

Determining the Characteristics of Diluted Wastewater in the Lagoon

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ABSTRACT
"Drink a minimum of two litres or eight glasses of 8 liquid ounces daily" is a statement with which we are all familiar; it is the recommendation by the UK Food Standard Agency (FSA), corroborated by the US-EPA (UKFSA 2002, & USEPA, 1945). However in Ghana, the Chemu Lagoon remains a main source of drinking water, while there is direct waste discharge from Tema Oil Refinery, with neither the management nor the government at large finding solutions to health risks it pose. It is in this interest that this study is aimed at analysing the extent of impurities and designing a filtration system which can be used for filtering diluted water of its type. Samples of the wastewater discharge as well as diluted lagoon water were analysed to determine its chlorine level, turbidity, etc. Having confirmed the presence of the impurities in the water, a filtration system was designed to serve as a means of purifying the water. A CFD/FloXpress analysis was carried out to determine the suitability of the filtration system while analysis of filtered water also confirmed that, production of the filters could help in enhancing the purification of the diluted Chemu lagoon and similar water system.
Keywords: Chemu, Pollution, Turbidimeter

Introduction

1.1 Background to the Study

Refineries all over the world use large volumes of water for processing of crude; from generation of steam in the boiler, cooling the products in the heat exchanger, washing of tanks during maintenance, flushing out spilled products (a practice of good housekeeping), to laboratory analysis and so on (Benyahia, 2006). Source reduction of waste as well as its minimisation can be achieved considering the process through which a product traverse; which means more profits being generated, increased efficiency of production and less of raw material extraction and saving the damage to the ecology.

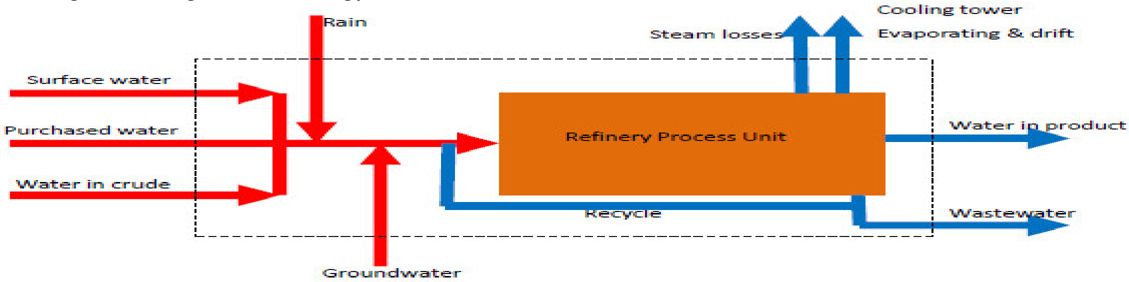


Figure 1: Overall refinery water balance

As part of the set up normally, the used water (wastewater) in a refinery is collected and treated at its Waste Treatment Plant (WTP) within the organisation with some recovery of product (of gasoline and oils) while the rest in the form of sludge is sent to landfill or other designated disposal sites. Waste water can leave a site through point sources deliberately to known receptacles or through (uncontrolled) non- point sources.
Contaminants in aquatic media get in either through point or diffused sources and their impact are a result of several factors that relate to pollutant strength (load), flow rate and volume of discharge, frequency and the use to which the receiving stream/ water body is put (Brady, 2005).
Very often, these wastes when allowed to drain into say, rivers over a period of time (intentionally or unintentionally), their negative cumulative effect become pronounced (Benyahia, 2006). In figure 1, water entry into the refinery system and exit is shown and of interest is the wastewater and how it is managed.

1.1.1 Water

Freshwater in the hydrosphere constitutes about 2.5% of total stock (Gleick,1993), the rest existing as ground water or ice which continuously goes through transpiration, evaporation, precipitation and condensation usually called the water cycle as shown in the figure 2 below. The quality of the ground water is affected by runoff which it joins by filtration.

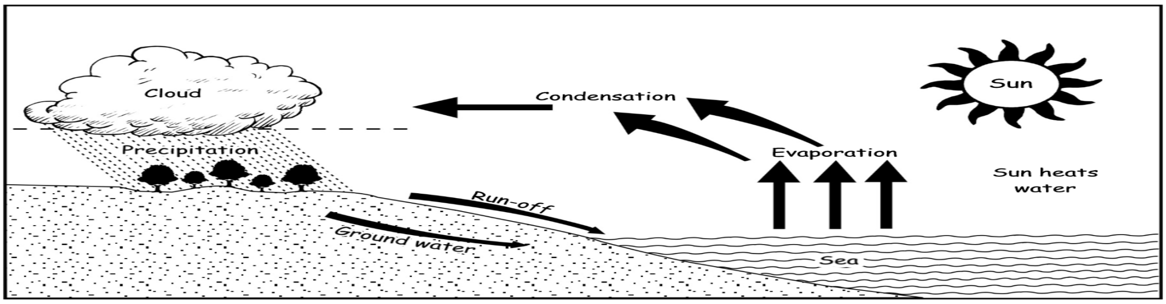


Figure 2: The water cycle
Source: Connexions, 2009 (online)

Safe water is odourless, tasteless and colourless making it ideal for human development while agriculture plays a major role in the economy of the world, access to which has improved in the past fifty years (Erickson, 1999). Water boils at 100°C under standard atmospheric pressure (s.a.p.) with a specific heat capacity of 4182 J/ kg °C whose density is of the order of 1000 kg/m^3occurring at 4 °C. It is known to be neutral with a pH of 7, whereas acids will have pH levels being less; the values for alkaline are in excess of 7.

Water fit for human consumption is called potable water and that which comes as a by- product after processing is called wastewater (not fit for consumption sometimes even after some treatment). Water that is safe for drinking is a basic necessity of humans but inadequacy in supply compels several families spending hour's on-end in its search. In Africa, about 800 million individuals have limited access to drinking water that is safe. Also, water- related illnesses kill children every now and then while 200 million productive hours are wasted daily in the search of water (PWB, 2006).

"Drink eight 8- ounce glasses of water a day" which is about 1.9 litres often referred to as "8 by 8" is not supported by evidence although popular and easy to remember. However, this daily minimum depends on factors such as; exercise, the environment, health conditions or illness, breast- feeding or pregnancy and availability of other fluid types (MFMER, 1998 - 2013).

To compound the problem, an estimated 90% of the wastewater generated in developing countries (Africa, for that matter) find sits way back into streams and other water bodies either because there is no technology to process it or because the regulatory bodies are too weak to act making it easy for the offender to escape prosecution (Ravindranath, 2002).

1.1.2 Contaminated Water (dirty water) from the refinery process

It is widely known that, 3.5 to 5.0 m^3 of wastewater are generated per ton of crude oil refined if recycled water is ensured. The wastewater produced contains biological oxygen demand, chemical oxygen demand, heavy metals, and varying amounts of other pollutants. Sludge and solid waste are about 3- 5 kg/ton of crude that is processed of which as much as 80% is toxic due to the presence of the heavy metals and hazardous chemicals (Benyahia, 2006).

Figure 3: illustration of reckless waste disposal

For a plant that processes about 150,000 to 200,000 barrels of crude daily, the situation becomes alarming in terms of the volume of toxic waste produced. As shown in figure 3 is raw waste being drained into the stream in Temainstead of treating it at to reduce its effect on the environment or disposed of in a more acceptable manner.

1.1.3 Environment of Africa in General

Industrialisation may be referred to as development experience that makes use of mechanised systems for exploitation of resources with its attendant high efficiency, maximum extraction and use of resources in a commercial way as opposed to subsistence form bringing in its trail, the conversion of raw materials into finished goods (Rapley, 1997).

This conversion comes with the generation of waste but how that waste is disposed of and the frequency with which it is generated are the concerns of community/ interest groups. This is likened to the classical cycle of the Carnot heat engine, Q – U = W (where Q is the crude, U is the waste and W representing the refined petroleum

product). Tema Oil Refinery (TOR) is a process organisation turning crude by the application of energy, chemicals, other resources (water, human, capital) and as a consequence into useful products and waste, dealing with which has become a problem.
Meeting the needs of people through the provision of clothing, shelter, improvement in living standards, transportation, and food is the essence of socio- economic development which must be done in a sustainable manner. Environmental regulations and laws focusing on specific media, end- of- process, wastes and pollutants commend- and- control have led to reduction in pollution considerably though not effective in cost.

The logical extension of pollution control is pollution prevention (P2) which is the reduction in waste or cut-back on toxic material at sources with focus on existing operations in manufacturing and finds application in minimising waste, production which is green, green chemistry, the utilisation of waste, ISO 14000 and a host of others (Shen, 2002 cited in Wang, 2004). When safe substitutes exist for toxic materials, they must be avoided long before they get to the facility and (P2) technologies occur as; process modification, in-process re-cycling, material separation and product & material substitutions hence the provision of amenities for society should not become a problem of pollution to deal with.
To different people, water has wide range of applications since it is essential for the sustenance of life and comes with quality control issues including pollution control. Used as a coolant, for navigation, cleansing, source of food, recreation, means of power generation, industry and to a lesser extent as a dumping ground for the waste of society. The quality and quantity however, affects human and aquatic life through its direct use which varies to a large extent (Koren, 2003).
Environments of aquatic nature exist as brooks, great and small rivers, streams, lakes, oceans and coastal estuaries. Below in figure 4 is part of the Chemu (Tema) lagoon with its natural vegetative cover. These environments may be affected in some way by factors such as latitude, altitude, mean depth, length of shoreline, run- off rate, physical composition, etc (Koren, 2003).

1.2. Problem Statement and Justification

The management of water at TOR has the potential of reducing cost through less volume used in an attempt to cut down on the operational expenses and amount paid for municipal water supplies and also realise a reduction in the concentration of the contaminant. When water is optimally utilised, it brings about a reduction in contaminant mass and improves the wastewater quality and subsequently its impact on the environment.

1.2.1 Tema Oil Refinery and Water Pollution

TOR is a state- owned organisation that was commissioned on the 12th December, 1963 with the mandate of providing refined petroleum products for automobiles and aircraft, LPG and kerosene for domestic use, and other intermediate products for industry with an initial crude distillation unit capacity of 45,000 b.p.s.d. equivalent to 2,000,000 t.p.a. Premium Reforming Unit of 6,500 b.p.s.d. (315,000 t.p.a) and a Residue Fluid Catalytic Cracker (RFCC) of 14,000 b.p.s.d equivalent to 685,000 t.p.a. The need to optimise the plant efficiency has required the increased capacity utilisation to meet the ever- increasing demands of its customers thereby putting the future distillation capacity at about 200,000b.p.d (UNEP, 2012).
TOR is located in the harbour city of Tema, which is about 24 kilometres east of the capital Accra, along the coast and very popular because the Greenwich Meridian promotes its tourism. Ghana is bound to the north by Burkina Faso, to the west by Cote d'Ivoire, to the east by Togo and to the south by the Gulf of Guinea (the Atlantic Ocean). Tema has a population of 288,020 (PHC, 2010) and is home of Volta Aluminium Company, Nestle Ghana Limited and Cocoa Processing Company Limited.

2.0 The Concept of Pollution Prevention

All types of industrial processes produce waste of one kind or another, as occurs in stream stripping, desalting and washing operation during refinery of petroleum products. When not treated and disposed of in an environmentally acceptable manner, leads to constituents getting to aquifers on the subsurface serving as the supply of water for drinking. Environmental pollution is the outcome of the improper design and use of equipment leading to system inefficiency during processing or manufacture. The pollutants come in the form of raw materials or as by- products from processing leading to loss of capital (profits).
Earlier measures of pollution control included the end- of- pipe treatment of wastewater, incineration of hazardous waste, monitoring equipment and landfills which are a basis for the shift to pollution prevention. The manufacturing of wastes (as in by-products) and the destruction of raw materials affect profitability and present a low or high risk environment at the workplace.
The first category of contaminants (pollutants) are those that carry agents which cause diseases after entry into untreated waste or sewage systems; examples are protozoa, parasitic worms, bacteria and viruses. Oxygen-demanding wastes are those that contain bacteria and require oxygen to decompose it, they are in the second

category. If their activities go unchecked, oxygen levels get depleted and make water unable to support living things. Toxic metals (mercury, lead, chromium, etc.), acids, salts are examples of water soluble inorganic contaminants which render water unsuitable for aquatic life and drinking for humans. This is a third categorization with a fourth category being the water plant and algae supporting nutrients that exhaust the supply of oxygen supporting fish life. Organic compounds for example plastics and oil can also pollute water making it unsafe for humans, living things in the water and plants. The figure5 below shows the extent of pollution with plastics and the turbid nature of the lagoon indicating the presence of other organic and/ or inorganic materials.

Figure 4: Example of pollution in Chemu Lagoon

Figure 5: parts of the lagoon with vegetative cover

Source: ModernGhana.com, 2013

Pollution in water is both harmful to the very equipment that carries it (that is, heat exchangers, tanks for storing, pumps and pipelines) for disposal as well as the humans that manage it (Nemerow, 1987 cited in 2003). Also, pollutants in water contribute to various ions for example, Cd^{++}, Pb^{++}, and Cd^{++} (which are toxic) being dissolved leading to failure of equipment as a result of corrosion (Salvato, 1982; Stuckey and Hamza, 1981 cited in Nosier, 2003).

2.1 Government policy

The main regulatory body in Ghana established by the government is the Environmental Protection Agency through Act 490 of 1994 bringing into being the EPA. As regards the supply of water, the EPA is mandated to control the activities and operations of the public in such a manner that harm was not caused to the environment, as well as its catchment area and undertake water conservation activities.

However the standards Decree 1967, 1973 of NRCD 173, 199 gave ultimate power to the Ghana Standards Board in the setting of quality for drinking water standard but at the community level, monitoring of the standard and responsibility for enforcement rested with the local councils.

The government through the EPA promulgated Legislative Instrument (LI) 1652 Environmental Assessment Regulation in 1999 to grant legal status to the procedures used in the assessment of environmental impacts (EPA Guideline Report, 2010).

It requires all activities that have the tendency to affect the environment adversely to be subjected to an assessment to ensure sustainable development. In that guideline, an assessment of the impact on water quality, the management of water and recommendations for solid effluents and liquids are addressed.

Of interest are the following thematic areas:

1. To consider current water resource use for industrial, commercial, domestic, recreational or agricultural purposes.

2.2. Research Approach

Samples of the untreated wastewater and dilute water (from the lagoon) were analysed at Ghana Atomic Energy Commission laboratory with the aid of turbidimeter, pH meter, milestone microwave labstation, atomic absorption spectrometer etc. A model filter was designed and with the kind of contaminants present in mind, five elements (membrane, activated carbon, zeolite, ion exchange resin) were selected for inclusion in the filter. The filter was built and tested. A CFD/ FloXpress analysis was performed to ascertain the suitability of the design and to make any changes where possible. After that, the filtration process was performed and tap-water was used as a standard to compare with by the help of standard test kit using litmus paper. Values were compared to WHO standards in drinking water while further tests of the treated water were sent for more detail analysis to confirm the absence of bacterial/ viral contaminants.

3.0 Methodology
This chapter is in two folds; in the first part, the methods, approaches, processes and tools used in the study is described and presented in an orderly manner. It focuses mainly on the sample of waste water and diluted Chemu Lagoon water, and describes the procedure and chemical analysis used in determining the properties of both the waste water and diluted Lagoon water. The second part describes the procedure, tools and methodological framework used in designing a draft of the filtration system.

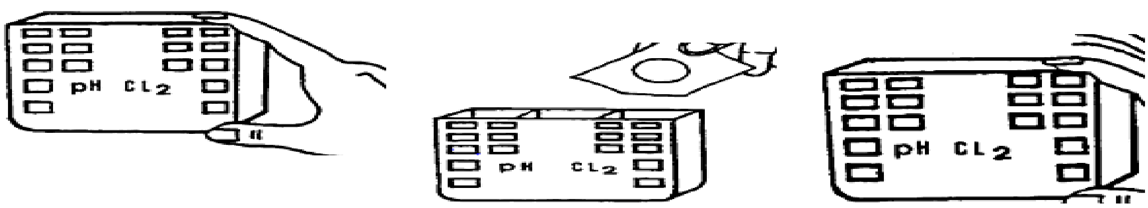
3.1 Sample/ Procedure
Water samples were taken at two different times of the same batch of discharged wastewater from the factory at 15minutes intervals to confirm the consistency of the constituents which were collected using the containers. Downstream water samples were taken in duplicate into 250ml plastic bottle/ re-sealable bag previously washed clean. The samples thus collected were placed in an ice chest to ensure samples were maintained at below 20^oC for transportation to the Ghana Atomic Energy Commission laboratory where the test was carried out.

4.0 Analytical Procedure
The digestate was made up to 20 ml with double distilled water and transferred to sample containers. VARIAN AA 240FS- Atomic Absorption Spectrometer using an acetylene- air flame as shown in figure 17 was used for these analyses. The tube leading from the atomiser was placed into the diluted digestate sample and aspirated into the ionisation chamber to begin the assay for the presence of Lead (Pb) and organo- metallic mercury (Hg). The HCI for each analyte was chosen one at a time to determine the absorbance of the blanks, standards, samples and duplicates.
The computerised read-out automatically compared the absorbances with those of the standards and calculated the corresponding concentrations. Reference standards used for the elements of interest, blanks and duplicates of samples were handled in the same conditions to ensure quality and serve as internal positive controls.

4.1 Determination of pH
The Eutech Cyberscan pH meter (PC 6000) was calibrated with buffer solutions of pH 4.0 and 9.2 at a temperature of 25^oC. An amount of 70 ml of each sample was measured into a beaker and tempered to 25^oC using water baths. The probe of the pH meter was immersed into the samples one after the other and stable readings were recorded within time interval of two minutes.

4.2. Determination of Turbidity in Water
After allowing the samples to attain room temperature, the bottles containing the samples were inverted several times to obtain homogeneity before the analysis was done. About 50ml of the sample was poured into the turbidimeter tube shown in figure 18 and the turbidity was recorded directly from the scale in Nephelometric Turbidity Unit (NTU). Where values exceeded 40 NTU, the analysis was repeated on a diluted sample prepared with turbidity- free water (deionised- distilled water). The turbidities of the original sample in this case were obtained by multiplying with the dilution factor.

4.2.3 Determination of Chlorine content in Water
Tests may be carried out using a chlorine comparator, filter photometer, spectrometer or the titration equipment. Fill the cells of the comparator with the water used to rinse it three times then drop the reagent tablet into the compartment. Add red tablet to cell if comparator shows 'phenol red.' Shake comparator after lid has been replaced and tablets dissolved. Raise cells for sunlight and look out for colour and match to scale. Pour out water and rinse comparator and use the similar procedure for pH. Step by step procedure is shown in figure 20 below.



(a) Rinse & fill with water (b) drop reagent inside (c) shake & expose to light

Figure 6: procedure for testing chlorine in water

Source: WHO, 2013

5.0 Conclusion

The study provided a platform for evaluating filtration systems used in achieving WHO stringent standards to safe drinking water quality. The study's major findings were as follows:

1. The combination of ion exchange resin, zeolite, and activated carbon reduced greatly the levels of hardness, turbidity, odour, taste, pH, chlorine, and colour of the treated water from the prototype.
2. The Solid works modelling and CFD/floXpress simulations proved powerful tools for designing and analysing the flow inside a solid body.

However, the reluctance of EPA to prosecute TOR for environmental abuses and the negligence of the process industry to organise its activities in an environmentally friendly manner has led to the pollution of the once vital resource that has been seen in the report. Although the study and its objective intended to reduce the burden on the community as well as the water-body, abatement of the practise and efforts at re- directing the spill into wastewater treatment will do more good for society.

Recommendation

More aggressive policies to be aimed at fostering a cordial relationship with the community and process industries generally in the catchment area so as to devise ways of solving the problem. In the meantime, sponsorship must be made available for the provision of potable water in place of the raw water usage.

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