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The Conversion of Paper Mill Sludge into Absorbent for Oil Spill Sanitation – The Life Cycle Assessment

Marko Likon,[*1] *Juko Saarela*[2]

Summary: A production of a sorbent material from papermill sludge positively effects the environment instead of landfilling it and replacing an expanded polypropylene absorbent with papermill sludge sorbent for oil spill sanitations. The life cycle's assessment study shows a reduction of carbon footprint for more than 14 times and reduction of water consumption for 372 kg, based on the production of sorbent material for cleaning 1,000 kg of oil spill.A conversion of the papermill sludge into sorbent material prolongs paper products' life cycle for additional two cycles. A controlled incineration converts the used sorbent into inert meta-kaolin product which can be further used as hydrophilic sorbent material. In this way the papermill sludge's life cycle is efficiently closed.

Keywords: absorbent; LCA; papermill sludge; recycling; waste

Introduction

Usuallyoil sorbent materials serve as cleaning agents for sanitation of negative environmental impacts. Commercially available oil absorbents are non-biodegradable synthetic organic products (e.g. polypropylene and polyurethane) and may cause serious disposal problems after they have been used.In many cases they are replaced with easily accessible and cheap materials, which can be used for the same purpose. These materials include natural or agricultural products such as rice, oat, wheat or flax straw, different hays, bagasse, cottonseed hulls, corn cobs and peat moss.[1–4] Industrial and public services dealing with possibility of oil spill accidents are obligated to have sorbent materials with the exact knowledge of their behavior in the case of their use. Usually they use synthetic absorbents because of their storage stability and exact sorbent specifications. But on the other hand, industrial and public bodies have to be sustainable. Furthermore, any use of these materials without deep knowledge of their origin can be questionable, that is because the whole life cycle, including production, usage and disposal must be taken into an account. From this point of view the life cycle assessment (LCA) can be valuable tool for comparing different sorbent materials.

Many materials have excellent sorbent characteristics. Among them are wasted natural fibers or industrial by products generated through different industrial processes and which are treated as a waste.The industrial symbiosis theory defines undeliberately produced material as by-products or valuable raw materials that can be exploited in other industrial branches. Paper industry is in many countries a strategic industry but at the same time paper production consumes high amounts of energy, chemicals and wood pulp. Consequently, paper industry produces high amounts of emissions into the environment mainly as carbon dioxide due to energy consumption and as papermill sludge (PMS) due to waste water treatment processes. The pulp and paper industry produce over 304 million tons of paper per year. Global production of the pulp and

[1] Insol Ltd., Cankarjeva 16a, 6230 Postojna, Slovenia
Fax: (+386) 59 959047;
E-mail: marko.likon@telemach.net
[2] SYKE Finnish Environment Institute, Mechelininkatu 34a, Helsinki, Finland

paper industry is expected to increase by 77% until 2020 andat the same time over 66% of paper will be recycled by then.[5] The majority of the generated waste from paper production and recycling is papermill sludge (PMS), which production can be up to 28.4% on a unit of produced paper. The countries joined in organization CEPI themselves produce more than 4.7 million tons of PMS per year[6]which presents an enormous environmental burden because more than 70% of generated PMS is landfilled.[7]

PMS consists as a mixture of short cellulosic fibers and inorganic fillers, such as calcium carbonate and china clay, and residual chemicals dissolved in the water. Characteristics of PMS vary depending on pulp and paper mill processes. Produced sludge can be considered to fall into two main types: high-ash sludge (> 30% dry weight) and low-ash sludge (< 30% dry weight). Due to a high organic content the landfilled PMS is a subject of aerobic and anaerobic decay. Theoretically, when landfilling 1 ton of low-ash PMS approximately 2.69 tons of CO_2 and 0.24 ton of $CH_4$is released into the environment.[8]

In practice, approx. 20% of PMS is incinerated on the site due to energy recovery, but economy of incineration is questionable because PMS contains 30 to 50% of water and only 30 to 50% of cellulosic fibers calculated on dry solids. On the other hand PMS is very interesting composite material which can be used as a sustainable raw material for different applications. A big progress has been done in using paper mill sludge as land field cover material by replacing the clays or geocomposites. PMS behaves like a highly organic soil and has good chemical, hydrodynamic and geotechnical properties which make it efficient impermeable hydrodynamic barrier for the sanitary land field cover.[9] More than 21 different studies have been carried out in 2009 in using PMS as a landfill body.[10] The characteristics of PMS have been exploited also as road bed construction for the non-heavy loaded roads and tennis courts.[11]

According to modern industrial trends on eco symbiosis the economic efficiency is a key factor on planning modern technological processes. This includes decreasing waste streams during production and use of produced waste as by-products or raw materials with higher added values.

As can be seen from Figure 1 PMS is chemically and physically complex material that can be usefully used in different industrial branches. One of the promising utilization is the use of PMS as heat insulation material with thermal conductivity factor lower than 0.055 $W/m^2 K$ which is comparable to insulation materials available on the market today.PMS which contains a high part of inorganic fractions can be utilized in the production of building materials.[12] Due to its combustion matrix, it can be used as valuable raw material in brick and cement production industry.[13–15]

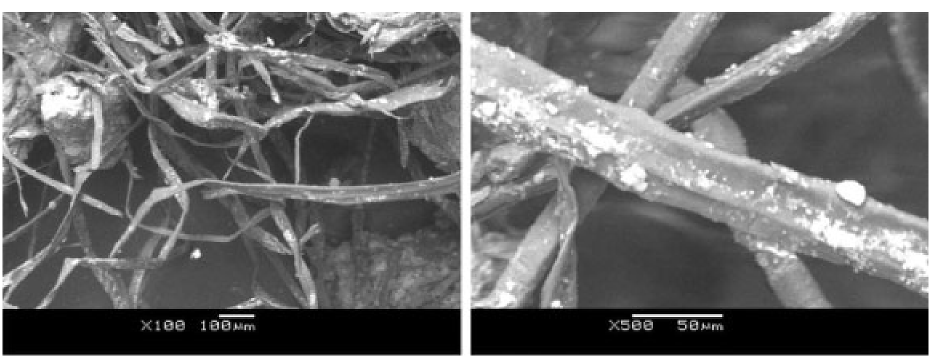

Figure 1.
SEM image show complex structure of PMS (cellulose fibers and kaolin).

PMS with its high organic content has an energy content that makes it an efficient alternative fuel in the production of Portland cement. According to the Cembureau classification of alternative fuels it is currently classified as liquid alternative fuel.[16] The US company Minergy has implemented technology for incineration of PMS under controlled condition and the product of incineration is a highly efficient water absorbent composed of meta-kaoline granules. The use of the PMS for paper and wood adhesive is an interesting idea which is under ongoing investigation.[17] Promising research has been conducted to use PMS as an sorbent material. The usageof PMS as a sorbent material is well documented, but currently the market is non receptive to such sorbent material due to cheap and efficient synthetic sorption materials. The results of research studies have shown that PMS can be indirectly used as an active absorbent by converting it into activated carbon[18] or it can be used directly as binding material forthe removal of heavy metals ions from water,[19–22], removal of phenols [23] and as an absorbent for hard surfaces cleaning.[24,25] A variety of the processes and different absorbent products have been developed from PMS used for commercial purposes.[26,27] However, modern industry faces frequent and serious oil spills and subsequently sanitation demands high costs for sorbent materials. Offering a cheap and efficient natural material such PMS could become a welcome solution.The CAPS (Conversion of papermill sludge into absorbent) is an eco-innovative solution in the 'market's uptake' phase, therefore prior to the expansion of industrialization in Slovenia and Finland. The CAPS process uses the surpluses of thermal energy which paper mills usually waste into the environment. In addition, CAPS uses paper mill waste as a secondary raw material and converts it into a high added value sorbent. The technology is relatively cheap, simple and easily replicable particularly in markets with developed paper industry. PMS is dried up to the point where it can be efficiently mechanically and/or chemically treated to release cellulosic fibers from its inorganic matrix. The humidity of the papermill sludge as a raw material is between 50 to 70%, whereas the content of cellulosic fibers is approx. 52%, the remainder is inorganic. After drying between 70–80% of solid content, PMS proceeds through special mechanical treatment (unraveling). This stage is crucial for the entire process due to the fact that in this section cellulose fibers are released from the inorganic matrix which allows material to float on the water surface (Figure 2 and 3).

A chemical treatment (esterification, silanization) is an option when higher sorption capacity and better floatability are required. Distributed (chemically prepared) paper mill sludge is dried at 130 °C to 150 °C until the humidity oscillates between 1% and 10% to get a final product with an active surface area of 36 m^2/g, a sorption capacity up to 8 oil/g PMS and the capability to float on the water surface.[28,29] The properties of PMS as oil sorbent

Figure 2.
Raw PMS (left), unraveled PMS (middle) and fluffed PMS (right).

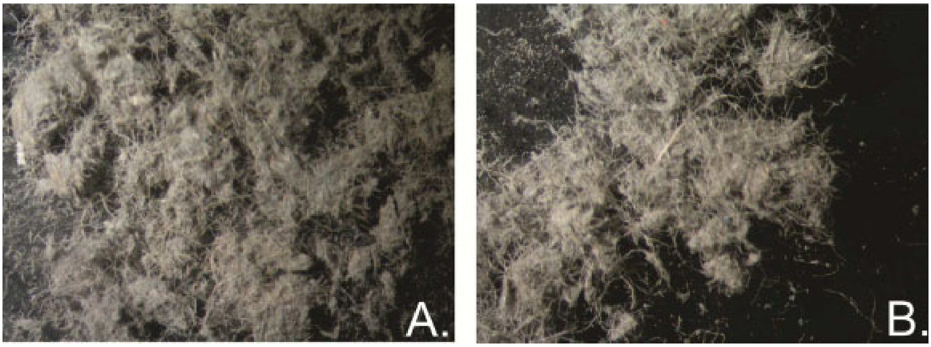

Figure 3.
Microscope pictures of raw PMS (A) and unraveled PMS (B) at 8 x magnification.

material have been extremely improved by mixing it with silanized cellulosic fibers.[30]

The produced natural sorbent may be used in oil, chemical, logistic and transport industry as well as in public bodies like fire brigades and in civil protection and disaster relief institutions. These institutions need an environmental, friendly, efficient, cheap and at the same time sustainable product for cleaning oil spills from water surfaces and/or for maintenance of oil separators. Produced sorbent has a calorific value of approximately 3.8 MJ/kg and an absorption capacity of up to 8 kg of oil per 1 kg of absorbent. A sorbent soaked by oil has a calorific value up to 33.5 MJ/kg and can be used as high quality fuel in co-generation processes. The incineration under controlled conditions leads to the conversion of a papermill sludge'skaolin part into a meta-kaolin substance in the form of vitrified granules. These vitrified granules can be used again as inert hydrophilic absorbent.

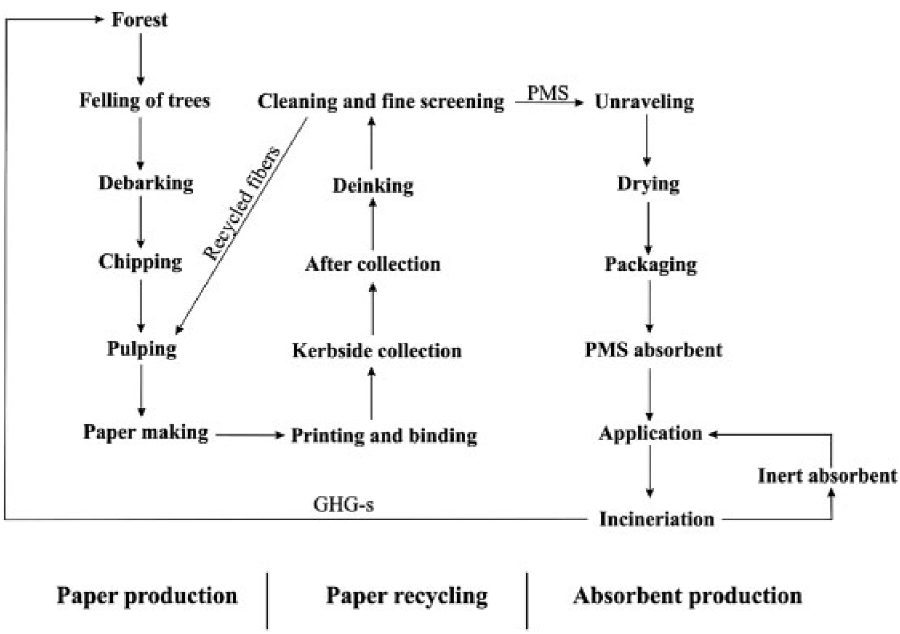

Figure 4.
LCA calculationmodel for production of PMS absorbent.

A sustainability of different sorbent materials for oil spill sanitation is questionable because the experts compare only their efficiency and price performance but they do not compare their environmental impact from cradle to grave. In present paper we are presenting life cycle assessments (LCA) of PMS sorbent versus expanded polypropylene sorbents which is a base for discussion about sustainability of using synthetic absorbents compared to sorbents which are produced from wasted materials.

Methods

Life cycle assessments (LCA) of PMS and expanded polypropylene were accomplished by using the BUWAL 250 database included in the software package SimaPro 7.1, and data from peer reviewed literature.[31–34] The data for the uncontrolled anaerobic decay were calculated according to Buswell and Mueller[35] and the data for energy production were calculated according to Martin et al.[36] Papermill sludge was considered as unwanted by-product in paper and cardboard recycling processes, that is without water and energy consumption and without GHG-s generation for its production. Expanded polypropylene (EPP) was considered as an absorbent produced from non-renewable raw materials (propene). The calculations were based on the quantity of the absorbent needed for the absorption of 1,000 kg of oil

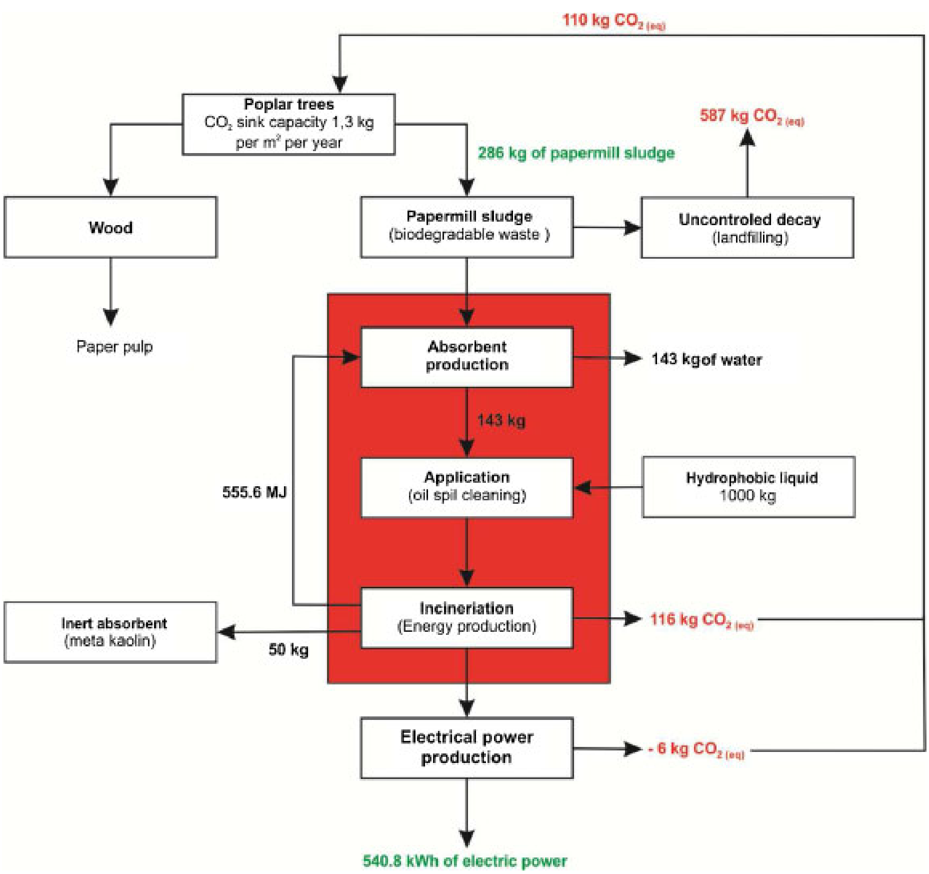

Figure 5.
Life cycle circle for conversion of PMS into absorbent material.

with the following presumptions: the sorption capacity of the absorbent produced from PMS and from EPP is 7 kg of oil/kg absorbent and 26 kg of oil/kg absorbent, respectively. It was considered that used absorbents were incinerated for energy recovery. Absorbed hydrophobic substances were not included in LCA calculations. The model for LCA calculation for PMS absorbent is shown in Figure 4.

Conclusion

As can be seen in Figure 5 and 6, the production and application of PMS as the sorbent for oil spill sanitation reduced carbon footprint for 2.75 times compared to the production and application of EPP.

Further on, if we would take into the consideration the production of absorbent instead of land filling PMS we could decrease carbon footprint for additional 5.25 times. The modern sustainable management of production processes should be based on the industrial ecology approach - its essential element is the eco-symbiosis theory.

The CAPS process for the conversion of PMS into absorbent which can be used for cleaning water surfaces fulfills all the above mentioned requirements. Even more, it includes also the surpluses of usingthermal energy that paper mills usually dispose into the environment. The results of this study have shown that LCA calculations offer a useful tool to estimate the sustainabilityof recycling processes.

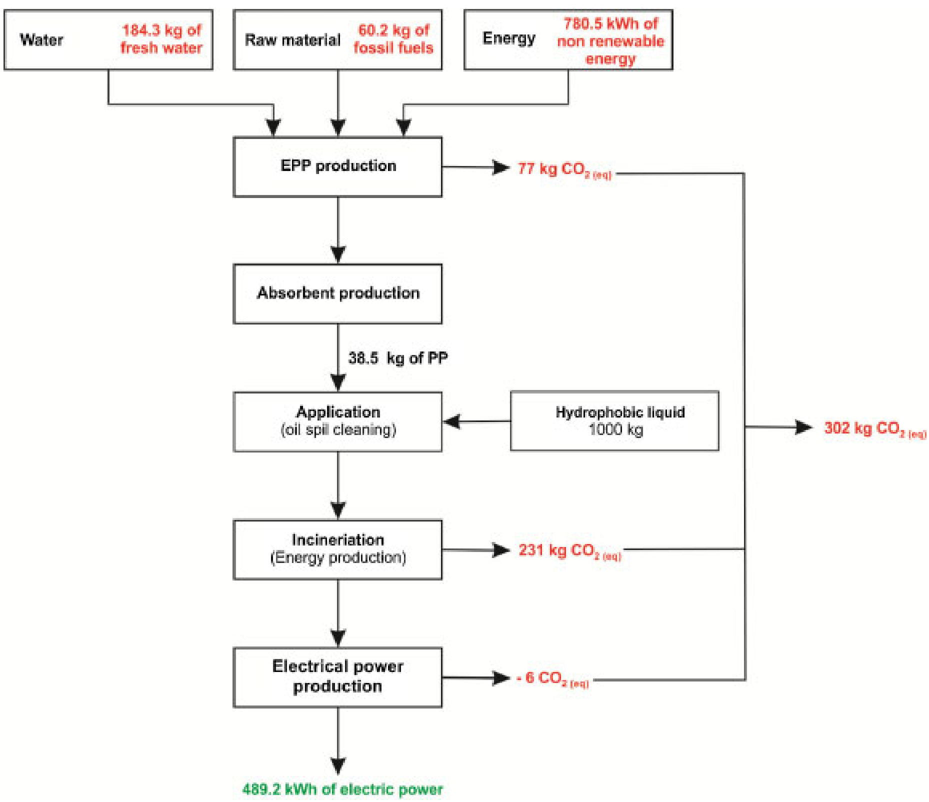

Figure 6.
Life cycle circle for production and application of the EPP absorbent.

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