines a Startup Mentality with Established Leadership to Ensure Consistent Growth and Market Strength

Hydrolysis is a common chemical reaction in which bonds are broken, releasing energy. The acquisition of Ashland Water Technologies by private investment firm Clayton, Dubilier & Rice (through a fund managed by CD&R) was, in many ways, a type of hydrolysis, cleaving the Industrial Water and the Pulp and Paper business units from Ashland Inc. to form Solenis, a standalone specialty chemical business. The energy produced by the transaction propelled the new organisation forward and enabled it to establish a strong corporate foundation while preparing for future growth and innovation. The failure of heat transfer in industrial applications: A problem-solution approach

Building a Growth Culture

Everything began with the emerging Solenis culture. Solenis is grounded in a strong heritage that includes Ashland Water Technologies, Betz Laboratories, Drew, Stockhausen and Hercules. While that heritage comes with a number of benefits, it also encourages employees to embrace legacy brands and belief systems. According to Jeff Fulgham, Senior Vice President and Chief Marketing Officer, "There was a lot of debate about the kind of company we should be, even the name we should use. Some people wanted to go back to Hercules, but we felt strongly that we needed a new name. It gave us a chance to start fresh."

Beyond the name itself, starting fresh meant creating a single unified culture with common goals and values. Driven by Solenis President and Chief Executive Officer John Panichella's vision of an organisation commercially focused around customers, the company embarked on an intensive culture-building initiative built on 12 core beliefs organised around three priorities – People, Performance and Results. Every belief is driven by experiences that support that belief, which in turn cultivates behaviours and actions to drive results.

The culture work began in September 2014, soon after the new company was formed, and by June 2015, the core beliefs were vetted and approved. By October, the company began broadcasting videos – 72 in all, with scripts translated into nine languages – featuring employees who could share experiences directly tied to each of the beliefs. A series of surveys have since measured the pulse of the Solenis employee population, and participation rates have been as high as 93 percent.

The ultimate goal, however, is not simple participation but acceptance and internalisation. As Katy Abernathy, Director, Global Marketing and Business Communications, points out, "Safety is a metaphor we use all of the time. We are one of the safest organisations in our industry, thanks to a conscious and deliberate campaign we have executed over the years. Now, safety is part of the daily routine of our employees. That's where we want to be with the Solenis corporate culture."

Even though there is still work to do on the culture front, the progress has been impressive. In fact, speed and agility have been equally important watchwords. Consider that the new Solenis organisation began with no HR department, no financial officer and no IT infrastructure. Some companies can take a year or longer to get these new functions established and staffed, but Solenis was able to do it all in just a few months. One of the biggest accomplishments was establishing a robust recruitment and training program to attract and retain talent.

According to Iris Melendez, Director of Global Talent Management, Solenis put some stopgap recruitment measures in place to keep the organisation moving forward. "That got us from point A to point B," Melendez notes. "Now we have a recruiting manager in place, and we're somewhere between point B and point C – looking at recruitment with totally fresh eyes, figuring out how we want it to work in the new Solenis culture. Same thing with training: We stopped training in the transition from Ashland, but now we've launched an extensive global leadership curriculum, as well as a global sales curriculum, and we're investing heavily in the professional development of all our employees."

Creating an IT team from scratch required another herculean effort. The company's approach, according to Solenis Chief Information Officer Charles Wallace, was to keep the IT function small. "We looked for high-energy people who could see through the confusion, visualise an end state and then fight their way to it," he says. "We also decided that, while we wanted to own the IT strategies, we wanted to take advantage of managed services for key capabilities. This approach has enabled us to get a lot done — initiate the digitisation of business processes, consolidate our enterprise resource planning platform to a single instance of SAP, assess and mitigate security threats – but has also enabled us to look toward the future so we can help the company grow."

Blueprint for Success

Growth, more than anything else, defines the still-coalescing Solenis. Building a sustainable business that is 100 percent committed to helping its customers succeed is an idea that permeates the culture and drives all of the key strategic decisions. "Growth is our number-one priority," Jeff Fulgham observes. "We need consistent top-line revenue growth, and to get it, our strategy must have several legs. Mergers and acquisitions are important – we've closed five deals in the last two years and we have a rich pipeline of deals in the works. Aggressive growth in emerging markets is also critical. And, of course, innovation – bringing new products to the market – has always been a high priority."

What's different today is how Solenis innovates. Coming from so many legacy companies, the organisation didn't have a clear approach for early-stage innovation. Some teams embraced one methodology, while others went in different directions. Also, there wasn't always a clear focus on customer needs. As a result, the business launched a number of products that received only lackluster attention from the market.

To re-energise its innovation strategy, Solenis adopted the Blueprinting framework and software, developed by the AIM Institute, and appointed Melinda Burn, Global Director, Strategic Marketing and Innovation, to lead the company's effort. "Blueprinting takes the voice of the customer and makes it quantifiable," Burn explains. "It's a two-phased approach that starts with Discovery Interviews to identify actionable problems, followed by Preference Interviews to discover market satisfaction gaps – problems that are felt across the market for which there are no solutions."

Over the last eight months, Solenis has engaged a significant number of its customers across all key segments, standardising its approach to early-stage innovation while filling its pipeline with market-defined product development opportunities. At the same time, the company has looked closely at new product introductions – how to launch more effectively and how to evaluate NPI performance in the market. "We're really trying to understand our tracking process," Burn says. "For example, we're looking at both the percentage of products classified as NPIs – less than five years old – as well as the percentage of revenue coming from NPIs."

The focus on innovation is paying off. Solenis has recently introduced a number of products, technologies and services that have had significant impact – for customers and the company. On the water and process side of the business, as Vice President of Marketing, IWT, Jeff Ballew points out, the focus has been on execution. "We have a number of products – antiscalants, rheology modifiers, biocides – that are exciting." For example, the launch of new Polystabil™ scale inhibitors and Performax™ cooling water treatments have helped enterprises in a variety of industries improve operations, reduce downtime and still adhere to increasingly severe regulatory guidelines for chemical usage.

On the pulp and paper side, introductions of innovative products, such as the Biobond. Improving the Sustainability of Paper℠ program and new Crepetrol™ creping adhesives, have enabled packaging, paperboard and tissue and towel manufacturers to truly revolutionise how they make paper.

Across all market segments, OnGuard™ controllers and analyzers, as well as a web-based service to collect data from those technologies, continues to impress customers who need to monitor system performance in real time. And the rollout of Solenis' Equipment Services Team, first in North America and then in Europe, makes it possible to deliver even better service to its customers by keeping Solenis-owned equipment online and running at peak efficiency.

Fast Forward

All of this adds up to make Solenis a strong company with a bright future. As Solenis Vice President of Marketing, Pulp and Paper, Ricardo De Genova points out, "We're really excited by the opportunities ahead of us. We're undisputed leaders in certain markets, but we have plenty of room to grow. And in certain markets, we think we can reinvent the industry. The overall scenario for Solenis is very positive."

Jeff Fulgham agrees. "We're doing well in spite of a number of big global changes. There's a lot of noise in the financial markets, a lot of deflation in oil markets, anticipated inflation in raw materials, yet we still have been able to consistently achieve top-line growth and deliver our products 98 percent on time – our best supply chain performance ever."

This positions the company well as it prepares for the future, now a smaller, stronger, more adaptable organisation, thanks to its hydrolysis from Ashland Inc.

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3 Feedback Steps That Won't Crush Your Team

Top tips on how to improve feedback skills.

Giving feedback is one of the most important - and most challenging - tasks all managers face.

For first-time managers, it can be especially difficult.

No longer a peer to co-workers, new leaders take on the role of “boss.”

Instead of focusing solely on their own career and development, they must develop their teams and work toward achieving broader company goals.

One of the best ways to help a team improve is to provide frequent, effective feedback. But what exactly is feedback? And how can first-time managers deliver criticism without isolating their team?

Three key points to remember about feedback are:

- It should be specific and fact-based.
- It should be “wise” and focus on employee development.
- It should be ongoing and not a one-time event.

What Is Feedback?

Feedback can be in the form of one-on-one meetings, performance reviews, or a simple conversation at the coffee maker.

Feedback can be positive or negative, but the common theme is that it is actionable information about how someone is doing in meeting specific goals.

“We all know receiving feedback can be awkward or painful at times,” says William Gentry, author of *Be the Boss Everyone Wants to Work for: A Guide for New Leaders*. “Delivering it can be just as awkward and painful. But providing positive and negative feedback to your direct reports, staff, or team is the only way they will know how they are performing well, or if they are not, how they can become better.”

In other words, giving feedback means holding employees accountable for their responsibilities. Without feedback, teams won’t know when they are performing well and when they are not.

Helpful feedback guides employees; that’s why giving it is crucial to being a successful manager.

Just the Facts, Please!

Confronting employees with negative feedback can be uncomfortable, especially for first-time managers.

Telling a former co-worker, and possibly friend, that they are not doing something well isn’t easy. Emotions can run high. That’s why it’s important to stick to the facts.

Gentry's book offers a simple, three-step model for giving non-judgmental feedback (**SBI**):

Situation
Behaviour
Impact

As the book explains, this process can be a tool for giving both positive and negative feedback.

1. **Situation** – Describe the specific situation in which the behaviour occurred.

   For example, "This morning at the 11 a.m. team meeting …" Avoid generalities, such as "one morning last week," as they can lead to confusion.

2. **Behaviour** – Describe the actual, observable behaviour being discussed. Keep to the facts. Don't insert opinions or judgments.

   For example, say, "You interrupted me while I was telling the team about the monthly budget," instead of "You were rude."

3. **Impact** – Describe the results of the behaviour. If the effect was positive, words like "happy" or "proud" help underscore the success of the behaviour.

   For example: "I was impressed when you addressed that issue without being asked."

   If the effect of the employee's behaviour was negative and needs to stop, managers can use words such as "troubled" or "worried."

   For example, "I felt frustrated when you interrupted me because it broke my chain of thoughts."

Because you are describing exactly what happened and explaining your true feelings - not passing judgment—the employee is more likely to listen and learn.

Someone who has gotten into the habit of interrupting may not have realised the effect of his or her behaviour.

An employee who took the initiative on a project may decide, after positive feedback, to continue being proactive.

Give Wise Feedback

Wise feedback is given with the understanding that the ultimate goal is to support and help that employee.

In his book, Gentry suggests using a variation of the following phrase (based on the work of researcher David Yeager) when giving tough feedback: "I'm giving you these comments because I have very high expectations, and I know that you can reach them."

Such a phrase demonstrates belief in employees and their ability to learn from mistakes or ineffective behaviour.

Wise feedback is about teaching and supporting employees; it is never about “fixing” them or implying there is something “wrong” with them.

Keep It Going

The most effective feedback is given more than just once or twice a year at formal performance reviews. It’s timely, meaning that it’s offered soon after the incident, and it’s ongoing.

This allows team members to adjust their behaviour, as needed, and then get more input on how they are progressing on their goals.

Keep in mind, however, that in especially emotional or stressful situations, it’s okay to wait to give feedback until both parties have calmed down. Remember SBI, and stick to the facts!

To learn more about what it takes to become a successful manager, see William Gentry’s book, *Be the Boss Everyone Wants to Work for: A Guide for New Leaders*, Berrett-Koehler Publishers, ISBN-13: 978-1626566255

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How Leadership Development Is Like the Olympics

The coaching and mentoring skills needed in business are a lot like those used to train top athletes. Here are some ideas that can be used as part of a leadership development programme.

As we watched the best athletes in the world compete in the Summer Olympic Games in Brazil, it's worth keeping in mind that they didn't get there alone. Though the coaches don't sprint around the track, plunge into the pool, or don the medals on the podium, they make instrumental contributions to their athletes' success.

Any organisation working to develop world-class leaders should pay attention to that lesson. That's why the most successful leadership development programs include coaching as an integrated element.

The biggest challenge leadership development programs face is ensuring that participants take what they learn and apply it to their jobs and their organisations.

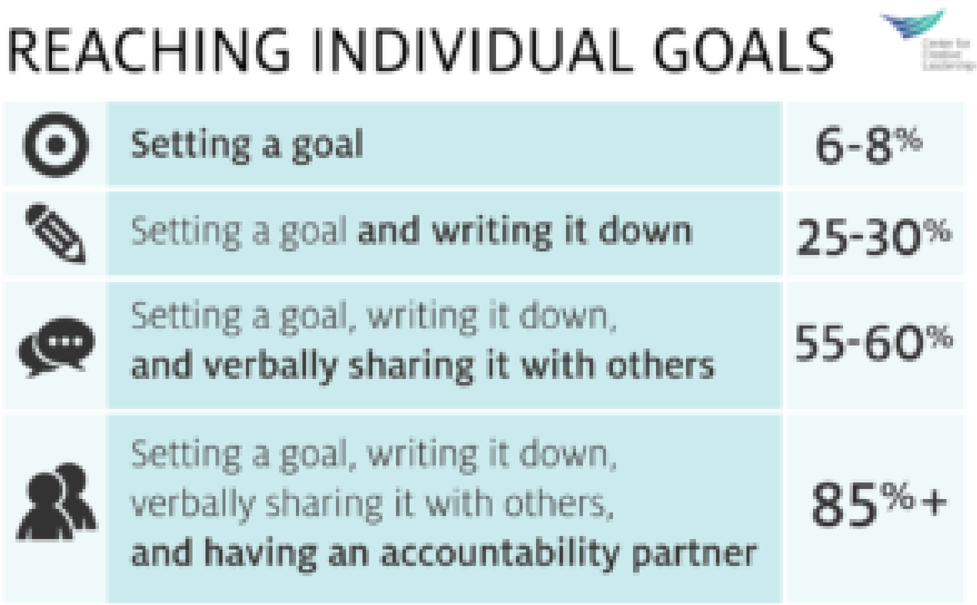
The idea behind integrated coaching is straightforward: Help participants in these development programs deepen, apply, and sustain what they're learning.

Effective integrated coaching, with skilled coaches collaborating with participants using a proven development framework, can provide the edge that drives leaders, and their organisations, into first place.

It's the difference between just competing in the Olympics and taking home a medal. It's also the difference between getting your full ROI from a leadership development program and struggling to defend that budget item next time.

How Integrated Coaching Works
Research shows the odds of acting on something you've learned go up if you write down specific goals focused on applying that learning.

The odds of achieving a goal increase more if the goal is shared with someone else, and even more when an accountability partner is involved.



Coaches who work with leadership development program participants provide that accountability – and more. They work with managers to create developmental goals that translate their learning into behaviour change and improved performance on the job.

The coach can also help them overcome specific challenges they may face.

Integrated coaching can take several forms.

- It may simply include a one-on-one follow-up call between an LD program participant and coach. A coach and the participant will work together to identify the greatest challenges in implementing what they learned, and then together figure out how to move forward.

- In other circumstances, integrated coaching might include a session to help a participant understand evaluations they took, a session together to write a personalised development plan with specific goals and objectives, and maybe even sessions with the participant's supervisor to align expectations and solicit ongoing support and feedback.

- Many leadership development programs even kick off with an integrated coaching session before participants show up in a classroom. This initial coaching session is designed to help participants clarify why they are embarking on this leadership development experience and helps them articulate what they hope to get out of the program.

Whatever the case, the goal is the same – to maximise the value of the LD program for both the organisation and individuals by ensuring participants have the challenge, support, and accountability they need to implement and sustain their new skills.

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Paper Industry Technical Association
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3 Ways to Boost Employee Motivation

The route to enhancing employee motivation is not solely based on financial remuneration. This short piece looks at the effect an organisation's environment has on motivation.

In the race to hire – and keep – top talent, benefits are getting a lot of attention. Compensation, of course, but also leave policies, insurance, and perks.

The Washington Post recently ran an article about a small company leasing Teslas for employees and another paying up to $20,000 for employees' weddings, showing that creativity of benefits may know no bounds.

As important as compensation and benefits are, you know they are not the only things that matter when it comes to keeping employees productive and engaged. These benefits are a part of a larger motivation equation.

But, what are the other important factors to consider? And what can employers do to boost motivation?

A team of CCL researchers looked at these questions. Building on an established theory that people have four different types of motivation at work, they looked at how motives work together to influence job attitudes that are important for employees' retention and performance.

The research involved 321 US managers from numerous organisations, working at the middle, upper-middle, and executive levels. The study measured levels of external motivation and three types of internal motivation, which in combination, resulted in six "managerial motivational profiles."

The research findings are published in the *Journal of Vocational Behavior*.

Managers who were the most satisfied with their jobs and committed to their organisations had 1 of 2 profiles:

> **The internally driven profile**. Their motivation comes primarily from within; they are motivated by a desire to maintain their self-images, pursue their values and goals, and engage in enjoyable or interesting work.
>
> **The self-directed profile**. Their primary sources of motivation are pursuing their personal values, goals, and interests. These managers do what is personally important to them or enjoyable. They are less concerned about pursuing rewards or maintaining their self-images.

In both cases, high internal motivation is the key to unlocking satisfaction, commitment, and performance.

3 Ways to Boost Motivation

This research also suggests that organisations can create environments that foster internal motivation in three primary ways:

1. **Expecting bosses to provide support and encourage self-direction**. Managers must believe that their bosses value their contributions and care about them as individuals.

Managers who are supported by their boss have a sense of security and self-worth that allows them to draw on internal motivation. In contrast, when support is lacking, managers feel threatened and insecure and will draw on less internal motivation.

Bosses should also behave in ways that allow managers to use their inner resources, including giving feedback in ways that encourage problem solving rather than imposing solutions. They should listen to managers' ideas, understand their interests and preferences, and find ways to align organisational needs with work that is personally meaningful.

2. **Creating rewards systems that affirm**. Extrinsic rewards are a fundamental part of organisational life; their impact depends on how the rewards are designed and administered.

Affirming rewards recognise managers for fulfilling important, challenging goals. Common rewards such as pay increases, bonuses, stock options, promotions, and recognition are affirming if they are tied to important goals and are not administered in an oppressive manner.

Being rewarded for achieving such goals boosts managers' feelings of competence and task mastery. Managers' sense of their own capabilities is enhanced, thereby increasing their internal motivation.

3. **Minimising organisational politics and promoting fairness**. In many organisations, the environment is highly politicised and managers feel that they must engage in political behaviour (e.g., connecting to players with clout, manipulating others, stifling honest criticism, going along with others' ideas and actions) to maintain or advance their own status.

Such an environment interferes with managers' internal motivation, as they work to maintain their image and gain external approval rather than acting from within. Organisational systems and leaders should ensure that rewards and promotions are based on valid measures of qualifications and performance rather than connections to powerful people.

By all means, offer the compensation, benefits and perks that employees need, deserve, and expect. But, for the most positive outcomes, be sure to pair that with an environment that fosters internal motivation.

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Products & Services

The Paper Industry Technical Association (PITA) is an independent organisation which operates for the general benefit of its members – both individual and corporate – dedicated to promoting and improving the technical and scientific knowledge of those working in the UK pulp and paper industry. Formed in 1960, it serves the Industry, both manufacturers and suppliers, by providing a forum for members to meet and network; it organises visits, conferences and training seminars that cover all aspects of papermaking science. It also publishes the prestigious journal *Paper Technology* and the *PITA Annual Review*, both sent free to members, and a range of other technical publications which include conference proceedings and the acclaimed *Essential Guide to Aqueous Coating*.

BOILER WATER TREATMENT

As many of you will know, the CEA have partnered with ICOM to produce ***BG04; Boiler Water Treatment***, guidance for shell boilers, coil boilers, steam generators & hot water boilers, and both organisations are proud to announce the launch of BG04 as part of the ongoing production of guidance in the Boiler Guidance (BG) series.

The guide has been written for the layperson who does not have 'O' level chemistry but who is responsible on site for boilers and boiler water treatment, either directly or subcontracting it to a third party.

CEA hosted a very successful seminar at the Cambridge Belfry on Thursday 14th July 2016 explaining:

- Boiler Water Treatment (BG04) launched.
- Industrial Gas Accreditation Scheme (I-GAS) launched.
- Medium Combustion Plant Directive (MCPD) updates.

Ideally we would like you to attend the next seminars where a hard copy will be included as part of the delegate pack. However if you wish to purchase your copy of BG04 for £75.00 plus £2 p&p please contact the CEA office on **01740 625538** or email **info@cea.org.uk**.

About This Guide
Having considered who is responsible for looking after steam boilers, steam generators and hot water boilers and also who is responsible for managing the safe operation of this type of equipment, the Combustion Engineering Association (CEA) and ICOM Energy Association agreed to write this guide, with the help of our respective Members.

It is aimed as a document that can be read and understood by boiler operators, engineers and personnel with limited or no knowledge of water treatment chemistry. It is also intended to help them understand what effect any water and its subsequent treatment will have on their boiler plant.

This comprehensive guide deals with all aspects of water treatment for steam boilers, steam generators and hot water boilers. This document applies to industrial and commercial steam and hot water boiler plant including steam generators, operating at a working pressure of between 0.5 and 60bar gauge (except where stated) and a working temperature between 110°C and 400°C. We trust that by studying the contents and following the freely given advice your boiler plant will operate safely and more efficiently, and provide you with a trouble-free system.

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BREAKTHROUGH 8T ELECTRIC FORKLIFT

Hyster Company has previewed its forthcoming J8.0XN forklift truck, claiming it is the first time an 8 tonne electric truck can deliver ‘near ICE (Internal Combustion Engine) performance’. Achieving 100% charge in just two hours, it has the endurance to support three shift operations.

“The new electric J8.0XN provides similar performance to the Hyster® LPG equivalent in most normal paper, timber and steel applications, giving businesses the option for zero emissions and quieter operations,” says Phil Ireland, Senior Product Strategy Manager.

“It is an 8 tonne capacity forklift that will suit companies with large fleets and will be particularly interesting for timber firms that produce their own electricity,” he says. “The truck combines Lithium ION with high voltage systems and superior motor technology.”

The Li ION battery is large enough to ensure long endurance, giving a stable performance over a full shift before recharge. From flat, the battery can be fully charged in two hours and will sustain high endurance levels during its operational life.

The J8.0XN was previewed at the Hyster® HUB event held in Weeze, Germany in October 2016 where international press and VIPs witnessed a comparison between the J8.0XN and an equivalent ICE (internal combustion engine) truck.

“The new J8.0XN is faster to accelerate over the first 15 metres and lifts at the same speed as the Hyster® ICE model,” he says. There is a top speed of 21.4km/h (unladen) and 18km/h (laden) which Hyster claims is a full 4km/hr more than the nearest competitor, while noise levels at the operator’s is just 73 dB(A).

The initial cost of the truck, battery and charger is higher, but in the right applications, the overall cost of operation over the life of the truck is reported to be significantly less.

For more information, visit **http://www.hyster.eu**.

DOUBLE DIAPHRAGM PUMP

michael smith engineers ltd

A comprehensive range of Air-Operated Double Diaphragm pumps (AODD) which represent one of the most reliable, rugged and affordable of their type available on the market have been introduced. The all-new Finish Thompson FTI AIR range has been meticulously designed using the extensive resources available to FTI and include all the benefits of AODD pumps in addition to FTI's own innovative features.

The FTI AIR range offers the important benefits of using AODD pumps: simple installation, easy to operate and run with low maintenance and running costs, self-priming, portable, dry-running, can handle abrasive, viscous and shear-sensitive liquids and even 'dirty' liquids with particles.

In addition, a unique lube-free air valve design contributes towards the philosophy of a simple, rugged and reliable design. This design features significantly fewer components compared to other air valves, resulting in reduced servicing time and the associated maintenance costs and downtime. The air valve components include: a low friction slide valve on a ceramic plate to allow for long-life and superior sealing, and a moulded Buna gasket which ensures total sealing and eliminates flat gasket tearing. Also, air is used through a slot in the diaphragm shaft to shift the valve, eliminating the need for a separate pilot valve or mechanically operated pilot valve.

In addition to their rugged and simple design with fewer components, is a modular construction which also results in simplified maintenance with individually replaceable, lower cost wearing parts which do not require special tools for fitting. Single piece flow assembly procedures means that every pump is built to the highest quality of specifications and every pump is tested with a three point test for vacuum, leakage and run ability.

FTI Air pumps provide outstanding installation flexibility. For example, while flooded suction is the most common installation, they can also be used in suction lift applications where the pump is installed above the liquid, or even submerged in the liquid.

Thanks to the numerous benefits of using air-operated double diaphragm pumps they are ideally suited to a wide range of pumping applications in many industries such as: chemical manufacturing, mining, paints & coatings, ceramics, pulp & paper, electroplating & anodising and waste water.

Further details at:
http://www.michael-smith-engineers.co.uk/products/finish-thompson/air-operated-double-diaphragm-pumps

Michael Smith Engineers Ltd, Unit E, Scotswood Park, Forsyth Road, Sheerwater, Woking GU21 5SU.

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Email: Info@michael-smith-engineers.co.uk

DRIVES HELP INCREASE PRODUCTIVITY AND REDUCE ENERGY COSTS

Rockwell Automation has introduced a suite of drive solutions that will help users reduce energy costs and increase machine uptime for assets running in high-demand applications. The **Allen-Bradley PowerFlex 755T** drives provide harmonic mitigation, regeneration and common bus system configurations.

The latest PowerFlex drive offering marks the introduction of TotalFORCE technology from Rockwell Automation. This new drive technology delivers superior motor control through precise, adaptive control of velocity, torque and position for electric motors. TotalFORCE technology incorporates several patented features that are designed to help optimise a user's system and maintain productivity.

The expanded Allen-Bradley drive portfolio now includes the PowerFlex 755TL low-harmonic drive, PowerFlex 755TR regenerative drive, and PowerFlex 755TM common DC bus drive system, all compliant to the IEEE 519 specification. These new drives offer the additional advantages of a world-class footprint, comprehensive diagnostic and maintenance features, and simplified startup and installation.

PowerFlex 755TL drive: The PowerFlex 755TL drive uses active, front-end technology and an internal harmonic filter to reduce harmonic distortion. The drive is available from 250 to 1,800 Hp (160 to 1250 kW).

PowerFlex 755TR drive: Delivering power from 250 to 3,000 Hp (130 to 2,300 kW), the PowerFlex 755TR drive includes both regenerative and harmonic mitigation solutions. The drive helps reduce energy consumption and costs by delivering energy back to the incoming supply, resulting in a more energy-efficient solution.

PowerFlex 755TM drive system: This allows users to build the system that best fits their needs for regeneration and coordination of multiple motors in common bus configurations. To optimise their system requirements and meet power-consumption needs, users can select from a series of predesigned modules with a power range from 250 to 3,000 Hp (130 to 2,300 kW).

The three drive solutions have advanced, predictive diagnostics to estimate and provide notification of the remaining life span of drive components, such as fans, relay contacts, power semiconductors and capacitors. Users can actively monitor parameters, such as temperature and runtime, of the drive and motor to allow for preventive action if necessary.

The drives can be fully configured in the Rockwell Software Studio 5000 design environment as part of the Premier Integration experience when working with Logix controllers. This helps to reduce programming time, simplify startup and streamline diagnostics.
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DUST DOCTOR CAMPAIGN

A specialist dust extraction firm in the UK has launched a 'Dust Doctors' campaign, which sees it offer free dust assessments to businesses – helping them to determine the best ways to improve processes in order to remove threats to workers' health and production processes, as well as improving overall output efficiency.

With over 40 years of experience, Dustcontrol UK is offering its expertise as 'Dust Doctors' to provide workplace assessments in a bid to encourage what it refers to as 'Healthy Business'. James Miller, Dustcontrol UK's General Manager, commented: "The central element of the Dust Doctor campaign is education. Whilst awareness of the dangers of dust is improving, there is still a huge amount of work to be done. Many people simply don't realise that benefits can be made in both health and safety as well as efficiency."

He continued: "For example various industrial dusts can be extremely hazardous to health. Silica dust, present in a wide range of building materials, if inhaled over time can cause incurable lung disease. Allergens in flour and grain can result in occupational asthma for bakers. Woodwork facilities run the risk of dust explosions. The risks associated with dust are many and varied. Some businesses may be unsure if they have an issue or what to do about it. We're aiming to assist with that with our combined knowledge and range of high quality products and accessories."

Dustcontrol UK operates across a wide variety of industries and has specialist knowledge in the construction, pharmaceutical, aviation, manufacturing, food, transit, wood, metal and ceramics industries amongst others. Each industry has its own needs, whether that be Atex rated equipment, Hepa filtration, coloured antistatic brushes and bristles for the food industry, spring retractable hose reels or bespoke extraction hoods for on-tool extraction - Dustcontrol has a range of solutions.

James Miller commented: "Our equipment is applicable in a really diverse range of industries but is specific to removing dust at source. Dust is often regarded as a nuisance rather than a hazard, but it's much more than that. Our team can help to highlight the areas where the right dust management processes can really aid a business – be that to do with health or addressing productivity and product quality issues."

The assessments are free for those businesses that sign up, with a member of the Dustcontrol UK team arranging a suitable time to visit premises and assess where suitable dust extraction can help. Offering solutions that can incorporate either cyclone based mobile extraction equipment or permanent central vacuum systems, Dustcontrol UK ensures that a tailored approach sees specific requirements accommodated.

Those interested in signing up for a free assessment should visit **www.dustdoctors.co.uk** or visit **www.dustcontroluk.co.uk** for more information.

Alternatively please phone **Dustcontrol UK** on **01327 858001** or email **sales@dustcontrol.co.uk**

ENERGY EFFICIENCY GUIDE

ExxonMobil and ENER-G have created a free downloadable guide describing general energy efficiency strategies that can be adopted by industry: ***The Energy Saving Guide for Business and Industry***.

The guide provides advice and practical recommendations on how managers can prioritise productivity while also saving energy. It recommends adopting an integrated energy strategy, including smart metering and control strategies, energy audits, decentralised energy generation such as combined heat and power (CHP), and changing to more energy-efficient lubricants.

The guide also offers best-practice tips on reducing energy demand in offices, factories and warehouses; summarises the financial help available for implementing energy efficient measures such as CHP; describes how the right lubricant selection can help companies save energy; and provides guidance on legislative and regulatory compliance.

"Industrial energy bills can be reduced by as much as one fifth through simple, cost-effective measures to cut wastage," said Chris Marsland, technical director for ENER-G. "The guide outlines how on-site energy generation using efficient, low carbon technologies, such as combined heat and power, can create enormous savings. The latest research shows that inefficient energy production is costing the UK £9.5 billion per year, whereas decentralised energy production using CHP can achieve cost savings of up to 40 per cent over electricity sourced from the grid and heat generated by on-site boilers."

The guide also contains advice from experts at ExxonMobil on how high-performance synthetic lubricants can help companies save energy.

"High-performance lubricants, such as the Mobil SHC Gear series, can help businesses to enhance energy savings, improve productivity, and provide safety benefits by cutting unscheduled maintenance," said Andrea Jacobsen, industrial marketing manager for Europe, Africa and Middle East, ExxonMobil. "The paper sector, like many other energy-intensive industries, is looking at ways to cuts its energy consumption without hampering productivity. We hope this guide will help increase awareness of the important role that lubricants can play in attaining that goal."

ExxonMobil has a range of lubricants with proven energy efficiency benefits, such as the Mobil SHC™ 600 Series, which is formulated to provide balanced performance in demanding applications at both high and low temperatures. Mobil SHC 600 Series products have demonstrated up to 3.6 per cent improvement in energy efficiency in controlled laboratory testing while also providing excellent resistance to oxidation and deposit formation at elevated temperatures. Their exceptional resistance to rusting and corrosion offers additional protection, which can help increase productivity.

For more information about energy-efficient Mobil-branded lubricants, or any other Mobil-branded products and services, visit **mobilindustrial.com**.

EU RULING GIVES UK CHEMICAL COMPANY THE EDGE IN PULP HYGIENE

Paper and pulp businesses can now source EU-approved biocidal disinfectants from the UK as Airedale Chemical, the only British-based producer receives BPR approval for its peracetic acid (PAA) products.

Following confirmation of its place on the EU Biocidal Products Regulation (BPR) Airedale Chemical has cemented its position as one of the country's leading chemical companies by becoming the sole UK-based manufacturer directly approved for the production of PAA.

Peracetic acid plays an essential role in the prevention of slime formation in paper machines. It is also used as a disinfectant against odours which occur due to bacteria present in the organic environment of paper mill water circuits.

The Biocidal Products Regulation stipulates that chemicals such as disinfectants, pest control products and preservatives now have to be approved by the European Chemicals Agency (ECHA) and covers biocidal products used in the protection of materials, humans and animals against bacteria, pests and other harmful organisms.

Chris Chadwick, managing director at Airedale Chemical who has been integral in the bid for registration, said the company is delighted to be the only UK manufacturer directly approved by ECHA: "Securing Airedale Chemical's registration has been a lengthy process but incredibly worthwhile as the purpose of the Europe-wide regulation is to ensure the greatest protection of people and the environment from the use of biocides – and to improve how the biocidal market operates within the EU."

He added: "This approval demonstrates how our company and our family of peracetic acid products meets the stringent requirements set by the governing body.

"Biocides are used extensively in the paper and pulp process and our new status allows us to further develop our peracetic acid products and continue to lead the way with a range of effective and approved biocides."

Airedale Chemical supplies PAA in dilutions of 5% and 15% and is also available as Airocide PAAD, the DEFRA approved peracetic and detergent solution for agricultural, dairy and avian applications.

Airedale Chemical is a family owned, West Yorkshire-based company. Established in 1973, the company specialises in the manufacture of industrial and speciality chemicals, surfactants, phosphates and phosphonates to an expansive range of market sectors across the UK and Europe.

Uniquely, Airedale Chemical owns and operates its own chemical transportation fleet allowing it to provide a flexible and reactive chemical distribution service.

To find out more about its products, chemical distribution, chemical manufacturing and toll manufacturing for the UK chemical industry, visit **www.airedalechemical.com**.

GROWTH PREDICTIONS FOR PALLET TRUCK MARKET

The pallet truck market is often seen as niche. Yet they're used in more settings than people often imagine. Useful for every business – whether large or small – they add value and help businesses go from strength to strength. Particularly important in the digital age where orders are turned around quickly, pallet trucks have become imperative for businesses all over the world to keep up with demand and stay ahead of competitors.

Midland Pallet Trucks has welcomed the news that the global pallet market is set to grow at a Compound Annual Growth Rate of 4.90% between 2016 and 2020.

Phil Chesworth, Managing Director at Midland Pallet Trucks, said, "Pallet trucks, although often seen as an addition to a business, are actually imperative to its success. One of the main driving forces behind constant streams of orders, new products and efficient shipping, robust pallet trucks give businesses the edge in this ever-competitive market."

The report, undertaken by ReportsnReports, has stated the reason for this incredible growth is due to the increase in manufacturing output. The revival of the manufacturing sector and projected economic expansion worldwide will boost demand in the materials transport segment over the coming years.

Phil, added, "It's extremely promising that the manufacturing industry is predicted to grow. The country needs a boost after all the doom and gloom of late. Therefore businesses should take this on board and look to a prosperous future."

The global pallet market analyst also highlighted another reason for the predicted market growth; vertical integration by companies. There's high demand for lumber used for manufacturing pallets in the construction and furniture industries, yet sawmills are unable to meet the growing demand. This results in a shortage of lumber in the market, and as a result, pallet manufacturers find it difficult to complete their orders. This has caused the supply of raw materials to pallet manufacturers to be significantly affected. Some pallet manufacturers are vertically integrating and investing in logging and sawmills, which enables them to offer high-quality pallets at affordable prices.

Midland Pallet Trucks stock a huge range of equipment, ideal for businesses of all sizes and in all sectors. To find out more and browse their range available to purchase online, visit the website: **www.midlandpallettrucks.com**

About
Midland Pallet Trucks are pallet truck specialists, with a diverse range of models and specifications held in stock for immediate shipping. The company is based in the West Midlands, England, importing high-quality pump trucks and lift tables directly from the manufacturer. It carries sufficient stocks in its 60,000 square feet warehouse to supply the whole of the UK market with any kind of hand-operated truck or lift.

KEY ADAPTOR PREVENTS MACHINERY START-UP

To prevent the inadvertent startup of dangerous machinery, Fortress Interlocks has developed an extracted key adaptor for use with its robust amGardpro, amGardS40 (IP69K) and mGard interlock ranges.

By forcing an operator to extract the safety key when operating an interlock, the adaptor ensures the key cannot be turned and left in place, inadvertently re-starting machinery.

It is designed to be kept with the operator, ensuring any access points cannot be closed and re-started while working in a hazardous area. Additional safety keys can be released following the forced extraction of the initial key, allowing the protection of multiple users at the same time.

The extracted key adaptor utilises the 'CL lock', which has over 200,000 unique combinations, meaning it works with even the largest systems. It is also available with a padlockable dust cover to be compatible with standard lockout procedures.

About Fortress Interlocks
Fortress Interlocks is a world leader in safety interlock systems. Its products guarantee that actions and events are undertaken in a pre-determined sequence. This creates a safe working environment where employees are safeguarded from injury and equipment is protected from damage. This helps customers protect their personnel and capital assets. The company has over 40 years' experience in the safety market, designing and manufacturing safety access and control systems at its headquarters in Wolverhampton, UK. Fortress is a Halma company.

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L&W ONLINE FREENESS MEASUREMENT

ABB has launched L&W Freeness Online, a reliable, repeatable and cost-effective online system for measuring, monitoring and controlling key quality variables - Canadian Standard Freeness (CSF) and Schopper-Riegler (SR) - in paper stock preparation. This helps pulp and paper customers to save production costs by reducing energy consumption through elimination of over-refining, and to improve quality by generating uniform pulp furnish for the paper, board or tissue machines.

L&W Freeness Online solves the problem of inconsistent and inaccurate manually-measured results with an automatic and complete measurement cycle, reporting results that are compensated for consistency and temperature, with measurement results that approach laboratory standards.

The system also allows for multiple sampling points with a single instrument, reducing initial investment cost and ongoing maintenance costs.

”Now we can offer a robust and responsive CSF/SR measurement online, which gives our customers an easy way to pinpoint and follow trends on pulp quality while its being made, and at the same time helps them to reduce refining energy,” says Anna Schärman, Global Product Manager, ABB Pulp & Paper products.

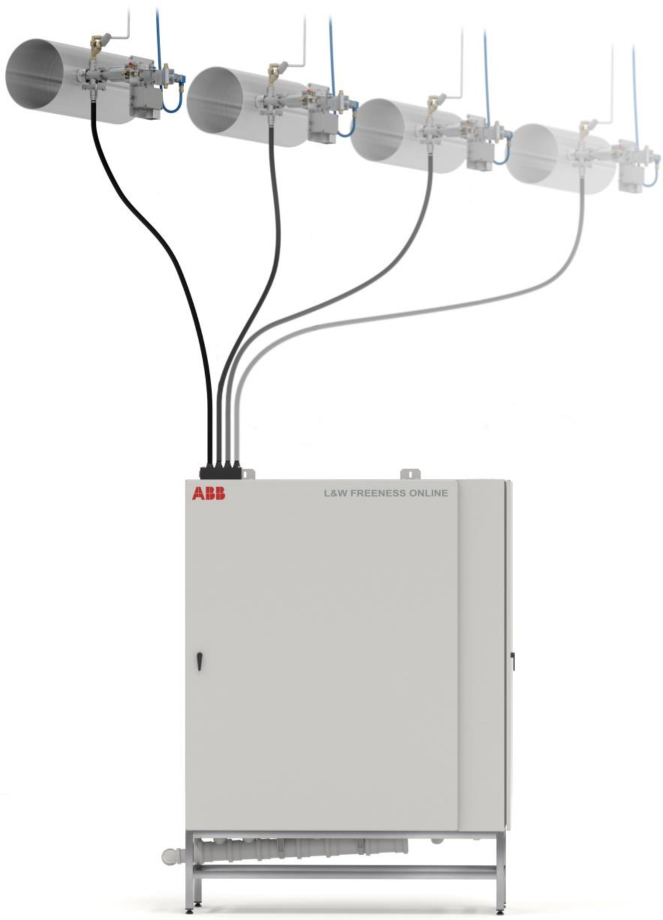

ABB (ABBN: SIX Swiss Ex) is a pioneering technology leader in electrification products, robotics and motion, industrial automation and power grids, serving customers in utilities, industry and transport & infrastructure globally. Continuing a more than 125-year history of innovation, ABB today is writing the future of industrial digitalization and driving the Energy and Fourth Industrial Revolutions. ABB operates in more than 100 countries with about 135,000 employees. **http://www.abb.com**

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LUBRICANT ANALYSIS PROGRAMME

ExxonMobil

ExxonMobil has launched Mobil Serv℠ Lubricant Analysis, a new mobile-enabled used oil analysis service. The new service will help operators identify equipment issues before they happen and avoid unscheduled equipment maintenance.

The service, which replaces ExxonMobil's Signum℠, is vital in helping engineers maintain a healthy and reliable operation. When monitored regularly, the used oil analysis programme helps to enhance equipment reliability, reduce maintenance costs and unscheduled downtime, improve equipment durability and reduce lubricant consumption. It can also help to extend oil drain intervals, which improves safety by reducing intervention with machinery.

Designed to streamline the entire used oil analysis process from initial sample gathering to final reporting, the service leverages scan-and-go technology with QR Codes so customers can easily deliver used oil samples to ExxonMobil's oil analysis laboratory. Customers can then access results and customised equipment recommendations on mobile or tablet devices using a cloud-based app and share it with any other parties, as needed.

The new services package can also eliminate labels and paperwork and facilitates real-time communication of sampling scheduling and results. However, customers will still be able to manage and assess their reporting manually. In addition to the new, user-friendly interface, the system also offers improved response time - all to help operators protect their equipment and business.

"The Mobil Serv Lubricant Analysis programme can be accessed via any mobile device and our new report layout and expanded trend analysis make it simpler for users to understand the diagnosis and act on our recommendations" said Ayman Ali, ExxonMobil's industrial marketing adviser for Europe, Africa and the Middle East. "The launch of this new service builds on ExxonMobil's long tradition of providing leading used oil analysis services to companies around the world, enabling them to extend oil drain intervals and, in turn, benefit from reduced maintenance costs and improved efficiency."

The used oil analysis programme offers a full 360° analysis allowing operators to track productivity trends and spot any anomalies. With 25 testing options available users are able to pick and choose the right test package for their operation.

The new service is available now and customers previously registered to Signum will have automatically migrated to the new programme, along with their analysis history.

Mobil Serv Lubricant Analysis is a new addition to the Mobil Serv family, ExxonMobil's new lubricants services brand launched in late 2015.

For more than 100 years, ExxonMobil has delivered an extensive range of leading technical services to help customers optimise their maintenance programs and enhance equipment performance, and it has now brought all these services together under one brand to help deliver these services even more efficiently.

To find out more about Mobil Serv Lubricant Analysis or to join the programme, please visit **mobilserv.mobil.com**.

O-RING FFKM SEALS

DICHTOMATIK

The deformation of metal O-ring seals can occur where process operating conditions reach temperatures up to 300°C, with liquid pressures also as high as 100 bar. This form of seal failure can result in leaks, causing safety concerns while also necessitating clean-up operations and the interruption or total suspension of production line activities.

However, costly breakdowns can be reduced or even virtually eliminated by utilising the DuPont™ Kalrez® perfluoroelastomer (FFKM) O-ring seals. In examples where these high performance products have replaced the OEM fitted metal seals, uninterrupted production periods in excess of 10 years have been experienced without any lost production processes due to seal failures. Scheduled maintenance periods can also be safely extended leading to manpower savings coupled with increased production outputs.

The Kalrez® O-ring seals are available in the UK from authorised distributor Dichtomatik Ltd. Finished O-rings, custom shapes, sheet and cords are manufactured exclusively by DuPont™ from raw material right through to the finished products, and Kalrez® is now the choice of elastomer for the most demanding sealing applications.

Kalrez® is recognised as the market leading perfluoroelastomer which is resistant to over 1800 different chemicals while offering the high temperature stability of PTFE (327°C). The advanced properties of the product help maintain seal integrity with increased production safety, while also helping to minimise manufacturing and maintenance costs.

Typical worldwide markets that can benefit from the proven advantages offered by Kalrez® products include aggressive chemical processing, food and pharmaceutical production activities, oil and gas recovery, petroleum applications, power generation together with semiconductor wafer processing involving a wide range of industrial and electronic grade chemicals.

Subsequent removal or *in-situ* repairs of affected equipment such as gear pumps, centrifuges, reactors and quick-release couplings can be expensive, particularly if the MTBF times are of short duration, leading to high unscheduled costing levels together with production shut-downs and process liquid losses. Labour costs alone covering major component strip-downs or complete unit replacements can be very substantial.

Further information is available from:

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PALM VALVE INNOVATION

Palm valves, also known as edge tracking units, are pneumatic-mechanical devices that detect the position of the fabric edge and drive the guide in order to keep the fabric running straight, parallel to the paper machine centreline.

Weingrill Srl, a major manufacturer of electro-mechanical products for the paper-making industry and represented in the UK by Jarshire Ltd., has developed a new model, known as Series 50000, to complement its 25600 range.

Totally enclosed within a hermetically-sealed body, the 50000 brings two major additional benefits – one, it avoids the detrimental collection of pulp and/or unwanted contaminants inside the body; and two, it significantly decreases the contact pressure between anti-wear sliding surface and fabric. This design feature makes it ideal for use in harsh and humid environments, such as the drying section, whilst the gravity-generated, reduced-contact pressure, guarantees longer life to fabric edges.

All Weingrill palm valves are of robust stainless steel construction with sliding surfaces of anti-wear ceramic material. Both have the same control valve (centre closed) solution that is suitable for the precise and reliable control of guiding devices with two actuators.

Further information may be obtained from:

Jarshire Ltd
Levels House
Bristol Way
Stoke Gardens
Slough
SL1 3QE

Tel: 01753 825122

sales@jarshire.co.uk www.jarshire.co.uk

PLASTIC PALLETS FOR PULP AND PAPER INDUSTRY

In 2008, M-real Office Papers approached us looking for a solution for transporting its recycled wet-lap pulp. The company, which was then manufacturing 550,000 tonnes of office paper every year, needed help moving the pulp from its Kemsley paper mill in Kent to its paper mill near Rouen in Normandy, and then returning the recycled office paper to the UK.

Wet-lap pulp is transported at about 50 per cent moisture content. The recycled matter is stacked in large bales measuring approximately 1400mm (L) x 1200mm (W) x 1200mm (H) and weighs a hefty 1.3 tonnes. M-real therefore needed a pallet that offered optimum strength and could fit the specific bale dimensions.

Initially, M-real asked us to look at sourcing a made-to-measure pallet. While bespoke pallets offer the advantage of being designed to suit individual requirements, on small orders they can often prove more costly. Following consultation with our technical team, we ruled out designing a made-to-measure pallet on the basis of high moulding costs and instead looked at suitable models from our existing range.

The plastic pallet we recommended was the APB 1420 Full Perimeter pallet, which measures 1420mm x 1120mm and is produced by Cabka-IPS. Although the width of the pulp bales exceeded the width of the pallet, M-real was able to slice the bales at any width, making this pallet fit for purpose.

Manufactured in high-density polyethylene, the APB 1420 Full Perimeter pallet has a low-pressure injection moulded construction that provides strength, close tolerance, dimensional consistency and stability.

Whilst we selected this pallet primarily for its size and durability, another important criteria in transporting wet-lap pulp is being able to record batch production for quality control purposes. With recessed areas for UPC barcoding on all four corners, the APB 1420 Full Perimeter pallet allows users to quickly identify any batch of wet-lap pulp.

One problem we had to overcome in handling the wet-lap pulp was the tipping process. When offloading wet-lap pulp, the pallets are lifted on rotating forks and tipped to remove the recycled matter. This tipping process together with the weight and consistency of the wet-lap pulp applies considerable stress on the pallets. As a solution, during the manufacturing process we incorporated a specially moulded section inside the pallets, to strengthen the design and offer further reinforcement to withstand manual handling.

In early 2008, M-real ordered 4,500 pallets, which we delivered efficiently during a two-week period. The operation was so successful that they then placed two further orders totalling 1,400 pallets. Later that same year, the Kemsley paper mill was sold; however the new owners continue to use the same plastic pallets and have ordered a further 6,500 new ones to help increase production.

For advice about handling and transporting paper and board products, call **Goplasticpallets.com** on **01323 744 057** or email **sales@goplasticpallets.com**.

SAFETY SWITCH - PILZ- PSENM-LOCK

Pilz is adding PSENmlock to its range of safety switches. PSENmlock offers safety gate monitoring (also known as interlocking) and safe guard locking for the protection of personnel and processes to the highest levels up to PL e (of EN ISO 13849) in one device. It fully satisfies the requirements of the latest interlocking standard EN ISO 14119. The slimline yet robust design and the many different installation options make PSENmlock both flexible to use and easy to install.

PSENmlock is a reliable door guard switch both for small or large, light or heavy, swinging or sliding doors, gates, covers and flaps. Above and beyond these possible applications the flexibly mounted actuator ensures high tolerance compensation and unrestricted functionality even with sagging gates. Thanks to a bi-stable solenoid, the currentless guard locking system reduces the energy consumption of the safety gate system. Diagnostic data is easily identifiable in many installation positions: LEDs on three sides of the housing support user-friendly diagnostics whatever the installation situation.

Extremely strong

With a holding force of 7500 N and the integrated latching force of 30 N, the safety gate system prevents the guard from opening inadvertently. This makes PSENmlock particularly suitable for machines with a hazardous overrun that makes guard locking up to PL d or PL e absolutely essential, such as rotating knives, flywheels or robots. In addition, an integrated mechanical restart interlock prevents the guard locking system from being activated inadvertently, without the need for separate accessories. Not only does the restart interlock make operating the machine safer, it also prevents an inadvertent restart during maintenance operations!

The integration of RFID into the tongue actuator means that, in the unlikely event that it breaks off in the switch, such a failure is detected and a safe state is preserved. The outputs of the switch are cross-monitored semi-conductor types with short-circuit detection built in.

Three levels of coding are available, and a high level of protection against manipulation is assured. Mounting plates and brackets are available for 40mm profile structural systems.

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TANK CLEANING HEAD SAVES WATER & MONEY

THE SPRAY NOZZLE PEOPLE
SNP
Bete Limited

The new ORBITOR ECO from the SPRAY NOZZLE PEOPLE is a new class of tank cleaning head. Whilst similar in design to a standard fluid powered impingement tank cleaner it has been modified to serve a different function and promises to dramatically reduce water consumption, particularly for applications with smaller tanks, or those with lighter residues.

Impingement tank cleaners have always been the most water efficient way to clean tough residues or larger tanks in most process, chemical and food industry applications. The powerful cleaning jets break down even the toughest of residues with minimal water and they remain the most cost-efficient cleaning method. However, in smaller tanks or those with light soluble residues, impingement cleaners are often regarded as an unnecessary expense. Their powerful cleaning action is not normally required in such situations and the set time to complete a cycle significantly reduces their overall water efficiency when only quick cleans are needed.

The Orbitor Eco changes all this. It's still a powerful impingement cleaner but has been specially geared to complete its cleaning cycle much faster, ranging from 1.7mins up to 6 minutes. Cycle time will depend on the specifics of the application, particularly water pressure, although the Eco is designed to operate at pressures ranging from 4 to 12 bar. The fast rotation sacrifices some of its cleaning power but it also dramatically reduces the water used per cleaning cycle and minimises downtime. When compared directly with other types of cleaning nozzles like spray balls, it can complete a similar job in far less time using up to 95% less water.

The savings in water translate directly to savings in the pocket for any business, particularly when you factor in that water actually costs a business three times. Firstly, to buy it, then to pump it, and finally to dispose of contaminated water.

How much depends on the specifics of each tank cleaning application, but it does illustrate the potential triple savings when ALL the costs are included in the calculation.

For example, if you do the maths on using 500 litres as opposed to 4000 litres to clean a tank each time (a not un-typical water saving) the return on investment for deploying a new breed fast cycle impingement cleaner like the orbitor Eco will be measured in months or weeks, rather than years.

The Orbitor Eco is one of a wide range of spray nozzles available from The Spray Nozzle People who have been supplying spray nozzles for over 15 years to the engineering, food processing, chemical and petro-chemical industries in the UK.

Contact: **ivan@spray-nozzle.co.uk**
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http://www.spray-nozzle.co.uk/

PAPERmaking!

FROM THE PUBLISHERS OF PAPER TECHNOLOGY

Volume 2, Number 2, 2016

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Installations

The following pages contain a summary of the various installations and orders from around the world of papermaking, wood panel and saw mills, and bio-power generation, received between March 2016 and November 2016.

The Paper Industry Technical Association (PITA) is an independent organisation which operates for the general benefit of its members – both individual and corporate – dedicated to promoting and improving the technical and scientific knowledge of those working in the UK pulp and paper industry. Formed in 1960, it serves the Industry, both manufacturers and suppliers, by providing a forum for members to meet and network; it organises visits, conferences and training seminars that cover all aspects of papermaking science. It also publishes the prestigious journal *Paper Technology* and the *PITA Annual Review*, both sent free to members, and a range of other technical publications which include conference proceedings and the acclaimed *Essential Guide to Aqueous Coating*.

COMPANY, SITE	SUPPLIER	DESCRIPTION	START-UP
Action Group, India	Valmet	To deliver a new defibrator system for the new fibreboard line being built	2017
Ahlstrom, Kentucky Plant, USA	tba	To invest in engine and industrial filtration production capacity	2018
Arjowiggins, Papeteries du Bourray, France	Valmet	To replace automation system on PM1	2016
Arkhangelsk Pulp & Paper Mill (PPM), Russia	Valmet	To supply an extensive rebuild of BM2	2018
Babcock & Wilcox Vølund A/S, Dunbar energy recovery facility (EFR), East Lothian, Scotland	Valmet	To supply automation technology for this energy from waste plant	2017
Bashundhara Paper Mills, Bangladesh	Andritz	To supply a turnkey tissue production line (1.85m, 2100m/min)	2017
Borås Energi och Miljö, Sweden	Valmet	To supply a biofuel-fired power plant and related flue gas cleaning and condensing systems	2017
Carta Fabril, Anápolis, Brazil	Andritz	To supply a PrimeLineST W22 tissue machine with steel Yankee and steam-heated hood	2019
Cartiere Carrara, Ferrania Mill, Cairo Montenotte, Liguria region, Italy	tba	To install a new TM (60ktpy) and co-generation plant (4.3MW)	
Cheng Loong Binh Duong Paper Company, Ben Cat Mill, Binh Duong Province, Vietnam	Valmet	To supply key process technology for its new BM1 containerboard machine	2018
CMPC S.A., Maule, Chile	Andritz	To upgrade the complete bleaching system	2017
CMPC subsidiary Protisa, Cañete, Peru	Voith	To supply TM4,a double-width tissue machine	2017
Essel Selüloz ve Kâğıt Sanayi Tic. A.ş., Caycuma production site, Turkey	A.Celli	To rebuild tissue machine, by supplying a 12-foot steel Yankee and a new headbox	
Europac, Dueñas Site, Spain	tba	Install double layer coating on paper line, upgrade corrugating line, develop smart warehouse and install printer	2018
Green Forest (QingXin) Paper Industrial Limited, Qingxin County, Qingyuan, China	Valmet	To supply a headbox upgrade and two headbox recondition service packages	2017
Greenply Industries Ltd, Routhu Suramala, Mandal, Andhra Pradesh state, India	Valmet	To deliver a chipping line and defibrator system for MDF production	2017
Grupo Gondi, various facilities, Mexico	Bobst & BHS Corrugated	To supply eleven new corrugated production lines	2016/2017
Helsingør Kraftvarmeværk A/S, Helsingør, Sjælland island, Denmark	Andritz	To deliver a biomass boiler island for a combined heat and power plant	2018
Heze Baishida Wood Co., Ltd, Sunlaojia town, China	Valmet	To rebuild an existing fibreboard line	2017
HOFOR Energiproduktion A/S, Copenhagen, Denmark	Valmet	To supply biomass boiler, biofuel storage and conveyor systems	2019

COMPANY, SITE	SUPPLIER	DESCRIPTION	START-UP
ITC, Bhadrachalam Mill, India	Valmet	To supply an extensive board machine rebuild of PM1	2017
ITC Limited, Paperboards & Specialty Papers Division, Tribeni, India	Voith	New decor paper machine (PM4)	
Ji'An Group Co. Ltd, Jiaxing City, Zhejiang province, China	Andritz	To supply a set of reject handling equipment for paper production lines PM11, PM12, and PM13	2016
JSC Volga, Balakhna, Nizhegorodskaya oblast, Russia	Andritz	To deliver a complete state-of-the-art ATMP (Advanced Thermo-mechanical Pulp) line, which will process 100% spruce for the production of soft wood pulp	2019
KapStone Paper and Packaging Corporation, Ontario, California	tba	To install a new state-of-the-art sheet plant with 60ktpy capacity	
Kimberly-Clark GmbH, Coblenz Mill, Germany	Andritz	To supply components for rebuild of the wet lap plant - scope includes rebuild of the 1.2m wide twin wire press and heavy-duty press	2016
Kyiv CPM	Bellmer	Modernization of machine coater	2016/2017
Kyiv CPM	Valmet	To supply new Yankee cylinder	2016
Kotkan Energia, Hovinsaari power plant, Kotka, Finland	Valmet	To modernise turbine automation	2016
Kruger Products, Crabtree plant, Quebec	tba	To add 20ktpy tissue machine (PM8)	2017
Kuban Papir, South Russia	PMP	To rebuild TM1 – in particular to add a single layer Intelli-Jet V® hydraulic headbox of 2850mm ponside, and deliver design engineering for silo and flume reworks	2017
Laakirchen Papier AG, Laakirchen, Austria	Andritz	To convert PM10 from SC to containerboard	2017
Laakirchen Papier AG, Laakirchen, Austria	Valmet	To supply paper machine modifications and a new winder	2017
Lee & Man, Dongguan, China	Voith	To supply two TMs (TM11 & TM12) – each 5.6m, 2200m/min, 60ktpy	2017
Lee & Man, Jiangxi Jiujiang facility, China	A.Celli	To supply four tissue rewinders (width 5.6m)	2016
Lenzing, Lenzing Austria	tba	To invest and increase production capacity of dissolving pulp	
Lenzing, Paskov, Czech Republic	tba	To invest and increase production capacity of dissolving pulp	
Liansheng Paper Industry (Longhai) Co., Ltd., Zhangzhou Taiwanese Investment Zone	Voith	To supply new 400ktpy packaging machine (PM9)	2017
Little Rapids Corporation, Shawano, Wisconsin, USA	Voith	To supply new TM (TM3) to produce 119tpd at 1830 m/min	2017
Mariyski CBK, Russia	Papcel	To supply technological parts to PM1 upgrade	

COMPANY, SITE	SUPPLIER	DESCRIPTION	START-UP
Metsä Board, Husum Mill, Sweden	Valmet	To deliver Valmet IQ to new extrusion coating line	2017
Metsä Fibre, Äänekoski Mill, Finland	SKF	To provide lubrication technology and engineering support services	2017
Metsä Tissue GmbH, Kreuzau Mill, Germany	Andritz	To supply a FibreFlow drum FFD pulper for deinking line of TM5	2017
Metsä Tissue GmbH, Raubach, Germany	Vamet	To equip TM3 with the same headbox as TM1	
Metsä Tissue, Paulistöm, Sweden	Valmet	To replace existing shoe press and Yankee dryer with Advantage ViscoNip press and cast iron Yankee cylinder	
MPM Oji Eco Energy Corporation (MOE), Mitsubishi Paper Mills Limited plant, Hachinohe city, Aomori prefecture, Japan	Valmet	To supply a multifuel power boiler and flue gas cleaning system for a multifuel boiler	2019
Munksjö, Arches facility, France	tba	To rebuild speciality paper machine that produces abrasive backings	2017
Naberezhnye Chelny Paper Mill, Chelny, Russia	Andritz	To upgrade and modernize PM K-28 – and deliver a PrimeCoat Size press with a PrimeAir Glide air turn and a new PrimeReel pope reel with two new under-the-machine pulpers as well as complete new mechanical and electric drives for the paper machine and a new QC system	2018
Nippon Paper, three different mills, Japan	Valmet	To supply Advanced Process Control (APC) systems and Valmet Kappa Analyzers for the mills' bleaching and lime kiln processes	2016
Panel Plus MDF Co. Ltd, Hat Yai Mill, Thailand	Andritz	To supply pressurised refining equipment and chip washing systems for MDF production lines I and II	2017
Papel San Francisco, Mexicali Mill, Mexico	Valmet	To supply an Advantage DCT 100TS tissue production machine	2017
Pro-Gest Group, Mantova Mill, Italy	Andritz	To deliver the complete waste paper processing plant and approach system for this new paper machine	2017
Roto-cart, Castelminio di Resana, Italy	Valmet	To supplier a new rewinder at this greenfield converting plant	2017
Rottneros Bruk AB	Renewa Oy	To supply 20MW biomass boiler	
SAICA, Beaulac, France	Valmet	To supply Valmet IQ Moisturizer system	2016
SAICA, El Burgo de Ebro, Spain	Andritz	To supply a gravity table and a sludge screw press	2016
SAICA, El Burgo de Ebro, Spain	Andritz	To supply a FibreFlow drum - including the complete feeding and dewiring system - for a new OCC line	2017
SAICA, El Prat, Spain	Valmet	To supply Valmet IQ Moisturizer system	2016

COMPANY, SITE	SUPPLIER	DESCRIPTION	START-UP
Sappi, Ngodwana Mill, South Africa	Valmet	To supply a dissolving pulp cooking demonstration plant to explore and optimise the extraction of biorenewable chemicals	2017
Sappi, Somerset Mill, Skowhegan, Maine	Andritz	To upgrade debarking line and woodyard equipment	2017
Saugbrugs Bioenergi AS, (part of the Norske Skog Group), Halden Mill, Norway	Andritz	To supply a new sludge dewatering line for thickening and dewatering of fibrous sludges	2017
SCA, Bowling Green, Kentucky, USA	tba	To install a new production line for adult incontinence products	
Schoellershammer, Düren Mill, Germany	Voith	To supply electrical and I&C system installation, control cabinet manufacture and commissioning for the new PM6	2016
Segezha Pulp and Paper Mill, Republic of Karelia, Russia	Valmet	To deliver a biomass-fired boiler plant and related automation and environmental systems	2017
Smurfit Kappa Papelsa, Barbosa mill, Colombia	Toscotec	To supply a dryer section rebuild to PM1	2017
Sofidel America, Circleville, Ohio, USA	Valmet	To deliver two Advantage NTT tissue lines including stock preparation equipment and automation systems	2018
Sofidel, European site (not yet decided)	A.Celli	To supply rewinder model E-WIND®	2017
Solenis LLC	PulpEye	To supply Dynamic Drainage Analyzer (DDA) No.100 which gives drainage values comparable to drainage in a wire section	
Sonoco Alcore, Ciriè facilities, Turin, Italy	A.Celli	To supply a 2.7m paper rewinder	2016
ST Tissue, Franklin, Virginia, USA	Toscotec	To supply the widest Steel Yankee ever to be manufactured (6.5m), as F5 machine converts to tissue production	
Stora Enso, various	Konecranes	To supply 7 Agilon material management systems	2016/2017
Stora Enso, Veitsiluoto Mill, Kemi, Finland	Andritz	To supply state-of-the-art equipment for brown stock washing and oxygen delignification	2017
Stora Enso, Skoghall Mill, Sweden	ÅF	To design new chemical plant	2017
Stora Enso, Skutskär Mill, Sweden	ÅF	To build a new lean gas system	2017
Stora Enso, Sunila Mill, Sweden	Valmet	To supply Valmet IQ Process and Quality Vision system	2016
Tampereen Sähkölaitos, Tampere, Finland	Valmet	To supply an automation solution to boost district heat production	2018
Tembec, Tartas SAS, France	Valmet	To deliver QCS at this dissolving pulp mill	2016

COMPANY, SITE	SUPPLIER	DESCRIPTION	START-UP
Wepa, Piechowice, Poland	ABB	To install a new 110/20 kV substation	
Zhejiang Dongda Paper Co. Ltd., Hangzhou, Zhejiang Province, China	Valmet	To supply IQ Moisturizer, to improve board quality on PM2	2016
Zibo Green Energy New Energy Co., Ltd., Zibo, Shandong province, China	Valmet	To supply its first Waste to Energy boiler plant to China	2017

PAPERmaking!
FROM THE PUBLISHERS OF PAPER TECHNOLOGY
Volume 2, Number 2, 2016

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Research Articles

Most journals and magazines devoted to the paper industry contain a mixture of news, features and some technical articles. However, very few contain research items, and even fewer of these are peer-reviewed.

This listing contains the most recent articles from the five main journals that publish original research:

- *APPITA JOURNAL*
- *IPPTA JOURNAL*
- *J-FOR*
- *NORDIC PULP & PAPER RESEARCH JOURNAL*
- *TAPPI JOURNAL*

The Paper Industry Technical Association (PITA) is an independent organisation which operates for the general benefit of its members – both individual and corporate – dedicated to promoting and improving the technical and scientific knowledge of those working in the UK pulp and paper industry. Formed in 1960, it serves the Industry, both manufacturers and suppliers, by providing a forum for members to meet and network; it organises visits, conferences and training seminars that cover all aspects of papermaking science. It also publishes the prestigious journal *Paper Technology* and the *PITA Annual Review*, both sent free to members, and a range of other technical publications which include conference proceedings and the acclaimed *Essential Guide to Aqueous Coating*.

APPITA JOURNAL, Vol.69 No.3 – Jul-Sept 2016

1. Decomposition of hydrogen peroxide by manganese in the presence of lignin
2. One bag mix of modified tapioca starch as an adhesive for corrugated fibreboard application
3. Optimisation of froth flotation for removal of wood extractives in paper manufacture
4. Integrating prehydrolysis kraft pulping of softwood and viscose fibre manufacturing

IPPTA JOURNAL, Vol.28 No.1 – Jan-Mar 2016

1. MBBR,the Most Appropriate Waste Water Treatment Technology for Paper Effluents
2. Use of A Dual Polymer System to Improve Brown Paper Strength and Machine Efficiency
3. Pulp & Paper Mill Waste Water Decolouration With Ozone
4. How To Recover More Used Paper For Recycling
5. Resource Conservation As A Key To Competitiveness Case Study From J K Paper Mills, Unit Rayagada, Odisha
6. Prospects of use of Solar Energy in Paper Industry (R)
7. Application Of Dynamic Simulation For The Pulp And Paper Industry
8. Varieties and A To Z Importance Of Paper
9. Innovative Approach for Improved Energy & Chemical Recovery Efficiency in Straw Based Paper Mill
10. Efficient Resources Management For Reduced Production Cost In Pulp Mills (Part 1)
11. Pulp & Paper Mill Waste Water Decolouration With Ozone
12. Application Of Dynamic Simulation For The Pulp And Paper Industry

J-FOR, Vol.5 No.3 – 2016

1. Chip Refining at Higher Specific Energy
2. Peroxide Bleaching Optimization Program: Port Hawkesbury Paper Mill
3. Ozone Bleaching: The Role of Hexenuronic and Muconic Acids on Pulp Viscosity
4. Adsorption of Acetic Acid from Pre-hydrolysis Liquor from Kraft-based Dissolving Pulp Production Using Amine-based Resin
5. Cellular Modifications in Pinewood During Delignification and Hydrothermal Pretreatment

J-FOR, Vol.5 No.4 – 2016

1. Reminiscences of a Paper Chemist: Past Trends and Future Directions
2. A Sensitivity Analysis of Wet-end Chemistry by Kinetic Calculations: A Case Study
3. From Surface Sizing Agents to Nanotechnology
4. On the Mechanical and Chemical Factors Governing Retention and Formation of a Fine Paper Stock: The Case of Headbox Elongational Shear
5. Effect of Fibre Size on Wettability and Barrier Performance of Hydrophobic Cellulosic Papers
6. A Short Review of Using Wood Fibres in Food Packaging
7. Electronic Structure Calculations of Twisted Cellulose Crystalloids
8. Sustainable Synthesis of Vaterite Using a Forest Nano-product

NORDIC PULP & PAPER RESEARCH JOURNAL, Vol.31 No.2 – 2016

1. Environmental, Health & Safety (EHS) aspects of cellulose nanomaterials (CN) and CN-based products

2. Effects of charge density and molecular weight of cationic polyacrylamides on growth and structural characteristics of ground calcium carbonate aggregates
3. Analysis of mesopore structures in wood cell walls and pulp fibers by nitrogen adsorption method
4. A new method showing the impact of pulp refining on fiber-fiber interactions in wet webs
5. Complex Matters: Things that matter
6. 3D synchrotron X-ray microtomography for paper structure characterization of z-structured paper by introducing micro nanofibrillated cellulose
7. Preliminary investigation on the potential of fractionation for stratified forming: application to maximising bending stiffness
8. Planar fluidic channels on TiO2 nanoparticle coated paperboard
9. Foam forming of long fibers
10. Fundamental properties of handsheets containing TEMPO-oxidized pulp in various weight ratios
11. Effect of cellulose nanofibers as a coating agent for woven and nonwoven fabrics
12. 3D synchrotron X-ray microtomography for paper structure characterization of z-structured paper by introducing micro nanofibrillated cellulose
13. BIOREFINERY - From forest residues to hydrophobic nanocomposites with high oxygen-barrier properties
14. BIOREFINERY - Lignin separation from kraft black liquor by combined ultrafiltration and precipitation: a study of solubility of lignin with different molecular properties
15. CHEMICAL PULPING - Inhibition of agglomeration by calcium-based zeolite as bed material during the combustion of reed black liquor in fluidized bed
16. MECHANICAL PULPING - Pulp property development Part II: Process non-linearities and their influence on pulp property development
17. MECHANICAL PULPING - Pulp property development Part II: Process non-linearities and their influence on pulp property development
18. MECHANICAL PULPING - Pulp property development Part III: Fiber residence time and consistency profile impact on specific energy and pulp properties
19. PAPER CHEMISTRY - Pilot-scale papermaking using Layer-by-Layer treated fibres; comparison between the effects of beating and of sequential addition of polymeric additives
20. PAPER PHYSICS - Permutation of refining and cellulase treatments determines the overall impact on drainability and strength properties in kraft pulp
21. PAPER PHYSICS - Shape accuracy analysis of deep drawn packaging components made of paperboard
22. COATING - Influence of nanolatex addition on cellulose nanofiber film properties
23. PAPER CHEMISTRY - Papermaking trials in a pilot paper machine with a new silica coated PCC filler
24. COATING - Effects of coating composition and folding direction on the fold cracking of coated paper

***NORDIC PULP & PAPER RESEARCH JOURNAL*, Vol.31 No.3 – 2016**

1. BIOREFINERY - A comparative study of the rheological properties of three different nanofibrillated cellulose systems
2. BIOREFINERY - A comparative study of the properties of three nano-fibrillated cellulose systems that have been produced at about the same energy consumption levels in the mechanical delamination step
3. BIOREFINERY - Enhancing the properties of carboxymethylated nanofibrillated cellulose by inclusion of water in the pre-treatment process

4. CHEMICAL PULPING - Some process aspects on single-stage bisulfite pulping of pine
5. MECHANICAL PULPING - ATMP refining of Norway spruce – Defibration characteristics and fibre wall properties
6. MECHANICAL PULPING - Initiation of wood defibration in groundwood pulping, single asperity indentation and scratching
7. PAPER CHEMISTRY - Soy flour and soy lecithin improve paper strength and formation
8. PAPER PHYSICS - Flow imaging characterisation of morphological changes of chemical pulp due to refining
9. PAPER PHYSICS - Densification by wet pressing versus refining of never-dried high-yield softwood kraft pulp – effects on compression strength, tensile stiffness, and tensile strength
10. PAPER PHYSICS - Comparison and analysis of in-plane compression and bending failure in paperboard
11. PAPER PHYSICS - Mixing of cellulose nanofibrils and individual furnish components: Effects on paper properties and structure
12. PAPER PHYSICS - Development and evaluation of a high-speed creping simulator for tissue
13. PAPER PHYSICS - On the nature of joint strength of paper − Effect of dry strength agents – Revisiting the Page equation
14. PAPER PHYSICS - Extracting fiber and network connectivity data using microtomography images of paper
15. PAPER PHYSICS - Performance evaluation of CD and MD control strategies utilizing image-based measurements
16. PAPER PHYSICS - Effect of some printing nip variables on web tension
17. COATING - Study of starch and starch-PVOH blends and effects of plasticizers on mechanical and barrier properties of coated paperboard
18. COATING - Cellulose nanofibers influence on properties and processing of paperboard coatings
19. PRINTING - Headspace-GC determination of volatile organic compounds from the printed paper packaging materials

***NORDIC PULP & PAPER RESEARCH JOURNAL*, Vol.31 No.4 – 2016**

1. CHEMICAL PULPING - Separation and recirculation of bulk crystals to potentially mitigate sodium salt scaling in black liquor evaporators
2. PAPER PHYSICS - Multi-ply forming of linerboard by successive twin-wire roll forming
3. CHEMICAL PULPING - Potential energy improvements in a multiple-effect evaporation system: case studies of heat recovery
4. PAPER PHYSICS - A laboratory study on the use of maple CTMP and calcium carbonate fillers in fine paper production
5. PAPER PHYSICS - A model for moisture-induced dimensional instability in printing paper
6. CHEMICAL PULPING - The Sequential Liquid-Lignin Recovery and Purification process: Analysis of integration aspects for a kraft pulp mill
7. PAPER CHEMISTRY - Using a Rapid-Kothen paper machine to simulate the effect of system closure on the contamination load of whitewater
8. RECYCLING - Deinkability of thermochromic offset inks

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Technical Abstracts

The general peer-reviewed scientific and engineering press consists of several thousand journals, conference proceedings and books published annually. In among the multitude of articles, presentations and chapters is a small but select number of items that relate to papermaking, environmental and waste processing, packaging, and wood panel manufacture. The edited abstracts contained in this report show the most recent items likely to prove of interest to our readership, arranged as follows:

The Paper Industry Technical Association (PITA) is an independent organisation which operates for the general benefit of its members – both individual and corporate – dedicated to promoting and improving the technical and scientific knowledge of those working in the UK pulp and paper industry. Formed in 1960, it serves the Industry, both manufacturers and suppliers, by providing a forum for members to meet and network; it organises visits, conferences and training seminars that cover all aspects of papermaking science. It also publishes the prestigious journal *Paper Technology* and the *PITA Annual Review*, both sent free to members, and a range of other technical publications which include conference proceedings and the acclaimed *Essential Guide to Aqueous Coating*.

COATING

Specular gloss versus surface topography for oil-filled nanoparticle coatings on paper, Pieter Samyn, Jürgen Van Erps, Hugo Thienpont, *Color Research & Application*, Vol.41, No.6. The appearance or printing quality of paper surfaces is mostly characterised by their glossiness, measured with a glossmeter as specular reflectance. The gloss properties of a base paper substrate can be improved after application of a poly(styrene-co-maleimide) nanoparticle coating under pure conditions or in the presence of different vegetable oils. The specular gloss properties of 11 different nanoparticle paper coatings have been determined under 75° and 85° incident light angles; the gloss properties for the different coatings have been further related to the surface topography.

FILLER / PIGMENT

Coaggregation of mineral filler particles and starch granules as a basis for improving filler-fiber interaction in paper production, Ting Li, Jun Fan, Wensen Chen, Jiayan Shu, Xueren Qian, Haifeng Wei, Qingwen Wang, Jing Shen, *Carbohydrate Polymers*, Vol.149. The concept of coaggregation of mineral filler particles and starch granules for improving filler-fibre interaction in paper-based cellulosic networks is presented. Coaggregation of precipitated calcium carbonate filler particles and uncooked, unmodified corn starch granules by cationic polyacrylamide in combination with bentonite prior to addition to cellulosic fibre slurry delivered enhanced filler bondability with cellulosic fibres.

Surface modification of PCC with guar gum using organic titanium ionic crosslinking agent and its application as papermaking filler, Wei Xie, Zhanqian Song, Zhenhua Liu, Xueren Qian, *Carbohydrate Polymers*, Vol.150. Utilising the principles of guar gum (GG) gelation and crosslinking, a novel modified precipitated calcium carbonate (MPCC) papermaking filler was prepared by using organic titanium (OT) ionic crosslinking agent. Handsheet testing results showed that strength properties of handsheets were obviously improved when using MPCC as papermaking filler. This research suggests that the GG modified PCC by using OT as crosslinking agent can be used to manufacture high filler content paper products.

MOULDED PULP

Production planning in the molded pulp packaging industry, Karim Y.P. Martíneza, Eli A.V. Tosob, Reinaldo Morabitoa, *Computers & Industrial Engineering*, Vol.98, August 2016. Production planning in moulded pulp packaging companies involves decisions about setting up appropriately the production process to meet the demands of different products. This production process comprises stages such as blending, moulding and drying, and the major challenges for the production planning occur in the moulding stage, where the mix of products manufactured simultaneously depends on the combination of moulds attached to the moulding machine, called moulding pattern. In this study we propose a novel optimisation approach to deal with the problem of deciding which moulding patterns should be used, how long each pattern should be used and the production sequence that should be operated.

NANOCELLULOSE

Rheological properties of nanocrystalline cellulose suspensions, Yang Chen, Chunjiang Xu, Jing Huang, Defeng Wu, Qiaolian Lv, *Carbohydrate Polymers*, Vol.157. Rheological behaviour, including linear and nonlinear as well as transient rheology, of nanocrystalline cellulose (NCC) suspensions was studied in this work. Two kinds of polymer solutions, aqueous poly(vinyl alcohol) (PVA) with flexible chain structure and aqueous carboxymethyl cellulose (CMC) with semi-rigid chain structure, were used as the suspension media to further explore the role that the interactions among NCC and polymers play during shear flow.

Sustainable commercial nanocrystalline cellulose manufacturing process with acid recycling, Saurabh Jyoti Sarma, Mariem Ayadi, Satinder Kaur Brar, Richard Berry, *Carbohydrate Polymers*, Vol.156. Nanocrystalline cellulose is produced industrially by concentrated acid hydrolysis of cellulosic materials. In this process, the sulphuric acid rich liquor can be concentrated and reused; however, removal of sugar monomers and oligomers is necessary for such recycling. Membrane and ion exchange technology can be employed to remove sugars; as a part of the present study, activated carbon was evaluated. Based on this finding, a sustainable method has been proposed for commercial nanocrystalline cellulose manufacturing.

NOVEL PRODUCTS

Facilitated fabrication of high strength silica aerogels using cellulose nanofibrils as scaffold, Jingjing Fu, Siqun Wang, Chunxia He, Zexiang Lu, Jingda Huang, Zhilin Chen, *Carbohydrate Polymers*, Vol.147. Monolithic cellulose nanofibrils (CNF)-silica composite aerogels were successfully prepared by immersing CNF aerogels into a silica solution in a two-step sol-gel process (initial hydrolysis of tetraethyl orthosilicate (TEOS) followed by condensation of silica particles). The compression properties of the composite aerogel improved greatly compared with those of the silica aerogel. Moreover, the compressive strength of the composite aerogel prepared in this work greatly exceeded the conventional insulation materials found in the recent commercial market, and without substantial increases in thermal conductivity. Hence, the findings of this research offer a promising application for composite aerogels and give a theoretical basis for developing new advanced materials.

Strong and electrically conductive nanopaper from cellulose nanofibers and polypyrrole, Makara Lay, J. Alberto Méndez, Marc Delgado-Aguilar, Kim Ngun Bun, Fabiola Vilaseca, *Carbohydrate Polymers*, Vol.152. In this work, we prepare cellulose nanopapers of high mechanical performance and with the electrical conductivity of a semiconductor. Cellulose nanofibres from bleached softwood pulp were coated with polypyrrole via *in situ* chemical polymerisation, in presence of iron chloride (III) as oxidant agent. The structure and morphology of nanopapers were studied, as well as their thermal, mechanical and conductive properties.

Spray freeze-dried nanofibrillated cellulose aerogels with thermal superinsulating properties, Clara Jiménez-Saelices, Bastien Seantier, Bernard Cathala, Yves Grohens, *Carbohydrate Polymers*, Vol.157. Nanofibrillated cellulose (NFC) aerogels were prepared by spray freeze-drying. Their structural, mechanical and thermal insulation properties were compared to those of NFC aerogels prepared by conventional freeze-drying. The purpose of this investigation is to develop superinsulating bioaerogels by reducing their pore size.

Application of nanocomposite cellulose fibers with luminescent properties to paper functionalization, A. Erdman, P. Kulpinski, K. Olejnik, *Cellulose*, Vol.23, No.3. Cellulose fibres modified with luminescent inorganic compound were obtained by using N-methylmorpholine-N-oxide as a direct solvent. The fibres were cut and introduced to the unrefined and refined paper pulp samples. Results showed that cellulose man-made fibres with luminescent properties express similar properties to natural cellulose fibres (e.g. external fibrillation and bonding properties) which are useful for the purpose of secure paper production. Cellulose man-made fibres introduced to the paper do not have any disadvantageous impact on paper properties.

Synthesis of Nanosilver Particles in the Texture of Bank Notes to Produce Antibacterial Effect, Mohammad Hossein, Asadi Lari, Vahid Esmaili, Amir Hossein Kimiaghalam, Emadaldin Sharifaskari, *International Journal of Nanoscience*, Online. Silver particles show antibacterial and antiseptic properties at the nanoscale. Such properties result from an alteration in the binding capacity of silver atoms in bits of less than 6.5nm which enables them to kill harmful organisms. Silver nanoparticles are now the most broadly used agents in the area of nanotechnology after carbon nanotubes. Given that currency bills are one of the major sources of bacterial dissemination and their contamination has recently been nominated as a critical factor in gastrointestinal infections and possibly colon cancers, here we propose a new method for producing antibacterial bank notes by using silver nanoparticles.

Green coconut shell extract and boric acid: new formulation for making thermally stable cellulosic paper, Santanu Basak, Prashant G Patil, Abdul J Shaikh, Kartick K Samanta, *Journal of Chemical Technology and Biotechnology*, Vol.91, No.11. For the first time, green coconut shell extract (GCSE) has been employed along with boric acid as a novel fire retardant agent to be applied to cellulosic paper. GCSE can be considered a condensed phase based flame retardant agent as it contains silicate, other metals like potassium, zinc, copper and magnesium in the form of metallic salts, oxides etc. When GCSE was applied on paper, the combined synergistic action of all these metal salts and oxides catalyze dehydration of the treated paper and also increased char formation.

PACKAGING TECHNOLOGY

Morphological, physical, antimicrobial and release properties of ZnO nanoparticles-loaded bacterial cellulose films, Fereshteh Shahmohammadi Jebel, Hadi Almasi, *Carbohydrate Polymers*, Vol.149. Bacterial cellulose (BC) monolayer and multilayer films, incorporating 5wt.% ZnO nanoparticles (NPs) were produced. Antibacterial activity of ZnO-BC films against *S. aureus* was more than *E. coli*. Results suggest that ZnO-BC films may be used as controlled release antimicrobial food active packaging.

Active bio-based food-packaging: Diffusion and release of active substances through and from cellulose nanofiber coating toward food-packaging design, Nathalie Lavoine, Valérie Guillard, Isabelle Desloges, Nathalie Gontard, Julien Bras, *Carbohydrate Polymers*, Vol.149. Cellulose nanofibres (CNFs) were investigated for the elaboration of new functional food-packaging materials. Their nanoporous network was especially of interest for controlling the release of active species. This work aims to model CNF-coated paper substrates as controlled release system for food-packaging using release data obtained for two model molecules, namely caffeine and chlorhexidine digluconate.

Silver coated anionic cellulose nanofiber composites for an efficient antimicrobial activity, Mayakrishnan Gopiraman, Abdul Wahab Jatoi, Seki Hiromichi, Kyohei Yamaguchi, Han-Yong Jeon, Ill-Min Chung, Kim Ick Soo, *Carbohydrate Polymers*, Vol.149. Herein, we report a comparative study of silver coated anionic cellulose nanocomposite before (CMC-Ag) and after (AgNPs/CMC) chemical reduction for antibacterial activity. The nanocomposites were characterised by FE-SEM, FTIR, XPS and SEM-EDS. Antimicrobiality tests were conducted using *S. aureus* and *E. coli* bacteria following standard test method JIS L1902, 2008.

PAPERMAKING

Nanofibrillated cellulose as an additive in papermaking process: A review, Sami Boufi, Israel González, Marc Delgado-Aguilar, Quim Tarrès, M. Àngels Pèlach, Pere Mutjé, *Carbohydrate Polymers*, Vol.154. During the last two decades, cellulose nanofibres (CNF) have emerged as a promising, sustainable reinforcement with outstanding potential in material sciences. Though application of CNF in papermaking is recent, it is expected to find implementation in the near future to give a broader commercial market to this type of cellulose. The present review highlights recent progress in the field of the application of cellulose nanofibres as additives in papermaking. This review also revises the mechanisms behind CNF reinforcing effect on paper and the effect of chemically modified CNF as additives.

POWER & ENERGY

Evaluation of pine kraft cellulosic pulps and fines from papermaking as potential feedstocks for biofuel production, Kamila Przybysz Buzała, Piotr Przybysz, Halina Kalinowska, Kazimierz Przybysz, Marta Kucner, Marcin Dubowik, *Cellulose*, Vol.23, No.1. Results of enzymatic hydrolysis of pine kraft cellulosic pulps (Kappa numbers ranging from 17.2 to 86.2) and waste fines from paper production line suggest that they are potential feedstocks for biofuel production. Enzymatic hydrolysis of the fines from pine wood processing in a paper mill yielded around 75% glucose and 78% total reducing sugars on a dry weight basis that corresponded to around 34% and 36% on a pine wood dry weight basis.

PULP

Composite films prepared from agricultural by-products, Ivan Šimkovic, Ivan Kelnar, Raniero Mendichi, Tomáš Bertok, Jaroslav Filip, *Carbohydrate Polymers*, Vol.156. In our study we used holocelluloses from sugar beet and bagasse for film preparation. Results show both types of agricultural by-products could be used for preparation of composite film with high strength and stiffness suitable for broad range of applications.

Upgrading old corrugated cardboard (OCC) to dissolving pulp, M. Sarwar Jahan , M. Mostafizur Rahman, Mamon Sarkar, *Cellulose*, Vol.23, No.3. Delignification and pentosan dissolution of old corrugated cardboard (OCC) pulp was carried out using formic acid (FA) followed by alkaline extraction at atmospheric pressure. The kappa number of the initial OCC pulp was 41.4, which was decreased to 18.0 after FA treatment. The overall pulp yield after FA treatment and alkaline extraction reached 48.0 %. Alkaline-extracted pulp was bleached to 85% brightness using a D0EpD1EpD2 bleaching sequence, with α-cellulose content of 94.7%.

Strength of individual hardwood fibres and fibre to fibre joints, Marina Jajcinovic, Wolfgang J. Fischer, Ulrich Hirn, Wolfgang Bauer, *Cellulose*, Vol.23, No.3. In the present study hardwood fibre strength and fibre to fibre joint strength measurements using bleached, industrial eucalyptus kraft pulp have been performed. The device used for the measurements was a micro bond tester developed at Graz University of Technology. Results were compared to those obtained in previous studies.

Morphology and rheology of cellulose nanofibrils derived from mixtures of pulp fibres and papermaking fines, Jérôme Colson, Wolfgang Bauer, Melanie Mayr, Wolfgang Fischer, Wolfgang Gindl-Altmutter, *Cellulose*, Vol.23, No.4. The rheological behaviour of homogenised fibres originally having different lengths was evaluated. For this purpose, mixtures of pulp fibres and fines were fibrillated mechanically without pre-treatment and characterised with regard to morphology and viscosity.

Microfibrillated cellulose from agricultural residues. Part I: Papermaking application, Abeer M. Adela, Ahmed A. El-Gendy, Mohamed A. Diab, Ragab E. Abou-Zeid, Waleed K. El-Zawawy, Alain Dufresne, *Industrial Crops and Products*, Vol.93. In this work, we evaluated the preparation of MFC from biomass wastes using a new chemical pre-treatment method before applying the traditional mechanical method. Composite paper sheet samples were prepared from bleached rice straw and bagasse pulps by adding different percentages of MFC and both mechanical and optical properties of the resulting papers were studied.

Research on mechanical combined with biological modification of OCC pulp to improve the strength of paper, Xiao-Di WANG, Chuan-Shan ZHAO, Yi-Fei JIANG, Wen-Jia HAN, *Material Science and Environmental Engineering*: Chapter 1. Material Science and Engineering, pp.48-56. Experimental results show that the water retention value and carboxyl content improved with the increase of beating degree. The performance of the paper generally increased with the increase in beating degrees. When beating combined with laccase/histidine, the physical properties of the pulp had undergone great changes. The laccase/histidine treated pulp gave the highest WRV value and carboxyl content, which led to the highest bonding of pulp fibres resulting in the highest strength of the paper.

TESTING

Theoretical modeling of water vapor transport in cellulose-based materials, Alemayehu H. Bedane, Mladen Eić, Madjid Farmahini-Farahani, Huining Xiao, *Cellulose*, Vol.23, No.3. The theory of mass transport in porous media is of fundamental importance for different applications such as food, paper packaging, textiles, and wood for building materials. In this study, a theoretical water vapour transport model has been developed for cellulose-based materials, such as paper and regenerated cellulose film.

X-ray absorption and diffraction analysis for determination of the amount of calcium carbonate and porosity in paper sheets, O. Cherkas, T. Beuvier, S. Fall, A. Gibaud, O. Cherkas, T. Beuvier, S. Fall, A. Gibaud, *Cellulose*, Vol.23, No.5. Calcium carbonate as a filler provides specific properties to the paper like brightness, porosity, etc. Because of low retention, it is therefore interesting to develop some methods to analyse in a non-destructive way the content of calcium carbonate that remains in the paper. We report in this article an X-ray study of paper sheets with the aim to determine not only the content of calcium carbonate in a non-destructive way but also the porosity of the paper sheets.

Porous structure of fibre networks formed by a foaming process: a comparative study of different characterization techniques, Al-Qararah AM, Ekman A, Hjelt T, Kiiskinen H, Timonen J, Ketoja JA., *Journal of Microscopy*, Vol.264, No.1. Recent developments in making fibre materials using the foam-forming technology have raised a need to characterise the porous structure at low material density. In order to find an effective choice among all structure-characterisation methods, both two-dimensional and three-dimensional techniques were used to explore the porous structure of foam-formed samples made with two different types of cellulose fibre.

New correction terms concerning three-point and four-point bending tests, Faustino Mujika, Ainhoa Arrese, Itziar Adarraga, Usue Oses, *Polymer Testing*, Vol.55. The present study deals with the effect of the variation of the contact point between the support and load application rollers in three-point and four-point bending tests and the possible influence of horizontal reactions, under the assumption of small bending angles.

WASTE & ENVIRONMENT

Bioremediation of Oriented Strand Board (OSB) Process Wastewater, L. Brad Stombock, Dragica Jeremic-Nikolic, Brian Baldwin, Hamid Borazjani, Susan V. Diehl, *BioResources*, Vol.11, No.4. This study investigated the use of bioreactors and constructed wetlands to remediate oriented strand board (OSB) process wastewater. This research suggests that an OSB facility may want to have an aerated pond that then feeds a constructed wetland. This could not only provide a means to treat and dispose of the wastewater in an environmentally favourable manner, but also provides the secondary benefits of a wetland and its associated land enrichment.

Water Recovery in the Paper Industry, Membranes for, Ángeles Blanco, M. Concepción Monte, *Encyclopedia of Membranes*, pp.1996-1999. There exists a worldwide trend in paper industries to reduce freshwater consumption for environmental and economic reasons (water stress, freshwater savings, and reduction of effluent treatment and disposal costs). As the mills increase the closure of their water systems, a considerable accumulation of contaminants exists; this is worse in recycling paper mills. Accumulation of contaminants can affect both product quality and efficiency of the papermaking operations. Therefore, an adequate internal purification of the process waters is necessary to reduce the organic and inorganic load of the water before its recirculation.

Water Recovery in Paper Industry by Membrane Operations, Mari Kallioinen, *Encyclopedia of Membranes*, pp.1995-1996. Papermaking processes high volumes of water. In efforts to decrease the water consumption of paper mills, the greatest benefits can be achieved by treating and recycling the effluent streams with greatest volumes. For instance, ultrafiltration of paper machine white water, which can constitute more than half of the total effluent load of a paper mill, enables significant reduction in freshwater use. Ultrafiltration removes from the clear filtrate suspended solids and microorganisms and reduces the amount of organic dissolved compounds (lignin, hemicellulose, etc.).

Papermaking wastewater treatment by hydrolytic-aerobic biological contact oxidation process—analysis of an example, Biao HAN, Chun-li JIANG, Wei ZHAO, Wei-wei ZHANG, Jun-he HE, *Materials Engineering and Environmental Science*: Chapter 7. Technology for Environmental Protection, pp.668-672. Hydrolytic-aerobic biological contact oxidation process was used to treat the wastewater from pulp washing and bleaching section. The method to resolve this problem is to build in some perforation pipes on the basin bed, which can let a little of aerobic sludge reflow back into the hydrolytic-acidification basin in a fixed period. The aerobic sludge can stir anaerobic sludge, so the sludge contacts to the wastewater sufficiently, and the hydrolytic-acidification becomes more effective. The results show that the removal rates of CODCr, BOD5 was 85% or above.

WOOD PANEL

Effects of the Addition of Citric Acid on Tannin-Sucrose Adhesive and Physical Properties of the Particleboard, Zhongyuan Zhao, Kenji Umemura, Kozo Kanayama, *Bioresources*, Vol.11, No.1. The effects of citric acid on the curing properties of tannin-sucrose adhesives and on the physical properties of particleboard utilising the adhesives were investigated. The addition of citric acid promoted the reaction between tannin and sucrose at a lower temperature, and the optimal hot pressing temperature decreased from 220 to 200°C. The mechanical properties and water resistance of the particleboards were also enhanced.

Bonding Ability of a New Adhesive Composed of Citric Acid-Sucrose for Particleboard, Ragil Widyorini, Pradana Ardhi Nugraha, Muhammad Zakky Arief Rahman, Tibertius Agus Prayitno, *Bioresources*, Vol.11, No.2. Citric acid is a potential binding agent for composite products that has three carboxyl groups that can be ester linked with the hydroxyl groups found in wood. The addition of sucrose provides hydroxyl groups and increases the amount of ester groups. This research investigated the bonding ability of a new adhesive composed of citric acid-sucrose for teak particleboard.

Oriented Strand Board: Opportunities and Potential Products in China, Juwan Jin, Siguo Chen, Robert Wellwood, *BioResources*, Vol.11, No.4. North America's first oriented strand board (OSB) mill was built in the early 1980s. Twenty years later, the industry was thriving, with over 50 mills producing the product. China's first OSB mill was built in 1990, and 25 years later, there are a few mills with a total capacity less than two large North America mills, most operating below capacity and struggling to identify domestic markets for the growing production. This paper briefly looks at the histories of OSB industries in North America and China, presents the current situation of China’s wood-based panels industry and its downstream industries, and identifies OSB opportunities and potential products in China.

Effect of addition of microfibrillated cellulose to urea-formaldehyde on selected adhesive characteristics and distribution in particle board, Eike Mahrdt, Stefan Pinkl, Clemens Schmidberger, Hendrikus W. G. van Herwijnen, Stefan Veigel, Wolfgang Gindl-Altmutter, Eike Mahrdt, *Cellulose*, Vol.23, No.1. Several studies demonstrate that the addition of microfibrillated cellulose (MFC) to urea-formaldehyde (UF) wood adhesive improves the mechanical bond strength of wood particle board. In order to elucidate potential underlying mechanisms, the distribution of unmodified UF as well as MFC-modified UF (UF-MFC) in particle board was studied by means of light microscopy.

PAPERmaking!
FROM THE PUBLISHERS OF PAPER TECHNOLOGY
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Events

Reviews of some old events, and details of selected forthcoming world events along with the latest copy of the PITA Calendar of World Events.

In this edition:

- MIAC 2016 – review of 2016, notification of video interviews and 2017 dates
- Tissue World Europe
- PTS Coating Symposium — Munich (call for papers)
- Paper & Biorefinery Conference — Austria (call for papers)
- CPA&G 22nd International Symposium — Serbia (call for papers)
- Calendar of World Events

MIAC

The organisers of MIAC have published some VIDEO INTERVIEWS taken at 2016 event made in Lucca, Italy, in October 2016. The video interviews can be watched on the MIAC Facebook page (**https://www.facebook.com/miac162906/**), on the MIAC website (**http://www.miac.info/en/**), on Papnews website (**http://www.papnews.com/video/**) and on their Social Channels. You can share the video interviews without any restriction.

MIAC 2017 (24th edition) will be held in Lucca/Italy on 11.12.13 October 2017.

PITA Review of 2016 event:

For those who have not visited MIAC, let me describe it as one of the major success stories in the field of exhibitions. Figures just in reveal attendance as 4,912 (compared to 4984 last year and 4236 in 2013) representing 52 countries. The event is held over three days; as you would expect the middle day is most busy, but we know the days topping and tailing the event also had very significant attendance. So what are they doing right, and what can others learn?

Venue is all important. Lucca is in beautiful Tuscany, within an hour of the airport and with easy transport links (if you don't want to drive, bus and train links are VERY cheap!) Lucca is an attractive and historic walled city, and the exhibition hall is only a mile or so away – well within walking distance. The venue itself houses space for 171 exhibitors; last year for the first time they added space upstairs away from the main auditorium, but footfall was limited due to it being a new venture – this year many more people found the add-on and there was much more interest shown in these extra stands.

Add to all of the above four conferences: Tissue Manufacturing and Converting (in two parts); Energy and Environment; and Recycling in Italy. Presentations are delivered in either English or Italian, but with simultaneous translation for those of us who are monolingual. Another feature of the conferences that makes MIAC differ from many other international events – they are all FREE – as is entry to the exhibition.

Food is another benefit. True, there is a small coffee bar on site, but no one really bothers with that. Come midday, many of the stands offer wonderful examples of the local repas; several even bring in local chefs. As with the rest of the exhibition, this is free, and is a wonderful example of Italian hospitality.

So what can exhibition organisers learn? Well, you cannot transplant Tuscan scenery or weather, that is true, but you can look to give your visitors great value and experience. All of the big players in paper equipment and consumables and chemicals are present, making it a 'one stop shop' for anyone wanting contacts – it really is a must attend event for these companies! The whole event is free to visit which means, particularly for the conferences, if there is just one paper you want to hear, it is easy and cost-effective to slip in for a limited period then exit and continue with meeting exhibitors. Although you cannot transplant Tuscany to another country, at least choose a venue that is easy to get to, with *good transport links both to the country and to the final destination, preferably where the accommodation and food is reasonably priced.*

My one complaint about MIAC is the lack of available seating; either inside or out. The inside venue is rather cramped given the volume of people attending, but a few seats placed outside the numerous exits would certainly not go amiss as it really takes it out of your legs given the amount of walking that is required to see everything.

Daven Chamberlain

TISSUE WORLD EUROPE

The World's Largest Dedicated Tissue Industry Trade Show is now in Milan

The original Tissue World, which began in Nice in 1993 and held in 2013 and 2015 in Barcelona, is THE BIG ONE: The world's largest show specifically for the tissue business. It gives tissue makers, converters and suppliers to the tissue making and converting industries a unique experience and opportunity to network, exchange ideas and learn.

A truly global event, the show attracts key tissue industry professionals from 89 countries, gathering to see latest innovations and learn about technological advancements in tissue manufacturing. Tissue World provides invaluable content and unique networking opportunities for buyers and decision makers.

The last Tissue World in 2015 attracted 2,589 participants, including 1,561 visitors from 89 countries and 712 exhibiting staff. Held in Barcelona, the event hosted more than 180 international and local companies exhibiting their latest technical and innovative developments.

The event takes place 10 - 12 April 2017 at Fieramilanocity Hall 3, Milan, Italy.

http://www.tissueworld.com/milan/

TISSUE WORLD
Milan

CONFERENCE

Many tissue companies are today at an important crossroads or tipping point where they must accurately assess potential changes. This may well determine if they will drive down the road into a commodity trap of low returns or, instead, move ahead on a different forward-thinking path based on new ideas for profitably growing their business.

With the conference theme entitled "Change is the Only Constant...but Where is the Tipping Point?", the 2017 Senior Management Symposium (SMS) at Tissue World Milan offers you the perfect opportunity to examine relevant issues and topics that can be change-drivers for success. To be held on Monday, 10 April 2017, the SMS covers the first day of the 3-day conference.

Whether you are a Senior Executive, a mid-level manager or a machine operator, the spectrum of topics covered at the SMS can provide you with insight and knowledge to boost your tissue operations. New ideas gained at the SMS, if systematically integrated with your current strategies, can support you in embracing progressive change for successful profit growth. It certainly isn't simple, but it's not rocket science either.

SENIOR MANAGEMENT SYMPOSIUM

To give you a glimpse of the preliminary speakers program, here are the current topics to be covered by top professionals at the Senior Management Symposium:

- Economic Outlook: The Good, the Bad and the Ugly
- Trendspotting: Consumer Preferences and Buying Patterns Softness: The Holy Grail of Tissue Products and How It Can Help You
- Globalization: How New Capacity and Trade Flows are Impacting the Tissue Business
- The Retailer's Power: A Major Buyer's View on Market Developments
- And the Winner Is: How Producers are Meeting Today's Challenges
- Sustainability and Environment: Where are We Now and Where are We Going?
- Pulp: 70% of Your Tissue Costs, but What's Happening in the Pulp Market
- Rolling Along: Developments with the Jumbo Roll Trade Today

(This is the preliminary programme of Senior Management Symposium. Speakers to be named.)

28th PTS COATING SYMPOSIUM 2017 – Call for Papers

Coated - Upgraded - Smart

With some 350 participants, the PTS Coating Symposium is internationally the largest and most prominent meeting place for the surface finishing of paper and board. It will be held on 5th-6th September 2017 in the Leonardo Royal Hotel in Munich. PTS aims to provide an impetus for innovation and initiate interdisciplinary and cross-sector co-operations between the partners of the added value chain.

Coating technology has undergone a sea change in the past few years to become a flexible coating process for innovative surface functions. Today, barriers and multifunctional surfaces can meet complex requirements for a wide range of applications in an endless variety of sectors. PTS is also observing new technological solutions for upgrading smart products as another emerging trend.

PTS invites to present current scientific trends and your industrial developments in coating technology for printing and packaging solutions or for special-purpose applications. PTS is especially interested in input from papermakers or paper converters, also in co-operation with their development partners from mechanical engineering, chemical industry, finishing, the raw material or research sectors.

We welcome your papers and contributions in the following priority areas:

- Markets in flux: e.g. changed consumer demands | converting strategies | new business models | new fields of application and customer segments
- Advances in coating and upgrading technology: e.g. successful new installations and rebuilds| recent developments in mechanical engineering and finishing | efficiency enhancement | quality assurance and process improvement | Industry 4.0 solutions
- Concepts for coating colour formulation: e.g. new bonding agents, pigments and functional additives | trends in formulation design | new approaches for functional barriers | hybrid printing paper | special-purpose applications
- Innovative products: e.g. new printing paper | white top liner | coated packaging board | smart packaging | formable surfaces | creative design applications | printed electronics

An informative summary in German or English not more than one page in length together with details concerning the author(s) and employer may be submitted to **frank.miletzky@ptspaper.de** or **ralf-gericke@ptspaper.de** on or before 20th January 2017. A template may be found at **www.coating-symposium.com**. An international programme committee will compile the contributions you submit into an attractive symposium programme. Product innovations may present within the framework of the symposium exhibition.

PAPER & BIOREFINERY

CONFERENCE 31 May - 1 June 2017, Graz TRADE SHOW

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November 2016

CALL FOR PAPERS

Dear ladies and gentlemen!

The annual "Paper Conference" has been taking place in Graz (Austria) for more than 60 years. About 450 representatives from industry and research get together each year to exchange knowledge and to strengthen their networks.

PAPER & BIOREFINERY CONFERENCE

From **31 May – 1 June 2017**, the conference will prove yet again that it is a premier event, where the latest trends and industry developments are discussed: With its **extended focus and international format** it sets the trend, highlighting the innovative move of the pulp and paper sector as an increasingly successful operator in the biorefinery segment.
Of course the conference will continue to address current topics in the pulp and paper industry presented by distinguished speakers. The Messecongress Graz offers again the ideal surroundings.

INVITATION / CALL FOR PAPERS

The APV (Association of Academic Paper Engineers Graz) together with the Austrian industry associations ÖZEPA and AUSTROPAPIER invites **experts active in industry and research** to present current results of their work at the PAPER & BIOREFINERY CONFERENCE 2017.

DEADLINE:
20 JANUARY 2017

When handing in a paper please use the enclosed **Abstract Submission Form** and observe the information and **deadlines** listed on the following page. From all submitted papers the conference's program committee will prepare the final program with about 30 presentations, which will be divided in two parallel sessions.

Please note:

You are kindly asked to give your presentation in ENGLISH, as no simultaneous translation will be offered.

Main topic 2017: **FANTASTIC FIBER!**
Adding value to forest products.

PREFERRED TOPICS OF PRESENTATIONS:

- **Innovative fiber based products and novel applications** for pulp, paper and board (e.g. nanocelluloses, viscose fibers, super hydrophobic papers, barrier materials, novel packaging solutions, paper based sensors ...)
- **Wood based biorefinery concepts** including **potential applications, realized projects** and **research results** pertaining **pulp & paper industry** (e.g. wood based chemicals, bioenergy, biofuels...)
- Advances in **chemical pulping**, **mechanical pulping** and **stock preparation**
- **Recycled Fiber**: new production processes, raw material input, product innovations
- **Advances in research** in all pulp and paper related fields
- Projects, ideas and initiatives to **strengthen collaboration** along the entire **wood based value-added chain**
- **Practical experience reports by pulp-, paper- and board mill professionals** (modernizations, rebuilds, optimization, energy projects...)
- **Improved energy efficiency** in the whole pulp and paper production chain
- Technological innovations in **paper and coating machinery** (including machine clothing, process and quality control...)
- New and improved **raw materials and chemical additives** and their optimal use in the furnish and in coatings
- Current developments in **measurement and control systems** in the pulp and paper industry
- **Innovative analysis routines** and **testing methods** in the pulp and paper industry
- **Innovative concepts** in the field of **human resource management** and **education** in the pulp and paper industry (staff recruitment, novel modes of working, workforce of the future)
- Occupational **health and safety** issues

EINE GEMEINSAME INITIATIVE VON / A JOINT INITIATIVE BY

APV — Academic Paperengineering-Association at the University of Technology Graz

ÖZEPA — Austrian Association of Pulp and Paper Chemists and Technicians

austropapier — Association of the Austrian Paper Industry

PAPER & BIOREFINERY

CONFERENCE **31 May - 1 June 2017, Graz** TRADE SHOW

PLEASE OBSERVE THE FOLLOWING DEADLINES:

20 January 2017: .... **Send your proposal per E-Mail to: office@paper-biorefinery.com**.
Suggestion of topic/title, including an informative abstract and all authors.
Please use the **enclosed Abstract Submission Form** and add – if desired – a separate abstract (max. 1 page in **English**, an additional German version is optional).

17 February 2017:................... **Notice** of acceptance to the authors.

30 April 2017: .... **Final short version (abstract)** due.
1-2 pages A4, Word-document; English (an additional German version is optional).

20 May 2017:.......................... **Presentation** due as PPT- and PDF-File.
All presentations will be published online in PDF-format on the conference homepage, which is only accessible for participants of the conference.
If you do not want your presentation to be published online, please let us know.

We are looking forward to your contribution!

APV – Association of Academic Paper Engineers
at Graz University of Technology

Institute of Paper, Pulp and Fiber Technology
Inffeldgasse 23/EG, 8010 Graz, Austria

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Fax: +43 (0)316/873 10 30 751
Email: office@paper-biorefinery.com

Web: www.paper-biorefinery.com

ABSTRACT SUBMISSION FORM

PAPER & BIOREFINERY

CONFERENCE 31 May - 1 June 2017, Graz TRADE SHOW

TITLE OF THE PRESENTATION:	
INFORMATIVE ABSTRACT:	❒ Please see enclosure.
AUTHOR(S):	For all authors: Full name, company and postal address
SPEAKER:	Full name, company, postal address, e-mail and telephone number
CONTACT PERSON:	If different from "SPEAKER": Full name, company, postal address, e-mail and telephone number
YOUR COMMENTS:	

Print the form

Please submit the completed sheet by 20 January 2017 at the latest to: office@paper-biorefinery.com – Thank you!

Send the form

Tehnološko-metalurški fakultet
Univerziteta u Beogradu
CPA&G
centar industrije

tmf

Faculty of Technology and Metallurgy, University of Belgrade
Tehnološko-metalurški fakultet, Univerzitet u Beogradu
Center for Pulp, Paper, Packaging and Graphics in Serbia
Centar za celulozu, papir, ambalažu i grafiku Srbije

FIRST ANNOUNCEMENT
PRVO OBAVEŠTENJE

22. MEĐUNARODNI SIMPOZIJUM IZ OBLASTI CELULOZE, PAPIRA, AMBALAŽE I GRAFIKE
13-16. jun 2017. Čigota, Zlatibor, Srbija

22nd INTERNATIONAL SYMPOSIUM IN THE FIELDS OF PULP, PAPER, PACKAGING AND GRAPHICS
June, 13th -16th 2017, Cigota, Zlatibor, Serbia

Official languages: English and Serbian • Službeni jezici: engleski i srpski

Naučni odbor simpozijuma - Scientific Board of Symposium

Prof. Slobodan Jovanovic, Ph. D., Faculty of Tehnology and Metallurgy, (TMF) Belgrade, Serbia, chairman
Prof. Djordje Janackovic, Ph. D., TMF, Belgrade, Serbia
Prof. Lothar Göttsching, Ph. D., Univesity of Technology, Darmstadt, Germany
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Prof. Valentin I. Popa, Ph. D., Faculty of Chemical Industry, lassi, Romania
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Prof. Salim Ibrahimefendic, Ph. D., Faculty of Technical Studies, University of Travnik, Bosnia & Herzegovina
Sefkija Botonjic, Ph. D., Faculty of Metallurgy and Materials Science, Zenica, Bosnia & Herzegovina
Prof. Rade Knezevic, Ph. D., Lepenka, Novi Knezevac, Serbia
Prof. Milorad Krgovic, Ph. D., TMF, Belgrade, Serbia

Organizacioni odbor - Organization Board

Milorad Krgovic, Faculty of Technology and Metallurgy, Belgrade, chairman
Nadezda Borna, TMF, Belgrade
Marina Krsikapa, CPA&G, TMF, Belgrade
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Josif Cosic, MAGNETIC, Cacak
Zoran Devic, PROGRES, Belgrade
Jesa Ercic, Serbian Chamber of Commerce, Belgrade
Ivana Zeljkovic, Belgrade Chamber of Commerce, Belgrade
Mirko Stanic, NATRON HAYAT, Maglaj, B&H
Husejin Durakovic, NATRON HAYAT, Maglaj, B&H
Vladimir Nikolic, FOPA, Vladicin Han
Predrag Zivkovic, TMF, Belgrade
Slobodan Jovanovic, TMF, Belgrade

22nd International symposium in the field of pulp, paper, packaging and graphics will be held on Zlatibor Mountain, hotel Cigota, from June 22nd to June 13th to 16th 2017.
Symposium is organized by Center for pulp, paper, packaging and graphics industry of Serbia and Faculty of technology and metallurgy in Belgrade, under the patronage of Ministry of Education, Science and Technological Development of Republic Serbia.

THE MAIN GOAL OF THIS SYMPOSIUM IS:

- To gather experts engaged in pulp, paper, packaging and graphic industry, as well as representatives of academic institutions and, with assistance of foreign lecturers (representatives of international companies), to deliver information about new technologies and new operations and processes in existing technologies, which could enable price cuts and quality improvement of products, followed by better preservation of environment.
- To give chance to our experts to present results they have achieved in their recent work, as well as to review the possibilities to create quality products demanded by world market with small investment in existing equipment and improved organization of their companies.

TOPICS OF SYMPOSIUM ARE:

- New technologies and trends in production processes in pulp and paper industry in order to increase business efficiency;
- New materials, technologies and methods in packaging and graphic industry;
- Standards and regulations in paper, cardboard and packaging industry;
- International ecological standards and certifications;
- Waste management and waste recycling plans;
- Waste paper as a strategic raw material;
- Renewable energy sources;
- Saving energy in technological processes;
- Energy efficiency and energy management in pulp. paper, packaging and graphic industry: Energy - Efficiency - Ecology - Economy;
- Examples of good practice and existing solutions in the industry;
- Education for pulp, paper, packaging and graphic industry - needs and opportunities.

SYMPOSIUM PROGRAM CONSISTS OF:

- Plenary lectures (20+5 minutes for discussion)
- Other lectures (15+5 minutes for discussion)
- Promotions of technology and products of local and foreign companies (as agreed)
- Round table - discussions on selected present themes.

Works presented on symposium will be printed in the Proceedings, in their original shape, without lectoring.
Invited lectures should include up to 10 A4 pages, other lectures up to 8 of typed text, including pictures and other attachments.
Autors will be provided with: video projector, computer, sound system and screen.
Should the authors have some special requests, they are asked to note it in advance.
Works must be delivered as camera-ready Microsoft Word files.
Please prepare your works according to following instructions:
A4 format, all margins 2,54 cm, font Times New Roman, single spacing, first line of each body text paragraph indented by 1,27 cm.
Apply the styles in following order:
MAIN TITLE (capital letter, 16 pt, bold), authors (12 pt), company / institution name followed by city and country, (12 pt), abstract (up to 7 lines, 12 pt, italic), key words (12 pt, bold italic), numbered chapter title (for example: 1. INTRODUCTION; 12 pt, bold), body text (12 pt), references (12 pt). Please insert all illustrations and tables into document, at appropriate places, with figure captions below pictures, and table titles above tables.
Photographs should be converted to grayscale with minimum resolution of 200 dpi for final size, and saved as tiff or jpg (without compression-maximum quality).
Drawings should be saved as "1-bit" tiff with minimum resolution of 600 dpi for final size.
All illustration should be imported into document by Inset-Picture command.
At the end of the document state name(s) and full postal and e-mail address of corresponding / presenting author.

Please send us Microsoft Word files to following e-mail: **peca@tmf.bg.ac.rs**

Accepted papers will be printed in Proceedings.
Time limit for application of your work is **March 30th 2017**
and if you want your work to be published in official Publication, you should send it before **May 1st 2017**
The membership for symposium is mandatory for all participants and is **150 EUR**, and it includes Proceedings, program of Symposium, badge and other material, refreshment during brakes and excursion.
Official languages are Serbian and English, and the simultaneous translation will be provided.
Should there be min. 20 Russian-speaking participants, simultaneous translation to Russian will also be organized.
For additional information contact:

- Marina Kršikapa, Tel/fax: +381 11 4081 002, Mobil: +38160 399 8777; e-mail: **m.krsikapa@gmail.com**.

Chairman of Organization Board
Prof. dr Milorad Krgovic

Chairman of Scientific Board
Prof. dr Slobodan Jovanovic

XXII međunarodni simpozijum iz oblasti celuloze, papira, ambalaže i grafike, održaće se na Zlatiboru, u hotelu «Čigota», od 13 do 16. juna 2017.
Simpozijum organizuju Centar za celulozu, papir, ambalažu i grafiku Srbije i Tehnološko-metalurški fakultet (Katedra za grafičko inženjerstvo) iz Beograda, pod pokroviteljstvom Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.

CILJ ORGANIZATORA SIMPOZIJUMA JE:

- Da na jednom mestu okupi stručnjake koji rade u industriji celuloze, papira, ambalaže i grafike, kao i sa odgovarajućih visokoškolskih ustanova i da im pruži informacije o novim tehnologijama i o novim operacijama i procesima u već postojećim tehnologijama, koji omogućavaju sniženje cene i poboljšanje kvaliteta proizvoda, uz zaštitu životne sredine.
- Da omogući našim stručnjacima da svojim kolegama izlože rezultate do kojih su došli u dosadašnjem radu, kao i da kritički sagledaju mogućnosti da sa malim investicijama u postojeću opremu i poboljšanom organizacijom rada u svojim firmama, ostvare kvalitetne proizvode kakve zahteva svetsko tržište.

TEME SIMPOZIJUMA SU:

- Nove tehnologije i trendovi u procesu proizvodnje u celulozno - papirnoj industriji u cilju ekonomičnijeg poslovanja;
- Novi materijali, tehnologije i metode u ambalažnoj i grafičkoj industriji;
- Standardi i propisi u vezi sa papirom, kartonom i ambalažom;
- Međunarodni ekološki standardi i certifikati;
- Upravljanje otpadom i planovi za reciklažu otpada;
- Stari papir kao strateška sirovina;
- Obnovljivi izvori energije;
- Štednja energije u tehnološkim procesima;
- Energetska efikasnost i energetski menadžment u CPAG industriji: Energetika - Efikasnost - Ekologija - Ekonomija;
- Primeri dobre prakse i izvedenih rešenja u industriji;
- Školovanje kadra za CPAG industriju, potrebe i mogućnosti.

PROGRAM SIMPOZIJUMA OBUHVATA:

- Plenarna predavanja (20 + 5 minuta za diskusiju)
- Ostala predavanja (15 + 5 minuta za diskusiju)
- Promocije tehnologija i proizvoda stranih i domaćih firmi (prema dogovoru)
- Organizovanje Okruglog stola - diskusije o odabranim aktuelnim temama.

Radovi koji budu uvršteni u program Simpozijuma biće štampani u Zborniku, u originalnom obliku, bez lekture i korekture.
Za predavanja po pozivu je predvidjeno do 10 stranica formata A4, za ostala predavanja do 8 stranica kucanog teksta, zajedno sa slikama i prilozima.
Autori će imati na raspolaganju: video projektor, računar, ozvučenje i platno. Ukoliko autori imaju posebne tehničke zahteve, mole se da ih naznače unapred.
Radove treba dostaviti u obliku Microsoft Word dokumenata, spremnih za štampanje (camera-ready), složenih prema sledećem uputstvu: format A4, sve margine po 2,54 cm, font TimesNewRoman, prored "single", prvi red svakog pasusa uvučen za 1,27 cm.
Redosled pisanja: naslov rada na srpskom i engleskom (velika slova, 16 pt, bold), imena autora (12 pt), naziv i organizacije sa imenom grada i države, (12 pt), izvod rada na srpskom i engleskom (do sedam redova, 12 pt, italic), ključne reči (12 pt, bold italic), numerisan naslov poglavlja (na primer: 1. UVOD; 12 pt, bold), tekst rada (12 pt), literatura (12 pt).
U rad treba uvrstiti sve ilustracije i tabele na odgovarajuća mesta, sa potpisom ispod svake slike i naslovom iznad svake tabele.
Fotografije pre ubacivanja u dokument treba pretvoriti u "grayscale" (crno-belu fotografiju) sa rezolucijom u konačnoj veličini od najmanje 200 dpi i snimiti kao tif ili jpg (maksimalni kvalitet – bez kompresije). Crteže snimiti kao "1-bit" tif sa rezolucijom od najmanje 600 dpi u konačnoj veličini. Sve ilustracije ubaciti u dokument primenom komande Insert-Picture.
Na kraju navesti ime i punu poštansku adresu i adresu elektronske pošte autora za korespodenciju/autora koji će prezentovati rad.

Molimo da rad u elektronskom obliku dostavite na e-mail: **peca@tmf.bg.ac.rs**

Prihvaćeni radovi biće objavljeni u Zborniku radova.
Rok za prijavljivanje radova je **30. mart 2017.** godine, a da bi radovi bili objavljeni u Zborniku radova, treba ih poslati najkasnije do **01. maja 2017.**
Kotizacija za učešće u radu Simpozijuma je obavezna za sve učesnike i iznosi **15.000 din**, a njome su obuhvaćeni: Zbornik radova, program simpozijuma, bedž i ostali materijali, osveženje u pauzama i izlet.
Službeni jezici skupa su srpski i engleski, i biće obezbeđen i simultani prevod. Ako se prijavi najmanje 20 učesnika koji govore ruski, biće organizovano i simultano prevođenje i na ruski jezik.
Kontakt osoba za sve dodatne informacije:
Marina Kršikapa, tel/fax:+381-11-4081-002; mobil:+381-60-399-8-777; e-mail: **m.krsikapa@gmail.com**

Predsednik Organizacionog Odbora Simpozijuma
Prof. dr Milorad Krgović

Predsednik Naučnog Odbora Simpozijuma
Prof. dr Slobodan Jovanović

PRELIMINARY PROGRAM - PRELIMINARNI PROGRAM

TUESDAY, June 13th
UTORAK, 13.06.2017.

19:00-21:00 **REGISTRATION OF PARTICIPANTS AND DISTRIBUTION OF MATERIALS**
PRIJAVA UČESNIKA I PODELA MATERIJALA

WEDNESDAY, 14th
SREDA, 14.06.2017.

08:00-09:00 **REGISTRATION OF PARTICIPANTS AND DISTRIBUTION OF MATERIALS**
PRIJAVA UČESNIKA I PODELA MATERIJALA
09:00 - 09:15 **OFFICIAL OPENING OF SYMPOSIUM – ZVANIČNO OTVARANJE SIMPOZIJUMA**
09:15 - 13:00 **WORKING SESSION – RADNA SEKCIJA**
13:00 - 15:00 **BREAK (LUNCH) – PAUZA (RUČAK)**
15:00 - 18:00 **WORKING SESSION – RADNA SEKCIJA**

THURSDAY, June 15th
ČETVRTAK, 15.06.2017.

08: 30 -12:00 **WORKING SESSION – RADNA SEKCIJA**
12:00 - 14:00 **ROUND TABLE – OKRUGLI STO**
14:00 - 14:15 **ZVANIČNO ZATVARANJE SIMPOZIJUMA – OFFICIAL SYMPOSIUM CLOSING**
14:45 - 18:00 **EXCURSION – IZLET:**

- **ANDRICGRAD, VISEGRAD**
- **MOKRA GORA (SARGAN, MECAVNIK) OR**
- **SIROGOJNO – ETHNO VILLAGE.**

20:30 – **CEREMONIAL DINNER – SVEČANA VEČERA**

INVITATION TO INDUSTRY:

The success of XXII International Symposium in pulp, paper, packing and graphic, greatly depends on generous help of industry and financial support of your company which years back had been participating in organization of this event, and we are mostly thankful to it.
We are hoping that you are as well satisfied with our cooperation and participation at these gatherings until now.
We are asking you to extend your help in this year and to request to be provided with the options for financial support and participation of your company in the activities of our Symposium.
We will emphasize that there are various possibilities for presentation of your company, products or technologies, such as: using exhibition area placed in front of congress hall during whole Symposium; presentation or lecture inserted into program of Symposium;as well as the status chosen from your side to correspond you mostly (Patron, Contributor or Sponsor).

POZIV INDUSTRIJI ZA PODRŠKU:

Uspeh ovog našeg i Vašeg simpozijuma u velikoj meri zavisi od velikodušne pomoći industrije i finansijske podrške Vaših firmi koje zajedno sa nama, godinama unazad, učestvuju u organizaciji ovog simpozijuma, na čemu Vam se najsrdačnije zahvaljujemo.
Nadamo se da ste i Vi zadovoljni dosadašnjom saradnjom i učešćem na ovim našim zajedničkim skupovima.
Molimo Vas da nam i ove godine pomognete, i da tražite od nas da Vam posaljemo mogućnosti finansijske podrške i učešća Vaše firme u radu ovog simpozijuma. Da naglasimo da imate više mogućnosti predstavljanja Vaše firme, proizvoda i tehnologija, i to: u toku čitavog trajanja simpozijuma korišćenjem izložbenog prostora-štandova, koji će biti smešteni u holu ispred kongresne sale, prezentacijom-predavanjem uvrštenim u program simpozijuma, kao i kroz odgovarajući status koji odaberete, a koji Vam najviše odgovara (Pokrovitelj, Pomagač ili Sponzor).

Time limits:
Time limit for application of your work is **March 30th 2017,** and for publishing in official Publication, you should send it before **may 1st 2017**

For additional information contact:
Marina Kršikapa, Tel/fax: +381 11 4081 002, Mobil: +381 60 399 8777;
e-mail: m.krsikapa@gmail.com.

Rokovi:
Rok za prijavljivanje radova je **30. mart 2017.** godine, a da bi radovi bili objavljeni u Zborniku, treba ih poslati najkasnije do **1. maja 2017**. godine.

Kontakt osoba za sve dodatne informacije:
Marina Kršikapa, tel/fax: +381-11-4081-002, mobilni: +381 60 399 8777;
e-mail: m.krsikapa@gmail.com.

ADDITIONAL INFORMATIONS

Place: ČIGOTA Hotel, Zlatibor (http://www.cigota.rs)
Location: ČIGOTA hotel on Zlatibor is situated at an altitude of 1,000 m, near Zlatibor Lake and King's Square.
Hotel's offer: Snack bar, cafe and confectionery, billiards hall, indoor pool 25mx12,5m, fitness hall, gym and outdoor sport stadiums, hydro and manual massage parlours, finnish sauna, steam bath with aroma therapy, hydro baths and solarium, beauty parlour and hairdresser, hotel boutiques and shops, congress hall, internet caffe, wireless internet, library, tv studio, club and gallery. http://www.cigota.rs, tel: +381 31 597 237, +381 31 597 597.
Service: Half-board (breakfast and dinner - organized as breakfast buffet)
Price of accomodation (123 din = 1 €):

- single rooms (1/1) in A BLOCK - 4.600,00 din;
- rooms with double bed (1/1F) in A and B BLOCK - 4.700,00 din.;
- two-bed rooms 1/2 in A BLOCK - 3.600,00 din.;
- three-bed apartment (1/3 AB) - 3.600,00 din.;
  * If apartment AB is used by one person, price is 50% higher, and if two persons use apartment price is 25% higher;
- All prices include the use of the swimming pool. Lunch is extra charged.
- The abovementioned prices do not cover assurance (10 din.) and local tax costs (120 din.), which should be paid at hotel reception on arrival

You can book your accommodation:

- Directly, through hotel reception: **tel: +381 31 597 237, +381 31 597 597.; e-mail: hotelcigota@gmail.com,**
- Through Organizational board, Marina Krsikapa: **tel: +381 60 399 8777, e-mail: m.krsikapa@gmail.com**

DODATNE INFORMACIJE

Mesto održavanja: Hotel ČIGOTA, Zlatibor (http://www.cigota.rs)
Lokacija: Hotel ČIGOTA na Zlatiboru nalazi se na nadmorskoj visini od 1.000 m, nadomak zlatiborskog jezera i Kraljevog trga.
Hotelska ponuda: aperitiv bar, kafe poslastičarnica, kafe bilijar, zatvoreni bazen 25m x 12,5m, fitnes sala, teretana i otvoreni sportski tereni za male sportove, saloni za hidro i manuelnu masažu, finske saune, parno kupatilo sa aroma terapijom, hidro kade i solarijum, frizerski i kozmetički salon, hotelski butici i prodavnice, internet caffe, wireless internet, kongresna sala, biblioteka, TV studio, klub i galerija. http://www.cigota.rs, +381 31 597 237, +381 31 597 597.
Cene smeštaja: Cene smeštaja na bazi polupansiona (švedski sto doručak i večera) u dinarima (123 din = 1 €) iznose:

- Smeštaj u 1/1 sobama A bloka je 4.600,00 dinara;
- Smeštaj u 1/1F sobama A i B bloka je 4.700,00 dinara;
- Smeštaj u 1/2 sobama A bloka je 3.600,00 dinara;
- Smeštaj u 1/3 AB apartmanima je 3.600,00 dinara;
  * Ukoliko dve osobe koriste apartman, cena se uvećava za 25%, a ako ga koristi jedna, za 50%;
- U cenu je uključeno i korišćenje bazena. Ručak se dodatno plaća.
- Boravišna taksa iznosi 120,00 dinara, a osiguranje je 10,00 dinara po osobi dnevno.

Rezervaciju sobe u hotelu Čigota možete izvršiti:

- direktno, preko recepcije, **tel: +381 31 597 237, +381 31 597 597; e-mail: hotelcigota@gmail.com,** ili
- preko Organizacionog odbora, Marine Kršikape: **tel: +381-60-399-8-777, e-mail: m.krsikapa@gmail.com.**

Zlatibor je turistička oaza mira, spokojstva i zdravlja.
Leži na 1000 m nadmorske visine, na 230 km od Beograda, na magistralnom, drumskom i železničkom putu Beograd-Bar. Poznat i priznat više od sto godina, ovaj istovremeno rustičan i moderan turistički centar, predstavlja jednu od najatraktivnijih destinacija u Srbiji.

Zlatibor (meaning "Golden Pine") is tourists oasis of peace, tranquility and health. It is situated at 1000 m above sea level, 230 km far from Belgrade, on the main road and railway Belgrade-Bar. Zlatibor is well known as a tourist destination for more than 100 years. Combining modern and ancient motives, it is one of the most attractive destinations in Serbia.

PITA Calendar of World Events

December 2016		
7 - 9	Tissue World Shanghai @ Shanghai, China	www.tissueworld.com/en
12	Printing for the Future @ Cambridge, UK	www.iop.org
13 - 15	Paper Arabia 2016 @ Dubai, UAE	www.paperarabia.com
February 2017		
1 - 2	Lignofuels 2017 Conference - Advanced Biofuels & Materials @ Helsinki, Finland	www.acieu.net
7 - 8	PITA Energy Optimisation Course @ PITA HQ, Bury, UK	info@pita.co.uk
13 - 17	Paperweek Canada 2017 @ Montreal, Canada	www.paperweekcanada.ca
March 2017		
1 - 2	Packaging Innovations @ NEC, Birmingham, UK	www.easyfairs.com
6 - 8	9th RISI European Conference @ Amsterdam, The Netherlands	http://events.risiinfo.com
14	PITA Pump Efficiency Course @ PITA HQ, Bury, UK	info@pita.co.uk
15 - 16	Gasification 2017 @ Helsinki, Finland	www.wplgroup.com/aci
15 - 17	IMFA's 20th International Molded Fiber Packaging Seminar @ Miami, Florida, USA	www.imfa.org
21 - 23	Maintec, Health & Safety Event, Fire Safety Event, Facilities Management @ NEC, UK	www.maintec.co.uk
26 - 28	PAPER2017 (AF&PA and NPTA) @ Chicago, Illinois, USA	www.gonpta.com
April 2017		
3 - 5	Specialty Papers Europe 2017 @ Cologne, Germany	www.smitherspira.com
4 - 5	Industry 4.0 Summit @ Manchester, UK	www.industry40summit.com
10 - 12	Tissue World Europe @ Milan, Italy	www.tissueworld.com/en
23 - 26	European PLACE 2017 @ Basel, Switzerland	www.tappi.org
23 - 26	PaperCon 2017 @ Minneapolis, Minnesota, USA	www.tappi.org
May 2017		
18 - 19	Aticelca Congress 2017 @ Riva del Garda, Italy	www.aticelca.it
June 2017		
5 - 8	Int. Conference on Nanotechnology for Renewable Resources @ Montreal, Canada	www.tappi.org
21	CPI Biennial Health & Safety Conference @ Chesford Grange Hotel, UK	www.paper.org.uk
26 - 28	Security Document World 2017 @ QEII Centre, London, UK	www.sdwexpo.com
July 2017		
4 - 6	Zellcheming 2017 @ Frankfurt am Main, Germany	www.mesago.de/en/ZEX/home.htm
13 - 16	CPA&G International Symposium @ Zlatibor, Serbia	
September 2017		
5 - 6	PTS Coating Symposium @ Munich, Germany	www.ptspaper.com
13 - 14	Packaging Innovations @ London, UK	www.easyfairs.com
22 - 24	BAPH Annual Conference @ Cheltenham / Gloucester, UK	www.baph.org.uk
October 2017		
11 - 13	MIAC @ Lucca, Italy	
31 - 3 Nov	IPEX @ NEC, Birmingham, UK	www.ipex.org
June 2018		
25 - 29	It's Tissue 2018 @ Lucca, Italy	