Review of pre-treated peat applied in treating domestic wastewaters and oily waters

Xiao Jiang, Cynthia A. Coles and Emmanuel S. Asapo
Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador, Canada

ABSTRACT
Peat is commonly used as a combustible fuel for energy and as an addictive to soil in horticulture. For hundreds of years, peat was widely used as a green energy source for heating in the northern parts of Europe and North America. Nowadays, people tend to lay decomposed peat on lawns or gardens as a top layer because of its good water and nutrient retention capacity. Recent research shows a new application of peat as a cleaning filter due to its specific physical and chemical structure. This review paper attempts to summarize the current knowledge on the application of peat in removing contaminants from domestic wastewater, oil contaminated water and soil. This review covers mainly pretreatment of peat before applying it to a polluted area, some general approaches in removing oil and other impurities from wastewaters and contaminated waters and soil, the feasibility and further value of this new application and its use in relation to environmentally sustainable development.

RÉSUMÉ
La tourbe sert généralement de combustible producteur d'énergie et d'amendement au sol en horticulture. Depuis des centaines d'années la tourbe est utilisée partout comme source d'énergie verte pour le chauffage dans les régions du nord de l'Amérique et de l'Europe. Aujourd'hui, la tendance est de mettre une couche de tourbe décomposée sur les gazons ou les jardins car elle a une bonne capacité de rétention d'eau et de nutriments. Des études récentes ont démontré que la tourbe à une nouvelle application, filtre nettoyant, dû à sa structure physique et chimique particulière. Cette étude tente de résumer les connaissances actuelles sur l'utilisation de la tourbe comme décontaminant d'eau et de terre polluées. Cette étude décrit principalement le prétraitement de la tourbe avant son application dans un endroit pollué; quelques approches générales pour l'extraction du pétrole et d'autres impuretés venant d'eaux usées, d'eaux contaminées et de la terre; et la faisabilité et la valeur ajoutée de cette nouvelle application et son utilisation en relation au développement soutenable par l'environnement.

1. Introduction

Problems such as greenhouse gas emissions, shortage of water resources, and the increasing global population have caused public concern in recent years. For many, especially in developing countries, the environmental outlook is gloomy. Furthermore, contamination beneath the earth's surface, such as oil leakage into groundwater is more serious because it is hidden from sight and more likely to be neglected than surface contamination which is more obvious and generates public environmental action. To solve these environmental problems, certain clean-up procedures are necessary. Sustainable development has been demonstrated to be a practical option that could be regulated by federal, regional and municipal governments to limit environmental damage and to protect the environment for the benefit of future generations (Mihelcic et al., 2003). Generally speaking, how to balance finite natural resources with close to infinite consumption and pollution is a major challenge.

As a common commercial fertilizer, peat is widely applied to topsoil as it enhances soil moisture retention and nutrient value because of its high water absorption capacity, ion adsorption capacity and cation exchange capacity (Jyrki, 2003). In addition, peat has been used as a biogas or green combustible fuel for heating, especially where peat deposits are considerable and easy to exploit (Buivid et al., 1980). Recently, for heating purposes, alternative fuels composed of traditional fuels and peat have been used together to conserve both the fuel and peat resources and to help ensure more sustainable development (Heavey, 2003; Oren et al., 1990; Robertson, 1984). Depending on the natural resources of a particular region, combining fuels could dramatically save on transportation costs. In addition, the application of peat as a filter or natural sponge for cleaning up landfill leachate, domestic wastewater and oily contaminated water has been studied for several years and the results suggest that peat is efficient in removing contaminants from water (Cohen et al., 1991; Corley et al., 2006; Rizzuti et al., 1996; Suni et al., 2006; Viraraghaven and Mathavan, 1988 and 1990).

This paper will summarize and comment on the present application of peat in removing contaminants from wastewater and polluted soil and will compare clean-up procedures. The main focus is on clean-up procedures for domestic wastewaters and oil contaminated waters. In addition this paper includes a comparison between peat and other potential natural organic materials that may be used for wastewater treatment by filtering or absorbing impurities.

2. Pretreatments

Peat is highly organic, providing a substantial absorptive and ion exchange capacity, media for microorganisms, fibrous material for filtration, and a high water retention capacity (Frostman, 1995). Lee et al. (2001) indicated that peat contains a vast myriad of chemical species and groups including carboxylic acids, phenolic groups, ketones and alcohols. Based on specific chemical and physical reactions among contaminants and peat functional groups, reactions such as chelation, complexation and adsorption enable peat to act as an adsorbent or filter for removing heavy metals, hydrocarbons, BOD, COD and SS from contaminated water (Cohen et al., 1991)

Based on its specific physical and chemical properties, peat has been used for treating city wastewater and industrial wastewater with oil impurities for over 25 years. Over this period, various treatment processes have been developed to suit the end-use application (Perez et al., 2005). Before being used for wastewater treatment, peat is usually sieved, washed and dried, whether it is intended to be used as a filter or as an absorbent and sprinkled on the surface of the water (Couillard, 1994). The following paragraphs summarize some specific pretreatments that have been applied when peat is used for treating domestic wastewater containing large amounts of BOD, COD SS and fecal bacteria and in the clean-up of oil contaminated water and soil.

Pretreatment processes are necessary to remove components in peat that could interfere with the treatment mechanisms and these components may affect the main aim which is to obtain the optimum adsorption capacity of peat and retain the maximum amount of contaminants. Rizzuti et al. (1996) reported a specific pretreatment that applied irradiation to peat to enable it to effectively increase BTEX extraction from oily contaminated water. Their study hypothesized that the porous media of peat bio-barriers may become clogged by bio-gas and waste products of microorganisms and that irradiation could kill off certain quantities of microorganisms in peat that would otherwise interfere with the BTEX uptake. The improved results from the study conducted by Rizzuti et al. (1996) could have been due to the increase in number and size of pores and the provision of more filtering space for the wastewater treatment. Rizzuti et al. (1996) recommended a radiation dosage of 4.5 to 6.5 megarad. Although there was some uncertainty in the involvement of the microorganisms in removing the BTEX the authors suspected that this dosage was not able to kill all the microorganisms and that some of the microorganisms were involved in the BTEX removal. So far little research has been completed in the field of applying irradiation for the pretreatment of peat when followed by pollutant removal procedures, although using radiated peat for agricultural sterilization has been shown by Bartonicek and Pipota (1990) to be effective. They reported that peat irradiated with gamma rays of 60-Co or with 4 MeV electrons could effectively resist the growth and reproduction of harmful bacteria. However, no results from this study suggested that irradiation performed positively in removing contaminants from peat.

More common pretreatments involve the use of chemical and physical methods. Dewatering is an important step before applying peat to remove pollutants. To do this, polymers are added to the raw material to encourage aggregation of the peat particles into larger colloidal particles that are easier to dewater (Jonsson et al., 1987). The total cost increases since the polymers are expensive and another drawback is that the larger particles may have reduced adsorption efficiency because of their relatively decreased specific surface areas. Forsberg and Aldén (1989) reported that particles sizes and their distribution are the two governing factors when dewatering, irrespective of the botanical origin or the degree of humification of the peat.

Pretreatment of peat using phosphoric acid has been reported by Smith et al. (1976) to have improved the physical characteristics of peat and especially its swelling capacity. Smith et al. (1976) indicated that a polymerization reaction took place during the pre-treatment process. The pre-treated peat was used in flow through systems but the phosphoric acid treatment compromised the peat's cation exchange capacity.

Ringqvist et al. (1991) added a solution of hydrogen peroxide with ferrous ions to sphagnum peat to dewater it. The cost of treatment and its effect on peat's filtration capacity were comparable to using polymers.

However, hydrogen peroxide played another important role in pre-treating peat for bioremediation when Goi et al. (2006) applied hydrogen peroxide to peat to decompose complex compounds so that bio-remediation could take place. Specifically, (Goi et al., 2006) added hydrogen peroxide to an oil contaminated peat sample in order to break down the complex compounds into smaller pieces to facilitate subsequent biological decomposition of the peat. They suggested that soils containing oily contaminants could be initially decomposed by strong oxidants such as hydrogen peroxide and then readily digested by the microorganisms. Bio-remediation may use incubated microorganisms or bacterial colonies on the surface of contaminated soil to decompose contaminants. The chemical reaction between hydrogen peroxide and contaminants releases oxygen that provides energy for the microorganisms to decompose the contaminants. Smaller molecules that have been decomposed by hydrogen peroxide are more readily adsorbed to peat particle surfaces and so the oil constituents would be more resistant to leaching if insufficient microorganisms existed in the soil to decompose the remaining hydrocarbon molecules (Goi et al., 2006).

When hydrogen peroxide is applied to contaminated soil it forms Fenton's reagent by reacting with naturally occurring ferrous ions, which act as a catalyst in the soil. According to Goi et al. (2006), the combination of Fenton-like pre-treatment and subsequent bio-treatment is demonstrated to be the most effective approach for removing transformed oil from organic-rich soil and especially from peat and the natural presence of ferric ions cuts processing costs.

3. Main Approaches

After pre-treatment, peat was proved to perform better in removing contaminants (Cohen et al., 1991). The following paragraphs will introduce main approaches which have been applied.

D'Hennezel and Coupal (1972) used dewatered peat moss as an adsorbent for different types of oil. Field experiments and laboratory indicated that it could be possible to use peat moss rather than straw which had been a common adsorbent material at that time. One significant conclusion from this study, however, was that the absorbency of peat moss decreased rapidly as the spilled oil changed from a natural state to an emulsified form.

Goi et al. (2006) also compared oil removal rates between sand and peat, found higher oil removal efficiency with the sand, and were able to conclude that the type of soil matrix significantly contributed to the final removal rate. Soil organic matter content was believed to be a factor in controlling the rate of hydrocarbon peroxide decomposition and hydroxyl radical formation, responsible for the oil desorption and oxidation, and thus greater chemical addition was required for the peat sample. (Goi et al., 2006). Since peat has been used successfully to adsorb oily contaminated water or domestic wastewater, peat could possibly be spread on top of oil contaminated sites as a precaution when dealing with potentially environmentally harmful procedures to avoid the spread of contamination.

Accelerated Solvent Extraction (ASE) has been developed to extract polycyclic aromatic hydrocarbon (PAH) components from contaminated peat (Dreyer et al., 2005). Based on the hypothesis that most of the components of oil are hydrocarbons and they perform similarly with PAHs in soil, ASE could possibly be used to extract oil from contaminated peat or other oily contaminated organic-rich soils, though the method would be time and labor consuming.

Ghaly et al. (1990) recommended passing tap water through an oily contaminated soil in a column and subsequently sprinkling peat on the surface of the contaminated water to give a relatively cleaned soil and water and to transfer the oil to the peat. They suggested thereafter that the contaminated peat could be used as an energy source because the presence of oil in the peat could increase its heating value. They reported that the initial heating value of a peat sample increased from 17.65 MJ/kg to 35.81 MJ/kg after the peat was submerged into a diesel contaminated solution.

A study by Viraraghaven and Mathavan (1990) reported that the removal rate for standard mineral oil and crude oil from wastewater using peat reached 83% and 70%, respectively. For treating domestic wastewater with high levels of COD, BOD and SS, Perez et al. (2005) showed that two types of peat, namely sapric (most decomposed) and fibric (least decomposed) peat performed equally well in removing the SS but performed unsatisfactorily in removing BOD and COD. On the other hand, Corley et al. (2006) reported BOD and COD removal rates by sapric and fibirc peat were as 96% and 84% respectively. For removing oil contaminants in water, Cohen et al. (1991) determined that the more humified the peat type, the better the adsorption of hydrocarbons. Table 1 summarizes some of the pretreatments and main approaches that have been employed in using peat to clean up domestic wastewaters and oil laden waters.

Ghaly and Pyke (2001) reported that applying commercial peat to the surface of oily contaminated water resulted in an oil removal efficiency of 99.998%. A 1.3 cm thick synthetically produced oil slick was almost completely removed by sprinkling peat on the surface of the water. Coagulation was proven to be the dominant mechanism in their experiment. However, simultaneously increasing peat's moisture content would adversely effect removal because the increasing moisture content could increase peat's weight and cause the sample to sink and the procedure would have to be discontinued.

Peat is believed to be a promising and effective sorbent for contaminant removal (McLellan & Rock, 1987). Nevertheless, some characteristics of peat and external factors may still be influential in determining the applicability and performance of peat. Arkhipov et al. (1999) showed that there is a decrease in performance efficiency when transitioning from laboratory-type columns to commercial conditions or from model solutions to real treatment procedures. Heavey (2003), however, showed that the use of peat as a filter is best suited to small communities and it is not suitable for cities with large populations as the hydraulic characteristics of the peat might not be able to meet their requirements since the relatively low hydraulic conductivity of peat could result in contaminant removal rates that are too slow. Therefore, alternative procedures could be better in large cities.

4. Peat and Other Adsorbents

Many studies have shown that applying only peat in wastewater and oily contaminated water clean-up treatment is not as effective as combining peat with other materials.

Lens et al. (1994) compared the difference when using peat or bark exclusively to remove contaminants from domestic sewage. The bark worked better at handling COD and peat was better at treating SS, BOD and fecal bacteria. When the peat and bark were mixed together the overall removal was better and fecal bacterial was removed. The main result that the authors discovered was that peat was able to disinfect the fecal bacteria. Lens et al. (1994) also found that wood chips were less effective in treating domestic wastewater and resulted in poor removal of COD and lack of disinfection.

Some other materials that have high adsorption capacity could be introduced into wastewater or oily contaminated water removal processes. Suni et al. (2004) indicated that one by-product of peat purification, cotton grass fibre, could remove over 99% of the diesel oil from the surface of water and could adsorb up to 20 times its own weight. Cotton grass fibers can be present in anoxic, low pH peat bog environments that discourage the decomposition of plant stems and roots. In addition to exhibiting a high degree of adsorption, the grass fibre floated on the surface of the contaminated water while sorbing the oil due to its low water retention capacity and higher preference for oil. Collection of the oil contaminated grass fibre was easily accomplished and secondary contamination was avoided since the grass fibre was very buoyant and there was no sinkage down to the bottom sediments where it could have adversely affected the benthic animals and plants. Since the floating grass fibre was so effective in removing the oil, the adverse effects of insufficient light on the aquatic animals and plants would have been minimized to the greatest possible extent. Suni et al. (2004) considered the glass fibre to be an excellent material for absorbing oil products from surface waters although its use in a marine environment is not yet clear because of the differing composition of marine water.

Gin by-products and kenaf have been demonstrated to be efficient materials for removing oil from water surfaces (Anthony, 1994). Hori et al. (2000) reported that kapok [Ceiba pentandra (L.) Gaertn] fiber, (the tissue of a tropical

Table 1 Comparison among different clean-up procedures

Contaminants	Pretreatments or approaches	Sapric	Fibric	Conclusion
BTEX[1]	Irradiation was used in peat pre-treatment. Peat types included sapric (taxodium and swamp) and fibric (sphagnum and nymphaea). 1-day and 5-day batch experiments were conducted.	Sapric peat sorbed more BTEX over the 5-day experiment than the fibric peat.	Fibric peat had a higher sorption capacity over the 1-day experiment than the sapric peat. Fibric peat sorbed oil more quickly than sapric peat but the total amount of oil sorbed was less than for the sapric peat.	Irradiating peat could increase the BTEX sorption capacity (by an additional 10-65%) until a BTEX sorption maximum was obtained. Fibric peat reached the maximum BETX sorption capacity faster than the sapric peat.
BTEX[2]	Various peat types were used to test BTEX removal rates. Peat types included sapric (taxodium), hemic (nymphaea, hemic and sawgrass) and fibric (sphagnum).	Sapric peat adsorbed hydrocarbons from saturated solutions more than the fibric peat.	For free phase hydrocarbons in water, this peat exhibited somewhat lower absorbency than the more humified peat.	The best hydrocarbon adsorbing peat tended to be lower in fiber content, higher in ash content and higher in lignin and furan pyrolysis products.
Domestic strength wastewater[3]	A mussel shell layer on top with different depths of fibrous peat and a free draining bottom layer of PVC pipes were tested for removal of contaminants in synthetic domestic strength wastewater.		No clogging and no noticeable degradation of the fibrous peat occurred.	BOD_5, COD_t and TSS were highly removed for all depths of peat and removals were 96%, 84% and 94% respectively.
Domestic wastewater[4]	A constant depth of peat (sphagnum) column was tested with different influent wastewaters (dairy and slaughterhouse). A layer of crushed stone was placed both on the top and bottom of the peat.		With an hydraulic loading rate of 3.55 m^3/m^2, the column clogged after 124 hours of running slaughterhouse wastewater. With a hydraulic loading rate of 2.13 m^3/m^2, the column clogged after 81 hours of running dairy wastewater.	For slaughterhouse wastewater, SS, BOD and COD_t were removals were 94%, 66% and 65% respectively and for dairy wastewater removals were 99%, 61% and 51% respectively.
Domestic sewage[5]	Fibric peat (sphagnum), woodchips and bark were combined to test contaminant removal rates.		With a peat density of 0.075 g/cm^3 and a hydraulic rate of 10 cm/d removals of 91% SS, 50% COD_t, and 99% BOD_5 were obtained.	The removal rates were not significantly affected the by hydraulic loading rates. Peat and combined materials were effective in removing faecal bacteria.
Urban wastewater[6]	A peat bed was used to test the contamination removal efficiency of fibric (sphagnum) peat and sapric (black peat) peat under varied hydraulic and pollutant loadings.	Low retention of OM was obtained when the hydraulic loading was high. Sapric peat performed better than the fibric peat, despite the varied hydraulic loadings.	For both peat types, increased hydraulic loading decreased the removal of COD and BOD.	A higher retention of SS was related to higher polluted loading for both types of peat.

Source:
[1] Rizzuti et al., 1996; [2] Cohen et al., 1991; [3] Corley et al., 2006; [4] Viraraghaven et al., 1988; [5] Lens et al., 1994 ; [6] Perez et al., 2005

fruit), could be effectively applied to recover oil spilled in seawater due to its significantly hydrophobic characteristics.

When natural materials fail to perform effectively, synthetic materials are sometimes applied though they are considered to be less environmentally friendly because of disposal issues. Al-Marzouqi et al. (2003) reported that 1 to 2 cm thick polyurethane sponge could obtain as high as a 99% removal rate when applied to the surface of crude-oil-contaminated water. This process was used successfully in a clean-up operation in a marine environment in the region of Kuwait. Zhou et al. (2002) studied a polymer PBED (terpolymer-4-tert-butylstyrene-ethylene-propylene-diene-divinylbenzene) which was demonstrated to be an effective sorbent for oil. However, it needs to be reiterated that the use of synthetic materials could later create another contamination problem.

5. Sustainable Development

Cost and benefit are two main issues when taking environmentally sustainable development into account. Basically, the use of appropriate materials and low energy consumption will significantly decrease costs. When successful remediation procedures are undertaken, even if the effects are not readily apparent there may be a great benefit to the environment for future generations. Mara (2003) indicated that preferring zero environmentally damaging disinfectants is an important part of sustainable development. Peat is an environmentally friendly resource and can be naturally decomposed most of the time and so meets the basic requirement of sustainability.

ITOPFL (1980) reported that oil spill clean-up costs have varied dramatically from \$6 per ton to \$6932 per ton due to the combination of many factors including the location of the incident, the type of the oil involved, the nature of the response, and the degree of clean-up. However, clean-up is believed to be worthwhile regardless of the cost involved. A report published by Alberta Municipal Affairs showed that it would cost on average \$10,000 to do an environmental site assessment (ESA), including drilling and sampling, for small retail gas stations that had been contaminated by oil for years. The ESA and site remediation combined was estimated to cost \$160,000 or more per site (Alberta Municipal Affairs, 2006). The amount of \$160,000 was estimated for remediation of gasoline contamination but higher costs would be expected for soils contaminated by heavier oils such as diesel. The goal of the provincial government was to provide the amount of \$160,000 to clean the polluted underground water and try to recover it to its original status and any additional costs would be borne by the gas station owner.

The application of new technologies has helped in the reduction of remediation costs. It has been reported, for example, that the use of hydrogen peroxide instead of polymers to dewater peat has reduced the cost by approximately one third (Ringqvist et al., 1991). Heavey (2003) showed that introducing a peat bed to remove BOD could significantly lower costs, especially when used to treat leachate from small-scale landfills. Thus, high-cost aerobic treatment systems may not be necessary any longer. For large-scale contamination, the choice of material is more important because any variation of unit cost will dramatically influence the total cost. Corley et al. (2006) investigated treatment of domestic wastewater for single dwellings using a top layer of mussel shells underlain by various depths of peat that were free draining at the bottom. Only an influent pump was required for the operation and good treatment was achieved at a very low cost.

Al-Marzouqi et al. (2003) reported that the clean-up operation in Kuwait cost 38 million dollars and took six months for a 1.7 million m^3 oil spill. The clean-up was necessary because further contamination would have been more costly and without cleanup the recovery time would have be extremely long.

Another pertinent problem is how to dispose of the natural and synthetic contaminated sorbents with the least contamination issues and while satisfying regulatory policies. Suni et al. (2006) determined that degradable fibric peat could be readily composted without the addition of microbial inoculums after it had absorbed oil. On the other hand, Cohen et al. (1990) reported that sapric peat tended to be more effective than fibric peat in removing contaminants. Further studies will be required to focus on solving the application and disposal dilemma since not only does the peat need to be easy to apply but the contaminated peat needs to be handled in an environmentally sustainable manner.

6. Conclusion and Further Prospects

Peat has been demonstrated to be an effective and low-cost material in environmental protection processes, especially in removing contaminants from domestic wastewater and oil contaminated water, though applying peat-related clean-up processes to cities with large populations and in industrial applications still needs further development. Peat's combustible nature allows peat to be used as a secondary energy after the sorption process. Peat is an abundant resource and it has been reported that about 90% of the 127 million ha of the wetlands in Canada were classified as peatlands by the end of 1988 (Rubec & Keys, 1993). While these figures are quite fascinating, they also show that the peat resource is finite. Thus effective harvesting and reasonable utilization should be carefully planed for the future.

7. Acknowledgements

The authors gratefully acknowledge the financial support provided by NSERC and Memorial University of Newfoundland.

REFERENCES

Alberta Municipal Affaire, 2006 http://municipalaffairs.gov.ab.ca/documents/0825_Tanks_QA_-_WEBSITE.pdf

Al-Marzouqi, A. H., Busamra, A., Mohammed, F., Al-Shehhi, S. and Abdulwahab, W. 2003. A Novel Absorbent-Skimmer Technology for Cleaning Oil Spill. *Environmental Studies, Coastal Engineering VI: Computer Modelling and Experimental Measurements of Seas and Coastal Regions*: 205-214.

Arkhipov, V. S., Maslov, S. G. and Memetova, S. B. 1999. Use of Peat for Removing Petroleum Derivatives and Iron from Engineering Effluents. *Journal of Water Chemistry and Techonology*, 5 (21): 47-51.

Anthony, W. S. 1994. Absorption of Oil with Cotton Products and Kenaf. *Applied Engeineering in Agriculture*, 10, (3): 357-361.

Bartonicek, B. and Pipota, J. 1990. New Rizobin Based on Radiation-Sterilized Peat Carrier. *Radiation Physics and Chemistry*, 35 (4-6): 478-482.

Buivid, M. G., Wise, D. L., Rader, A. M., McCarty, P. L. and Owen, W. F. 1980. Feasibility of a Peat Biogasification

Process. *Resource Recovery and Conservation*, 5: 117-138

Cohen, D., Rollins, M. S. and Zunic, W. M. 1991. Effects of Chemical and Physical Differences in Peats on Their Ability to Extract Hydrocarbons from Water. *Water Resources*, 25 (9): 1047-1060.

Corley, M., Rodgers, M., Mulqueen, J. and Clifford, E. 2006. The performance of fibrous peat biofilters in treating domestic strength wastewater. *Journal of Environmental Science and Health, Part A*, 41: 811-824.

Couillard, D. 1994. The Use of Peat in Wastewater Treatment. *Water Resource*, 28 (6): 1261-1274.

D'Hennezel F. and Coupal B. 1972. Peat Moss: A Natural Absorbent for Oil Spills. *Canadian Mining and Metallurgical Bulletin*, 65 (717): 51-53.

Dreyer, A. and Radke, M. 2005. Evaluation and Optimization of Extraction and Clean-up Methods for the Analysis of Polycyclic Aromatic Hydrocarbons in Peat Samples. *International Journal of Environmental Analytical Chemistry*, 85 (7): 423-432.

Forsberg S. and Alden L. 1989. Dewatering of Peat: Characterization of Colloidal and Subcolloidal Particles in Peat. Colloids and Surface, 34 (4): 335-343.

Frostman, T. M. 1995. Poster Session Peat/Wetland Treatment Systems for Water Quality Management. Proceedings: *1995 International Environmental Conference*: *Marriott Marquis, Atlanta, Georgia, May 7-10*, 2: 97-998.

Ghaly, R. A., Pyke, J. B., Ghaly A. E. and Ugursal, V. I. 1999. Remediation of Diesel-Oil-Contaminated Soil Using Peat. *Energy Sources*, 21: 785-799.

Goi, A., Kulik, N. and Trapido, M. 2006. Combined Chemical and Biological Treatment of Oil Contaminated Soil. *Chemosphere*, 63: 1754-1763.

Heavey, M. 2003. Low-cost Treatment of Landfill Leachate Using Peat. *Waste Management*, 23: 447-454.

Hori, K., Flavier, M. E. and Kuga, S. 2000. Excellent oil Adsorbent Kapok [Ceiba pentandra (L.) Gaertn.] Fiber: Fiber Structure, Chemical Characteristics, and Application. *Journal of Wood Science*, 46 (5): 401-404.

ITOPFL, the International Tanker Owners Pollution Federation Limited, 1980. *Measures to Combat Oil Pollution*. Graham and Trotman Limited. London

Jonsson, B., Petersson, E. and Lindman, B. 1987. Mechanical Dewatering of Peat. *Fuel*, 66 (6): 785-793.

Jyrki, H. 2003. Effects of Wood, Peat and Coal Ash Fertilization on Scots Pine Foliar Nutrient Concentrations and Growth on Afforested Former Agricultural Peat Soils. *Silva Fennica*, 37 (2): 219-243.

Lee, V. K. C., Porter, J. F. and McKay, G. 2001. *Modified Design Model for the Adsorption of Dye onto Peat. Food and Bioproducts Processing: Transactions of the Institution of Chemical Engineers, Part C*, 79 (1): 21-26.

Lens, P. N., Vochten, P. M., Speleers, L. and Verstraete, W. H. 1994. Direct Treatment of Domestic Wastewater by Percolation over Peat, Bark and Woodchips. *Water Recourse*, 28, (1): 17-26.

Mara, D. 2003. *Domestic Wastewater Treatment in Developing Countries*. Earthscan, London.

McLellan, J. K. and Rock, C. A. 1987. Pretreating Landfill Leachate with Peat to Remove metals. *Water, Air and Soil Pollution*, 37 (1988): 203-215.

Mihelcic, J. R., Crittenden, J. C., Small, M. J., Shonnard, D. R., Hokanson D. R.., Zhang, Q., Chen, H., Sorby, S. A., James, V. U., Sutherland, J. W. and Schnoor, J. L. 2003. Sustainability Science and Engineering: The Emergence of a New Metadiscipline. *Environmental Science and Technology*, 37 (23): 5314-5324.

Oren, M. J., David, G. and Mackay, M. 1990. Peat-Water-Oil Mixture as a Low Cost Liquid Fuel. *Fuel*, 69: 1326-1327.

Perez, J. I., Hontoria, E., Zamorano, M. and Gomez, M. A. 2005. Wastewater Treatment Using Fibrist and Saprist Peat: A Comparative Study. J*ournal of Environmental Science and Health, Part A*, 40: 1021-1032.

Ringqvist, L., Lind, E. and Wikander, G. 1991. Preatment Method for Peat Dewatering. *Fuel*: 70, 533-537.

Rizzuti, A. M., Cohen, A. D. and Stack, E. M. 1996. Effects of Irradiating Peats on Their Ability to Extract BTEX and Cadmium from Contaminated Water. *Journal of Environmental Science and Health Environmental Science and Engineering & Toxic and Hazardous Substance Control. Part A*: 31 (8): 1917-1949.

Robertson, R. A. 1984. Peat as an Energy Source in Scotland. *Pergamon Press*, 395-402.

Rubec, C. and Keys, D. Sustainability and Peatland Resources Use in Canada. Conference Proceedings: Newfoundland Peat Opportunities, an International Conference, September 7-10, 1993, Corner Brook, Newfoundland.

Smith E. F, MacCarthy P. and Mark H. B, (Jr) 1976. The Characterization of Phosphoric acid-treated Peat as a Cation Exchanger. Journal of *Environmental Science and Health- Environmental Science Engineering. A11 (2). 179-189*.

Suni, S., Kosunen, A. –L., Hautala, M., Pasila, A. and Tomantschuk, M. 2004. Use of a By-Product of Peat Excavation. *Cotton Grass Fibre, as a Sorbent for*

Oil-Spills. Marine Pollution Bulletin, 49: 916-921.

Suni, S., Kosunen, A. -L. and Romantschuk, M. 2006. Microbially Treated Peat-Cellulose Fibric as a Biodegradable Oil-Collection Cloth, *Journal of Environmental Science and Health Part A*, 41: 999-1007.

Viraraghaven, T. and Kikkeri, S. R. 1988. Peat Filtration of Food-Processing Wastewaters. *Biological Wastes*, 26: 151-155.

Viraraghaven, T. and Mathavan, G. N. 1988. Treatment of Oil-In-Water Emulsions Using Peat. *Oil & Chemical Pollution*, 4: 261-280.

Viraraghaven, T. and Mathavan, G. N. 1990. Treatment of Oily Waters Using Peat. *Water Pollution Research Journal of Cananda*, 25 (1): 73-90.

Zhou, M. H. and Cho, W. J. 2002 Sythesis and Properties of High Oil-Absorbent 4-tert-Butylstyrene-EPDM-Divinylbenzene Graft Terpolymer. *Journal of Applied Polymer Science*, 85: 2119-2129.