Utilization Of Waste From Recycled Paper Mills

Bajpai Pramod K.

ABSTRACT

In the pulp and paper industry several types of solid wastes and sludge are generated, mainly from pulping, deinking processes and wastewater treatment. The waste generation is strongly affected by the production process and wastewater treatment technologies. About 40-50 kg of ETP sludge (dry) is generated in the production of 1 tonne of paper at a paper mill and of that approximately 70% is primary sludge and 30% secondary sludge. The dryness of sludge varies from 20% in a newsprint mill to 40% in a tissue mill. As the present practices of land filling and land disposal have many disadvantages and environmental problems, new techniques are being developed. In this paper, generation and composition of wastes from recycled paper mills and their gainful utilization using newer techniques have been discussed.

Keywords: *Deinking sludge, primary sludge, secondary sludge, paper mill waste*

Introduction

As a result of de-inking and bleaching, solid waste is sometimes higher at recycled paper mills than mills that use fresh fibre. However, the use of recovered fibre in the manufacture of paper diverts paper from the waste stream and, viewed from this perspective, the sludge from manufacturing recycled paper may have a lower environmental impact than paper that would otherwise be land filled. Paper mill sludges have a net environmental advantage over sewage sludges in that they are nearly pathogen free; handling and use pose lower health risks.

Due to rapidly reducing landfill space and the secondary pollution issues associated with the conventional sludge disposal approaches and also the increasingly stringent environmental regulations, the disposal of sludges continues to be one of the major challenges for the most pulp and paper mills (1). This together with record high oil prices has contributed to a need to investigate methods of converting sludge waste into energy (2, 3). For example, the percentage of pulp/paper sludges disposed by landfills has constantly decreased in Europe in recent years, dropping from 40% in 1990 to 20% in 2002. In the meantime, the percentage of pulp/paper sludge used as a raw material in other industries and other applications - agriculture as soil improvers, in road construction, land reconstruction and for energy recovery has gradually increased.

This paper presents waste management in recycled paper industry, waste generation, its composition, processes and technologies for conversion of these wastes into valuable products, worldwide waste reduction techniques employed in the paper industry.

Department of Chemical Engineering,
Thapar University, Patiala – 47004 (Punjab)

Table 1 Generation of solid wastes in paper mills (4)

Sr. No.	Solid waste	Description
1	Rejects	From recovered paper: lumps of fibres, staples and metals from ring binders, sand, glass and plastics and paper constituents as fillers, sizing agents and other chemicals Screen rejects: produced during filtration steps with screens of very small slots to remove pulp possibly containing stickies that might, have a high content of cellulose fibre.
2	Deinking sludge	Generated during recycling of paper, contains mainly short fibres or fines, coatings, fillers, ink particles (a potential source of heavy metals), extractive substances and deinking additives. It has a poor heating value.
3	Primary sludge	Generated in the clarification of process water by kidney treatments, e.g. dissolved air flotation. It consists of mostly fines and fillers depending on the recovered paper being processed.
4	Secondary sludge	Generated in the clarifier of the biological units of the wastewater treatment. It is often difficult to handle (due to a high microbial protein content), and such solids are often mixed with primary sludge to permit adequate dewatering.

Table 2 Generation of wastes in production of different paper grades from recycled fibre (8)

Paper grade	Solid waste (dry basis, kg/t)
Packaging paper	50-100
Newsprint	170-190
Light-weight coated paper/super-calendared paper	450-550
Tissue and market pulp	500-600

Table 3 Rejects and sludge generation (kg/t) from different recovered paper grades and papers (5)

Paper grade	Recovered paper grade	Total waste	Rejects		Sludges	
			Heavy-mass and coarse	Light-mass and fine	Flotation de-inking	White water clarification
Market DIP	Office paper	32-46	< 1	1 4-5	12-15	15-25
Graphic paper	News, magazines	15-20	1-2	3-5	8-13	3-5
	High grades	10-25	< 1	= 3	7-16	1-5
Sanitary paper	News, magazines, office paper, medium grades	27-45	1-2	3-5	8-13	15-25
Liner, fluting	Old corrugated containers, Kraft papers	4-9	1-2	3-6	-	0-1
Board	Sorted mixed recovered paper, old corrugated containers	4-9	1-2	3-6	-	0-1

Generation of Wastes

Different types of solid wastes and sludges are generated in the pulp and paper industry at different production processes (4, 5). Table 1 shows solid waste generated in paper mills (4).

Treatment of wastewater generated at pulping, papermaking and deinking processes is the main source of wastewater treatment sludge and deinking sludge. It has been reported that about 300 kg of sludge is produced for each ton of recycled paper. The amount of waste generated in paper production varies within different regions, because of different recycling rates (6).

A greater amount of rejects is produced when processing recycled fibre, because of the unrecyclable filler proportion in the raw material. Great variations occur within plant types, depending on the processes and raw materials (7). The average quantities of waste generated through production of different paper grades from recycled fibre are presented in Tables 2 and 3 (5, 8, 9).

Wastewater treatment sludge

Joyce et al. (10) have reported that about 40-50 kg of ETP sludge (dry) is generated in the production of 1 tonne of paper at a paper mill in North America. Of that approximately 70% is primary sludge and 30% is secondary sludge. The primary sludge can be dewatered relatively easier. But, the secondary sludge is very difficult to dewater. It consists mostly of excess biomass produced during the biological process (11). The solid content is 0.5 to 2% solids. Moreover, tertiary treatment can take place in addition to the above mentioned treatment stages in countries with tight environmental regulations (12). Inorganic part of wastewater treatment sludge is mostly present in the form of sand, while organic part is present as fibre or other wood residuals. During the secondary (biological) treatment, soluble organic materials are converted to carbon dioxide, water and biomass by microorganisms present in active sludge and required for successful process implementation. Depending on a certain treatment scheme applied at a certain mill, primary sludge and secondary could be also either mixed together or collected separately.

Deinking sludge

Deinking sludge is generated in the mills producing recycled fibre from recycled paper (13, 14). The quantity on dry basis can vary from 20% in a newsprint mill to 40% in a tissue mill. Froth flotation deinking process is generally used in pulp and paper industry for selective deletion of ink particles only during recycled fibre processing. Wash deinking process is also used. This kind of deinking is aimed at removal of small particles, including fillers, coating materials, fines, and inks. In tissue paper production, in addition to deinking, de-ashing process is applied for better removal of fines and fillers (15). Total suspended solids can be categorized into organic matter, such as bark and fibre, and inorganic matter, such as, kaolin, clay, calcium carbonate, titanium dioxide that are resulting from coating materials and other chemicals used for paper production.

Composition of Wastes

The composition of sludge depends on the raw material, manufacturing process, chemicals used, final products and the wastewater treatment technique. In case of recycled

Table 4 Ultimate analyses of different types of paper mill sludge (18)

Sludge Type	*Analysis (%)*						
	Solids	*Ash*	*Carbon*	*Hydrogen*	*Sulphur*	*Oxygen*	*Nitrogen*
Deinking Mill 1	*42.0*	*20.2*	*28.8*	*3.5*	*0.2*	*18.8*	*0.5*
Deinking Mill 2	*42.0*	*14.0*	*31.1*	*4.4*	*0.2*	*30.1*	*0.9*
Recycle Mill	*45.0*	*3.0*	*48.4*	*6.6*	*0.2*	*41.3*	*0.5*
Bleached Pulp Mill	*33.4*	*1.9*	*48.7*	*6.6*	*0.2*	*42.4*	*0.2*
Pulp mill	*42.0*	*4.9*	*51.6*	*5.7*	*0.9*	*29.3*	*0.9*
Kraft mill 1	*37.6*	*7.1*	*55.2*	*6.4*	*1.0*	*26.0*	*4.4*
Kraft Mill 2	*40.0*	*8.0*	*48.0*	*5.7*	*0.8*	*36.3*	*1.2*

Table 5 Composition of sludges and rejects*(20)

	Dry solids, %	*Organic matter#, %*	*Mineral matter#, %*	*Energy content, MJ/ton_{wet}*
Primary sludge	*50*	*40*	*60*	*2690*
Secondary sludge	*40-50*	*50*	*50*	*4000-5000*
Deinking sludge	*56*	*50*	*50*	*3000*
Coarse rejects	*55*	*92*	*8*	*12000*
Screen rejects	*55*	*90*	*10*	*8000*

** The composition can vary as per paper mill. The figures in this table are an average based on different reports. # of dry content* papers, it also depends on the type of paper used and the number and types of cleaning stages used in the recycling operation. Sludge from mixed office wastepaper may contain high levels of clay and other types of fillers, printing inks, stickies from envelope adhesives, as well as fibres and paper fines. Sludges from mixed office wastepaper recycling operations may contain as much as 20% ash from fillers in the wastepaper. Because of the constituents that may exist, along with the water fraction, typical sludge analysis can vary widely. Kraft, sulfite and deinking mills by and large generate approximately 58, 102 and 234 kg of sludge per ton respectively (9). These sludges contain approximately 40-50% water by weight and a heating value of about 3600 Btu/lb (dry) (16, 17). The low heating value is a result of high levels of clay, calcium carbonate and titanium oxide. The ash content in paper mill sludge can be as high as 50%. High ash sludges have a significantly lower heating value than low ash sludges, which affect its suitability for certain disposal methods (e.g., incineration and gasification) (9). **Table 4 shows u**ltimate analysis of different types of paper mill sludges (18). It also includes the data of kraft mill and bleached mill for comparison.

The deinking sludge has been reported to contain highest ash content (19) as compared to other wastes. Along with that, carbon content of the sludge is lowest between all sludge types. Therefore, even if dry solids content of deinking sludge is somewhat comparable or higher than others, heating values on dry basis are the lowest (Table 5).

Utilization of Wastes

Several options are available for utilization of waste from pulp and paper industry. For this, the wastes need to be pretreated using techniques like thickening, conditioning and sometimes drying. The most utilized methods of pulp and paper sludge management have been land disposal, land application and incineration. Land filling is the most common method worldwide for the final disposal of paper mill wastes. However, the landfill capacities have already become very limited in densely populated countries and it is becoming more and more difficult to obtain authorization to open new landfill sites. Further development of land filling techniques has dramatically increased costs for construction and operation of landfills (21). Moreover, the major drawbacks associated with the landfill are the possible chance of contamination of land and ground water. Because of this reason, most of the developed countries are banning landfill in near future.

Land application (composting) is an acceptable and recommended means of recycling wastewater treatment sludge and is rapidly gaining acceptance in the world as a method for stabilizing/sanitizing organic wastes. Composting is biooxidative process, which involves the mineralization and partial humification of the organic matter; leading to a stabilized final product, free of phytotoxicity and pathogens and with certain humic properties. The advantages of composting are summarized in Table 6. However, land application is not a trouble free technology. Odours, groundwater contamination, heavy metals, and specific organic toxics are the most common problems. Other problems are noise, pathogens, excessive nitrogen application and surface water contamination. The process of applying sludge is dirty and noisy, so if there are houses in the vicinity, potential difficulties will arise.

Table 6 Advantages of composting

The recovery of valuable organic matter and nutrients which are normally lost from agricultural systems when deposited in landfills
Reduced mass and volume of material, and thus reduced transportation costs
Increased concentration of nitrogen and phosphorus through partial liberalization of the organic fraction, thereby decreasing the risk of damaging plants by the microbial immobilization of soil nitrogen
Minimization of odours which are normally produced following uncontrolled addition of raw organic materials to soils
Transformation of soluble nitrogen and phosphorus into organic forms, thereby extending the availability of these elements over the growing season, and a decreased chance of nutrient leaching
Increased humus content and cation exchange capacity, thereby improving nutrient retention and availability and the production of a higher value product suitable for horticultural and agricultural applications

Vermicomposting, a low cost technology system for the processing or treatment of organic wastes, could be another suitable technology for the transformation of solid paper mill sludges. The two factors limit the bioxidation processes; the difficult degradation of the structural polysaccharides and the low nitrogen content of the sludge. These problems can be solved by mixing the paper mill waste with some nitrogen-rich materials, which act as natural inoculants of microbial communities. However, the mixture will affect both the earthworm process and the quality of the final product.

Waste incineration is becoming a more widely used waste management option: burning waste to generate steam and electricity for use at the plant and to sell to the national grid (3). Some of the chlorinated organics not eliminated through process modifications could be trapped on the sludge from the external treatment process(es). Its disposal represents an increasing problem. However, if these sludges could be dried to 90%, in an energy-efficient manner, they could provide high enough flame temperature upon combustion to destroy the organic chlorides entrapped in the sludges. After drying, the sludge pellets can be produced to reduce the volume, odour control, and recovery of fuel value and byproduct applications. The most common reason for production of pellets is for use as an alternate fuel.

Several other new options of utilizing solid wastes are being evaluated and tried. Brief account of these newer options of utilizing solid wastes from paper industry is given in subsequent sections.

Recovery of raw materials

Efforts on the reclamation of fillers from high-ash (deinking) sludges started in early 1950s (22). Paper mill sludges usually contain significant percentages of both cellulose fibre and paper making fillers. Fibre and filler fractionation have been pursued from non-destructive and destructive perspectives, relative to the organic matter components in sludges. The objective of non-destructive material fractionation is to separate usable paper fibre from other solid materials contained in sludge. The configuration of the reclamation processes and complexities vary depending on the contaminants present in individual sludges.

Primary sludges have been the focus of fibre recovery initiatives. In most cases, the approaches to recovering fibres from paper industry sludges involve cleaning and screening processes to separate the usable long fibres from other sludge components. Results of trials using a Celleco Hedemora Fibre Recovery System and sludge from the Ponderosa Fibre Products mill, Baltimore indicated that up to 40% of the sludge matrix consisted of usable fibre (>200 mesh) (23). The system relies on a cleaning stage to remove grit, inks and lightweight contaminants, followed by fibre recovery in a SPRAYDISC filter system. Good results were reported for both virgin and recycled pulp sludges. The operational system at the mill was modified to recover fibre from high-fibre bearing streams before they enter the primary clarifier with an intention to minimize additional sludge cleaning associated with removal of contaminants, grit, dirt and other solids. Prime Fibre Inc. (PFI) constructed a facility to produce market pulp substitute from waste paper and primary paper sludges, with an operating capacity of 30-50 T/day (24). The 40% recoverable level is the minimum level for economic viability. Overall economics of the PFI system have been improved by further developments relative to the addition of filler recovery processes (25).

Use of fractionation system helps to recover filler. Most systems, for which pilot- or full-scale data are available, have employed a thermal oxidation technique for destroying the organic fraction of the sludge to yield filler in the form of ash (26). Experiments with calcination systems have showed that controlling the kiln temperature 816-843°C helps to avoid formation of fused agglomerates, which can cause the recovered filler to be excessively abrasive. Wet air oxidation method can be also used to recover filler materials from sludge. This process is capable of reducing sludge volume through oxidation of the organic fraction to yield an ash composed of inert materials, e.g., filler clay, titanium dioxide and calcium carbonate for reuse in the papermaking process. Both pilot- and full-scale systems have demonstrated some problems with low brightness of the recovered filler. Full-

Table 7 Advantages of paper mill sludge over other raw materials for ethanol production

Paper sludge consists of carbohydrate materials in the form of very fine fibres. These fibres have high specific surfacearea and lignin is present in very low amount.
The sourcing of sludge is easy at practically no cost because it is produced at a concentrated site and permanent production location.
The use of sludge for ethanol diverts material going to landfills. This avoids transportation costs and landfill investments.

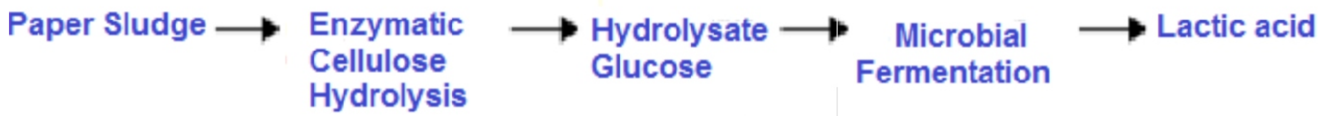

Figure 1 Scheme for production of lactic acid from paper sludge

scale studies indicate that the use of 28 bdt/d of waste primary sludge mill save $455,000/year on wood costs and $130,000/year on electricity costs. Another method of recovering filler clay from paper mill sludge has been reported by Ellis and Fenchel (27).

Kaolin clay and calcium carbonate (grounded or precipitated) are used in fillers and coating pigments (28). Also, talc (magnesium silicates) and titanium dioxide can be used. A study showed that calcium carbonate was removed more readily than kaolin in the flotation step, its reduction being two times higher than clay (29). As stated earlier, wet air oxidation method has been used for filler recovery but problems have occurred with brightness of the recovered fillers. The process has been anyway practiced in some mills in the United States to reduce the sludge volume (26)

Paper and board manufacture

Several industrial products have been produced from solid waste of pulp and paper mills. The industrial reutilization possibilities can be divided into two categories ones requiring high inorganic content and a minimum amount of organic compounds, the other ones benefiting from high fibre and low inorganic content of sludge. The most widely researched non-conventional management alternative has been the reuse of primary sludge as feedstock in the manufacture of hardboard, fibreboard, and building materials such as cement, bricks, and concrete.

Some efforts have been made to use paper mill sludge for value-added products, such as gypsum ***fibreboards*** or fibreboard additives (30). Types of fibreboard include particleboard, medium-density fibreboard, and hardboard.

Moulded pulp products have been produced since the early 1940's. Egg trays were the first product manufactured, but the range of products manufactured has increased since that time, to include fruit trays, simple containers, furniture corner protectors, industrial product packaging/partitions, and disposable products for catering and hospital applications. New techniques for producing smooth surfaces, precise shapes and dimensions have been developed by the introduction of the thermoforming process.

Millboard is also manufactured from 100% recycled fibre. It is a generic term referring to various high density and thickness board products. The product ranges in grammage from 1000 up to 5000 gsm, and is used in the automobile industry, shoe industry, furniture, luggage and leather products, and in the packaging and stationery industries. This type of use requires high fibre content and low ash content to guarantee wanted caliper (31). Millboard is a very hard board with high density and is manufactured by hard rolling (calendering) the semi-wet intermittent sheet on a solid board machine.

Softboard is primarily used for pin boards, and construction applications including insulation and fireproof applications. The raw material consists ideally of short fibres and has ash content below 10 % for optimal thickness. Soft board is produced from a thick wet pulp blanket, which passes through a high intensity press and a drying tunnel.

Production of ethanol

The idea of converting paper industry sludge to ethanol has been extensively studied in the past decades (32). Deinking sludge is not suitable for bioconversion due to the low content of cellulose fibres associated to the papermaking process. The advantages of paper mill sludge over other lignocellulosic raw materials for ethanol are presented in Table 7. Researchers at North Carolina State University (NCSU) have been developing novel conversion process to convert paper sludge into ethanol (33). The focus has been on low capital investment, operating costs and environmental impact.

Polysaccharides in recycled paper sludge are much more amenable to enzymatic hydrolysis, in comparison to raw wood or plant material because industrial paper sludge has already been subjected to an extensive mechanical and chemical processing. This process avoids costly pretreatments to make paper industry sludge more accessible to enzymes. Recycled paper sludge is basically made up of secondary poor-quality non-recyclable paper fibres. It is believed to be one of the most promising feedstock for near-term commercial application of technology for converting cellulosic raw materials into commodity products. (34, 35). In fact, this substrate has some distinctive advantages among cellulosic feedstocks including negative cost at many locations and the potential availability of pre-existing facilities.

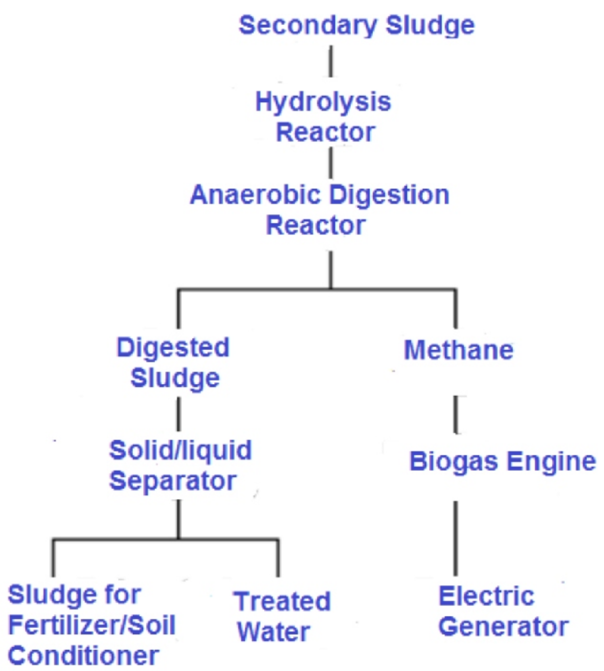

Fig 2 Anaerobic digestion of secondary sludge for biogas production

Production of lactic acid

Though limited in availability, paper sludge is more promising for such bioconversion processes as compared to other lignocellulosic biomass because it has already undergone processing and thus no pretreatment is required. This makes it an attractive point-of-entry and proving ground for commercial processes featuring enzymatic hydrolysis of cellulose (34, 36). It has been found to be a suitable substrate for lactic acid production (35, 37, 38). In comparison with alternative feedstocks, paper mill sludge shows several advantages, including; high enzymatic digestibility due to its low lignin content and very small particle size, high protein content (from secondary sludge), negative cost and environmental benefit due to the reduction of waste volume.

Lactic acid is manufactured either using a chemical or a biochemical route. The biochemical process involves fermentation of sugars such as glucose and lactose (39) using appropriate microorganisms. Figure 1 shows the scheme for production of lactic acid from paper sludge. The enzymatic hydrolysis and fermentation steps for lactic acid production can be performed as SHF or SSF. The SSF process offers various advantages over SHF such as the use of a single-reaction vessel for both steps (allowing process integration with the consequent reduction on capital cost), rapid processing time, reduced end-product inhibition of hydrolysis and increased productivity (40).

Production of lactic acid from paper sludge was studied by Budhavaram and Fan (41) using thermophilic *Bacillus coagulan* strains 36D1 and P4-102B. More than 80% of lactic acid yield and more than 87% of cellulose conversion were achieved using both strains without any pH control due to the buffering effect of calcium carbonate in paper sludge. The average lactic acid concentrations produced using semi-continuous SSCF was 77.0-77.5 g/L from 100 g/L cellulose equivalent and yields were 72-75% with the productivities of 0.82-0.96 g/L/h. *B. coagulan* strains 36D1 and P4-102B are promising for converting paper sludge to lactic acid via SSCF.

Animal feed

There are two basic techniques for using sludges in animal feed. One is to incorporate sludge directly into animal feed mixtures. This method exploits the presence of carbohydrates, which are primarily in the form of cellulose and other nutrients present in primary or combined sludges. Hardwood pulp residues tend to be more digestible than softwood residues *(42).*

The cellulosic component of sludges is available directly to ruminant animals such as cattle, but the digestibility is impaired by the presence of lignin and mineral matter. Conversion of mill sludge's cellulosic components to single cell protein can be achieved by a range of bacteria and fungi, but the overall yield is often low (around 25%) after a high incubation period (about one day). The product has shown to be reasonably digestible, but the economics are very sensitive to the fluctuating price of alternative protein sources. One mill in USA installed a process to convert secondary sludge into a saleable protein product for use in animal feed *(43, 44).*

Biochar production

Biochar is carbon-rich product. It is produced by thermal decomposition of organic materials under limited supply of oxygen, and relatively low temperature (700 ^{0}C), a process mirror the ancient production of charcoal. Biochar is often alkaline, so can have liming value. Biochars from materials such as paper mill sludge have a high content of minerals

(45), which can be a valuable nutrient source. Biochar appears to be a viable option for sequestering carbon in soil (46). It is also being considered as a soil amendment, adsorbent and fertilizer. Conversion of paper mill wastes into biochar through slow pyrolysis has several environmental advantages. The thermal processing of wastes into biochar has been identified as an opportunity to destroy contaminants (47). This makes beneficial land application possible.

A risk analysis was performed to study the bioavalability and eco-toxicity of heavy metals in biochar obtained from pyrolysis of sludge of a paper mill effluent treatment plant (48**).** It was observed that the leaching potential of heavy metals decreased after pyrolysis and the best results were obtained for biochar pyrolyzed at 700^{0}C. Pyrolysis is a promising sludge treatment method for heavy metals immobilization resulting in reduced eco-toxicity of the heavy metals after the pyrolysis and so the decrease in the environmental risk of biochar utilization.

Anaerobic digestion

Anaerobic digestion is biological decomposition of biodegradable materials resulting in methane and carbon dioxide production. The microbiology of anaerobic digestion is complicated and involves several bacterial groups forming a complex interdependent food web. The methane in biogas can be burned to produce both heat and electricity, usually with a reciprocating engine or microturbine often in a cogeneration arrangement where the electricity and waste heat generated are used to warm the digester or to heat the buildings. Thermophilic anaerobic digestion (at 55 ^{0}C) is generally more efficient in terms of organic matter removal and methane production than the mesophilic process (37 ^{0}C). Figure 2 shows the flow diagram of anaerobic digestion.

The treatment of deinking sludge by anaerobic digestion is quite questionable because of its high inorganic content. The major problem of anaerobic digestion of WWTS generated at paper mill is long residence time of sludge in the digester (20-30 days). However, modern sludge preconditioning methods allow shortening of the residence time to only 7 days. These pretreatment technologies include: untrasound treatment, thermal treatment, ozone treatment, mechanical degradation, etc. These methods are aimed at destruction of cellulose walls in order to make them easily degradable (49).

The biomethane potential of Swedish paper mill sludge has mostly been focused on biosludge, whereas the focus in other countries has been mainly on primary sludge (50). To improve the nutrient status of anaerobic digestion of pulp and paper mill sludge, several researchers have studied co-digestion with a nutrient rich waste material. Lin et al. (51) used co-digestion of pulp mill sludge and monosodium glutamate waste liquor to successfully eliminate the nitrogen deficiency problem. Berg et al. (52) presented a preliminary investigation of anaerobic co-digestion of bio-sludge with a large number of co-substrates, including cows manure. Municipal sewage sludge is an especially suitable co-substrate as it is rich in nitrogen and other required macro- and micro-nutrients.

A Canadian paper mill located in British Columbia has recently installed a high pressure cell disrupter named MicroSludge to breakdown bacteria's tough cell walls of activated sludge followed by anaerobic reactor to produce biogas (53). In fact, biogas synthesis is the only economical viable method to produce biofuels from activated sludges.

Mineral based products

Reuse possibilities of deinking sludge and other recovered paper residuals depends on the composition of inorganic compounds. Common inorganics in deinking sludge are calcium carbonate and clay. In the combustion ash of deinking sludge, calcium oxide and sintered clay are primary components. Generally, three methods have been used to use (paper mill) sludge in building material industry. One of these is the sludge use as a feedstock to cement kiln. Another option is to use sludge in cementitious composites, where the use of organic fibres would increase the durability of the product and reduce cracking related to shrinking. From the studies it was concluded that combining Portland cement with deinking sludge could contribute to a composite material suitable for building blocks, wallboards, panels, etc. Use of sludge in the production of lightweight aggregate was also studied (26). In the reference document of Best Available Technology (BAT) for pulp and paper industry (54), it has been proposed to use sludge in cement industry, brick production, building industry, as well as for road construction. In addition to the options mentioned, following options seem to be possible: building board, glass or lightweight aggregate. Fire resistant products manufacturing with sludge is also possible. However, the selection of a real option is influenced by a number of factors (26).

Following options of producing different products/ applications of paper sludge are: (i) cement and cementitious products as potential ingredient (in the cement kiln, contributing calcium, silica and alumina; the manufacture of blended cements), (ii) cement mortor products (based on organic filling material, produced from formation and solidification of mixture consisting of Portland cement, deinking sludge, chemical additives and water), (ii) pozzolanic material or simply pozzolan defined as: "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compound possessing cementitious properties", (iv) concrete (part of the cement replaced by waste paper sludge (v) ceramic material (deinking sludge in producing ceramic material/ ceramic bricks made of clay and deinking sludge), (vi) lightweight aggregates (using deinking sludge and cement), (vii) plasterboard (sludge as additive in gypsym), and (viii) insulating material (thermal and acoustic thermal conductivity lower than 0.055 W/m^2K).

Other applications

The use of paper mill sludge as a paper and ***wood adhesive*** is an interesting concept (55). Secondary sludge alone displayed adhesive properties with 0.87 MPa dry shear strength of panels with phenol formaldehyde, but primary sludge alone did not exhibit much bond strength. Recovered sludge protein was found to be compatible to formulate hybrid adhesive blends with formaldehyde and bio-based polymers.

Wastewater treatment sludges have been used as raw material in ***industrial absorbents***, which are available in the market. A Wisconsin company named Thermo Fibregen had developed a system to recover long fibres and extract water from sludge to use the fibres in papermaking and the material of short fibres and fillers were used as oil and grease absorbents, cat litter and granules. As the short fibre materials are highly exposed and have very large surface area, its absorption capacity is very high. The paper mill sludge can also be indirectly used as an ***active adsorbent*** by converting it into activated carbon.

Edalatmanesh (56) studied the use of pulp and paper mill sludge as renewable and cost-cutting ***filler in the composite***. The results of mechanical strength tests showed that a 10% secondary sludge content does not lead to any significant deterioration of either tensile or flexural strengths. Therefore, it was concluded that the secondary sludge may be used as filler to reduce the cost while maintaining the mechanical properties of Nylon.

Significant progress has been made in the use of paper mill sludge as a material for ***land fill cover*** by replacing the clays or geo-composites (57). Several countries within the European Union (Finland, Sweden, etc.), as well as Canada, the United Stated and South Africa are investigating the possibility of implementing paper sludge as the hydraulic barrier material in landfill cover systems. Paper mill sludge behaves similar to a highly organic soil and has good chemical, hydrodynamic and geotechnical properties which make it an efficient impermeable hydrodynamic barrier for the land field cover.

Production of ***nanocellulos***e from paper mill sludge seems to be a great opportunity, because this sludge is already partially bleached, therefore it is interesting to use it as raw material due to its features, very less lignin, hemicellulose and other low molecular weight components, in a way to isolate the pure cellulose. Leao et al. (58) reported the successful isolation of nanofibrils from primary sludge by steam coupled acid treatment. . The addition of only 4 wt% cellulose nanocrystals, obtained polyurethane nanocomposite with tensile strength of 45.6±1.4 MPa and modulus of 152.63±1.3. The developed nanocellulose and its composites confirmed to be a very versatile material having the wide range of biomedical applications and biotechnological applications.

Paper mill sludge, is a good material in ***asphalt road pavement*** work. The fibres from paper mill sludge can withstand harsh processing, including high temperature for mixing with asphalt, as shown by the presence of fibres that were recovered after extraction (reported the Los Baños-based Department of Science and Technology Forest Products R and D Institute (DOST-FPRDI). Recycled fibre can be used in bitumen modifiers to achieve better properties for ***road surfacing materials*** (31,59). The fibre additive is known to reduce noise, and provide enhanced binding, elasticity and durability to the pavements.

Indian Practices

As the dewatering of secondary sludge is very difficult due to its slimy nature, the excess secondary sludge from the activated sludge process is mixed with the primary sludge to facilitate dewatering. A small portion of the ETP sludge from few mills is sold to low grade board manufacturing. Recently, few mills like Emami Paper Mill have started using primary sludge in the power boiler to realize its heating value (60).

The secondary sludge is rich in nitrogen and other nutrients.

Few mills have started using it, in combination with other substrates like wheat straw wash water, in the anaerobic digester to produce methane and utilizing it as a fuel (Setia Paper personal communication). Other mills are also planning to use secondary sludge in anaerobic digester as its dewatering is not required in this application.

As far as deinking sludge is concerned, it contains appreciable proportion of inorganic compounds. It is considered to be hazardous due to presence of ink containing heavy metals and other toxic components. It needs to be disposed off with due caution. However, following options are available to utilize it in an environmentally friendly way: producing cementitious products, cement motor, pozzolanic material, concrete, ceramic material, lightweight aggregates, etc. In these applications, the heavy metals and other toxic components get stabilized/ immobilized for ever with the mineral based products. This application has not picked up in India but it is one of the best options to make use of deinking sludge. Only a few mills have used it once in a while in the pavements etc. in the mill itself.

Conclusions

There are good prospects for recovering usable fibre and fillers from paper sludges in papermaking, and, therefore, this area warrants further assessment for sludge from a variety of different mills and product lines. Wet air oxidation processes have been extensively examined in this regard, but have not been adopted widely due to costs. In light of current economic and environmental circumstances, it needs to be reevaluated. High-value product nanocellulose can be prepared, from the primary sludge, which has been found to improve the strength of polyurethane nanocomposite with tensile strength of 45.6 MPa and modulus of 152.6 by adding only 4wt%. The use of deinking sludge in cementitious product applications warrants considerable attention. Initial bench-scale testing is required for some of the prospective applications; pilot studies are required for many of them to establish the practical and technical feasibility of each sludge use option.

References

1. Mahmood T, Elliott A (2006) A review of secondary sludge reduction technologies for the pulp and paper industry. Water Research 40: 2093-2112

2. Xu C, Lancaster J (2008) Conversion of secondary pulp/paper sludge powder to liquid oil products for energy recovery by direct liquefaction in hot-compressed water. Water Research 42: 1571-1582

3. Xu C, Lancaster J (2009) Xu C, Lancaster J (2009) Treatment of secondary pulp/paper sludge for energy recovery. In: Dubois E, Nercier A (Eds) Energy Recovery, Nova Science Publishers Inc., New York, pp 187-212

4. Monte MC, Fuente E, Blanco A, Negro C (2009) Waste management from pulp and paper production in the European Union. Waste management, January, 29(1): 293-308

5. Gavrilescu D (2005) Sources of solid wastes in pulp mills, Bulletin of Polytechnic Institute of Iasi (Buletinul Institutului Politehnic din Iasi), LI (LV), 99 105

6. Balwaik SA, Raut SP (2011) Utilization of waste paper pulp by partial replacement of cement in concrete. International Journal of Engineering Research and Applications 1(2): 300-309

7. Glenn J (1997) Paper Mill Sludge: Feedstock for tomorrow. BioCycle [magazine] 38 (11). Available through: ABI/INFORM Global database. [Accessed 20 October 2011]

8. Kay M (2002) Development of waste management options for paper sludge. 4th Annual Dutch International Paper and Board Technology Event. Pira International

9. Scott GM, Smith A (1995) Sludge characteristics and disposal alternatives for the pulp and paper industry. In: Procedings of the 1995 International Environmental Conference, Tappi Press, pp.269-279

10. Joyce TW, Webb AA, Dugal HS (1979) Quality and composition of pulp and paper mill primary sludge. Resource Recovery Conserve. 4: 99-103

11. Ramalho RS (1983) Introduction to Wastewater Treatment Processes. 2nd ed. Academic Press, California, ISBN 0-12-576560-6

12. Bajpai P, Bajpai PK, Kondo R (1999) Biotechnology for Environmental Protection in Pulp and Paper Industry, Springer, Berlin, pp 209-238, Chapter 10

13. Bajpai P (2006) Advances in Recycling and Deinking, Smithers Pira, Shrewsbury

14. Bajpai P (2013) Recycling and Deinking of Recovered

Paper, Elsevier Science, Amesterdam

15. Deviatkin I (2013) Wastewater treatment and deinking sludge utilization possibilities for energy and material recovery in the Leningrad region. Master's thesis Lappeenranta University of Technology

16. Gavrilescu D (2008) Energy from biomass. In: Pulp and Paper Mills, Environmental Engineering and Management Journal September/October 2008: 17(5): 537-546

17. Frederick J, Iisa K, Lundy JR, O' Connor WK, Reis K, Scott AT, Sinquefield SA, Sricharoenchaikul V, Van Vooren CA (1996) Energy and materials recovery from recycled paper sludge. Tappi Journal, 79 (6): 123-131.

18. US-EPA (2012) Technology Assessment Report on Aqueous Sludge Gasification Technologies EPA/600/R-12/540 June 2012

19. Nissen WR (2002) Combustion and Incineration Processes, 3rd edn. Marcel Deller, New York

20. CEPI (2011). Maximum value from paper for recycling, towards a multi - product paper mill. www.paperforrecycling.edu/uploads/Modules//REC-05410final.pdf

21. Hamm U (2006) Environmental aspects. In: Handbook of Paper and Board, Holik H. (ed.), Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, p. 422-445

22. NCASI (1993) Alternative management of pulp and paper industry solid wastes. NCASI Tech Bull. 655

23. Moss, CS, Johnstone J (1993) Fibre recovery from paper-mill sludge at Ponderosa Pulp Products - Oshkosh, Wisconsin. Proc. Environ. Conf. (Book I), Tappi Press, p28.

24. Ferguson KH (1992) Prime fibre recycles laser-inked waste with chemical/mechanical technologies. Pulp and Paper. 57(Dec): 64

25. Maxham JV (1992) Conversion of pulp and paper mill waste solids into pulp substitute and papermaking clay. NSF SBIR Phase II Final Report, Grant #-ISI 8920723

26. Weigand PS, Unwin JP (1994) Alternative management of pulp and paper industry solid wastes. Tappi J. 77(4): 91-97

27. Ellis EG, Fenchel U (1980) Disposing of paper mill sludge and recovering filler clay. Indust. Waste 26(2): 12

28. Omya AG (2011) [internetsite]. Available at: http://www.omya.com

\

29. Krigstin S, Sain M (2006) Characterization and potential utilization of recycled paper mill sludge. Pulp and paper Canada, 107 (5): 29-32

30. Davis E, Shaler SM, Goodell B (2003) The incorporation of paper deinking sludge into fibreboard. Forest Products Journal. 53(11/12) 46-54

31. Rothwell A, Éclair-Heath G (2007) A new approach to paper mill sludge. Oxon: Waste and Resources Action Programme.

32. Prasetyo J, Park EY (2013). Waste paper sludge as a potential biomass for bio-ethanol production. Korean J. Chem. Eng.: 30(2), 253-261

33. Gonzalez R (2012) Ethanol Production from Paper Industry Sludge Examined. Ethanol Producer Magazine, October, 05 www.ethanolproducer.com/.../ethanol-production-from-paper-industry-s

34. Fan Z, Lynd LR (2006) Conversion of paper sludge to ethanol. I: Impact of feeding frequency and mixing energy characterization. Bioprocess and Biosyst Eng. 30:27-34

35. Marques S, Alves L, Roseiro JC and Girio MS (2008) Conversion of recycled paper sludge to ethanol by SHF and SSF using Pichia stipitis. Biomass Bioenergy 32:400-406

36. Yonghong F, Yingge Y, Zhiming Z, Wen L, Peng W, Liming Y, Zengliang Y (2008) Enhancement of L(+)-lactic acid production of immobilized Rhizopus oryzae implanted by ion beams. Plasma Sci Technol. 10:136-40

37. Nakasaki K, Akakura N, Adachi T, Akiyama T (1999) Use of wastewater sludge as a raw material for production of L-lactic acid. Environ Sci. Technol. 33:198-200

38. Lee SM (2005) Production of Lactic Acid from Paper Sludge Using Integrated Biological Process, Ph.D. Thesis 2005

39. Vadlani PV, Matthews AP and Karr GS (2008) A two-

stage fermentation process: production of propionate and acetate salt as road deicer from cheese whey. Bioeng: 1(1): 95-104

40. Sreenath HK, Moldes AB, Koegel RG, Straub RJ (2001) Lactic acid production by simultaneous saccharification and fermentation of alfalfa fibre, J. Biosci. Bioeng. 92: 518523

41. Budhavaram NK, Fan Z (2009). Production of lactic acid from paper sludge using acid-tolerant, thermophilic Bacillus coagulan strains. Bioresource Technology 100(23): 5966-5972

42. Millet MA, Baker AJ, Satter LD, McGovern JN, Dinius DA (1973) Pulp and paper making residues as feedstuffs for ruminants. J. Animal Sci. 37(2): 599-607

43. Rogers DS (1982) Conversion of waste activated sludge to animal feed. In: Symposium on Long Range Disposal Alternatives for Pulp and Paper Sludges Proceedings, University of Maine, Orono, p. 104.

44. Evans JC (1983) Rayonier produces animal feed from secondary sludge at sulfite mill. Pulp and Paper 57(3): 124-6 (March 1983).

45. Singh B, Singh BP, Cowie AL (2010) Characterization and evaluation of biochars for their application as a soil amendment. Aust. J. Res. 48: 516-525

46. Lehmann J, Joseph S (2009) Biochar for Environmental Management: An Introduction. In: Lehmann, J., Joseph, S. (Eds.), Biochar for Environmental Management: Science and Technology. Earthscan, London

47. Glover M (2009) Taking biochar to market: some essential concepts for commercial success. In: Lehmann J, Joseph S (eds) Biochar for environmental management. Earthscan Publications Ltd. ISBN: 9781844076581, pp 375392

48. Devi P, Saroha. AK (2014) Risk analysis of pyrolyzed biochar made from paper mill effluent treatment plant sludge for bioavailability and eco-toxicity of heavy metals Bioresource Technology 162: 308315

49. Allan E, Talat M (2007) Pretreatment technologies for advancing anaerobic digestion of pulp and paper biotreatment residues. Water Research, 41(19): 4273-4286

50. Yunqin L, Dehan W, Lishang W (2010) Biological pretreatment enhances biogas production in the anaerobic digestion of pulp and paper sludge. Waste Management and Research 28: 800-810.

51. Lin Y, Wang D, Li Q, Xiao M (2011) Mesophilic batch anaerobic co-digestion of pulp & paper sludge and monosodium glutamate waste liquor for methane production in a bench-scale digester Bioresource Technology 102 (4): 36733678

52. Berg A, Karlsson A, Jörgen E, Fredrik N (2011). Utvärdering av samrötningspotential för bioslam från massa-/pappersbruk. Skogsindustriella programmet 1175. Värmeforsk.

53. Caulfield, P (2012) Unlocking the value in sludge. Pulp and Paper Canada, May/June issue, 18-19

54. European Commission (2001) Integrated Pollution Prevention and Control (IPPC). Reference Document on Best Available Techniques in the Pulp and Paper Industry. Institute for Prospective Technological Studies: Seville

55. Likon M, Černec F, Svegl F, Saarela J, Zimmie TF (2011) Paper mill industrial waste as a sustainable source for high efficiency absorbent production. Waste Management 6(31): 1350-1356

56. Edalatmanesh M, Sain M, Steven N. Liss SN (2012) Enzymatic modification of secondary sludge by lipase and laccase to improve the nylon/sludge composite properties. Journal of Reinforced Plastics and Composites 3(3):179-188

57. Van Ham M, Dampier L, Morton K, Mullen S (2009) Pulp and paper sludge as a barrier layer in landfill closure: A new opportunity. Pulp and Paper Canda, April 2009: T42-44. Paper presented at the 2008 PACWEST Conference in Jasper, Alta., June18-21, 2008.

58. Leao AI, Cherian BM, Ferreira de Souza S, Sain M, Narine S, Cadeira MS, Toledo MAS (2012) Use of primary sludge from pulp and paper mills for nanocomposites. Mol. Cryst Liq Cryst 556(1): 254-263

59. Mari EM, Moran MSR, Austria CO (2009) Paper mill sludge as fibre additive for asphalt road pavement. Philipp J. Sci 138(1): 29-36

60. Khuntia RC, Maheswari HK, Choudhury KR, Nair MBS (2015) Optimization of energy and chemicals with increase in usage of indigenous waste paper and closure of water circuit. Paper India 18(3): 4,6,8,10,12,14