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REVIEW ARTICLE

Developments in nano-additives for paper industry

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Abstract The economic benefits of the paper industry made it one of the most important industrial sectors in the world. This review will focus on the recent development of nanotechnology, in the context of additives used in the paper industry. Nanotechnology is used to alter the production process based on the changes towards resource-based and industrial knowledge, prompting the changes in a similar direction, with much greater emphasis on stability. Nanofiber, nanofiller, nanocomposites, and nanoscale chemicals used in paper applications forms the crux of the work. The application and production of nano-additives to the paper industry have attracted the attention of scientists and researchers, due to the resulting profound improvement to the properties of the produced papers, encompassing mechanical, printability, glossiness, and gas barrier properties. The purported benefits of nano-additives are numerous, among them high surface area, strength, and low weight, high stiffness, and maintained sustainability. However, the integration of nanotechnology in the paper industry could not be up-scaled or commercialized, due to a few challenges, which are increased cost, lack of compatibility among materials, and knowledge gap.

Keywords Nanoparticle · Surface area · Adsorption · Wettability

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An overview: paper industries

The global production of paper and paperboard is now comfortably in excess of 400 million tons, with the slowdown in the USA and Europe more than offset by corresponding growth in Asia [1]. The Asian production is in excess of 40 %, while ∼30 % comes from Europe and ∼25 % from North America [2, 3]. This total volume is only expected to rise significantly, in real (not inflated) terms, in 2014, as the Asian market starts to make up for the decrease in the American and European markets [4].

The primary stage of the manufacturing process of paper is related to material preparation, pulp manufacturing, pulp bleaching, paper manufacturing, and fibers recycling [5]. The refined, and if necessary, bleached wood pulp, is prepared as a thin slurry, together with a number of additives, especially fillers, to create the correct mix for the wanted paper quality [2, 4] (Fig. 1).

Manufacturing: paper industries

The paper manufacturing industry converts different materials into variant board products and paper via mechanical and chemical process known as pulping [3]. With advances in the paper industry, more attention has been paid on producing high-quality paper in a cost effective manner [6]. The final properties of the paper, such as its quality, weight, surface gloss, smoothness, and reduced ink absorber, are of paramount importance [7–9]. The incorporation of nanostructured and low levels of organic into the paper formulation is expected to enhance the properties of the produced paper.

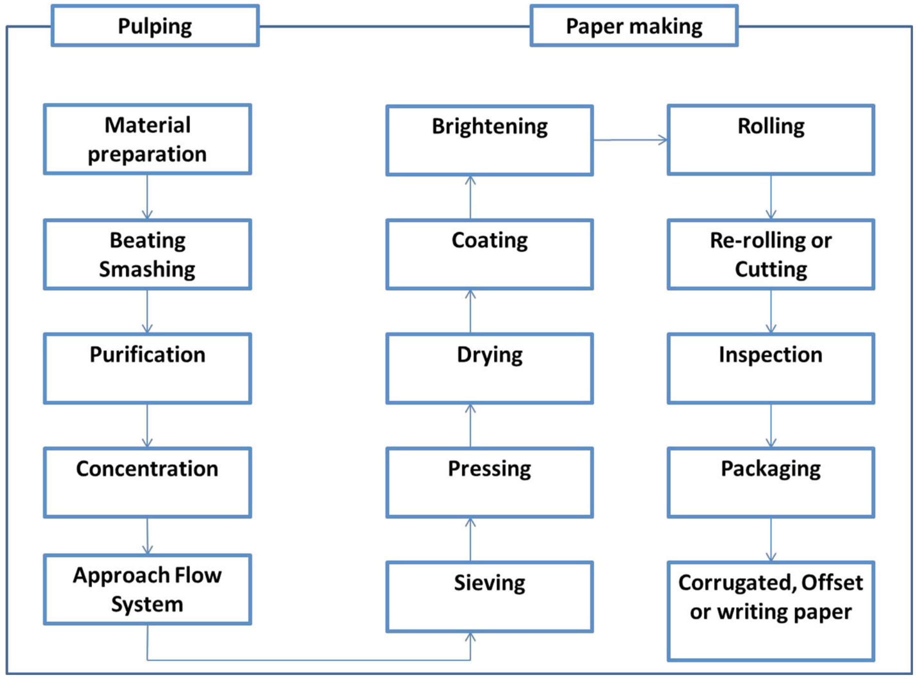

Fig. 1 The general flow system of papermaking

Current nanotechnology

Nanotechnology is of great importance in almost all modern-day industries, targeting high-quality and efficient market potential [10–12]. The large interest in the nanoscale range is due to the fact that nano-additives possess enhanced properties compared to its bulk counterparts [11]. Current nanotechnology is leading the development and global economic growth. Nano-scale techniques are also prominent in multi-disciplinary fields, providing glimpses towards exciting new capabilities for materials, devices, and systems [12, 13]. Nano-additives with unique advantages are expected to remodel the facets of controlled technology. The main purpose of nanotechnology, in this context, is to control and manipulate materials to obtain special functionalities. Nanotechnology-based developments provide incremental and evolutionary changes [14], and are a new tool that is recently added to a wide range of applications, with pulp and papers among them.

Nanotechnology: paper industries

The unique advantages and properties of the paper can be improved via nano-additives. The advances of nanotechnology resulted in the development of multiple nano-additives, which is the byproduct of extensive fundamental studies associated with advances in nanotechnology. The size of nano-additives is significant, due to a variety of factors [13–15]. Light scattering attribute are affected by nano-additives, gloss and opacity, the calendaring steps, the rate of drying, and paper penetrance. The nanosize particles have a propensity to aggregate [16]. In reality, due to the insufficient specific surface, it is difficult to obtain larger diameter nano-additives [17, 18]. For example, due to the bigger surface area that competes for sizing, furnishes containing tiny particles nano-additive are more resistant towards the internal sizing agent.

Nano bleaching agents: paper industries

The pulp and paper industry decolorize or whiten papers with a bleaching agent. Chromophores generally contain groups of colored atoms [19–21], which are capable of absorbing visible light, characteristic wavelengths, and reflect or transmit part of the light [20]. These absorbing groups of chromophores are destroyed by oxidation/reduction of the bleaching agents [22–24].

Nano calcium silicate particle

Nano calcium silicate are examined as fillers in 45–55 g m^{-2} newsprint, where its opacity increased [25–27] by about 3.7 points for the 45 g m^{-2} newsprint at 2 wt% loading, while for the 55 g m^{-2} newsprint, it was about 1.3 points [26]. This basically proves that nano calcium silicate is capable of increasing the newsprint's sheet's opacity [27]. The excellent light scattering surface afforded by the nano-structured framework is desirable, resulting in enhanced opacity [28–30]. Both these factors will result in a significant improvement to print quality.

The nano phase calcium silicate platelets are stacked to form t open network structures, which enables it to quickly absorb printing ink, preventing the forfending image from being visible on the reverse side of the paper [31]. Overall, nano calcium silicate results in higher quality printed image, localization of ink dots, and prevent undesirable spreading across the paper [29, 32].

Nanosizing agents: paper industries

Protecting the filler or glaze by applying sizing or size is a practical technique of incorporation in pulp and paper industry [33–35]. The paper and textile manufacturing industry utilized sizing to alter the absorption and wear characteristics of the resulting material; it is the phase used for oil-based surface provision for gilding (in this context), recognized as a mordant [36–38], and is used for some art techniques by painters and artists to prepare papers and textile surfaces [39, 40].

Nano silica/hybrid

Properly selecting nano sizing is crucial towards the transmission of functional confidants, including anti-fungal and UV protection. This is achieved mostly through the presence of nano silica via dewatering, which is the act of lowering the water transmission rate, while retaining water retention and strength [41]. Nano silica usually provides paper with the high abatement and anti-bacterial activity, which usually results in high degradation [42]. The introduction of nano silica usually results in the reduction of print-through and the improvement of optical properties [43]. The addition of 1.8 wt% of nano silica reduced print-through by about 30 % and increased the opacity and brightness by about 1.7 points each, collectively representing a significant improvement [44]. Furthermore, nano silica reduced print-through by 40 % at a 2.2 wt% addition for yellow directory papers, which is rather significant. Some studies compared coated and uncoated nano silica, and confirmed that coated nano silica results in good print quality, optical density, color gamut, water permanence, color performance, and dimensional stability as opposed to uncoated ones [45–47] (Fig. 2). Nano silica can be prepared by the sol–gel technique, which involves simultaneous hydrolysis and condensation reactions. A sol of sodium silicate, silicon alkoxide, or halide gets converted to a polymeric network of gel. Partial hydrolysis of orthosilicate takes place when it is mixed with water and ethanol.

Nanostructured silica, with an open network structure and regulated by regulated precipitation from geothermal water, has been synthesized and used bleaching agent. It resulted in a print through reduction of 30 % for newsprint and 40 % for full-scale paper mill manufacturing [48].

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Nano titanium oxide/hybrid

TiO_2 imparts deodorizing and antimicrobial to the paper, on top of improving its opacity, refractive index, and whiteness [49]. However, some disadvantages, such as cost and dependence on UV, restrict its usage to printing papers on a commercial scale [49–51]. As an alternative, TiO_2 hybridized with other metal oxides, such as ZnO, demonstrated excellent chemical and optical properties, which makes it viable for a broad range of antimicrobial and UV applications of paper [52]. Coating the surface of the paper with TiO_2/ZnO gave way to superb anti-fungal and UV properties, which are essential towards the enhancement of its life [53].

Nano wet/dry strength agents: paper industries

Tensile properties of the paper both in wet and dry phases can be improved by crosslinking the cellulose fibres based on its covalent bonds during wet/dry strength chemicals, which do not break upon wetting [54–57]. The variety of the wet strength chemicals are involved with process improvements, such as wet strength resins or neutral sizing agents [58–60].

Nanocellulose

Paper products made of nanocellulose have been widely used as packaging materials, owing to their promising attributes such as biodegradability and sustainability with low environmental impacts. Generally, cellulose is a semicrystalline linear polysaccharide compound of β-1,4 linked glucopyranose units, with its polymer chains combined with hydrogen bonds forming bundles of fibrils consisting of ordered excellent crystallinity and disordered amorphous domains [61, 62]. The crystalline domains can be isolated in the nano-scale, with highly ordered and regular rod-like nanocrystals, after the removal of the amorphous domains via acid hydrolysis, also known as cellulose nanofibers, crystalline nanocellulose, or nano-whiskers [62–69] (Table 1). Furthermore, nanocellulose can be obtained from cheap and abundant renewable natural resources such as wood, plants, vegetables, and other agricultural residues and processing waste [65].

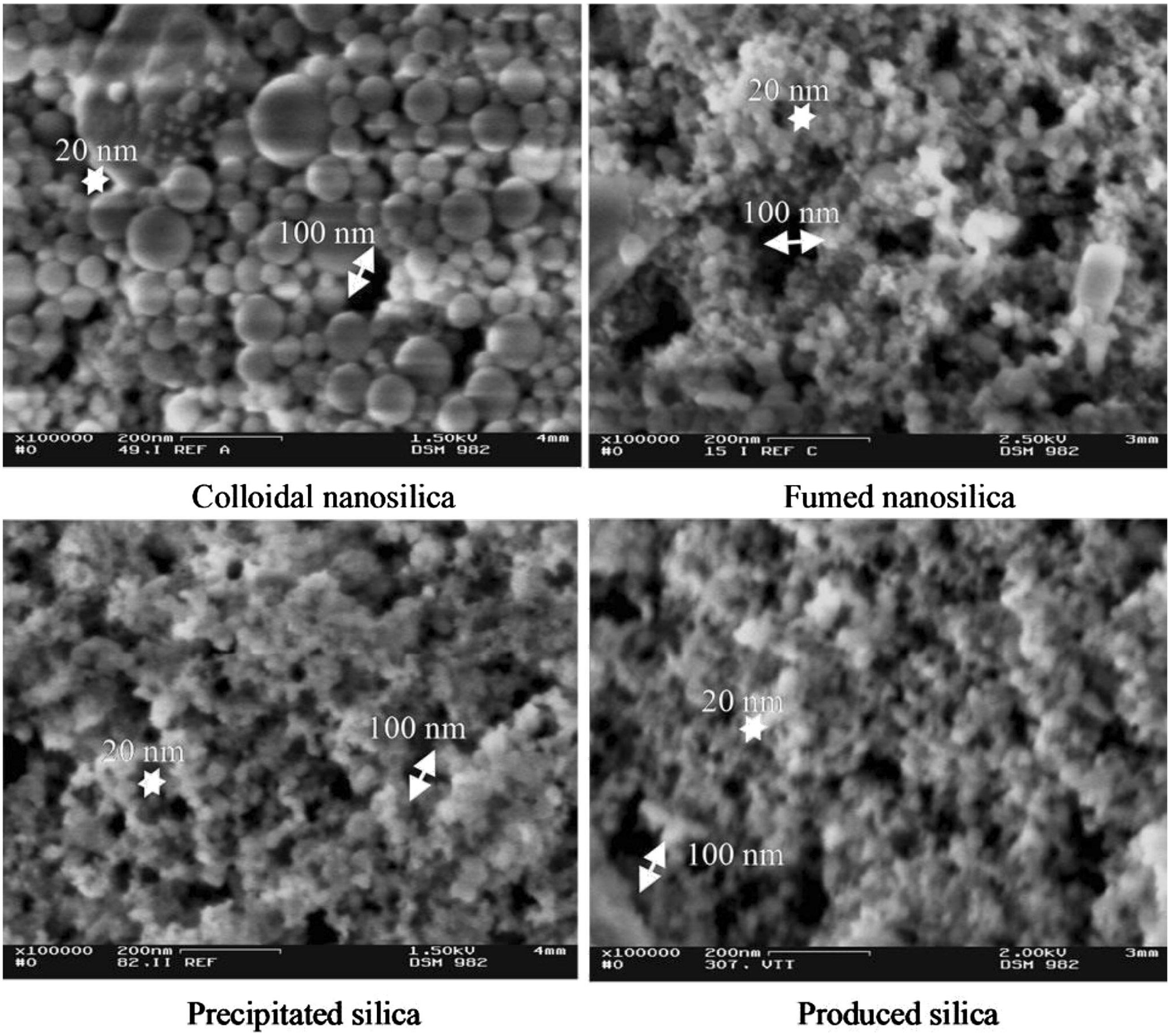

Fig. 2 SEM image of coatings containing silica pigment on the fine paper surface. Magnification of 100,000 [45]

Table 1 Nanocellulose derivatives and their dimensions

Nanocellulose derivatives	Diameter (nm)	Length (nm)	Aspect ratio (L/d)	References
Microcrystalline cellulose	>1000	>1000	1	[62]
Micro fibrillated cellulose	10–40	>1000	100–150	[63]
Microfibril	2–10	>1000	>1000	[64]
Cellulose whisker	2–20	100–600	10–100	[65]
TEMPO-oxidized nanocellulose	3–4	>1000	1000	[66, 67]
Carboxymethyl nanocellulose	5–15	>1000	200–100	[68, 69]

However, the hydrophilic properties of nanocellulose created a low H_2O vapor barrier of paper-based packaging material [66]. Consequently, it limits the requirement for high barrier or extended applications in packaging [67]. This encourages the advent of research works on chemical modification of nanocellulose, intended to improve its hydrophobic properties. Over the past few years, some works have successfully realized an eye-catching cellulosic nano paper, with remarkably high toughness using wood nanofibril [68]. Increasing tensile index yields a significantly stronger paper, mostly via the addition of nanocellulose. Sheet drainage is also improved, although it comes out as slightly impaired. To overcome this limitation, cationic polymers, such as polyacrylamide, have been used as a fixative for the retention of nanocellulose, as well as for better suspension drainability [69, 70]. Compared with micro-sized cellulose, nanocellulose are more effective as an additive for the paper industry, due to the interactions between the nanosized elements, which is connected by hydrogen bonds, form a percolated network when the nanocellulose is dispersed in the pulp's slurry [66–85].

Therefore, it was determined that the nanocellulose paper was a network composed of inter-wined nanofibrils (Fig. 3), with an aspect ratio exceeding 100, and with a tensile index of 214 MPa, which is quite close to that of industrial steel (250 MPa) [69]. The orientation of nanofibrils cellulose is assumed to be incorporated into the inter-fibrillar region and form lateral interlinks between fibrils via H_2 bonding.

However, there are still several challenges associated with this approach, such as the efficiency of grafting and tailored barrier properties of the paper being produced. Therefore, increasing the hydrophobic properties of paper products and improving vapor barrier properties by lowering its water vapor transmission rate is fast gaining some guarded interest [70]. Many methods have been applied for nanocellulose surface modification, including acetylation,

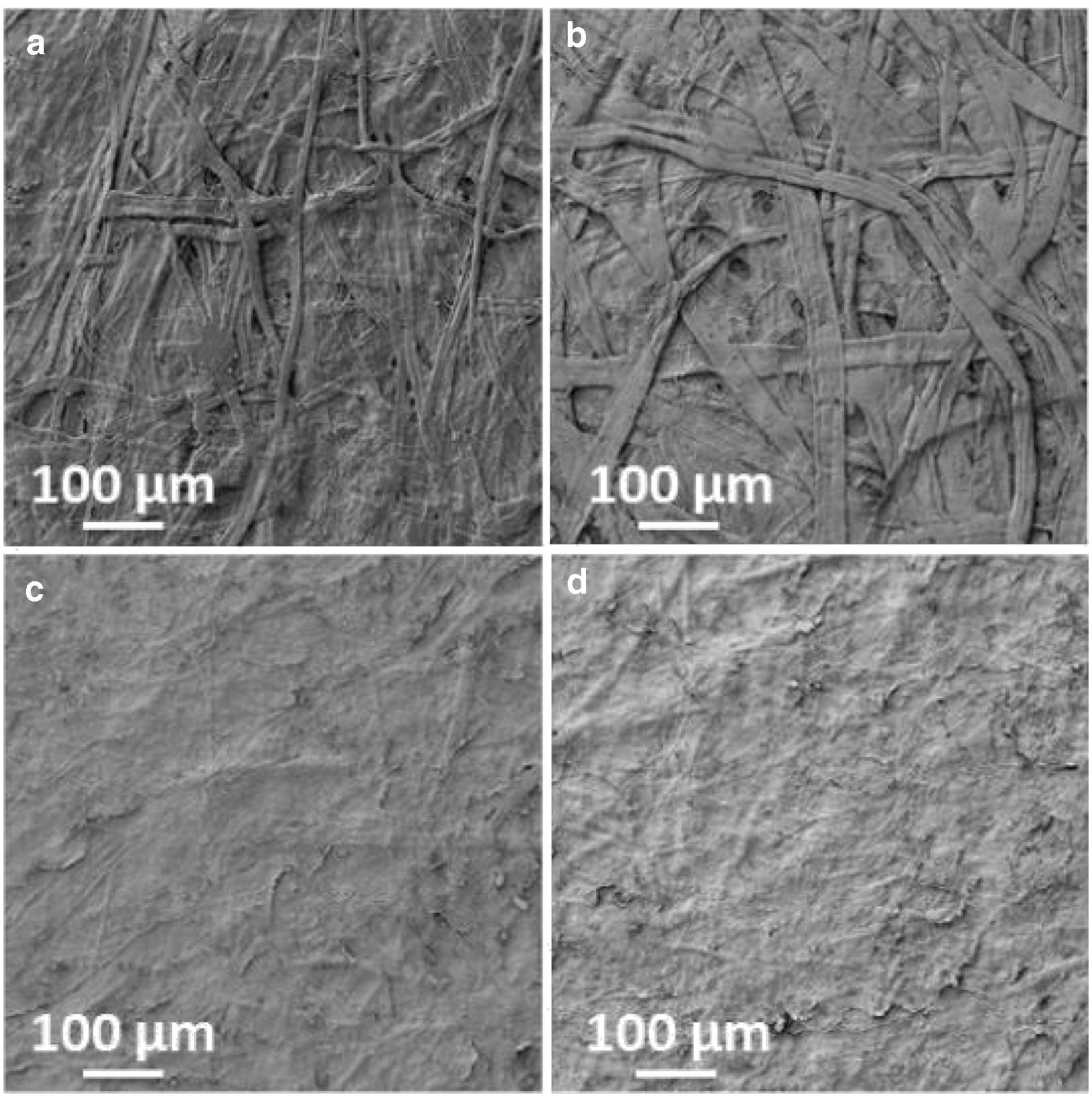

Fig. 3 SEM micrographs of the four paper samples: **a** standard tracing paper. **b** laboratory paper sample. **c** microcrystalline cellulose paper and **d** Nanocellulose paper [85]

silylation, grafting, and the use of coupling agent [71, 72]. For example, some research works focus on the development of carboxylated nanocellulose, based on TEMPO (2,2,6,6-tetramethylpiperidine 1-oxyl) mediated oxidation [73–75]. Through this modification, a nanocellulose, with a promising thermal and mechanical properties, is obtained [74, 76]. The produced paper possessed extremely high tensile strength and tearing resistance in the machine direction, as well as air permeability.

Nano pigment: paper industries

Pigment is an abundant component in the paper industry, and naturally, the most important factor affecting the final properties of the paper [77, 78]. Paper pigment agents generally consist of inorganic compounds, such as kaolin, calcium carbonate, binder, soluble co-binder, dispersants, water as carrier, and other additives [79, 80]. The use of nano pigments with an appropriate binder in the coating formulation will help fill the micro-voids and offer better barrier properties [81, 82].

Nano kaoline

Nano kaoline is one of the most widely used pigments in the paper industry, and it is used in a large range of coating applications. Nano kaoline or kaolinite, with the chemical formula of $Al_2Si_2O_5(OH)_4$, is the principle nano mineral in China clay [82]. Structurally, it is a dioctahedral 1-to-1 layered Al_2O_3 to Si_2O_5, and consists of two basic units, including an octahedral sheet comprising of closely packed O_2 and OH where Al, Fe, and Mg atoms are arranged in the octahedral coordination [83]. The second structural unit is the SiO_2 tetrahedral layer, where the silicon atom in the center is equidistant from four O_2, or possible OH. The inherent impurities in nano kaolinite include titanoferrous minerals, iron oxides, and mica, each giving a different color, from yellow to dark brown on produced paper [84–86]. It has processed for paper industry applications that demand very high brightness, low yellowness, and other physical and optical properties [85].

Various modification methods applied to cover the disadvantages of natural nano kaoline included centrifuge or sedimentation process, acid activation, chemical bleaching, thermal treatment or calcination [83, 85–87]. Surface modification of nano kaoline about the intercalation process involved the insertion of low molecular weight organic regents included guest molecules (urea, formamide, potassium acetate and dimethysulfoxide) between layers consisting of two-dimensional arrangements of tetrahedral and octahedral sheets [88]. Indeed, intercalation not only enhances the possibilities of kaoline exfoliation as nanostructured mineral, but also modifies the nano kaoline surface via complexation of H_2 bonding [89]. The formation of intercalates happens when the organic material located and stacked between kaolinite layers. Chemical bleaching is a standard beneficial technique used to enhance the brightness of nano kaoline for high value applications [86]. The process discolors the nano kaoline and allows the small proportion of total iron removal in solution. In some of the studies, nano kaolin modified with polymer material resulting black liquor after alkaline pulping. The modification carried out in order to change its nature [90, 91]. The results suggest enhance of the mechanical attributes and the water absorption of that manufactured nano kaoline trough polymer [92]. Thus, the prepared paper can use for the specific use that needs greater absorption and higher dewatering time [93].

Nano ZnO/hybrid

Nano ZnO is a material with potential pigment suitable for paper coating to expose brightness and greater printing properties. Nano ZnO provides paper coating pigment a high covering power apart from anti-fungal and UV protecting properties due to its extremely small size [94]. In some work, ZnO/starch composites were prepared by a simple and novel wet chemical method using zinc nitrate and NAOH as precursors and soluble starch as stabilizing agents [95].

Nano carbonate

The use of nano calcium carbonate is important when opacity is needed at a low-basis weight; they are invaluable in packaging grades where low permeability is combined with opacity to protect food from light [96–99]. The presence of nano calcium carbonate, however, affects fiber to fiber contact and reduces paper strength [100–103]. Other properties are improved rendering the paper useful for special purpose [104–106]. For example, the fine proportions of nano calcium carbonate and nano kaolin used for the coating of paper surface [107].

Nano retention agents: paper industries

Improvements in the retention of a functional chemical in a substrate are achievable by the retention agent which is a chemical process [108]. Eventuate is that totally less chemicals are used to get the same effect of the functional chemical and less chemicals goes to waste [109, 110].

Nano zeolite

Nano zeolite filler materials used for improving properties of asphalt and paper functioning when mixing with pulp

[111]. Meanwhile, the addition of nano zeolite also assists in removing gas emissions within the scope of high quality paper. This is due to their crystal structure that composed of millions of channels and cavities with a very wide surface area [112, 113]. Furthermore, natural nano zeolite has a significant tendency to attract moisture and can return the water absorbed without any change in the crystal structure and moisture absorption properties [114]. Therefore, activated nano zeolites are extensively used as desiccants in the paper industries due to the said characteristics. Compared to synthetic zeolites, however, natural zeolite provides significant advantages of cost effectiveness, abundant resources and easier accessibility towards paper industries [111–114].

Nano TiO_2

Nano TiO_2 is possible used as retention agent for supporting materials on paper sheet. There are two possible mechanisms on nano TiO_2 as a retention agent, where a nano TiO_2 suspension is coated on the sheet surface and wet end addition, where nano TiO_2 is deposited onto individual fibre before sheet formation, leading to a bulk distribution of the TiO_2 loading [115–120] (Fig. 4). For example, the surface properties of nano TiO_2 with hexadecanoic acid demonstrated that the wetting and dispersion of the mixture improved greatly. The paper with nano TiO_2 had higher dynamic elastic modulus than the unfilled ones [116]. This encourages the development a modern method of advance paper with super hydrophobic surface prepared with the addition of modified nano TiO_2 to cellulosic fibers [115, 118]. Superb speed homogenizer was used to disperse Nano TiO_2, and the surface modification was done using coupling agent, 3-(trimethoxysilyl) propyl methacrylate [116]. The results show that the increasing hydrophobicity of water contact angles for modified paper from 126.5° to 154.2°.

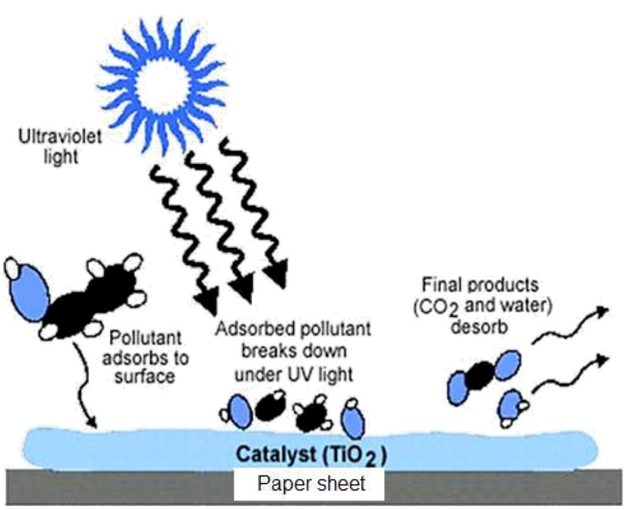

Fig. 4 TiO_2 paper sheet in photocatalysis system [120]

A binder can be used in the latter approach not only to increase the TiO_2 loading and dispersion in the paper, but also to protect the fiber against radiation. Thus, the produced paper displays high stability when exposed to solar like light [119]. For example, some studies carried out on sludge recovered from paper ash containing nano TiO_2 that obtained via acid treatment with that the crystal structure of TiO_2 of the anatase and crystal size was 10–20 nm [120]. The stability and degradability activity of nano TiO_2 in the paper sludge then evaluated by gases acetaldehyde removal. It found that the obtained paper capable of completely decomposing acetaldehyde to CO_2 under solar and UV light [121].

Nano mineral filler: paper industries

Due to the hydrophilic, fibrous, organic and highly porous nature, paper simply subjected to ultraviolet degradation, microbial attack and high water vapor transmission rate [122, 123]. In addition, the sizing agents included starch that applied to the surface of the paper make the condition still worse [124–126]. To overcome these disadvantages, novel nano mineral fillers being attracted as paper coating to meet the improved quality standards of excellence-grade papers [127].

Nano clay

Low gas permeability is one of the most interesting property enticements from nano clay as an additive in paper industry, particularly for the nylon based paper [128]. It claimed to supply a 100-fold lessening of O_2 permeability and provide a CO_2 barrier giving improved the total shelf life of the paper [129]. Conventionally, nano clay used as barrier layers in multilayer polyethylene terephthalate bottles, meat and cheese containers. Nano clay also used as replacement for ethylene glycol copolymer in food packaging and high density polyethylene containers [128, 130]. Therefore, once nano clay applied in paper industry, it can be act as waterproof barrier [131]. It offered a more suitable alternative to conventional polyethylene and acrylic acid that are commonly used and has a high potential application in paper beverage technology [132].

Nano calcium carbonate

Some studies examined the light scattering of precipitated calcium carbonate filler coated with novel silicate and zinc sulfide nanoparticle [27]. The precipitated calcium carbonate showed an enhancement in the light scattering from a pigment coating of paper using nano-additives [28, 29].

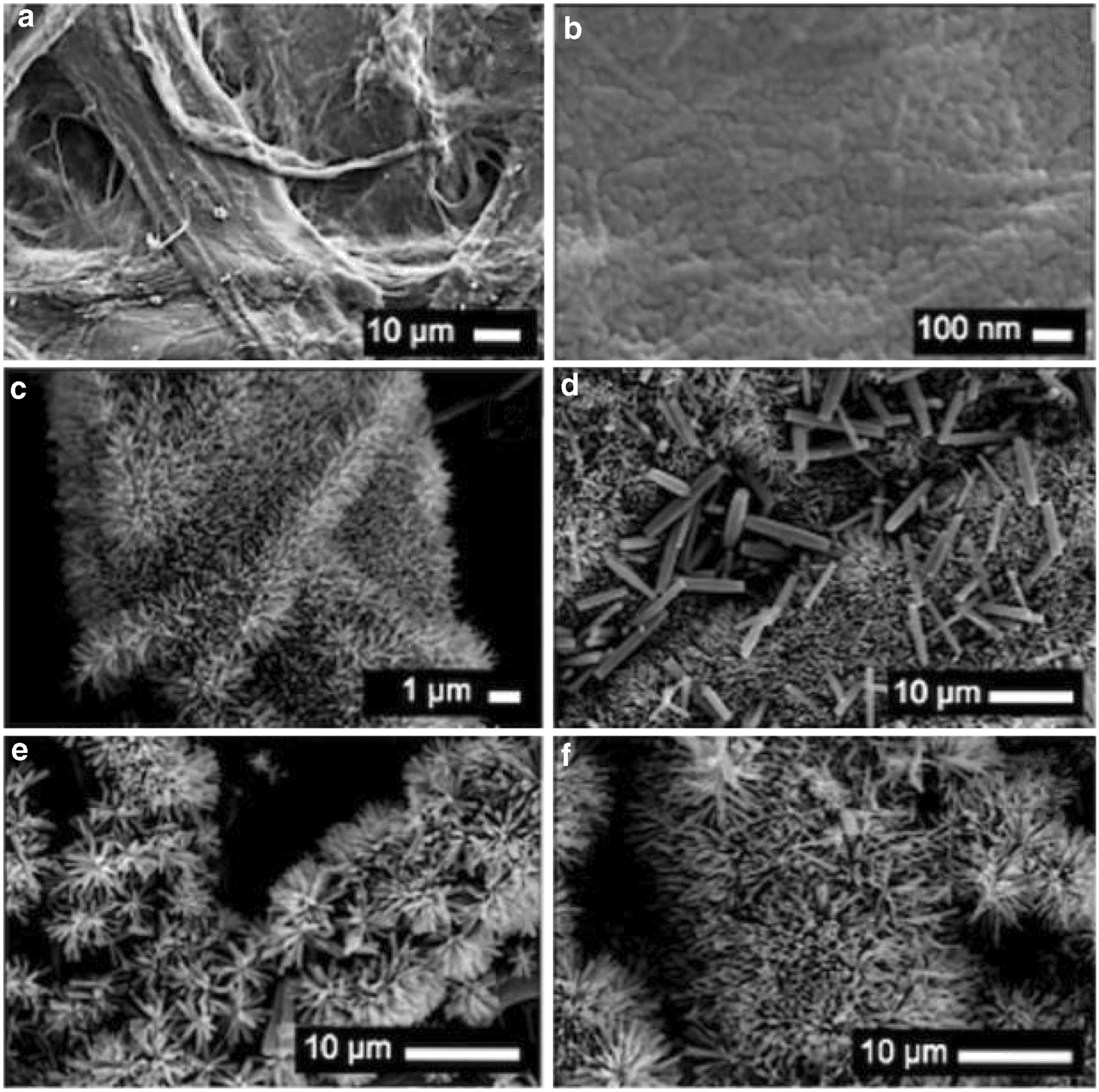

Fig. 5 SEM micrographs showing **a** untreated handsheet paper; **b** after seeding with ZnO nanoparticles; **c** ZnO nanorods grown on paper at a concentration of 10 mM for 10 h; **d** ZnO nanorods grown on paper at a concentration of 10 mM for 20 h; **e** ZnO nanorods grown on paper at a concentration of 20 mM for 10 h; and **f** ZnO nanorods grown on paper at a concentration of 20 mM for 20 h [137]

Nano TiO_2/hybrid

Some studies reported on the photocatalytic degradation of xylene with nano TiO_2 hybrid with beta-cyclodextrin coated paper [116]. Paper coated with a combination of nano TiO_2 and beta-cyclodextrin had a better effect on the degradation than paper coated only with nano-TiO_2, which the hybrid system has a significant synergistic effect on the degradation of xylene [120].

Nano superconductor agents: paper industries

Superconductor agent is an element or compound that will conduct electricity without resistance below a certain temperature towards produced paper [133–135].

Nano ZnO

ZnO nano additives can also use on a paper surface without the use of binders. ZnO nano additives can coat onto paper, which achieved first by ammonia and heat treatment of zinc oxide and cellulose, followed by ultrasound treatment [53, 136]. Paper products coated with zinc oxide nano additives exhibit antibacterial activity against *E. coli*. This is showing that, with the addition of nano ZnO, an excellent antifungal and UV protecting properties of paper consequently produced (Fig. 5). Meanwhile, demonstrated that the brightness, whiteness, smoothness, print density, print uniformity, picking velocity and oil absorbency of the paper significantly improve with addition on certain composition of nano ZnO [137].

Nano dispersion agents: paper industries

Dispersing agent or dispersant or plasticizer or a superplasticizer is either a non-surface active polymer or a surface-active substance added to a pulp suspension, to improve the separation of cellulose particles and to prevent settling or clumping [138–140].

Nano polymer

Many of nano polymers, especially those with high charge densities can be used as additives

for papermaking and they should be used in dilute solutions, to facilitate their dispersion throughout the stock, which in consequence avoid high turbulence [141]. In general, nanopolymer is a polymer-based material with a complex architecture, high density and durability. Nanopolymer reinforced some components of plasma conduits in emergency repairs or hazardous conditions. A wide variety of water-soluble nano polymers used for papermaking and categorized as naturally occurring polymers included nano polysaccharides/protein, modified naturally occurring polymer and synthetic polymers [142].

Nano polyacrylic acid or nano polyphosphates often used, with anchoring cations, to reduce the zeta potential of some fillers [143]. This helps filler dispersion, but may interfere with their aggregation during drainage [144, 145]. Neutral synthetic nano polymer retention aids included nano polyacrylamide, nano polyvinyl alcohol and nano polyethylene oxide [146]. They are generally inexpensive nano polymer, easily formulated for high molecular weight about several millions g/mol and added to the dry strength [143]. In other studies, polymeric nano xylan may use as the strength-increasing paper additives. In contrast to dissolving pulp production, a high polymeric nano xylan concentration is desirable for paper grade pulp to increase the pulp yield and strength properties [141]. The subsequent addition of isolated polymeric nano xylan during the paper making process may improve mechanical properties. Because the pulping and bleaching processes introduce COOH groups, the cellulosic fibers carry a slightly negative charge [142]. These negative charges cause electrostatic repulsion between single anionic fibers and reduce the possible inter fiber linkages [146]. The absorption of polymeric nano xylan as cationic additives into the anionic pulp surface decreases the electrostatic repulsion effect and therefore enhances the inter-fiber linkage and mechanical properties of the produced paper [147]. Cationic side groups lead to higher additive retention; however, a number of cationic groups are not directly proportional to the mechanical properties of the paper [148]. For example, a slight cationization of polymeric nano xylan to the degree of substitution of 0.1 causes increase in tensile and tear strength of paper up to 60 %. Polymeric nano xylan exhibited as a good O_2 barrier, suggesting possible applications in food packaging [149]. Polymeric nano xylan may easily extract from agricultural residues than wood because woods contain more lignin and the xylan integrated strongly into the lignified tissue [150].

Certain challenges associated with nano additives

Due to their lower particle size nano-additives need special attention so that they could be retained in the fiber matrix during the papermaking process [60, 107]. Papermakers can select an appropriate nano-additives and the process for the development or enhancement of desired paper properties or making a new product.

Conclusion and future prospective

Nano-additives can add new functionalities to paper industries. The main parameters of nano-additives are particle size and size distribution, aspect ratio, stabilization and surface modifications. Being lower in particle size, nano-additives could provide better performance than traditional additives such as adsorption, which can benefit from a high surface area. With respect to this, they may confer certain unique attributes and functionalities of paper, which is also one of the major concerns of papermakers. Incorporation of nano-additives into paper slurry could also have such attributes as high smoothness, good appearance or other previously unimagined functions. The advantages combined with the use of nano-additives expected to persuade worldwide papermakers to attract to this potentially promising research area and to make every effort to create positive breakthroughs.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

References

1. Atakelty H, Terrence SV (2000) Environmentally sensitive productivity analysis of the canadian pulp and paper industry. 1959–1994: an input distance function approach. J Env Eco Manag 40:251–274
2. Atakelty H, Terrence SV (2001) Non-parametric productivity analysis with undesirable outputs: an application to the Canadian pulp and paper industry. Am J Agric Econ 83:605–616
3. Marcus W, Nguyen VP, Théophile A, Walter W (2002) The relationship between the environmental and economic performance of firms: an empirical analysis of the European paper industry. Corp Soc Responsib Environ Manag 9:133–146
4. Philippe B (2007) ISO 14001 certification and environmental performance in Quebec's pulp and paper industry. J Environ Econ Manag 53:291–306
5. del Pablo RG (2005) Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. Bus Strateg Environ 14(1):20–37
6. Marcus W (2005) How to reconcile environmental and economic performance to improve corporate sustainability: corporate environmental strategies in the European paper industry. J Environ Manag 76(2):105–118
7. Talat M, Allan E (2006) A review of secondary sludge reduction technologies for the pulp and paper industry. Water Res 40(11):2093–2112
8. Zaieda M, Bellakhal N (2009) Electrocoagulation treatment of black liquor from paper industry. J Hazard Mater 163(2):995–1000
9. Tosco T, Petrangeli PM, Cruz VC, Sethi R (2014) Nanoscale zerovalent iron particles for groundwater remediation: a review. J Clean Prod 77:10–21
10. Muhd Julkapli N, Bagheri S (2015) Graphene supported heterogeneous catalysts: an overview. Int J Hydrog Energy 40:948–979
11. Chekin F, Bagheri S, Arof AK, Abd Hamid SB (2014) Preparation and characterization of Ni (II)/polyacrylonitrile and carbon nanotube composite modified electrode and application for carbohydrates electrocatalytic oxidation. J Solid State Electrochem 16:3245–3251
12. Chekin F, Bagheri S, Abd Hamid SB (2014) Electrochemistry and electrocatalysis of cobalt (II) immobilized onto gel-assisted synthesized zinc oxide nanoparticle—multi wall carbon nanotube—polycaprolactone composite film: application to determination of glucose. Anal Method 4:2423–2428
13. Bagheri S, Mohd Hir ZA, Termeh Yousefi A, Abd Hamid SB (2015) Photocatalytic performance of activated carbon-supported mesoporous titanium dioxide. Desal Water Treat 5:1–10
14. Bagheri S, Muhd Julkapli N, Abd Hamid SB (2014) Titanium dioxide as a catalyst support in heterogeneous catalysis. Sci World J 1:1–10
15. Ramimoghadam D, Bagheri S, Abd Hamid SB (2014) Biotemplated synthesis of anatase titanium dioxide nanoparticles via lignocellulosic waste material. BioMed Res Int 3:1–10
16. Westcott NP, Luo W, Yousaf M (2014) Controlling cell behavior with peptide nano-patterns. J Coll Interf Sci 430:207–213
17. Rodorico G, Luigi D, Massimo C, Claudius S, Piero B (2002) Nanotechnologies for conservation of cultural heritage: paper and canvas deacidification. Langmuir 18(21):8198–8203
18. Liangbing H, Yi C (2012) Energy and environmental nanotechnology in conductive paper and textiles. Energy Environ Sci 5:6423–6435
19. Grigoray O, Järnström J, Heikkilä E, Fardim P, Heinze T (2014) Modification of pine pulp during oxygen delignification by xylan self-assembly. Carbohydr Polym 112:308–315
20. Huber P, Burnet A, Petit-Conil M (2014) Scale deposits in kraft pulp bleach plants with reduced water consumption: a review. J Environ Manag 141:36–50
21. Winestrand S, Sjöde A, Cassland P, Hildén L, Nilvebrant NO, Jönsson LJ (2014) Evaluation of oxalate decarboxylases in industrial bleaching filtrates and in pulp-mill experiments. Ind Biotechnol 10(2):126–129
22. Miao Q, Zhong G, Qin M, Chen L, Huang L (2014) Influence of alkaline treatment and alkaline peroxide bleaching of aspen chemithermomechanical pulp on dissolved and colloidal substances. Ind Eng Chem Res 53(6):2544–2548
23. Li ZG (2014) Bleaching process of cashmere with sodium percarbonate. Wool Text J 42(2):45–47
24. Gomes VJ, Longue D Jr, Colodette JL, Ribeiro RA (2014) The effect of eucalypt pulp xylan content on its bleachability, refinability and drainability. Cellulose 21(1):607–614
25. Mathur V, Brennand B (2013) Novel silicate nano-fibers and super nano carbonates for dematerialization—basis weight reduction. Paper conference and trade show, PaperCon, 2013, 2, pp 1092–1118
26. Liu QX, Yin YN, Xu WC (2013) Characteristics of hydrated calcium silicate and paper filler. Appl Mech Mater 395:577–581
27. Liu QX, Yin YN, Xu WC (2013) Study on application of hydrated calcium silicate in paper from wheat straw pulp. Adv Mater Res 774:1277–1280
28. Wu P, Zhang MY, Wang J, Liu F, Song SX (2013) Application of CPAM-bentonite micro-particle system in papermaking with using fly ash based calcium silicate as filler. China Pulp Paper 32(9):5–10
29. Kato M, Isogai A, Onabe F (2002) Distribution of Al, Ca, Si and Mg components in cross sections of pulp fibers in paper sheets. Nord Pulp Paper Res J 17(1):85–88
30. Mo JC, Yu G, Liu Y, Liu JW (2011) Manufacture of heat insulation paper based on in situ synthesis of calcium silicate. China Pulp Paper 30(6):17–21
31. Shen J, Song Z, Qian X, Liu W (2009) Modification of precipitated calcium carbonate filler using sodium silicate/zinc chloride based modifiers to improve acid-resistance and use of the modified filler in papermaking. BioResources 4(4):1498–1519
32. Shen J, Zb Song, Qian X, Liu W (2009) A preliminary investigation into the use of acid-tolerant precipitated calcium carbonate fillers in papermaking of deinked pulp derived from recycled newspaper. BioResources 4(3):1178–1189
33. Sharma A, Kakkar S, Chauhan VS, Chakrabarti SK, Varadhan R (2012) Efficacy of ASA sizing with agro-residue and recycled pulps using different fillers. IPPTA Quart J Ind Pulp Paper Tech Assoc 24(3):93–98
34. Ma Y, Chen Y, Sun X, Zhao C, Nie S (2012) Application study of cationic polymethyl acrylate emulsion as papermaking sizing agent. Adv Mater Res 479:504–507
35. Bai LK, Hu HR, Luo C (2012) Application of xylan hemicellulose in surface sizing and improving pulp strength. China Pulp Paper 31(1):5–9
36. Ding P, Liu W, Zhao Z (2011) Roles of short amine in preparation and sizing performance of partly hydrolyzed ASA emulsion stabilized by laponite particles. Colloids Surf A: Physicochee Eng Asp 384(1):150–156

37. Muhd Julkapli N, Bagheri S, Abd Hamid SB (2014) Recent advances in heterogeneous photocatalytic decolorization of synthetic dyes. Sci World J 1:1–10
38. Resalati H, Koskela JP (2009) The effects of sizing on the enzymatic de-inking of copy printed wood-free paper, TAPPI press—TAPPI engineering, pulping and environmental conference 2009—innovations in energy, fiber and compliance, 1, Memphis, Tennessee, USA, 2009, pp 50–79
39. Moutinho IMT, Kleen AM, Figueiredo MML, Ferreira PJT (2009) Effect of surface sizing on the surface chemistry of paper containing eucalyptus pulp. Holzforschung 63(3):282–289
40. Ibrahim MM, Mobarak F, El-Din EIS, Ebaid AE-HE, Youssef MA (2009) Modified Egyptian talc as internal sizing agent for papermaking. Carbohydr Polym 75(1):130–134
41. Lourenço AF, Gamelas JAF, Ferreira PJ (2014) Increase of the filler content in papermaking by using a silica-coated PCC filler. Nord Pulp Paper Res J 29(2):240–245
42. Zhang X, Zhao Z, Ran G, Liu Y, Liu S, Zhou B, Wang Z (2013) Synthesis of lignin-modified silica nanoparticles from black liquor of rice straw pulping. Powder Tech 246:664–668
43. Duarte K, Justino CIL, Pereira R, Panteleitchouk TSL, Freitas AC, Rocha-Santos TAP, Duarte AC (2013) Removal of the organic content from a bleached kraft pulp mill effluent by a treatment with silica-alginate-fungi biocomposites. J Environ Sci Health Part A Toxic/Hazar Subst Environ Eng 48(2):166–172
44. Gu W, Li Y, Zhang X (2012) Preparation of silica hollow spheres used as filler for paper. Appl Mech Mater 200:339–342
45. Atik C, Ates S (2012) Mass balance of silica in straw from the perspective of silica reduction in straw pulp. BioResources 7(3):3274–3282
46. Wu W, Jing Y, Zhou X, Dai H (2011) Preparation and properties of cellulose fiber/silica core-shell magnetic nanocomposites. 16th international symposium on wood, fiber and pulping chemistry—proceedings, ISWFPC, Tiajin, China, 2, pp 1277–1282
47. Liu QX, Xu WC, Lv YB, Li JL (2011) Application of precipitated silica in low basis weight newspaper. Adv Mater Res 236:1107–1111
48. Nelli L (2007) Improving inkjet print performance with fumed silica at the size press. Annual meeting of the pulp and paper technical association of Canada (PAPTAC), Montreal, Canada, 2007, A229–A232
49. Chauhan I, Chattopadhyay S, Mohanty P (2013) Fabrication of titania nanowires incorporated paper sheets and study of their optical properties. Mater Express 3(4):343–349
50. Sha L, Zhao H (2012) Preparation and properties of Nano-TiO_2 photo-catalytic silk respirator paper. Fibers Polym 13(9):1159–1164
51. Manassah J (2011) Treatment of highly polluted paper mill waste water by solar photocatalytic oxidation with synthesized nano TiO_2. Proceedings of the international conference on green technology and environmental conservation, GTEC-2011, Chennai, Tamil Nadu Madras India, article number 6167693, pp 356–361
52. De Bem Luiz D, José HJ, Peralta Muniz Moreira RDF (2014) Kinetics of photocatalytic reduction of nitrate in synthetic and real effluent using TiO_2 doped with Zn as photocatalyst. J Chem Technol Biotechnol 1:1–10
53. Costa SV, Gonçalves AS, Zaguete MA, Mazonb T, Nogueira AF (2013) ZnO nanostructures directly grown on paper and bacterial cellulose substrates without any surface modification layer. Chem Commmun 49:8096–8098
54. Hamzeh Y, Sabbaghi S, Ashori A, Abdulkhani A, Soltani F (2013) Improving wet and dry strength properties of recycled old corrugated carton (OCC) pulp using various polymers. Carbohydr Polym 94(1):577–583
55. Lindqvist H, Salminen K, Kataja-aho J, Retulainen E, Fardim P, Sundberg A (2012) The effect of fibre properties, fines content and surfactant addition on dewatering, wet and dry web properties. Nord Pulp Paper Res J 27(1):104–111
56. Su J, Mosse WKJ, Sharman S, Batchelor W, Garnier G (2012) Paper strength development and recyclability with polyamideamine-epichlorohydrin (PAE). BioResources 7(1):913–924
57. Gong C, Hasan A, Bujanovic BM, Amidon TE (2012) Novel blend of biorenewable wet-end paper agents. TAPPI J 11(1):41–48
58. Chae HJ, Park JM (2011) Study on drainage and physical properties of KOCC handsheet containing pretreated wooden fillers. J Korea Tech Assoc Pulp Paper Ind 43(3):21–29
59. Hasan A, Bujanovic B, Amidon T (2009) Use of PLA as a paper-reinforcing agent. TAPPI 2nd annual PaperCon'09 conference—solutions for a changing world, St. Louis, Missouri, USA, Code 78522, pp 1–10
60. Miao C, Leduc M, Pelton R (2008) The influence of polyvinylamine microgels on paper strength. J Pulp Paper Sci 34(1):69–75
61. Reddy JP, Rhim JW (2014) Characterization of bionanocomposite films prepared with agar and paper-mulberry pulp nanocellulose. Carbohydr Polym 110:480–488
62. Zhang W, Johnson RK, Lin Z, Chandoha-Lee C, Zink-Sharp A, Renneckar S (2013) In situ generated cellulose nanoparticles to enhance the hydrophobicity of paper. Cellulose 20(6):2935–2945
63. Moritz S, Wiegand C, Wesarg F, Hessler N, Müller FA, Kralisch D, Hipler UC, Fischer D (2014) Active wound dressings based on bacterial nanocellulose as drug delivery system for octenidine. Int J Pharm 471(1):45–55
64. Liu DY, Sui GX, Bhattacharyya D (2014) Synthesis and characterisation of nanocellulose-based polyaniline conducting films. Compos Sci Technol 99:31–36
65. Dwivedi AD, Dubey SP, Hokkanen S, Sillanpää M (2014) Mechanistic investigation on the green recovery of ionic, nanocrystalline, and metallic gold by two anionic nanocelluloses. Chem Eng J 253:316–324
66. Abe K, Iwamoto S, Yano H (2007) Obtaining cellulose nanofibers with a uniform width of 15 nm from wood. Biomacromolecules 8:3276–3278
67. Saito T, Nishiyama Y, Putaux JL, Vignon M, Isogai A (2006) Homogeneous suspensions of individualized microfibrils from TEMPO-catalyzed oxidation of native cellulose. Biomacromolecules 7(6):1687–1691
68. Isogai A, Saito T, Fukuzumi H (2011) TEMPO-oxidized cellulose nanofibers. Nanoscale 3:71–85
69. Wågberg L, Decher G, Norgren M, Lindström T, Ankerfors M, Axnäs K (2008) The build-up of polyelectrolyte multilayers of microfibrillated cellulose and cationic polyelectrolytes. Langmuir 24:784–795
70. Loranger E, Jradi K, Daneault C (2012) Nanocellulose production by ultrasound-assisted TEMPO oxidation of kraft pulp on laboratory and pilot scales. IEEE international ultrasonics symposium, IUS, Taipei, Taiwan, article number 6562112, pp 953–956
71. Kajanto I, Kosonen M (2012) The potential use of micro-and nanofibrillated cellulose as a reinforcing element in paper. J-FOR 2(6):42–48
72. Walker C (2012) Cellulose nanomaterials: now appearing in paper, coating, films and composites. Coat Intern 45(11):24–25
73. Sacui IA, Nieuwendaal RC, Burnett DJ, Stranick SJ, Jorfi M, Weder C, Foster EJ, Olsson RT, Gilman JW (2014) Comparison of the properties of cellulose nanocrystals and cellulose nanofibrils isolated from bacteria, tunicate, and wood processed using acid, enzymatic, mechanical, and oxidative methods. ACS Appl Mater Interfac 6(9):6127–6138

74. Jaušovec D, Vogrinčič R, Kokol V (2014) Introduction of aldehyde vs. carboxylic groups to cellulose nanofibers using laccase/TEMPO mediated oxidation. Carbohydr Polym 1:1–10
75. Jiang F, Hsieh YL (2014) Super water absorbing and shape memory nanocellulose aerogels from TEMPO-oxidized cellulose nanofibrils via cyclic freezing-thawing. J Mater Chem A 2(2):350–359
76. Xu QH, Li WG, Cheng ZL, Yang G, Qin MH (2014) TEMPO/NaBr/NaClO-mediated surface oxidation of nanocrystalline cellulose and its microparticulate retention system with cationic polyacrylamide. BioResources 9(1):994–1006
77. Kim BY (2014) Investigation of coating color penetration depending on the properties of base paper. J Korea Tech Assoc Pulp Paper Ind 46(2):16–21
78. Nadagouda V, Parikh J, Shukla MD (2012) Screening of fungal cultures for their dye degradation or decolorisation ability. Res J Chem Environ 16(3):56–59
79. Huber P, Carré B (2009) Decolorization of process waters in deinking mills and similar applications: a review. BioResources 7(1):1366–1382
80. Peruvemba SK (2012) Dual-pigment electrophoretic displays for reading textbooks. Info Disp 28(2):26–29
81. Ray AK, Tyagi S, Mathur RM (2011) Coating color pigments for paper—how to evaluate them for agricultural residue base papers. AIChE annual meeting, conference proceedings, Minneapolis, Minnesota, USA, Code 88259, pp 1–2
82. Basilio C (2013) Kaolin-based reagent improves waste paper deinking. Paper360 8(5):22–23
83. Choudhary RP, Sheoran AS, Trivedi SK (2013) A small kaolin beneficiation unit: state of art. Int J Earth Sci Eng 5(4):775–781
84. Hallam BT, Nutbeem C (2012) Novel kaolin for use with high yield pulp. Asian paper 2012—new applied technology (NAT) conference proceedings, Srinivasa Institute, India, Code 91170
85. Galán E, Fernández-Caliani JC, Aparicio P, Miras A, Márquez MG (2010) Mineralogical and geochemical constraints on the origin of the residual kaolin deposits derived from variscan granitoids of Galicia (Spain). SME annual meeting and exhibit 2010, Phoenix, Arizona, USA, 2010, pp 180–186
86. Basilio C, Sheppard S (2009) Modified Kaolin-based deinking reagent for recycled paper. TAPPI press—TAPPI engineering, pulping and environmental conference 2009—innov energy, fiber & compl, Memphis, Tennessee, USA, 1, pp 676–702
87. Kohl C (2008) Amberger Kaolinwerke: impact of selected physical properties of kaolin on the quality of SC paper. International Paperworld IPW, Issue SPEC. ISS, Zellcheming, Germany, 2008, pp 42–45
88. Addai-Mensah J, Yeap KY, McFarlane AJ (2007) The influential role of pulp chemistry, flocculant structure type and shear rate on dewaterability of kaolinite and smectite clay dispersions under couette Taylor flow conditions. Powder Technol 179(1):79–83
89. Hosseini MR, Pazouki M, Ranjbar M, Habibian M (2007) Bioleaching of iron from highly contaminated Kaolin clay by *Aspergillus niger*. Appl Clay Sci 37(3):251–257
90. Wang B, Gu L, Ma H (2007) Electrochemical oxidation of pulp and paper making wastewater assisted by transition metal modified kaolin. J Hazar Mater 143(1):198–205
91. Ray AK, Tyagi S, Mathur RM (2011) Coating color pigments for paper—how to evaluate them for agricultural residue base papers. AIChE annual meeting, conference proceed, code 88259
92. Ouyang D, Xu W, Lo TY, Sham JFC (2011) Increasing mortar strength with the use of activated kaolin by-products from paper industry. Constr Build Mater 25(4):1537–1545
93. Sabedot S, Petter CO, Sampaio CH (2013) Spectrophotometric characterization of iron and titanium minerals in sedimentary kaolin deposit. Int J Miner Process 124:35–41
94. Kansal SK, Singh M, Sud D (2008) Effluent quality at kraft/soda agro-based paper mills and its treatment using a heterogeneous photocatalytic system. Desalination 228(1):183–190
95. Fukahori S, Koga H, Kitaoka T, Tomoda A, Suzuki R, Wariishi H (2006) Hydrogen production from methanol using a SiC fiber-containing paper composite impregnated with Cu/ZnO catalyst. Appl Catal A 310(1):138–144
96. Mohamadzadeh-Saghavaz K, Resalati H, Ghasemian A (2014) Cellulose-precipitated calcium carbonate composites and their effect on paper properties. Chem Papers 68(6):774–781
97. Mathur V, Brennand B (2013) Novel silicate nano-fibers and super nano carbonates for dematerialization—basis weight reduction. paper conference and trade show, PaperCon 2013, Atlanta, Georgia, USA, 2, pp 1092–1118
98. Selvamaharajan G, Chauhan Vipul S, Bhardwaj Nishi K, Varadhan R (2013) Impact of different fillers during papermaking using multi-layer fabrics. IPPTA Quart J Ind Pulp Paper Tech Assoc 25(4):135–139
99. Sreenivas T, Rajan KC (2013) Studies on the separation of dissolved uranium from alkaline carbonate leach slurries by resin-in-pulp process. Sep Purif Technol 112:54–60
100. Varhimo P, Konn J, Lillandt M, Paltakari J (2013) Brightness reduction of calcium carbonate and calcium sulfate fillers in the wet end of a paper machine. Nord Pulp Paper Res J 28(1):59–67
101. Im W, Lee HL, Youn HJ, Seo D (2013) Structure characterization of ground calcium carbonate flocs by fractal analysis and their effects on handsheet properties. TAPPI J 12(3):17–23
102. Kim JJ, Ahn JW, Lee MW, Kim YW, Lee JK, Seo YB (2013) Improving recycled fibres in printing paper by application of an in situ $CaCO_3$ formation method 2. Paper properties. Appita J 66(1):54–58
103. Kumar P, Negi YS, Singh SP (2013) In -situ precipitation of $CaCO_3$ within pulp fibers enhances optical and printing properties of paper. AIChE annual meeting, conference proceedings, San Francisco, California, USA, Code 94591
104. Hu K, Li M, Hu B (2013) The study on refining calcium carbonation with lime mud from reed pulp black liquor as filler for papermaking. Adv Mater Res 610–613:2429–2432
105. Wang J, Wei P, Liu P, Sun W (2012) Identifying appropriate conditions for producing spindle-like causticizing precipitated calcium carbonate for paper filler applications. BioResources 7(4):5894–5903
106. Zeli C, Huajing Z (2013) Study of preparation and the influencing factors of chrysanthemum-shaped calcium carbonate applied to paper industry. Adv Mater Res 621:111–116
107. Lee JY, Kim YH, Lee SR, Kim CH, Joo Sung Y, Lim GB, Kim SY, Kim JS, Park JH (2013) Effect of precipitated calcium carbonate on paper properties and drying energy reduction of duplex-board. J Korea Tech Assoc Pulp Paper Ind 45(6):24–29
108. Wang Y, Song X, Qian H (2013) Carboxymethylation fiber of dissolved air flotation rejects and its influences on paper properties. Adv Mater Res 651:67–72
109. Svedberg A, Lindström T (2010) The effect of various retention aids on retention and formation. Nord Pulp Paper Res J 25(2):195–203
110. Chen XF, Wang W, Liu YJ (2010) Preparation and application of the hydrophobic acrylate as the waterproof agent for paper. China Pulp Paper 29(11):19–22
111. Fukahori S, Ichiura H, Kitaoka T, Tanaka H, Wariishi H (2003) Photocatalytic decomposition of bisphenol A in water using composite TiO_2-zeolite sheets prepared by a papermaking technique. Environ Sci Technol 37(5):1048–1051
112. Ichiura H, Kitaoka T, Tanaka H (2003) Removal of indoor pollutants under UV irradiation by a composite TiO_2–zeolite sheet prepared using a papermaking technique. Chemosphere 50(1):79–83

113. Ichiura H, Kubota Y, Zonghua W, Tanaka H (2001) Preparation of zeolite sheets using a papermaking technique. J Mater Sci 36(4):913–917
114. Montalvo SJ, Guerrero LE, Borja R (2014) Improvement in nitrification through the use of natural zeolite: influence of the biomass concentration and inoculum source. Int J Environ Sci Technol 11(1):43–52
115. Adjimi S, Roux JC, Sergent N, Delpech F, Thivel PX, Pera-Titus M (2014) Photocatalytic oxidation of ethanol using paper-based nano-TiO_2 immobilized on porous silica: a modelling study. Chem Eng J 251:381–391
116. Naguib M, Mashtalir O, Lukatskaya MR, Dyatkin B, Zhang C, Presser V, Gogotsi Y, Barsoum MW (2014) One-step synthesis of nanocrystalline transition metal oxides on thin sheets of disordered graphitic carbon by oxidation of mxenes. Chem Com 50(56):7420–7423
117. Senadeera GKR, Kitamura T, Wada Y, Yanagida S (2006) Enhanced photoresponses of polypyrrole on surface modified TiO_2 with self-assembled monolayers. J Photochem Photobiol A 184(1–2):234–239
118. Hyoung-il K, Gun-hee M, Damián MS, Yiseul P, Wonyong C (2012) Solar photoconversion using graphene/TiO_2 composites: nanographene shell on TiO_2 core versus TiO_2 nanoparticles on graphene sheet. J Phys Chem C 116(1):1535–1543
119. Linlin R, Yu-Ping Z, Dongliang J (2007) Fabrication of gradient pore TiO_2 sheets by a novel freeze–tape-casting process. J Am Ceram Soc 90(9):3001–3004
120. Subrata N, Pillay SA, Manas C (1998) Photocatalytic degradation of organic dyes in aqueous solution with TiO_2 nanoparticles immobilized on foamed polyethylene sheet. J Photochem Photobiol A 113(3):257–264
121. Laisheng L, Wanpeng Z, Pengyi Z, Zhongyin C, Wenya H (2003) Photocatalytic oxidation and ozonation of catechol over carbon-black-modified nano-TiO_2 thin films supported on Al sheet. Water Res 37(15):3646–3651
122. Yang H, Qiu L, Qian X, Shen J (2013) Filler modification for papermaking with cationic starch and carboxymethyl cellulose: a comparative study. BioResources 8(4):5449–5460
123. Richardson DE, Grubb MJ (2013) Evaluation of mineral filler interaction with wood extractive colloids in pulp and paper mill process waters using flow cytometry. J-FOR 3(2):16–21
124. Polverari M, MacDonald J (2012) The use of rheology to predict dewatering, final sheet formation and final sheet properties of paper making furnishes in-line. Asian paper 2012—new applied technology (NAT) conference proceedings, Avanca, Portugal, Code 91170
125. Ramimoghadam D, Bagheri S, Abd Hamid SB (2014) Progress in electrochemical synthesis of magnetic iron oxide nanoparticles. J Magn Magn Mater 368:207–229
126. McLain L, Turner E, Veal P, Wygant R (2009) Productivity gains for board and packaging using mineral fillers. Prof Paper 6(2):18–21
127. Dong C, Song D, Patterson T, Ragauskas A, Deng Y (2008) Energy saving in papermaking through filler addition. Ind Eng Chem Res 47(21):8430–8435
128. Zhao HZ, Zheng SW (2013) Study of coating binder migration and affected parameters. Adv Mater Res 790:45–48
129. Ling Y, Luo Y, Luo J, Wang X, Sun R (2013) Novel antibacterial paper based on quaternized carboxymethyl chitosan/organic montmorillonite/Ag NP nanocomposites. Ind Crops Prod 51:470–479
130. Narvestad H, Gregersen ØW, Kure KA (2013) Effect of sodium dithionite post-bleaching on the clay-induced discolouration of a hydrogen peroxide bleached mechanical pulp. Nord Pulp Paper Res J 28(3):1–10
131. Narvestad H, Gregersen ØW, Kure KA (2013) Filler clay induced discolouration of bleached mechanical pulp. Nord Pulp Paper R J 28(1):68–81
132. Muñoz P, Juárez MC, Morales MP, Mendívil MA (2013) Improving the thermal transmittance of single-brick walls built of clay bricks lightened with paper pulp. Energy Build 59:171–180
133. Liangbing H, Yi C (2012) Energy and environmental nanotechnology in conductive paper and textiles. Energy Environ Sci 5:6423–6435
134. Peng CQ, Thio YS, Gerhardt RA (2008) Conductive paper fabricated by layer-by-layer assembly of polyelectrolytes and ITO nanoparticles. Nanotechnology 19:505603. doi:10.1088/0957-4484/19/50/505603
135. Mangilal A, Qi X, Bong SS, Nicholas K, Kody V, Yuri L (2009) Conductive paper from lignocellulose wood microfibers coated with a nanocomposite of carbon nanotubes and conductive polymers. Nanotechnology 20:215602. doi:10.1088/0957-4484/20/21/215602
136. Yu Q, Heqiu Z, Lizhong H, Dechao Y, Lina W, Bin W, Jiuyu J, Guoqiang L, Xin L, Jianfan L, Fei L, Shijun H (2012) Flexible piezoelectric nanogenerators based on ZnO nanorods grown on common paper substrates. Nanoscale 4:6568–6573
137. Jang SD, Maniruzzaman M, Yun GY, Kim J (2013) Hybrid nanocomposites made with cellulose and ZnO nanoparticles and its biosensing application. Proceedings of SPIE—int soc optical eng, 8691, Sydney, Australia, article number 869118, pp 1–5
138. Zegui Y, Qiujuan L, Yulin D, Arthur R (2005) Improvement of paper strength with starch modified clay. J Appl Polym Sci 97(1):44–50
139. Bagheri S, Muhd Julkapli N, Yehye WA (2015) Catalytic conversion of biodiesel derived raw glycerol to value added products. Renew Sustain Energy Rev 41:113–127
140. Ando Y (2006) Solutions for papermaking problems with new spraying chemicals part II—a study of deposit control agents for shower application by measuring zeta-potential on flat plates. Jpn TAPPI J 60(9):50–59
141. Testova L, Roselli A, Costabel L, Kovasin K, Tenkanen M, Sixta H (2014) Combined production of polymeric birch xylan and paper pulp by alkaline pre-extraction followed by alkaline cooking. Ind Eng Chem Res 53(19):8302–8310
142. Deutschle AL, Römhild K, Meister F, Janzon R, Riegert C, Saake B (2014) Effects of cationic xylan from annual plants on the mechanical properties of paper. Carbohydr Polym 102(1):627–635
143. Gustafsson E, Larsson P, Wågberg L (2012) Treatment of cellulose fibres with polyelectrolytes and wax colloids to create tailored highly hydrophobic fibrous networks. Colloids Surf A: Physicoch Eng Asp 414:415–421
144. Ryu J, Youn HJ, Chin SM, Lee S (2011) Effect of pH and conductivity in weak polyelectrolytes multilayering on paper properties. Nord Pulp 7 Paper Res J 26(4):410–414
145. Wang GS, Li J, Chen FS (2006) Layer-by-layer deposition of polyelectrolytes on the surface of pulp fibers. Trans China Pulp Paper 21(3):52–55
146. Gärdlund L, Forsström J, Andreasson B, Wågberg L (2003) Influence of polyelectrolyte complexes on strength properties of papers made from unbleached chemical pulps. International paper and coating chemistry symposium, proceedings, Monteral, USA, pp 233–238
147. Saukkonen E, Lyytikäinen K, Geydt P, Backfolk K (2014) Surface selective removal of xylan from refined never-dried birch kraft pulp. Cellulose 1:1–10
148. Tavast D, Mansoor ZA, Brännvall E (2014) Xylan from agro waste as a strength enhancing chemical in kraft pulping of softwood. Ind Eng Chem Res 53(23):9738–9742

149. Deutschle AL, Römhild K, Meister F, Janzon R, Riegert C, Saake B (2014) Effects of cationic xylan from annual plants on the mechanical properties of paper. Carbohydr Polym 102(1):627–635

150. Gomes VJ, Longue JRD, Colodette JL, Ribeiro RA (2014) The effect of eucalypt pulp xylan content on its bleachability, refinability and drainability. Cellulose 21(1):607–614