

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF ENGINEERING

ODOUR CONTROL OF A BIOLOGICAL WASTEWATER FACILITY

KNUST

By

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DECLARATION

I hereby declare that this submission is my own work towards the M. Sc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This work is dedicated to my wife and children

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I would like to express my profound gratitude to the Almighty God for my life, strength, guidance, and sustenance throughout the course. I am extremely grateful to my supervisor, Prof. K. Obiri-Danso for his devoted attention, painstaking support, productive scrutiny and suggestions without which this work would not been in the limelight.

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ABSTRACT

Industrial wastewater effluents are a major health concern globally. Thus many industries are encouraged to treat their wastewater before discharge into receiving waters. The efficiency of a wastewater treatment plant in a beverage industry in Kumasi, Ghana was studied to ascertain the cause of an odour that is produced from the treatment facility especially during plant shutdown and flavour change over and also to determine the quality of the effluent discharged into receiving waters. Measured parameters include pH, Total Suspended Solids, electrical conductivity, Biological Oxygen Demand, Chemical Oxygen Demand, Total Hardness, Total Alkalinity, dissolved oxygen, colour, turbidity, phosphorus, iron, lead, copper, zinc total coliforms, faecal coliforms, *Enterococci* and *E. coli* using standard protocols set by APHA. The physicochemical quality of the effluent wastewater was significantly better than the influent wastewater except for Phosphorus which was more in the effluent (2.35 mg/L) than the influent (1.40 mg/L). Dissolved oxygen was significantly higher in the effluent than the influent. Iron and Zinc concentrations were higher in the influent (11.31 mg/L and 0.32 mg/L respectively) than in the effluent (1.42 mg/L and 0.08 mg/L respectively). However, the opposite was recorded for Lead and Copper concentrations. Differences in microbial numbers between that in the influent and effluent were not statistically significant. The plant shut down phase recorded a higher concentration in all the physicochemical parameters analysed except for B.O.D. Higher concentrations of B.O.D, C.O.D and D.O above the WHO standard were recorded, accounting for the high odour emitted from the treatment plant.

The high odour released from the treatment facility can be attributed to the high concentration of C.O.D and B.O.D and the low concentration of D.O resulting in anaerobic respiration with the resultant release of ammonia and other gases which accounts for the odour.

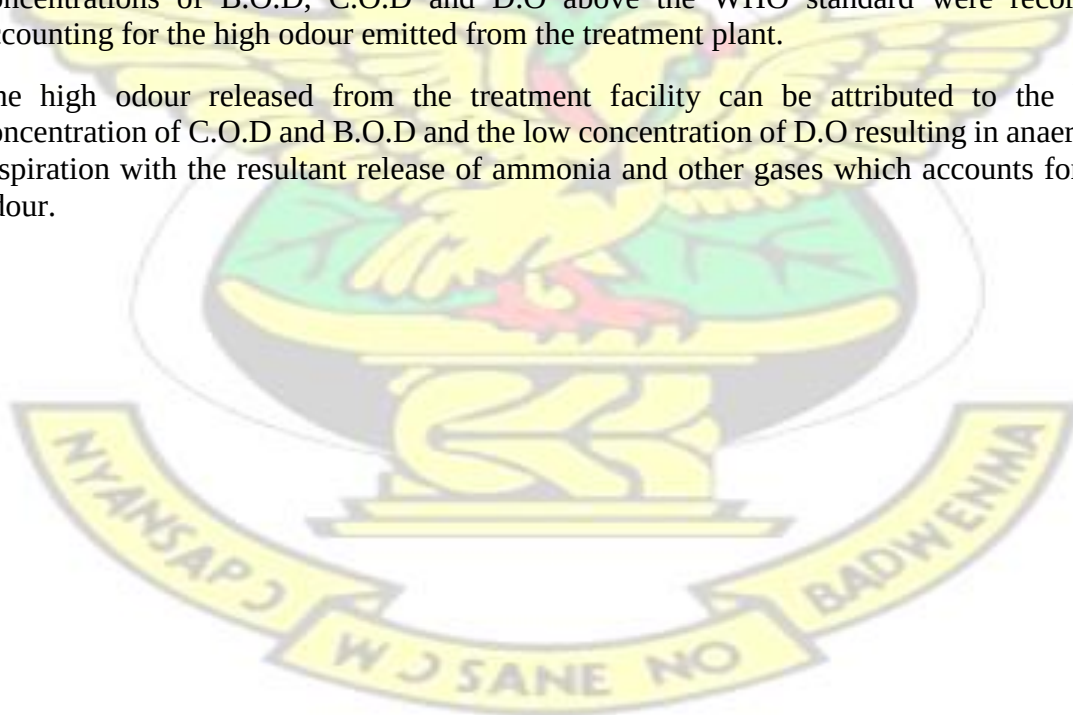


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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Odour nuisance has become a major environmental issue worldwide with increasing public demand for better control of odorous emissions from community and industrial wastewater treatment facilities. Community odours remain one of the top three complaints to air quality regulators and government bodies around the country. More than 70% of all air pollution complaints to the EPA are odor related (Wang and Howard, 2004). In his analogy, Zarra (2007) makes the inference that odour annoyance affects the population directly and there is a trend that more and more people are becoming less tolerable with obnoxious odour emissions.

Bad smell is often regarded as an indicator of a possible health risks (Stuetz and Frenchen, (2001). Offensive odours affect the quality of air as much as the conventional air pollutants. Compared to other air pollutants, odour has different characteristics and it is the most complex of all the air pollutants to be dealt with. While some developed nations are confronting this situation through regulations and other strategies, in Ghana, not much investment has been placed on the prevention of nuisance odour emissions from all the public-owned and private wastewater treatment plants and continuing research has been put into the development of better and more cost-effective odour control procedures. In many countries, environmental odour control strategies have already been developed and the standardization of odour has progressed significantly. In the Netherlands, Denmark, Germany, Belgium, Austria, Switzerland, Ireland, United Kingdom, Japan, Korea, the U.S.A. and Australia the development of odour measurement, regulation and control technique has been greatly progressed (Zarra, 2007). Recently, as a result of the common

market in the European Union, there is a movement to achieve a high degree of environmental protection. These developments have led to a gradual introduction of regulations and guidelines that increasingly depended on quantification of impacts and criteria for acceptable exposure to odours (Sneath, 2001).

Expressively, wastewater treatment facilities have contributed to the management of odour from industry set ups across the world like the beverage industry. The principal objective of a production wastewater treatment facility is generally to allow industrial effluents to be disposed off without danger to human health or unacceptable damage to the natural environment. Such facilities in some cases are intended to be part of water stewardship programs where treated wastewater effluent are recycled for purposes such as flushing of toilets, watering of lawns, compound cleaning among others to reduce water cost.

Nuisance odours can be said to be a common occurrence at wastewater treatment plants where proper management practices and controls are not adequately implemented. Proper facility design, operation, management, control and careful oversight are necessary controls to minimize odour emissions. Among the most successful odour control programs are those that take a holistic approach and examine the complete system from sewer users to land application practices (van Harreveld, 2002).

The concept of planning and development of such a facility should be based on the criteria to protect land, water resources, aquatic life in streams and rivers and marine life from pollution and to safeguard public health as a high priority. Occasional release of unpleasant or objectionable odours from such facilities is a public nuisance which can have detrimental effects on aesthetics, property values, and the quality of life in communities subjected to them.

In order to regulate odorous substances, sources of odour must be identified followed by the emission and immission measurements at these sources. It is central therefore that a reliable method of controlling odour of a biological wastewater facility must be established. Therefore, there is a demand for such a study in order to form the basis for the solution of such problems.

1.2 Statement of the Problem

The beverage industry is a key sector of the economy given its contribution to Ghana's socio-economic development. At the current rate of proliferation of the industry, one of the key concerns is its impact on the environment. In recent years there has been a legitimate public outcry against objectionable odours emanating from industrial operations from which wastes are discharged. As one would expect in this era of environmental protection, a strong desire has developed for the abatement of objectionable odours. The problem however is that efforts at managing the odour problem do not match the scale of the problem.

Essentially, the objective of wastewater treatment is to produce a disposable effluent without causing harm to the surrounding environment, and also prevent pollution. When air inside the wastewater network comes into contact with wastewater, gases can be released. These gases can sometimes escape from the network and cause unpleasant smells in the environment. In most cases, these odour or gases are composed of hydrogen sulfide and emits a 'rotten egg' smell as well as methane and ammonia. The volume and intensity of gases released from our wastewater network (at any location) could be said to be on a lower side, however, the intensity has impact on the local community, work force and the Company's corporate image.

Odour control is a significant environmental concern of manufacturing, food processing and institutional locations today with the view of improving relationship with all stakeholders. The general perception or impression on such odour releases could have a detrimental effect on the image of the Company as a good corporate citizen. Poor management of such incidents could lead to complaints by the public, agitations, legal tussles, sanctions by regulators and in some cases fines to compensate or settle disputes. These negative connotations in the long term could also greatly affect product adoption because of credibility issues leading to negative implications on the sales volumes and profitability of the business.

It is for this reason that there will be the need for research investigations or study to help correct the anomaly. Such an initiative will bring about an improved relationship between the Company on one side and the community, regulators on the other side, as well as sustainability of the environment. Among the bottleneck that is anticipated will be the measurement of odour intensities at the emitting and receiving ends. Confirming the actual in this regard will bring about the needed inputs to implement the desired strategies and other modules to predict future occurrence.

1.3 Objective of the Study

The study assessed the rate of odour releases from a biological wastewater treatment facility of a bottling plant which has become a source of worry for the surrounding community and the Company.

1.3.1 Specific Objectives

1. To assess the possible causes of the objectionable odours from the treatment facility
2. To establish management controls needed to address the gap

1.4 Research Questions

To achieve the set objectives, the following research questions were posed:

1. What are the possible causes of the objectionable odours from the treatment facility?
2. What are the management controls needed to address the gap?
3. What is the future likely occurrence using data obtained from the research?

1.5 Significance of the Study

The study will help create an understanding of the odour problem at the wastewater facility of a non alcoholic beverage bottling plant in Kumasi. This will help in identifying a solution to control the odour situation and prevent its effect on the staff and people in the neighbourhood. Findings will also contribute to any regulatory framework that is aimed at addressing such challenges. Finally, the study will contribute to academic discourse and serve as a reference material for similar studies in future.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is a review of literature that guides the data collection and analysis of empirical findings. The chapter puts into perspective the theories relevant to the current focus such as the nature of odour, sources of odour and control of odour. These are all discussed in the context of the wastewater treatment facility.

2.2 Definition of Odour

Odour molecules spread from all existences that constitute the nature. Zarra (2007) in his commentary makes the point that we live in a world of odours; some are considered as pleasant and some as unpleasant. According to him, whether an odour is offensive or not, it is subjectively based upon individual preferences, sensitivities, and daily experiences.

In the opinion of Harsman and Barnette (2010), odour can be defined as the —perception of smell or in scientific terms as —a sensation resulting from the reception of stimulus by the olfactory sensory system. Again, Henze and Herremoe (2002) citing the ISO 5492 consider odour as —organoleptic attribute perceptible by the olfactory organ on sniffing certain volatile substances. As noted by Henze and Herremoe (2002), unlike conventional air pollutants, odour has distinctly different characteristics, which, to an extent, can be comparable with noise pollution. Similar to noise, —nuisance is the primary effect on people.

2.3 Sources of Odour

Odours can arise from several sources and most of these sources are man-made.

Unscientific landfill design, increased sewage load and improper sewage treatment can produce unpleasant odour. Most commonly reported odour-producing compounds are hydrogen sulphide (rotten egg odour) and ammonia (sharp pungent odour). Carbon disulfide, mercaptans, product of decomposition of proteins (especially of animal origin), phenols and some petroleum hydrocarbons are other common odorants. Most offensive odour is created by the anaerobic decay of wet organic matter such as flesh, manure, feed or silage. Warm temperatures enhance anaerobic decay and foul odour production (Henze and Herremoe, 2002).

Tchobanoglous, Burton, and Stensel (2002) describe the sources of odour based on the emission types, classified as follows:

- **Point sources:** sources which have either a stack or ventilation channel exhausting the odorous gases with a known flow rate, such as a discharge stack from a slaughter house or a ventilation channel from a bone mill.
- **Area sources:** sources where the odorous gases are emitted from a wide surface. It can be a water or solid surface, such as the water surface of a slurry storage tank, solid waste landfill, composting or a cattle feedlot.
- **Building sources:** sources that have a number of openings where the odorous gases escape to the atmosphere, such as chicken and pig sheds.
- **Fugitive sources:** sources where odour emissions are given to the atmosphere unintentionally, such as emissions from soil bed or biofilter surface. The emission normally has an outgoing or upward gas flow (Tchobanoglous, Burton, and Stensel, 2002).

2.4 Impact of Odour on Society

Odour has many effects that result in strong annoyance or even severe health problems.

However, the classical —odour discussion deals with the ‘annoyance aspect’ of odorants in the ambient air rather than the ‘health aspect’ (Evans, 2000). Strong, unpleasant or offensive smells can interfere with a person’s enjoyment of life especially if they are frequent or persistent. Odour nuisance is generally defined according to Henze and Herremoe (2002) by the following factors; Frequency (how often an odour occurs), Intensity (the strength of an odour), duration (the length of time the odour is encountered), and offensiveness (the unpleasantness or ‘hedonic’ character of the odour).

2.4.1 Adverse Health Effects

People who are exposed to offensive odour for long periods and suffer from bad smells usually feel unwell. According to the WHO (2010) health is a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity.

Unhealthiness caused by foul odour is not caused by the fact that the odour is poisonous. Foul odour damages health because of the irritation and the nuisance it causes. On the contrary, it is possible for certain odorous emissions to have an impact on physical health. The most frequently reported symptoms attributed to odours include eye, nose, and throat irritation, headache, nausea, hoarseness, cough, nasal congestion, palpitations, shortness of breath, stress, drowsiness, and alterations in mood (Santiago *et al.*, 2006)

2.4.2 Economic Effects

On the economic front, loss of property value near odour causing operations/ industries and odorous environment is partly a consequence of offensive odour. In Ghana, there are odour problems not only in the residential and industrial areas, but also at the tourist sites. This problem is especially being very disturbing at the tourist sites and will affect the tourist incomes. The local authorities and the experts fail to solve these problems since there is no regulation for odour control at present.

2.5 Measurement Techniques Used For Odour Determination

Cohn (2010) suggests that odour assessment is a critical component of odour control and regulation procedures. Odours are often a composite of many single odorous substances. Therefore, due to this complexity it is difficult to evaluate odours. The primary methods used for odour evaluation includes; electronic nose technology, gas chromatography and olfactometry (Cohn, 2010). These measurement techniques and detailed information related with their potential to represent human olfactory response is discussed below.

2.5.1 Electronic Noses

The —electronic nose is a developing technology. Scientists are studying the mechanism of the smell process that works in humans and trying to use electronics to mimic the process involved. For this purpose, an array of electronic chemical sensors with partial specificity is used (Todar, 2008). One or more sensors of arrays emulate the different type of olfactory sensors found in the human nose. The sensor response results in specific patterns. The patterns are then compared to the responses of known sample standards to characterize the odour.

Each sensor is designed to sense different odour. As its selectivity capacity increases, the price of the sensor also increases and its production becomes more difficult. The signals which sensors collect from the environment is turned into dual-codes by electronic systems and sent to a computer. The computer defines the odour pattern by a model and classifies the type of odour. The electronic systems mimic the olfactory sensors and the computer mimics the human brain. The computer is programmed to evaluate the incoming information from the electronic system so that it can interpret signals consisting of dual-codes (Andersson, *et al.*, 2008).

The application areas of electronic noses are for automated detection and also for classification of odours, vapours and gases. Electronic noses are generally used for quality control applications in the food, beverage and cosmetic industries. Other application fields are detection of odours specific to diseases for medical diagnosis, and the detection of pollutants and gas leaks for environmental protection (Todar, 2008).

Due to its ease of use and rapid response rate, when used in routine operations, electronic noses have advantages over other odour determination techniques (Fried *et al.*, 2000). Electronic noses have high sensitivity for certain odours, high reproducibility and can be used for onsite evaluations. According to Fried *et al.*, (2000), despite these advantages, they are typically large and expensive. It is difficult to determine the correct odour concentration with electronic sensors since they designate intensity of odour depending on the chemical dose. No absolute calibration is currently available for electronic noses. In addition, the detection of different components of odours occurs sensitively but not selectively (Todar, 2008).

2.5.2 GC/MS + Sniffing Port

Valeur (2002) describe Gas chromatograph as a method used to differentiate between very similar compounds in a mixture. The components present in a gas mixture can be found by using this method. When definite quantitative and qualitative results are needed, a mass spectrometer coupled to the gas chromatograph is used. A chromatography system is composed of a gas chromatograph and a recorder for plotting chromatograms or a data station for generation and evaluation of chromatograms.

Valeur further describe that a gas chromatograph consists of a sample injector, gas supplies, oven with temperature control for the chromatographic column and the detector

(FID, FPD, MS). Once a sample solution is introduced into the GC inlet it is vaporized immediately because of the high temperature (250°C) and swept into the column by the carrier gas (usually Helium). The vapour then is transferred into the column either completely or partially (split technique). The sample flows through the column experiencing the normal separation process. As the various sample components emerge from the column opening, they flow into the capillary column interface. This device is the connection between the GC column and the MS. Then the sample enters the ionization chamber. The mass spectrometer acts as a filter, transmitting ions with a preselected mass/charge ratio. These transmitted ions are then detected with a channel electron multiplier (Cohn, 2010).

Describing further, Valuer (2002) states that the detector sends information to the computer by generating a more or less intense electrical signal (response) that is specific to a substance. The electrical signals are then converted into visual displays (chromatogram) and hard copy displays (numerical report) through the analogue (recorder) or digital (computer) processing. Gas chromatograms are analytical sensors that can only identify single odours in a mix of compounds. In the gas chromatogram a correlation of certain signals to odours is almost impossible. The combination of human nose (by inserting a sniffing port in the system) with GC-MS will be successful to find the main odour components. On the other hand, this method is not practical, time consuming and expensive (Cohn, 2010).

2.5.3 Olfactometer

Olfactometry is the most practical method among the others to evaluate odours because it is an —effect related measurement method. It uses the human nose as sensor and the effect on the human sense of smell is the unit of measurement. Olfactometry deals with the

controlled presentation of odorous gas to a panel of selected and screened human assessors (called panellists) and the evaluation of their reactions to the odour sample. Of the gas to be investigated either a continuous partial flow is conducted into the olfactometer or gas samples in odourless vessels which were filled at the source of odour are connected to the olfactometer (Robinson, 2005).

The odour concentration of the gas is determined by presenting odorous gas to the panellists in gradually increasing concentrations. The odorous gas is diluted with neutral air. In this way, different concentrations, starting from the lowest concentration, reach the nose of the panellists via sniffing tubes (nose masks). In the beginning the most diluted odorous gas is given to the panellists, later on the concentration increases (dilution decreases) gradually. Each panellist is individually required to identify which gas presentation contains the odorous gas sample. If a panellist is unable to detect the odour in the gas sample presented to him/her, the panel leader increases the dilution by one increment. According to the panellists' response to the gas presented, the odour concentration is determined (Robinson, 2005).

According to Martins *et al.*, (2008), many types of olfactometers are in use around the world and they can be categorized in three groups on the basis of dilution system used: Static method (syringe method in U.S.A., triangle bags in Japan), Rotameter/fixed orifice based olfactometers (VIC. EPA B2 in Australia, TO7 in Germany, IITRI in U.S.A.), Mass flow controller (MFC) based olfactometers (Ac'scent olfactometer in U.S.A., Olfaktomat as used in the Netherlands).

All olfactometers use human panellists to detect odours and these olfactometers range from single panellist to multi-panellist units. Since —rotameter or fixed orifice based olfactometers are able to dilute odorous sample dynamically, these types of olfactometers

are called —dynamic dilution olfactometry. Dynamic dilution olfactometry is used in the United States, Europe, and Australia and is accepted as standard practice by ASTM

(American Society for Testing and Materials) and CEN (European Committee for Standardization) (Cohn, 2010).

2.6 Industrial Wastewater Characteristics

This section examines industrial wastewater characteristics. The discussion looks at the physical characteristics, chemical characteristics and Biological characteristics.

2.6.1 Physical characteristics

According to Ron & George (1998), the principal physical characteristics of wastewater include solids content, colour, odour and temperature.

2.6.1.1 Total Solids

The total solids in a wastewater consist of the insoluble or suspended solids and the soluble compounds dissolved in water. The suspended solids content is found by drying and weighing the residue removed by the filtering of the sample. When this residue is ignited the volatile solids are burned off. Volatile solids are presumed to be organic matter, although some organic matter will not burn and some inorganic salts break down at high temperatures (Ron and George, 1998).

Further, Ron and George (1998) state that, the organic matter consists mainly of proteins, carbohydrates and fats. Between 40 and 65 % of the solids in an average wastewater are suspended. Settleable solids, expressed as millilitres per litre, are those that can be removed by sedimentation (Ron and George, 1998).

Finally, Ron and George (1998) suggest that usually about 60 % of the suspended solids in a municipal wastewater are Settleable (Ron and George, 1998). Solids may be classified in another way as well: those that are volatilized at a high temperature (600 °C) and those that are not. The former are known as volatile solids, the latter as fixed solids.

Usually, volatile solids are organic.

2.6.1.2 Colour

Colour is a qualitative characteristic that can be used to assess the general condition of wastewater. Wastewater that is light brown in colour is less than 6 h old, while a light-to-medium grey colour is characteristic of wastewaters that have undergone some degree of decomposition or that have been in the collection system for some time. Lastly, if the colour is dark grey or black, the wastewater is typically septic, having undergone extensive bacterial decomposition under anaerobic conditions. The blackening of wastewater is often due to the formation of various sulphides, particularly, ferrous sulphide. This results when hydrogen sulphide produced under anaerobic conditions combines with divalent metal, such as iron, which may be present. Colour is measured by comparison with standards (Wang and Howard, 2004).

2.6.1.3 Odour

The determination of odour has become increasingly important, as the general public has become more concerned with the proper operation of wastewater treatment facilities. The odour of fresh wastewater is usually not offensive, but a variety of odorous compounds are released when wastewater is decomposed biologically under anaerobic conditions.

2.6.1.4 Temperature

The temperature of wastewater is commonly higher than that of the water supply because warm municipal water has been added. The measurement of temperature is important

because most wastewater treatment schemes include biological processes that are temperature dependent. The temperature of wastewater will vary from season to season and also with geographic location. In cold regions the temperature will vary from about 7 to 18 °C, while in warmer regions the temperatures vary from 13 to 24 °C (Ron & George, 1998).

2.6.2 Chemical characteristics

2.6.2.1 Inorganic chemicals

The principal chemical tests include free ammonia, organic nitrogen, nitrites, nitrates, organic phosphorus and inorganic phosphorus. Nitrogen and phosphorus are important because these two nutrients are responsible for the growth of aquatic plants. Other tests, such as chloride, sulphate, pH and alkalinity, are performed to assess the suitability of reusing treated wastewater and in controlling the various treatment processes (Rein, 2005).

Trace elements, which include some heavy metals, are not determined routinely, but trace elements may be a factor in the biological treatment of wastewater. All living organisms require varying amounts of some trace elements, such as iron, copper, zinc and cobalt, for proper growth. Heavy metals can also produce toxic effects; therefore, determination of the amounts of heavy metals is especially important where the further use of treated effluent or sludge is to be evaluated. Many of metals are also classified as priority pollutants such as arsenic, cadmium, chromium, mercury, etc. Measurements of gases, such as hydrogen sulphide, oxygen, methane and carbon dioxide, are made to help the system to operate (Wang and Howard, 2004).

According to Wang and Howard, the presence of hydrogen sulphide needs to be determined not only because it is an odorous and very toxic gas but also because it can affect the maintenance of long sewers on flat slopes, since it can cause corrosion.

Measurements of dissolved oxygen are made in order to monitor and control aerobic biological treatment processes. Methane and carbon dioxide measurements are used in connection with the operation of anaerobic digesters.

2.6.3 Biological Characteristics:

Biological constituents of wastewater include coliform organisms, specific microorganisms and toxicity. These characteristics are used to assess the presence of pathogenic bacteria, specific organisms present and to detect the level of toxicity, whether acute toxic unit or chronic toxic unit (Burton *et al.*, 2003).

2.6.2.2 Organic Chemicals

Over the years, a number of different tests have been developed to determine the organic content of wastewaters. In general, the tests may be divided into those used to measure gross concentrations of organic matter greater than about 1 mg/l and those used to measure trace concentrations in the range of 10^{-12} to 10^{-3} mg/l. Laboratory methods commonly used today to measure gross amounts of organic matter (greater than 1 mg/l) in wastewater include (1) biochemical oxygen demand (BOD), (2) chemical oxygen demand (COD) and (3) total organic carbon (TOC). Trace organics in the range of 10^{-12} to 10^{-3} mg/l are determined using instrumental methods including gas mass spectroscopy and chromatography. Specific organic compounds are determined to assess the presence of priority pollutants (Metcalf and Eddy, 1991). The BOD, COD and TOC tests are gross measures of organic content and as such do not reflect the response of the wastewater to various types of biological treatment technologies. It is therefore desirable to divide the wastewater into several categories, as shown in Figure 2.1.



Fig. 2.1 Partition of organic constituents of a wastewater (Eckenfelder, 1989)

2.6.2.3 Volatile organic carbons (VOC)

Volatile organic compounds such as benzene, toluene, xylenes, trichloroethane, dichloromethane, and trichloroethylene, are common soil pollutants in industrialized and commercialized areas. One of the more common sources of these contaminants is leaking underground storage tanks. Improperly discarded solvents and landfills, built before the introduction of current stringent regulations, are also significant sources of soil VOCs. Many of organic substances are classified as priority pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic, acetaldehyde, formaldehyde, 1,3-butadiene, 1,2dichloroethane, dichloromethane, hexachlorobenzene (HCB), etc, (Rein, 2005).

2.6.3 Heavy metals and inorganic species

2.6.3.1 Heavy metal discharges

According to White and Reddy (2003), heavy metals are discharged by several industries but chromium is the widely used and so forms a significant percentage of discharges to the environment. They further stressed that many of the pollutants (e.g., mercury lead, pesticides, and herbicides) discharged are harmful especially to the aquatic ecosystem (eg

is as shown in plate. 2.2 below. These pollutants as indicated have the capacity to lower reproductive success, prevent proper growth and development, and even cause death in some cases.



Plate 2.2 Pollutants entering aquatic Ecosystems

However, chromium is not the metal that is most dangerous to living organisms. Much more toxic are cadmium, lead and mercury. These have a tremendous affinity for sulphur and disrupt enzyme function by forming bonds with sulphur groups in enzymes. Protein carboxylic acid ($-\text{CO}_2\text{H}$) and amino ($-\text{NH}_2$) groups are also chemically bound by heavy metals. Cadmium, copper, lead and mercury ions bind to cell membranes, hindering transport processes through the cell wall. Heavy metals may also precipitate phosphate bio-compounds or catalyze their decomposition (Wang and Howard, 2004).

The pollutant cadmium in water may arise from industrial discharges and mining wastes. Cadmium is widely used in metal plating. Chemically, cadmium is very similar to zinc, and these two metals frequently undergo geochemical processes together. Both metals are found in water in the +2 oxidation state. The effects of acute cadmium poisoning in humans are very serious. Among them are high blood pressure, kidney damage, destruction of testicular

tissue, and destruction of red blood cells. Cadmium may replace zinc in some enzymes, thereby altering the stereo-structure of the enzyme and impairing its catalytic activity. Cadmium and zinc are common water and sediment pollutants in harbours surrounded by industrial facilities (White and Reddy, 2003).

Inorganic lead arising from a number of industrial and mining sources occurs in water in the +2 oxidation state. Lead from leaded gasoline used to be a major source of atmospheric and terrestrial lead, much of which eventually enters natural water systems. Acute lead poisoning in humans causes severe dysfunction in the kidneys, reproductive system, liver, and the brain and nervous system (Rein, 2005).

Mercury is found as a trace component of many minerals, with continental rocks containing an average of around 80 ppb, or slightly less, of this element. Cinnabar, red mercuric sulphide, is the chief commercial mercury ore. Metallic mercury is used as an electrode in the electrolytic generation of chlorine gas, in laboratory vacuum apparatuses and in other applications. Organic mercury compounds used to be widely applied as pesticides, particularly fungicides. Mercury enters the environment from a large number of miscellaneous sources related to human use of the element. These include discarded laboratory chemicals, batteries, broken thermometers, lawn fungicides, amalgam tooth fillings and pharmaceutical products. Sewage effluent sometimes contains up to 10 times the level of mercury found in typical natural waters. The toxicity of mercury was tragically illustrated in the Minamata Bay area of Japan during the period of 1953-1960. A total of 111 cases of mercury poisoning and 43 deaths were reported among people who had consumed seafood from the contaminated bay. Among the toxicological effects of mercury were neurological damage, including irritability, paralysis, blindness, insanity, chromosome breakage and birth defects (Rein, 2005).

2.6.3.2 Cyanide

Cyanide ion, CN^- , is probably the most important of the various inorganic species in wastewater. Cyanide, a deadly poisonous substance, exists in water as HCN which is a weak acid. The cyanide ion has a strong affinity for many metal ions, forming relatively less toxic ferrocyanide, $\text{Fe}(\text{CN})_6^{4-}$ with iron (II), for example. Volatile HCN is very toxic and has been used in gas chamber executions in the United States. Cyanide is widely used in industry, especially for metal cleaning and electroplating. It is also one of the main gas and coke scrubber effluent pollutants from gas works and coke ovens. Cyanide is widely used in certain mineral processing operations (Petzoldt and Uhlmann, 2006)

2.6.3.3 Ammonia

Ammonia is the initial product of the decay of nitrogenous organic wastes, and its presence frequently indicates the presence of such wastes. It is a normal constituent of some sources of groundwater and is sometimes added to drinking water to remove the taste and odour of free chlorine. Since the pK_a (The negative log of the acid ionization constant) of the ammonium ion, NH_4^+ is 9.26, most ammonia in water is present as NH_4^+ rather than NH_3 (Petzoldt and Uhlmann, 2006).

2.6.3.4 Other inorganic pollutants

Hydrogen sulphide, H_2S , is a product of the anaerobic decay of organic matter containing sulphur. It is also produced in the anaerobic reduction of sulphate by microorganisms and is developed as a gaseous pollutant from geothermal waters. Wastes from chemical plants, paper mills, textile mills and tanneries may also contain H_2S . Nitrite ion, NO_2^- , occurs in water as an intermediate oxidation state of nitrogen. Nitrite is added to some industrial processes to inhibit corrosion; it is rarely found in drinking water at levels over 0.1 mg/l. Sulphite ion, SO_3^{2-} , is found in some industrial wastewaters (WASAMED,

2004).

2.6.3.5 Organic pollutants

Effluent from industrial sources contains a wide variety of pollutants, including organic pollutants. Primary and secondary sewage treatment processes remove some of these pollutants, particularly oxygendemanding substances, oil, grease and solids. Others, such as refractory (degradation-resistant) organics (organochlorides, nitro compounds etc.), and salts and heavy metals, are not efficiently removed. Soaps, detergents and associated chemicals are potential sources of organic pollutants. Most of the environmental problems currently attributed to detergents do not arise from the surface-active agents, which basically improve the wetting qualities of water. The greatest concern among environmental pollutants has been caused by polyphosphates added to complex calcium, functioning as a builder (WASAMED, 2004).

Bio-refractory organics are poorly biodegradable substances, prominent among which are aromatic or chlorinated hydrocarbons (benzene, bornyl alcohol, bromobenzene, chloroform, camphor, dinitrotoluene, nitrobenzene, styrene etc.). Many of these compounds have also been found in drinking water. Water contaminated with these compounds must be treated using physical and chemical methods, including air stripping, solvent extraction, ozonation and carbon adsorption (Rein, 2005).

First discovered as environmental pollutants in 1966, polychlorinated biphenyls (PCB compounds) have been found throughout the world in water, sediments and bird and fish tissue. They are made by substituting between 1 and 10 Cl atoms onto the biphenyl aromatic structure. This substitution can produce 209 different compounds (Rein, 2005).

2.7 Pollution Load and Concentration

According to Todar (2008), in most industries, wastewater effluents result from the following water uses: Sanitary wastewater (from washing, drinking, etc.); Cooling (from disposing of excess heat to the environment); Process wastewater (including both water used for making and washing products and for removal and transport of waste and byproducts); and Cleaning (including wastewater from cleaning and maintenance of industrial areas). Excluding the large volumes of cooling water discharged by the electric power industry, the wastewater production from urban areas is about evenly divided between industrial and municipal sources. Therefore, the use of water by industry can significantly affect the water quality of receiving waters (Rein, 2005).

The level of wastewater loading from industrial sources varies markedly with the water quality objectives enforced by the regulatory agencies. There are many possible in-plant changes, process modifications and water-saving measures through which industrial wastewater loads can be significantly reduced. Up to 90 % of recent wastewater reductions have been achieved by industries employing such methods as recirculation, operation modifications, effluent reuse or more efficient operation. As a rule, treatment of an industrial effluent is much more expensive without water-saving measures than the total cost of in-plant modifications and residual effluent treatment. Industrial wastewater effluents are usually highly variable, with quantity and quality variations brought about by bath discharges, operation start-ups and shutdowns, working-hour distribution and so on (Rein, 2005). A long-term detailed survey is usually necessary before a conclusion on the pollution impact from an industry can be reached.

2.8 Industrial Waste stream Variables

This section discusses variables of industrial wastewaters, how they can be generally classified, the importance of knowing the frequency of generation and discharge.

2.8.1 Compatible and noncompatible pollutants

Compatible pollutants can be defined as those pollutants that are normally removed by the publicly owned treatment works (POTW) system. Biochemical oxygen demand (BOD), suspended solids (SS), oil and grease, and ammonia are considered compatible pollutants. The POTW is designed to treat primarily domestic wastewater and the compatible pollutants discharged by industry (Andersson *et al.*, 2008).

Noncompatible pollutants are defined as those pollutants which are not normally removed by the POTW, may be toxic to a biological IWTS (industrial wastewater treatment system), and may cause pass-through or interference with the treatment system. Even some biologically degradable wastes such as soluble, synthetic cooling oils may cause interference with the heavy metal removal system by inhibiting floc formation. Other examples of noncompatible pollutants include heavy metals such as copper, nickel, lead, and zinc; organics such as methylene chloride, 1,1,1-trichloroethylene, methyl ethyl ketone, acetone, and gasoline; and sludges containing toxic organics or metals (Rein, 2005).

From the perspective of the POTW, conventional pollutants sometimes exhibit the characteristics of noncompatible pollutants, and vice versa. Soluble BOD from a food industry may have some harmful effects on a POTW's secondary treatment system. The accidental discharge of ammonia by a fertilizer manufacturer may disrupt the nitrification/denitrification or stripping tower processes used by the POTW to treat ammonia. On the other hand, some of the heavy metals (usually classified as noncompatible pollutants) are used as micronutrients to aid in the production of biological mass and the

reduction of BOD. Certain organic chemical wastes such as acetone and isopropanol are biodegradable and, in dilute solutions, are removed by biological action in secondary treatment (Laskin *et al.*, 2005).

2.8.2 Dilute solutions

The discharges from continuous manufacturing processes are normally dilute solutions of compatible and sometimes noncompatible pollutants. They may be discharged to the industry's pretreatment system or directly to the POTW without any pretreatment. Manufacturing processes such as plating bath rinses, raw food cleaning, and crude oil dewatering are all examples of dilute solutions of pollutants that may be discharged directly to a POTW sanitary sewer. If a problem occurs in the manufacturing process, a probable result is that the quality of wastewater will change; it may be more laden with pollutants.

Some wastestreams from utility services, such as cooling tower and boiler blowdown, are continuous and represent the discharge of dilute solutions (Todar, 2008).

Another low-strength wastewater is storm water runoff from chemical handling and storage areas. Products which may have spilled on the industry's grounds are washed off during a rainstorm or during the spring thaw. The pollutant concentration is usually too dilute to require pretreatment before discharge to the sewer, but exceeds the discharge standards for discharge to surface waters. While the strength of the storm runoff may be low, the volume that must be treated in addition to normal flow to the pretreatment system or to the POTW can cause hydraulic capacity problems. Excessive flows can be diverted to storage reservoirs or basins and then gradually discharged to the pretreatment system. A great deal of attention is presently focused on cleaning up groundwater sources that have been contaminated by leaking underground storage tanks. Cleanup projects of this nature typically involve large quantities of wastes that may contain high concentrations of

solvents, fuels, heavy metals and pesticides. Because of the public attention surrounding groundwater cleanup projects, pretreatment of the contaminated water is almost always required and the result is usually a "high quality" industrial wastewater (Todar, 2008).

2.8.3 Concentrated solutions

Typically, concentrated solutions are batch-generated and the frequency of generation is usually not daily but weekly, monthly, annually, or even longer. These solutions are process chemicals or products that cannot be reconditioned or reused in the same manufacturing process. Concentrated solutions such as spent plating baths, acids, alkalies, static drag out solutions, and reject product may have concentrations of pollutants hundreds or thousands of times higher than the discharge limits of the POTW or higher than can be adequately treated by the pretreatment system if discharged all at once. Time have to be taken for examine and understand each manufacturing process, then identify these concentrated solutions and take the necessary steps to prevent damage to the treatment facilities (Rein, 2005).

Some wastes may be considered concentrated by the POTW but not by the industry. For example, the ten percent sulfuric acid solution used for pickling parts is considered "Dilute" by comparison to the 98 percent or 50 percent stock solution that the industry uses to make up the pickling solution. When this solution is spent or can no longer be used as a pickling solution, proper treatment and disposal are required. From the industrial manufacturer's point of view, the solution is spent and no longer concentrated.

However, from a wastewater treatment point of view, the solution is concentrated since it contains high concentrations of acid (pH less than 1.0) and heavy metals (1,000 mg/L) compared to the normal pH of 1.0 to 4.0 and heavy metal concentrations of less than 100 mg/L (I.W.T, 1999).

Another source of concentrated solutions is the wastewater from equipment cleanup. While the amount of material in the process chemical bath may be considered dilute by industry standards, it forms a concentrated wastestream when discharged during the cleanup of manufacturing equipment. Cleanup wastestreams contain a high concentration of the product during the first washing of the tank, pipe or pump. This discharge of concentrated waste is followed by successive rinses which contain less and less pollutants. If cleanup flow concentrations are not equalized, the cleanup cycle can cause problems in the (IWTs). Spills of process chemicals to the floor, if not contained, can flow directly to the floor drain and the pretreatment or sewer system. The adverse effects on the pretreatment system and POTW are the same as those of any other concentrated solutions. This is why chemical containment areas must not have drains (Rein, 2005).

2.9 Concentration versus mass of the pollution

An understanding of the concentration and the mass of a pollutant in an industrial waste is needed to determine the effects on the industry's pretreatment system, the POTW collection, treatment, and disposal systems, and the sampling of the industry's discharge. The concentration of a substance in wastewater is normally expressed as milligrams per litre (mg/L) and is a measurement of the mass per unit of volume. The mass of a substance is normally expressed in pounds or kilograms and is a weight measurement. A mass emission rate is a measurement of weight per unit time and is usually expressed as pounds or kilograms per day (Todar, 2008).

Many of the electroplating and all of the metal finishing categorical standards are written in concentrations, whereas most of the other categorical standards are written as mass emission rate standards. The mass emission rate standards recognize that with more production and water, the mass of pollutant will also increase. This approach prevents

dilution of the pollutant to meet concentration limitations. The mass emission rate of a substance can be calculated by knowing the concentration of the pollutant in the wastewater and the volume of wastewater (Todar, 2008).

The effects of pollutant concentration and mass on the POTW collection, treatment, and disposal systems are generally the same as their effects on the IWTs. However, hydraulic problems in any portion of the POTW system could cause pollutants to pass through the POTW untreated, even though the mass of the pollutant did not change. If the daily mass loading is the same, but the instantaneous mass emission rate is highly variable, the POTW's collection system may not equalize the slug loading of a highly concentrated solution. The result may be interference with the treatment system, causing violations of either or both effluent and sludge disposal limitations (Todar, 2008).

2.10 Frequency of Generation and Discharge

Important to both the operation of the industry's pretreatment system and the POTW's collection, treatment, and disposal systems is the frequency of industrial waste generation and discharge. Wastewater sampling to investigate process problems and to determine compliance with the discharge limits are also affected by the hours of discharge.

2.10.1 Hours of operation versus discharge

Normally, the hours of operation are also the hours of discharge to the IWTs. Thus the operator can generally expect to receive flow for treatment during the hours of operation. If the production is constant, the discharge volume and chemical constituents will also be constant. Several common situations where an industrial waste must be treated after the normal production hours are described below:

1. The "wet" processes run for one shift, but the "dry" processes run for two. The dry processes may require utilities such as compressed air or a boiler, each having a wastewater discharge.
2. In industries with long collection systems, production and wastewater flow to the system may stop, but the IWTs may continue to operate and discharge until the wastewater in the collection system has been processed.
3. Spills, accidental discharges or storm water flow that goes to the IWTs may cause the IWTs to operate outside of the normal production hours.
4. A food processing plant operates for one or two shifts, generating some wastewater, but most of the equipment cleaning operations occurs on an off shift. The cleaning generates most of the wastewater volume.
5. The IWTs have an equalization tank either at the beginning of the IWTs or at the end of the manufacturing system. Discharge from the equalization tank to the rest of the IWTs may continue after production stops because it is programmed to pump to the next unit process until it reaches its low level.

Equalization of the wastewater is an important factor affecting the actual hours of wastewater discharge to the IWTs and sewer. In order to deliver a relatively constant flow and concentration of pollutants to the IWTs, large wastewater collection sumps, equalization tanks or storage tanks may be used. As noted above, these equalization devices may also lengthen the time of discharge beyond the actual hours of operation of the manufacturing facility. Equalization of industrial wastewater flows can also be beneficial to the POTW. By lengthening the hours of discharge from the industry, there is an effective increase in the available hydraulic capacity of the POTW collection system because of the decreased industrial flow rates. Due to the normal diurnal variation in domestic wastewater flows (peak flows usually occur between 8:00 a.m. and 6:00 p.m.), the hydraulic capacity

of a sewer may be exceeded if a large industrial flow is allowed to be discharged to the sewer during a short period. Therefore, it may be necessary for the industry to discharge only at night. Sampling of this discharge would then be shifted to the night-time hours.

2.10.2 Discharge variations

Industries that have daily, weekly, or seasonal manufacturing cycles will show variations in wastewater generation. Business cycles for each of the various segments of the industrial community will have an effect on production, and therefore on the generation of wastewater. In certain industries, variations in the quantity of wastewater reflect the nature of the business or the business cycle of the particular business segment. Variations in the quality of industrial waste can also occur due to market forces or environmental concerns requiring a different type of product. In the metal finishing industry, for example, companies are moving from cadmium-plated metal, an environmentally more hazardous substance with more stringent discharge limitations, to zinc-plated parts. Knowledge of the industry, the manufacturing processes, and market forces are valuable tools needed by the industrial waste treatment plant operator to anticipate variations in industrial discharges.

2.10.3 Continuous and intermittent discharges

Discharges from manufacturing facilities usually reflect the type of manufacturing process used at the facility. Processes which are continuous tend to produce wastewater on a continuous basis, with relatively constant volume and quality. Batch processes, or activities that occur once per shift, per day, or per week, tend to produce an intermittent discharge. Also, as a general rule-of-thumb, the larger the manufacturing process, the more likelihood there is of a continuous discharge. Examples of manufacturing processes that have continuous discharges include rinsing or cleaning of parts or food, processing of crude oil, either at the well head or refinery, air or fume scrubbing, papermaking, and leather tanning.

Intermittent discharges of wastewater are characterized by discharges of a volume of wastewater separated by a time period between discharges.

These typically occur at the beginning or ending of a manufacturing process or during equipment cleanup, a spill, replacement of spent solution, or disposal of a reject product. Intermittent discharges also tend to be more concentrated and of smaller volume than the wastewater normally discharged. For an industrial pretreatment facility, the intermittent discharges and the variations in waste generation determine the design capacity of the system.

2.11 Industrial effluents

Whereas the nature domestic wastewater is relatively constant, the extreme diversity of industrial effluents calls for an individual investigation for each type of industry and often entails the use of specific treatment processes. Therefore, a thorough understanding of the production processes and the system organization is fundamental.

There are four types of industrial effluents to be considered:

- 1- General manufacturing effluents: Most processes give rise to polluting effluents resulting from the contact of water with gases, liquids or solids.

The effluents are either continuous or intermittent. They even might only be produced several months a year (campaigns in the agrifood-industry, two months for beet sugar production, for example). Usually if production is regular, pollution flows are known.

However, for industries working in specific campaigns (synthetic chemistry, pharmaceutical and parachechemical industries), it is more difficult to analyse the effluents as they are always changing.

2- Specific effluents: Some effluents are likely to be separated either for specific treatment after which they are recovered, or to be kept in a storage tank ready to be reinjected at a weighted flow rate into the treatment line. Such as, pickling and electroplating baths; spent caustic soda.

3- General service effluents: These effluents may include wastewater (canteens, etc.), water used for heating (boiler blowdown; spent resin regenerants), etc.

4- Intermittent effluents: These must not be forgotten; they may occur from accidental leaks of Products during handling or storage, from floor wash water and from polluted water, of which storm water may also give rise to a hydraulic overload. For the correct design of an industrial effluent treatment plant, the following parameters must be carefully established (I.W.T, 1999): types of production, capacities and cycles, raw materials used, composition of the make-up water used by the industrial plant, possibility of separating effluents and/or recycling them, daily volume of effluents per type, average and maximum hourly flows (duration and frequency by, type), average and maximum pollution flow (frequency and duration) per type of waste and for the specific type of pollution coming from the industry under consideration.

Since it can seriously, disturb the working of certain parts of the treatment facilities (glues, tars, fibers, oils, sands, etc.). When a new factory is being designed, these parameters will be ascertained after analysis of the manufacturing processes and compared with data from existing factories. The amount and degree of pollution depend on the methods of manufacturing.

2.12 Effects of Industrial Wastewater

Some of the effects of industrial wastewater discharges on collection and treatment systems were discussed briefly before. This section will describe in more details how industrial wastewaters can affect the operation and performance of both the IWTs and the POTW, and how direct discharges to the environment could affect receiving waters. If an industrial wastestream is discharged to an IWTs which was not designed to handle it, the discharge may cause serious problems. It could interfere with the IWTs processes and/or pass through untreated to the POTW sewer. Similar effects may occur at the POTW and result in a violation of the discharge permit or prevent the reuse or recycle of water.

The untreated industrial discharge could contaminate the industrial wastewater sludge or cause an air emission problem. It potentially could affect maintenance or production personnel working in or around the industrial sewer or treatment system through the generation of a toxic gas. The seriousness of the effect will depend on the characteristics of the industrial wastestreams, the size and design of the IWTs, and the standards for discharge, recycle or disposal of wastewater, sludge or air emissions. Accordingly, the effects of discharging the industrial effluent to the POTW or the environment will depend on the characteristics of the effluent, the type and size of the POTW system, and their standards for sludge and wastewater disposal or reuse. Waste characteristics such as temperature, pH, odor, toxicity, concentration, and flow must be evaluated to determine their acceptability to the IWTs. Similarly, understanding these characteristics of the IWTs effluent will also enable to predict the effect the effluent may have on the POTW system.

The effects of industrial waste discharges are not always negative; some beneficial effects also occur. For example, in a short POTW collection system, such as a small treatment system discharging to a trout stream, a continuous discharge of boiler blowdown from a large power plant can be cause for concern. High temperature discharges to sewers can

accelerate (1) biological degradation, (2) slime growths, (3) odor production from anaerobic decomposition, and (4) corrosion of concrete pipe and metal sewer appurtenances. The high temperature wastewater can cause a bacterial population shift in the secondary treatment causing floating sludge and reduced BOD removal efficiency. This in turn would endanger the treatment plant's ability to meet its discharge permit limits.

The high temperature wastewater may also cause the plant to exceed its temperature standards to the trout stream. On the other hand, the high temperature wastewater discharge from a power plant in a larger conveyance and treatment system located in a colder climate may, in fact, enhance the POTW secondary treatment processes removal efficiencies by keeping the wastewater temperature above 65 F (18 °C) all year. When evaluating an industrial wastestream, it is necessary to understand the specific characteristics of the waste and how they may affect each portion of the IWTs and in turn how the effluent will affect the POTW's conveyance, treatment, disposal, and reuse facilities.

2.12.1 Effects on the collection system

The IWTs collection system is designed and built to transport the individual and combined industrial wastestreams. If the collection system is not designed, built or operated correctly or if there is a spill, leak or accidental discharge of materials, the industrial discharges by themselves or in combination with other industrial wastewater can cause plugging, odors, erosion, corrosion, explosions, and numerous other problems. The good news, however, is that some industrial discharges contain substances that have a positive effect on the collection system, which may mitigate the effect of another industrial wastewater. The beneficial effects could include in-line neutralization. Large flows may produce scouring

velocities in low-flow sewers or dilute a concentrated spill enough to produce a treatable waste within the capabilities of the IWTS.

2.12.2 Hydraulic capacity problems

Hydraulic overload problems can occur if a large slug of wastewater or a continuous flow is discharged to the industrial sewer. The cause of a slug discharge may be a tank rupture or water line break. The cause of a continuous large flow may be a broken valve or one left open by mistake. The result in either case may be a sewer backup or pump station overflow. The smaller the capacity of the sewer or system, and the larger the contribution by the individual wastestream, the more likely it is this problem will occur. The solution may be to require flow restrictors on water valves or tank level switches to alarm high or low levels. If the condition regularly exists, for example, because of the introduction of a new manufacturing process that discharges a slug, equalization of the discharge may be necessary to store the effluent for off-peak hour discharge.

A hydraulic overload condition may also occur if similar manufacturing processes discharge at the same time. For example, in a food processing industry there may be two sections of the plant that clean tanks, reactors, or cooking pots at virtually the same time. While the discharge from one manufacturing line may not cause a problem, the similar discharge schedule from another line will combine the wastewater flows and cause a hydraulic overload condition. Possible solutions include equalization of flow at the IWTS or at the manufacturing process and scheduling production and cleanup so that both lines are not cleaning at the same time.

2.12.3 Plugging

If the discharge from a manufacturing process contains large amounts of fibrous or stringy materials, heavy solids, adhesives, or grease, plugging of the sewer system may result.

Plugging may occur just downstream of the discharge or in the pumping station. Fibrous or stringy materials get caught on rough surfaces and soon build up by entangling more solids.

These types of materials can also wind themselves around pump impellers or shafts causing the pump to fail. If problems are occurring, it may be an indication of a problem with the manufacturing process or that the waste should have been pretreated prior to discharge. Review the manufacturing process to determine if changes in the process or disposal of wastes are required or if the sewer needs to be enlarged to accommodate the materials. Heavy solids such as sand, ceramic or porcelain solids, or grindings can build up in a sewer or pump station wet well and reduce its hydraulic capacity. Solids that are not removed by pretreatment at the process may be discharged during peak wastewater flows during the day and may settle in pump station wet wells or oversized sewers downstream of the actual point of discharge when the flow subsides. The solids then have an opportunity to compact and may not become resuspended when the flow in the sewer returns to its peak flow.

This cycle of transporting the solids to a section of the collection system to settle, build up, and compact will eventually cause a restriction. A complete blockage may also occur if large objects are released to the sewer. Rags, tools, rejected food products, and discarded by-products may accidentally be released to the sewer due to operator carelessness or equipment malfunction. Because of their size, they can easily become wedged or entangled with other waste material and completely block the sewer or lift station pump.

2.12.4 pH Problems

The pH of an industrial discharge or the amount of acids and alkalies discharged to an industrial sewer are normally taken into account during design. While older plants in the petroleum, primary metals, and chemical industries have sewers constructed from less corrosion-resistant materials, many of the modern facilities use plastics, fiberglass or other

resin material for the industrial wastewater piping and sewer systems. Difficulties can arise when the manufacturing process changes or new chemicals are used that are not compatible with the existing sewer system. For example, fiberglass piping is an acceptable material of construction for sulfuric acid, but if the plating operation adds a process using hydrofluoric acid, the fiberglass may be severely damaged.

The industrial collection system may be designed to handle strong acids or alkalies, but may not be designed to withstand the heat of solution or reaction. For example, when a concentrated solution of sodium hydroxide (such as a spent alkaline cleaner) is discharged to the sewer, there could be a large temperature rise due to the heat of solution. If there is only a small quantity of stagnant wastewater in the sewer or pump station, the heat of solution may exceed 104 degrees Fahrenheit (40 °C), the deformation temperature of PVC (I.W.T, 1999). A spill of liquid chlorine can cause a temperature rise sufficient to produce steam resulting in a very toxic gas. Liquid chlorine can also damage plastics directly.

Acids will corrode concrete and cast iron sewers, concrete wet wells and tanks, the internal steel equipment in the primary and secondary clarifiers, trickling filters, aerators, and pumps. Mineral acids such as sulfuric, nitric, hydrochloric, and phosphoric acids are used extensively to clean base metals in the metal finishing industries. The fertilizer, iron and steel, mining, and petroleum industries also use vast quantities of these strong acids.

Mineral acids are also used in pretreatment systems for chromium reduction, neutralization of alkalies, and pretreatment of chelated metal plating solutions. Discharge of acid to the sewer from a spill or due to an equipment or control instrumentation failure can cause a pH violation and damage to the collection system. Spill containment provisions are essential in all areas where strong acids or alkalies are being used or stored. Too high a chlorine concentration is also corrosive to the collection system. Many platers will over-

chlorinate their cyanide wastewater to ensure they meet the requirements for cyanide concentrations. However, 40 to 50 mg/L excess chlorine can be corrosive to equipment and dangerous to personnel servicing a pump station.

The organic acids such as acetic, benzoic, oxalic and citric acids are weaker than mineral acids but, nonetheless, can have a pH of 4.0 or less. They too can corrode the sewer or attack the solvent joints of plastic or resin-based sewers. They also represent an organic load to the IWTS. If the pretreatment system does not remove organics, then these acids will represent an organic load to the POTW. Organic acids are typically used in food processing, beverage and consumer product manufacturing, and in the manufacture of chemical intermediates. Strong alkalies can corrode sewers and pumping stations; aluminium is particularly affected by high pH. High pH may also precipitate metals like calcium, potentially causing a solids build-up problem in the sewer. The strong alkalies include sodium hydroxide, lime, and ammonia. These are used in the metal finishing industry to clean and chemically mill base metals.

The water treatment industry uses significant quantities of lime to soften water, and pretreatment systems use strong alkalies to neutralize industrial wastes. The acceptable pH range for the discharge of industrial wastewater to the POTW collection system, as regulated in many industrial waste or sewer-use ordinances, is 6.0 to 9.0. In some ordinances, the pH range may be widened. Remembering that a pH of 7.0 is neutral, the trend is to allow more alkaline or basic material in the discharge rather than materials that are more acidic. The construction materials for sewers, pumping stations, treatment equipment, and biological processes all withstand alkaline discharges better than they withstand the discharge of corrosive acids. However, the discharge of strong alkalies to the POTW sewer may actually be beneficial in removing the anaerobic slime layer from the

sewer. When this is allowed, it should be done with the POTW's permission and knowledge of each discharge so that the POTW influent and secondary treatment can be monitored to prevent a treatment process upset.

The discharge of out-of-pH-range wastewater will result in damage to the sewer. Over a period of time such discharges can eventually corrode the pipe completely, causing exfiltration and contamination of the groundwater or infiltration of the groundwater into the sewer where the groundwater level is above the depth of the sewer. Industrial discharge violations of pH will also increase the maintenance requirements on pumps in the pumping stations. The damage to the pumps could eventually cause their failure, resulting in sewer backups and raw wastewater overflows.

2.12.5 Effects on the Treatment System

Industrial waste discharges damage treatment plant equipment in many of the same ways they damage the collection system. High volume discharges can exceed the pumping capacities; plugging of mechanical equipment such as bar screens or pumps can occur from a high solids discharge; acids and alkalies will corrode metal parts eventually causing failure; and flammables in the treatment plant are an explosive problem that can cause almost instantaneous damage. The added potential problem with industrial discharges is their effect on the treatment processes, including blinding of filters with oil; plugging microfiltration, nanofiltration or reverse osmosis membranes; interfering with recovery processes by contaminating the by-product; and overloading or upsetting the aerobic and anaerobic biological treatment processes.

2.12.6 Hydraulic overload

Unit processes such as neutralization, sedimentation, filtration and biological treatment operate best at a constant flow and constant loading conditions. Large changes in the

volume of flow or rapid changes in loading will decrease the efficiency of these processes. Hydraulic surges from an industrial process or utility discharge can cause these rapid variations. To compensate, the treatment plant must make a series of changes in their plant operating conditions, such as changing the sludge removal rate, increasing the blower output, or increasing the chemical addition rate. The alternative is to suffer possible effluent limit violations. Equalization of the flow at the source or installed as a part of the IWTs provides the best means of controlling hydraulic surges and operating the treatment processes at a constant or near-constant flow.

2.12.7 Interference

EPA defines interference as a discharge which, alone or in conjunction with discharges from other sources, inhibits or disrupts the POTW, its treatment processes or operations, its sludge processes, use or disposal, and is a cause of preventing the lawful use or disposal of sludge. This definition of interference applies equally well to discharges by industrial processes to the IWTs. By working closely with the manufacturing and utility operators, the IWTs operator can identify potential interference problems before they cause a discharge violation. Good communication between the operators in the manufacturing facility and the IWTs operator is the most reliable way to identify changes, whether sudden or gradual, in the operation of the plant or quality of the effluent. Discharge of untreated wastes or even large quantities of treated wastes can cause interference with the POTW treatment processes.

CHAPTER THREE

METHODOLOGY

3.1 DESCRIPTION OF STUDY SITE

Kumasi, the capital city of the Ashanti Region of Ghana, is located in the south-central part of the country, and is situated on 6°40'00"N 1°37'00"W. The Coca-Cola Bottling Company of Ghana Limited (TCCBCGL), Kumasi plant is located on plot No.2 Block 1 on the Lake Road at the Ahensan Industrial Area, Kumasi in the Ashanti Region. The site is bounded on the north-west by the Guinness Ghana Brewery Group –Ahensan (GGBGAhensan) and on the eastern and southern sides by the Ahensan Residential Area while the west is defined by the Lake Road and the Latex foam company.

The Coca Cola Bottling Company of Ghana (TCCBCGL), Kumasi has a work force of 234 out of which 225 are males and 9 females. The plant consists of the Production block, Administration block, Sales block, Warehouse, Wastewater Treatment plant, Canteen block and the Fleet Maintenance block.

3.2 COCACOLA BOTTLING COMPANY PRODUCTION DEPARTMENT

The Production Department of the Coca Cola Production Department operates 168 hours a week. The Department supervises a water treatment plant for the treatment of water from the municipal water supply for production of the beverage and the preparation of syrup which is used for the beverage. The department is also responsible for managing a biological wastewater treatment facility that discharges effluent into municipal drain as per regulatory standards.

Containers used in the final bottling of the product are washed at this section. It also has the quality assurance section that monitors and controlled all quality indicators in the plant.

TCCBCGL produces eight (8) branded products: Coca-Cola, Fanta, Burn, Sprite, Krest, Schweppes, Minute Maid and BonAqua. Twenty-four (24) flavours are currently bottled under the above mentioned brands, namely: Coca-Cola (Coke light, Coke Diet, CocaCola Regular), Burn Energy Drink, Sprite, BonAqua Drinking Water, Fanta (Fanta Orange, Fanta Cocktail, Fanta strawberry, Fanta Pineapple, Fanta Lemon Fanta Black Currant, Fanta Apple), Krest (Krest Ginger Ale, Krest Bitter Lemon, Krest Tonic Water, Krest Soda Water), Schweppes (Schweppes Bitter Lemon, Schweppes Soda Water, Schweppes malt drink), and Minute Maid (Minute Maid Pineapple, Minute Maid Apple, Minute Maid Cocktail, Minute Maid Orange).

The TCCBCGL operates two plants, Accra and Kumasi, made up of 5 production lines:

Four at the Accra plant and one at the Kumasi plant. From a sixty percent (60%) market share in 1995, the company in 2005 had control of eighty six percent (86%) and as of March 2007, the company controlled ninety five percent (95%) of the beverage industry in Ghana. A market leader in its own right, TCCBCGL has established extensive marketing and distribution networks since 1995 throughout the country.

To date, the company has created 31,000 new outlets; 8,000 mini-tables and 8,000 Electric coolers. It has established 10 distribution centres throughout the country and assisted individual Entrepreneurs to set up 60 Mini-Depots including manual distribution centres (MDC) which are independently managed.

3.3 SAMPLE COLLECTION

All samples for this study were collected from the Kumasi plant using the static sampling method. Wastewater samples were collected on shift bases, at flavour change over and when there were plant shutdown using Non-Pet Plastic bottles of 0.5 L and 1.5 L volumes

which had been thoroughly washed, cleaned with a detergent and double distilled water and labeled. Each bottle was rinsed with the water to be sampled. The bottles were then filled with its water content and tightly closed with its cap. These were transported in an ice chest to the Laboratory and analyzed within six hours. Samples for bacteriological analysis were collected in sterilized plain glass bottles and transported to the laboratory on ice packs in an ice chest.

Data obtained were analyzed and interpreted using Microsoft excel.

3.4 ANALYTICAL METHODS

3.4.1 pH

Hundred millilitres of the wastewater samples were measured into a beaker and its pH and temperature were determined using a Hanna pH meter (model HI 83141). Samples were analysed in triplicate.

3.4.2 Total Suspended Solids (TSS)

A filter paper was weighed and placed in a filtration apparatus. About 100 ml of the wastewater sample was mixed thoroughly and filtered through the filter paper. The residue retained on the filter paper was dried to a constant weight at 103°C to 105°C. The sample was then cooled in a dessicator and the filter paper together with the dried residue weighed

Calculation

$\text{TSS mg/l} = (A-B) \times 1000 / \text{Sample volume, ml:}$

Where;

A = weight of filter + residue

B = weight of filter

3.3.3 Conductivity

The conductivity of each sample was measured using a Tetra Con 325 cond 330i conductivity meter. The probe was immersed in a well shaken wastewater sample and the conductivity value recorded. The procedure was repeated three times for an average value to be determined.

3.3.4 Biochemical Oxygen Demand (BOD)

Dilution method

About 25 ml of the wastewater sample was measured and made up to 1 liter with dilution water. This was well mixed with a mixing rod. The mixed dilution was siphoned into two BOD bottles making sure that there was no air bubble. The Initial DO of one of the bottled samples was determined and the other bottle stoppered and incubated in the dark for five days at 20°C. Incubation in the dark prevents photosynthesis action by any algae contained in the sample that might give oxygen to interfere with the BOD determination.

Calculation:

$$\text{BOD}_5 \text{ mg/l} = (D_0 - D_1)/S$$

Where:

D₀ = initial DO

D₁ = final DO

S = volume of sample used

3.3.5 Chemical Oxygen Demand (COD)

Open refluxed method

Digestion tubes and caps were washed with 4M sulphuric acid to ensure that they were clean. Ten millilitres of wastewater sample was placed into the digestion tube and 6 ml

digestion solution added. Fourteen millilitres of sulphuric acid was carefully run down inside the tube to form an acid layer under the sample-digestion solution layer.

The tubes were tightly capped and inverted several times to mix completely. The samples were then refluxed for two hours and then cooled to room temperature. The samples were transferred into a larger container for titration. One to two millilitres of ferroin indicator was added and it was titrated with 0.1M FAS until the colour changed from blue-green to reddish brown. Again, the procedure was repeated for the blank sample.

Calculation:

$\text{COD mg/l} = (A-B) \times M \times 8000 / V_s$: Where:

A = volume of FAS used for blank

B = volume of FAS used for sample

M = Molarity of FAS

V_s = volume of sample used

3.3.6 Total Hardness

One gram portion of ammonium chloride buffer solution was added to 100 ml of the wastewater and two drops of Eriochrome Black T indicator solution added. The resulting solution was titrated against EDTA solution with continuous swirling until the last reddish colour changes to blue. The procedure was again repeated to determine an average value.

Calculation;

Total hardness in mg/L = $[A \times B \times M \times 1000] / \text{ml of sample}$

Where;

A= Volume of EDTA consumed

B= Concentration of EDTA

M= Molar mass of CaCO_3 (100g/mol)

3.3.7 Alkalinity (HCO_3)

Fifty millilitres of the wastewater sample was measured into a conical flask and two drops of methyl orange indicator added. This was titrated against 0.1M hydrochloric acid solution until a permanent pink colour develops.

Calculation:

$$\text{Alkalinity } (\text{HCO}_3) \text{ (mg/L)} = [C \times V_1 \times M \times 50000 / V_2]$$

Where, C= Molarity of Hydrochloric acid (0.1M)

V_1 = Volume of acid consumed

V_2 = Volume of sample taken

3.3.8 Dissolved Oxygen (DO)

Three hundred milliliters of the wastewater sample was measured and carefully transferred into a 250-300 ml bottle, 1.0 ml MnSO_4 was added to the sample followed by 1.0 ml alkali-iodide-azide, making sure that the tip of the pipette was held just above the liquid. The sample was stoppered carefully to exclude air bubbles and mixed by inverting the bottle a few times.

The precipitate was allowed to settle and the supernatant discarded. One milliliter conc. H_2SO_4 was added and swirled gently to dissolve the flocs formed. It was then titrated with 0.025M $\text{Na}_2\text{S}_2\text{O}_3$ to pale straw colour, a few drops of starch was added and titrated until the blue colour disappeared.

Calculation

$$\text{DO mg/l} = V \times M \times 8 \times 1000 / V_s - 2$$

Where

V = ml $\text{Na}_2\text{S}_2\text{O}_3$ used

M = Molarity $\text{Na}_2\text{S}_2\text{O}_3$

V_s = Sample volume

3.3.9 Colour

A Nessler tube was filled to the 50 ml mark with the wastewater sample. The sample was filtered if it was turbid. The tube was then placed in the right-hand compartment and the left-hand compartment left empty. The Disc NSA was placed in the disc compartment and the light of the Nessleriser switched on. The disc was then rotated to obtain a colour match. Then the colour was read in degree Hazen from the disc.

3.3.10 Turbidity

Twenty five millilitres of the wastewater sample was measured using a measuring cylinder and put into a clean sample cell. The surface of the sample cell was carefully cleaned with tissue paper. The sample cell was placed into the instrument light cabinet and covered with the light shield. Reading for turbidity was obtained in NTU.

Calculation in case of dilution

$$\text{Turbidity (NTU)} = A \times (B+C)/C$$

Where

A = NTU found in diluted sample

B = Volume of dilution water

C = Sample volume taken for dilution

3.3.11 Phosphorus

The spectrophotometer was switched ON and the programme number 490 was entered. The wavelength was rotated until the display showed 890 nm and then mg/l PO_4^{3-} -PV. A 10 ml Cell Riser was inserted into the cell compartment. The wastewater sample to be analyzed was well shaken and a 1ml portion measured and diluted with distilled water to 250 ml.

Ten millilitres of the sample was poured into a 10 ml sample cell. The content on one Phos Ver 3 phosphate powder pillow was added to the sample in the cell and immediately well shaken to mix. A blue colour forms if phosphate was present. The Shift Timer button was then pressed and allowed to react for two minutes. A second 10 ml sample cell was filled with a portion of the diluted sample which served as a blank. When the two minute reaction time was over the timer beeped and the display showed mg/l PO_4^{3-} -PV. The blank was placed into the cell holder and the light shield closed. The Zero button was pressed to set the machine to zero for that particular sample. The blank was removed and the prepared sample was put into the cell holder and the light shield closed. The Read button was pressed and the display showed the concentration of the PO_4^{3-} in mg/l. Other concentrations of phosphorus, P and polyphosphate (P_2O_5) were obtained by pressing arrow buttons in turn. The actual concentration was calculated by multiplying the read value by the dilution factor which was 250.

3.3.12 Determination of Coliforms (Total and Faecal) and Ecoli

Total and faecal Coliforms were Determined using the three-tube Most Probable Number method (MPN) according to standard procedures. Dilutions of 10^{-1} - 10^{-6} were prepared in 0.1% buffered peptone water (BPW) (Oxoid) and 1 ml of each dilution inoculated into 5 ml of Minerals Modified Glutamate medium (Oxoid). Tubes showing acid and gas production after incubation for 24 hours at 37 °C for total Coliforms and 44 °C also for faecal Coliforms were confirmed by plating on MacConkey no.3 agar (Oxoid) and the red or pink coloured colonies were examined. Counts were estimated from MPN tables. A loopful of the presumptive colonies were inoculated with 4ml of tryptophan broth in a tube and incubated at 44°C for 24 hours. 3-5 drops of Kovac's reagent were then added to the

tube and resulting red (cherry-red) colored ring on top of the media confirming positive indole test were examined. Ecoli counts were estimated from MPN tables.

3.3.13 Determination of *Enterococci*

Selective medium for enumeration of Enterococci according to Slanetz in water was used. 42g of selective Slanetz and Bartley Agar was measured and transferred into a sterilized narrow mouthed conical flask containing sterile distilled water. The flask was steamed on a hot plate and content poured into sterilized petri dish for it to set. One milliliter of the wastewater samples/suspension was transferred to cover entire surface of the media using sterilized automatic pipette. The Petri dishes with media facing down were incubated for 4 hours at 37 °C and for 24 hours at 44 °C. Using serial dilutions, the pink to dark colored colonies were examined. Counts were made and expressed as colony forming unit/ml (cfu/ml).

3.3.14 Determination of Metals

Fifty milliliters of wastewater samples were placed into a 100 ml beaker. Fifteen millilitres of concentrated nitric acid was added to the wastewater sample and the mixture heated until 50 ml of the mixture evaporates. The mixture was allowed to cool and an additional 5 ml of concentrated nitric acid was added and then heated again until 15 ml of the mixture was left. The sides of the beaker were washed with distilled water and the solution was transferred into a 100 ml volumetric flask.

3.3.15 Instrumental Analysis

Metal samples were analysed using the Atomic Absorption Spectrophotometer (AAS). The lamps are first calibrated using known concentration of the various metals to be measured or analyzed and distilled water as blank. Filtrates were aspirated, sprayed into fine aerosol

and converted into atomic vapour in a chamber aligned to the optical path of a spectrophotometer designed with a Hollow Cathode Electrode made of the element to be determined.

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CHAPTER FOUR

RESULTS 4.1 PHYSICOCHEMICAL PROPERTIES OF INFLUENT AND EFFLUENT

WASTEWATER IN A BEVERAGE INDUSTRY

Of all the physicochemical parameters measured, influent wastewater recorded higher mean values compared to the effluent wastewater except for dissolved oxygen (DO) and Phosphorus, where the effluent wastewater mean values were higher, 8 mg/L and 2.35 mg/L respectively (Table 1). The differences between the influent and effluent mean values were statistically significant (Table 1). Comparing these mean physicochemical parameters with the WHO standards, influent and effluent wastewater levels were all within the set limits for beverage industries, except for the effluent water which recorded E.C, Total alkalinity, D.O and Phosphorus values above the set limit (Table 1).

Table 1: Mean Physicochemical properties of influent and effluent Wastewater in a Beverage Industry

Parameter	Influent	Effluent	Standard Deviation-Influent	Standard Deviation-Effluent	P-Value	WHO Limit
pH	13.49	8.79	2.08	0.23	0.0178	9
Total Suspended Solids(mg/L)	168.11	38.22	14.70	5.31	0.0001	50
Electrical Conductivity (µs/cm)	2665.56	1746.44	89.32	200.56	0.0019	1500
Biological Oxygen Demand (mg/L)	97.22	19.11	7.90	3.69	0.0001	50
Chemical Oxygen Demand(mg/L)	778.67	81.78	100.82	4.69	0.0003	250
Total Hardness (mg CaCO ₃ /L)	88.56	64.44	2.22	8.18	0.0079	N/A

Total Alkalinity (mg CaCO ₃ /L)	754.78	260.22	21.88	28.00	< 0.0001	150
Dissolved Oxygen(mg/L)	3.15	8.00	0.90	0.99	0.0033	1
Colour (TCU)	158.45	90.78	17.08	5.31	0.0028	100
Turbidity (NTU)	67.78	27.78	3.47	3.66	0.0002	75
Phosphorus (mg/L)	1.40	2.35	0.19	0.07	0.0013	2

4.2 HEAVY METAL CONCENTRATION IN INFLUENT AND EFFLUENT WASTEWATER IN A BEVERAGE INDUSTRY

Iron and Zinc concentration in the influent wastewater (11.31 mg/L and 0.32 mg/L respectively) were higher compared to that in the effluent wastewater (1.42 mg/L and 0.08 mg/L respectively) (Table 2). However, in the influent wastewater, Lead (2.83 mg/L) and Copper (0.35 mg/L) were lower compared to 3.96 mg/L for Lead and 0.44 mg/L for copper in the effluent wastewater. There were statistically significant differences between mean values recorded for all the parameters in the influent and effluent wastewater except for Copper ($p = 0.4877$) (Table 2). In comparison with the WHO standard, mean Iron and Lead values in both influent and effluent wastewater exceeded the set limit (Table 2).

Table 2: Mean Heavy metal concentration in influent and effluent wastewater in a Beverage industry

Parameter	Influent	Effluent	Standard Deviation- Influent	Standard Deviation- Effluent	P-Value	WHO Limit
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Iron (mg/L)	11.31	1.42	0.16	0.06	< 0.0001	1
Lead (mg/L)	2.83	3.96	0.01	0.30	0.0029	0.1
Copper (mg/L)	0.35	0.44	0.04	0.21	0.4877	1
Zinc (mg/L)	0.32	0.08	0.07	0.01	0.0039	2

4.3 MICROBIAL NUMBERS IN INFLUENT AND EFFLUENT WASTEWATER IN A BEVERAGE INDUSTRY

Mean microbial numbers (MPN/100ml) in the wastewater effluent were higher for total coliforms (5.91) and *E. coli* (4.87) compared to that in the influent wastewater which were 5.54 for Total coliforms and 4.76 for *E. coli* (Table 3). However, faecal coliforms and *Enterococci* numbers were higher in the influent wastewater (Table 3). There were no statistically significant differences in the mean values recorded for both the influent and effluent wastewaters (Table 3).

Table 3: Mean Microbial Numbers in Influent and Effluent Wastewater in a Beverage Industry

Parameter	Influent (Log ₁₀)	Effluent (Log ₁₀)	Standard Deviation- Influent	Standard Deviation- Effluent	P-Value	WHO Limit
Total coliforms (MPN/100ml)	5.54	5.91	0.58	0.73	0.5312	2.6
Faecal coliforms (MPN/100ml)	5.87	5.15	0.57	0.78	0.2650	1
<i>Enterococci</i> (MPN/100ml)	2.88	1.30	0.45	1.36	0.1291	N/A

<i>E. coli</i> (MPN/100ml)	4.76	4.87	0.76	0.23	0.8162	1
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4.4 PHYSICOCHEMICAL PROPERTIES OF BEVERAGE INDUSTRY WASTEWATER DURING FAVOUR CHANGE OVER AND PLANT SHUTDOWN

Generally, during plant shut down and flavor change, samples of wastewater recorded higher mean values for all the parameters (Table 4),except Dissolved Oxygen and Phosphorus which recorded low mean values during flavor change over and at Plant Shutdown. There were no statistically significant differences between wastewater mean values recorded during flavour change and plant shut down except for C.O.D ($p=0.02$),Phosphorus ($p=0.00$) and Colour ($p=0.04$) (Table 4). Results obtained were above WHO standards except flavour change results for COD (205.33) and turbidity (55.67).

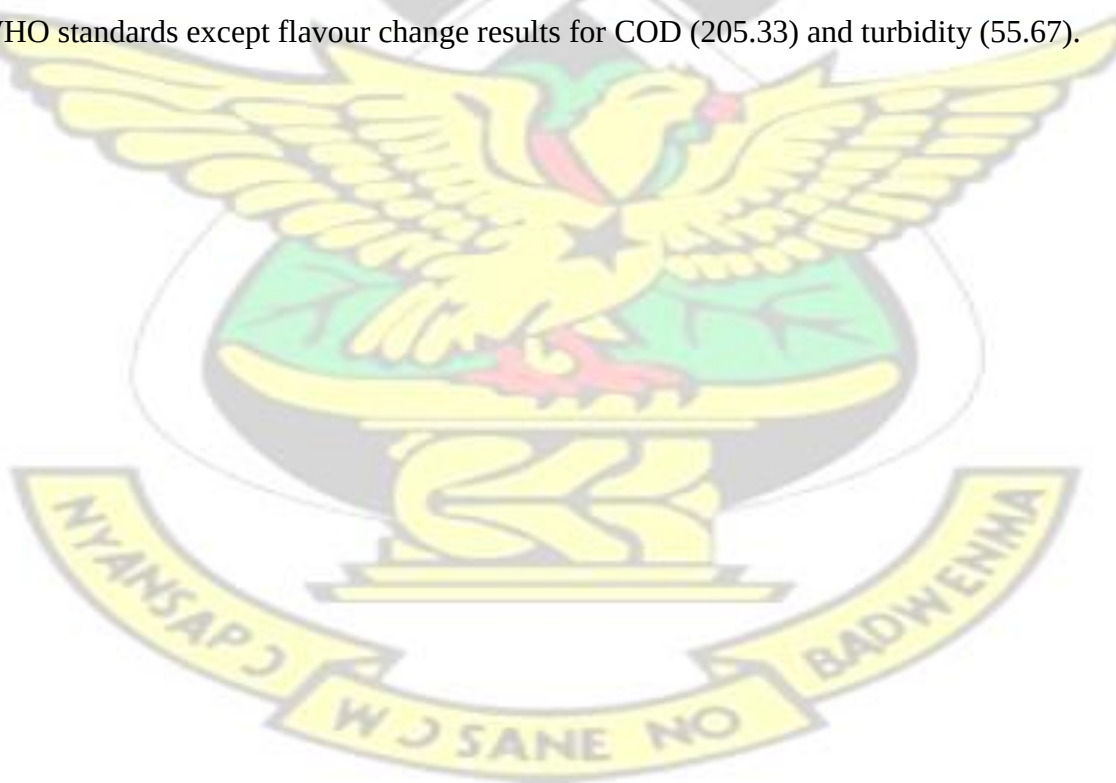


Table 4: Mean Physicochemical Properties of Beverage Industry Wastewater during Favour change over and plant Shutdown

Parameter	Flavour Change Over	Plant Shut Down	Standard Deviation -Change Over	Standard Deviation -Shut Down	P-Value	WHO Limit
pH	12.43	14.08	2.37	2.16	0.4225	9
Total Suspended Solids (mg/L)	157.78	181.50	43.47	17.35	0.4296	50
Electrical Conductivity (µs/cm)	2474.17	2695.50	118.46	153.73	0.1194	1500
Biological Oxygen Demand(mg/L)	112.17	111.67	8.13	6.93	0.9393	50
Chemical Oxygen Demand(mg/L)	205.33	497.50	96.13	109.29	0.0254	250
Total Hardness(mg CaCO ₃ /L)	79.83	130.50	7.69	53.90	0.1823	N/A
Total Alkalinity (mg CaCO ₃ /L)	430.5	577.83	50.94	87.36	0.0651	150
Dissolved Oxygen (mg/L)	6.03	7.03	0.61	0.51	0.0940	1
Colour(TCU)	119.67	196.33	20.71	40.60	0.0435	100
Turbidity (NTU)	55.67	84.83	5.92	18.01	0.0561	75
Phosphorus (mg/L)	2.20	2.61	0.05	0.12	0.0051	2

4.5 HEAVY METAL CONCENTRATIONSIN WASTEWATER DURING FAVOUR CHANGE OVER AND PLANT SHUTDOWN

Heavy metals concentration in the wastewater during Plant shutdown and Flavour Change Over were higher compared to the WHO standard except for Zinc (Table 5). These differences were however not statistically significant except for Zinc ($p=0.00$) and Iron

9p=0.01) (Table 5). Mean concentrations for Iron and Lead were also above the WHO Standard limit for wastewater.

Table 5: Mean Heavy metal Concentration in Wastewater during flavour change over and plant shutdown

Parameter	Flavour Change Over	Plant Shut Down	Standard Deviation Change Over	Standard Deviation- Shut Down	P-Value	WHO Limit
Iron (mg/L)	10.42	7.43	1.11	0.37	0.0114	1
Lead (mg/L)	3.12	4.07	0.67	0.82	0.1981	0.1
Copper (mg/L)	0.47	0.41	0.06	0.08	0.3962	1
Zinc (mg/L)	0.31	1.06	0.11	0.13	0.0016	2

4.6 MICROBIAL NUMBERS DURING FAVOUR CHANGE OVER AND PLANT SHUTDOWN

Total coliforms, *Enterococci* and *E. coli* numbers (MPN/100ml) in the wastewater samples during Plant Shutdown were generally higher than numbers recorded during Flavour Change over except for faecal coliforms (Table 6). There were no statistically significant differences in bacterial numbers between the two phases. However all the bacterial numbers in the two phases were above the WHO limits (Table 6).

Table 6 Mean Microbial numbers during favour change over and plant shutdown

Parameter	Flavour Change Over (Log ₁₀)	Plant Shut Down (Log ₁₀)	Standard Deviation Change Over	Standard Deviation- Shut Down	P- Value	WHO Limit
Total coliforms (MPN/ 100ml)	5.08	6.16	1.34	1.55	0.4141	2.6
Feacal coliforms (MPN/ 100ml)	5.77	5.49	0.48	1.16	0.7157	1
<i>Enterococci</i> (MPN / 100ml)	2.61	3.11	2.26	0.40	0.7255	N/A
<i>E. coli</i> (MPN/ 4.28 100ml)	4.28	4.90	0.88	0.16	0.2951	1

CHAPTER FIVE

DISCUSSION

The study has shown that wastewater treatment facilities play an integral part in the treatment of wastewater and its subsequent re-use or release into the environment with no or minimal impact. A good wastewater treatment produces effluent of better quality than the influent and at the same time meeting set standards of specifications by regulatory bodies. All the measured physicochemical parameters in this study recorded higher

concentrations in the influent compared to the released effluent after treatment (except for Dissolved Oxygen) (Table 1). Differences between the influent and effluent concentrations were statistically significant. However, despite a reduction in the values of these parameters indicating a possible treatment of the wastewater, mean electrical conductivity (E.C), total alkalinity, colour, turbidity and phosphorus concentrations exceeded the WHO set limit for wastewater from beverage industries (WHO, 2006).

Hajira *et al.*, (2013) has shown that the food and beverage industries discharge effluents with high E.C because of the combination of cleaning agents (detergents and NaOH) and additives for food and beverages (e.g. sodium benzoate- C_6H_5COONa and common salt - NaCl) that get into the cleaning water stream. These same chemicals were used in the beverage industry studied and could account for the high in alkalinity recorded. Imoobe and Koye (2011) reported lower E.C values compared to this study. However, in that study, water from rivers that receive effluents from the beverage industry were analyzed. Thus it is possible that the effluent from the factory was diluted with the stream water thereby reducing the E.C values considerably.

Although this study recorded significant reduction in the concentration of phosphorus, the effluent water still had concentrations above the WHO set limit. According to Perry *et al.* (2007), nitrogen, phosphorus, or both may cause aquatic biological productivity to increase, resulting in low dissolved oxygen and eutrophication of lakes, rivers, estuaries, and marine waters. Besides adding to nutrient-content of the water, addition of some forms of nitrogen and phosphorus will increase BOD and COD (Mahdieh and Amirhossein, 2009). However, the BOD and COD in the effluent wastewater from this study was lower than the WHO set limit, although it was higher in the influent. Through discharge of wastewater, phosphorus ends up in surface waters near the factories that use it. Phosphorus is generally the limiting

nutrient in fresh water systems and any increase in phosphorus usually results in more aquatic vegetation. There can be more phosphate in rivers and lakes, resulting in excessive algae growth (USEPA, 1986). These phosphates become detrimental when they over fertilize aquatic plants and cause stepped up eutrophication (Phiri *et al.*, 2005). Results from our study corroborate these findings.

The higher concentration of D.O reported in the effluent indicates that the treatment was effective in increasing the amount of this essential parameter of water. In an aquatic ecosystem, a greater number of aquatic organisms are supported when the dissolved oxygen (DO) concentration is high. Oxygen depletion due to waste discharge into a water system has the effect of increasing the numbers of decomposer organisms at the expense of others. When oxygen demand from a water system is so high because of the input of waste, it eliminates most of the dissolved oxygen from that stretch of water body. Secondly, organic matter degradation will occur through the activities of anaerobic organisms which do not require oxygen (Meertens *et al.*, 1995). The water then becomes devoid of aerobic organisms, and then also anaerobic decomposition also results in the formation of a variety of foul smelling volatile organic acids and gases such as hydrogen sulphide, methane and mercaptans. The stench from these can be quite unpleasant and is frequently the main cause of complaints from residents in the vicinity. Also the blower unit of the treatment plant which provides oxygen containing air might be faulty as is observed on some occasions therefore unable to supply the required amount of oxygen resulting in anaerobic respiration. The level of D.O recorded in this study is similar to results obtained by Imoobe and Koye (2011), where they accessed the effect of effluent from a soft drink processing factory on the physicochemical quality of a stream in Benin city, Nigeria. Recorded concentrations of BOD and COD in this study corroborate work by Attiogbe *et al.* (2002) at the same factory.

Attigboe *et al.* (2002) reported higher figures of B.O.D and similar values of C.O. D (202-678 mg/L and 535-1457 mg/L respectively).

Heavy metal contamination of surface water is a major health concern, therefore most wastewater treatment facilities pay attention to the reduction of these contaminants before release into receiving waters. The concentration of Iron and Zinc in the effluent wastewater was significantly lower compared to levels in the influent wastewater. However the final concentration of Iron in the effluent (Table 2) was still higher than the WHO set limit for beverage effluents (WHO, 2006). Iron can be present in several forms and easily combines with a variety of other ions. Little animal life may be found in streams with low pH (such as 3.5) and an elevated Iron concentration as was recorded in this study. The effect of iron on aquatic life is difficult to separate from the effect of low pH.

The release of wastewater from the beverage factory studied is released into the Sisa river, a feeder stream into the Subin river therefore contamination of the river water with low quality wastewater from the industry contributes to the degradation of aquatic life in the water body. The concentration of Lead and Copper in the influent was lower than the values recorded in the effluent giving an indication of possible accumulation in the treatment process resulting in the effluent having a higher concentration than the influent.

This high concentration of Lead in the effluent could be attributed to the inability of the treatment process to substantially remove the Lead in the wastewater and even at the end increasing its concentration. It is however worth noting that both the influent and effluent wastewater concentrations of Lead exceeded the WHO set limit. Heavy metals such as Lead can lower reproductive success, prevent proper growth and development, and even cause death of aquatic organisms. Lead has tremendous affinity for sulphur and disrupts enzyme

function by forming bonds with sulphur groups in enzymes. Protein carboxylic acid (-CO₂H) and amino (-NH₂) groups are also chemically bound by heavy metals including Lead. Ions of these heavy metals bind to cell membranes, hindering transport processes through the cell wall. Heavy metals may also precipitate phosphate biocompounds or catalyze their decomposition. Much lower concentrations of heavy metals were reported by Walakira and Okot-Okumu (2011) in Uganda from rivers receiving wastewater effluents from industries.

Microbial pathogens pose a serious health threat to a population due to the plethora of diseases that they could cause. Therefore the treatment of wastewater plays a role in reducing their numbers so as to limit the cases of disease incidence. In this study there was no significant reduction in the numbers of total coliforms and *E. coli* in the effluent as was expected of any wastewater treatment process. Additionally, bacterial numbers in the final effluent released into the environment contained bacterial pathogens well above the WHO limits (Table 3). This raises issues of concern due to the possibility of accumulation of pathogens in the treatment process, defeating the purpose of treating the water in the first place, which is to reduce the level of contaminants. The amount of bacteria in the treatment system is also critical to the release of odour, this is because during the biological treatment it is these bacteria that breakdown the waste through aerobic respiration, therefore fewer bacterial pathogens in this process would result in inadequate breakdown and the subsequent release of foul scents from the treatment system. However it is worth noting that the levels of these pathogens in the influent wastewater were above the WHO limit before the treatment began. Ekhaïse and Anyansi (2005) reported high counts of bacterial numbers in the Ikpoba River in Benin City Nigeria receiving a brewery industrial effluent. Similar results were reported by Kanu *et al.*, (2006) the effect of brewery discharge into Eziam River, Aba, Nigeria.

The characteristics of wastewater from industries depend largely on the type of industry and then also activities within the same industry or during a particular phase of its operations. In the factory studied there are two major phases, plant shutdown and flavour change over. The physicochemical quality of wastewater produced during these two phases indicated that all parameters except Biological Oxygen Demand were higher in the wastewater from plant shutdown as compared to the flavour change over. During plant shutdown there is the use of water to wash down the whole production channel, thereby introducing wastes from the whole production process into the water thereby significantly increasing the levels of these parameters. However significant differences were only recorded in the values recorded for Chemical Oxygen Demand, colour and phosphorus. Wastewater from soft drink production may contain residuals of soft drink and syrup spills or leaks, effluent from bottle cleaning, lubricants associated with the machinery, and facility wash down water, including caustics and detergents. As a result, wastewater will include total suspended solid (TSS), BOD, chemical oxygen demand (COD), nitrates, phosphates, sodium and potassium (Kosaric, 1992).

Lead and zinc concentrations in wastewater from the plant shut down phase were higher than during flavour change over. However, only Iron and Zinc concentrations recorded significant differences between the results obtained for the two phases in the production process. As was the case in the influent and effluent wastewater only copper and zinc concentrations in the two phases did not exceed the WHO limit, this confirms therefore that the concentration of these heavy metals in the wastewater is linked to their concentrations in wastewater generated during the production process.

Bacterial pathogens in wastewater from the two phases studied were all above the WHO limit (Table 6). However all the types of pathogens analyzed had higher concentrations in

the plant shut down phase than the flavour change over phase except for faecal coliforms although these were not statistically significant. During plant shut down the complete washing of the facility introduces a higher concentration of contaminants both faecal and physicochemical into the water thereby resulting in higher numbers recorded than during flavour change over. High pathogen concentration in wastewater from food processing, soft drink production and brewery industry has been reported by Imoobe and Koye, (2011), Kanu *et al.*, (2006) and Safo-Afriyie, (1999).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.0 CONCLUSION

The wastewater treatment plant was effective in improving the physicochemical quality of the wastewater from the factory in accordance with the WHO (2006) standards for the beverage industry except for electrical conductivity, chemical oxygen demand and phosphorus. These parameters although reported significant reduction from the influent to the effluent, were still above the WHO limit. A significant improvement in dissolved oxygen was recorded which is critical in the reduction of odour from the treatment plant.

There were significant reductions in the concentrations of Iron and Zinc from the influent to the effluent though the concentration of Iron in the effluent was still higher than the WHO upper limit. However there was an increase in the concentration of Lead and Copper from the influent to the effluent, although only the increase in Lead concentration was significant. The concentration of these metals (Lead and Copper) in the effluent were higher

than the WHO limit. Indicating that the wastewater treatment plant was ineffective in removing heavy metals.

Microbial contamination in the wastewater recorded mixed results with increase in the numbers of total coliforms and *E. coli* from the influent to the effluent. The decrease or increase in microbial numbers from the influent to the effluent was not significant and then also their numbers in the effluent were higher than the set standards, therefore the wastewater treatment plant was unable to treat the wastewater generated effectively due to higher concentrations of microbial pathogens, electrical conductivity, chemical oxygen demand, phosphorus, Lead and copper in the effluent wastewater ready to be released into the environment.

Wastewater produced during the plant shutdown was found to be higher in all physicochemical parameters studied (except B.O.D), although significant differences were only recorded in concentrations of C.O.D, total alkalinity, D.O, colour and phosphorus. Lead and copper concentrations were however higher in the flavour change over wastewater. Again microbial pathogen concentration in the wastewater produced during these two phases was higher in water generated during plant shutdown although the differences were not significant. Therefore it is concluded from the findings that the plant shutdown phase produces highly contaminated wastewater than the flavour change over phase.

It is therefore concluded that, odour released from this wastewater treatment plant is due to a high concentration of volatile organic compounds. A low concentration of D.O in the influent water and wastewater from the two phases studied coupled with high B.O.D and C.O.D concentrations indicate that respiration in the treatment process is anaerobic resulting in the production of ammonia sulphuretted hydrogen, mercaptans, hydrocarbons,

etc that result in the release of the odour. Then also as observed, the breakdown of the blower unit of the treatment plant would also result in inadequate aeration of the wastewater thereby contributing to the low D.O and then the anaerobic respiration with the attendant release of odour.

6.1 Engineering Management Controls

Findings from the study clearly suggest the need for effective control systems to be able to drastically reduce or contain the odour releases. There is therefore the need to establish additional controls to the existing ones developed by the facility for the purpose of continually and consistently improving on the efficiency to prevent anaerobic conditions from being established.

A careful study of the influent sources and pipings suggest the need for a technology that will help clean all underground pipes with the view of getting rid of biofilms aligned to them. These biofilms can be a source of the odour releases and for that matter must be cleared. An alternative to this will be to replace all pipes.

The pre-treatment unit of the facility is one of the most important units of the treatment process as it prepares the grounds for the biological treatment at the main reactors. This unit ensures physical particles removal, oil separation, pH balancing and temperature control of the influent. Any deviation or non compliance to these treatment regimes will be detrimental to the effectiveness of the biological treatment system. There will be the need to redesign this treatment unit to allow for circulation of the wastewater at this point to prevent stagnation that will create conditions for anaerobic respiration in times there is no production or continuous supply of influent.

Wastewater getting to the pretreatment unit carries along with all manner of debris and particulate matter that will eventually affect the treatment process if allowed to go through.

These debris ends up accumulating at the base of the pretreatment tanks to form sludge. Level of accumulation increases as per production activities each day. Our study confirms high level of sludge accumulation above the sensor for pH control thereby affecting its effectiveness and balancing of influent before transfer. This calls for an effective prevent maintenance plan that will ensure timely removal sludge from the unit. The removal plan will also help control levels of microbes and heavy accumulation at the pre-treatment stage. Another critical unit also examined was the blower unit supplying air to the biological reactors. The study confirms that though there is a maintenance plan in place, it is not strictly adhered to resulting in frequent break downs of the unit. Quality of fan belts used for running of the blowers is not comparable to the ones supplied by the manufacturer. These breakdowns tend to affect the level air or oxygen supplied to the reactors thereby creating conditions for anaerobic respiration. The preventive maintenance plan as outlined by the manufacturer must be strictly be adhered to ensure frequent breakdowns are prevented. Measuring units and gauges on the treatment facility are expected to be taken through a rigorous audit process that will ensure effectiveness at all times. The study confirms that the pH measuring unit at the pre-treatment station is not routinely calibrated as per required internal procedures. This tends to affect pH balancing of the wastewater before transfer to the main biological reactors. The audit process is expected to arrest this situation.

6.2 RECOMMENDATIONS

Due to the findings made in this study the following recommendations are made;

1. A thorough study should be carried out on the factors that lead to low quality of the effluent as was seen in this study.

2. Effluents from the treatment plant should not be released directly into water bodies since it has the potential to disturb the quality of aquatic life of these water bodies.
3. More nutrients could be added to the treatment process to improve on the B.O.D.
4. There is also the need to examine the piping system that supplies the facility with air as to determine the cause of the frequent breakdowns and therefore find a solution so as to have a constant supply of oxygen.
5. Microbial and chemical odour reduction technologies could also be used in order to reduce the amount of odour released into the environment.

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APPENDIX

APPENDIX I

GRAPHS OF RESULTS

MEAN PHYSICOCHEMICAL RESULTS OF INFLUENT AND EFFLUENT WASTEWATER

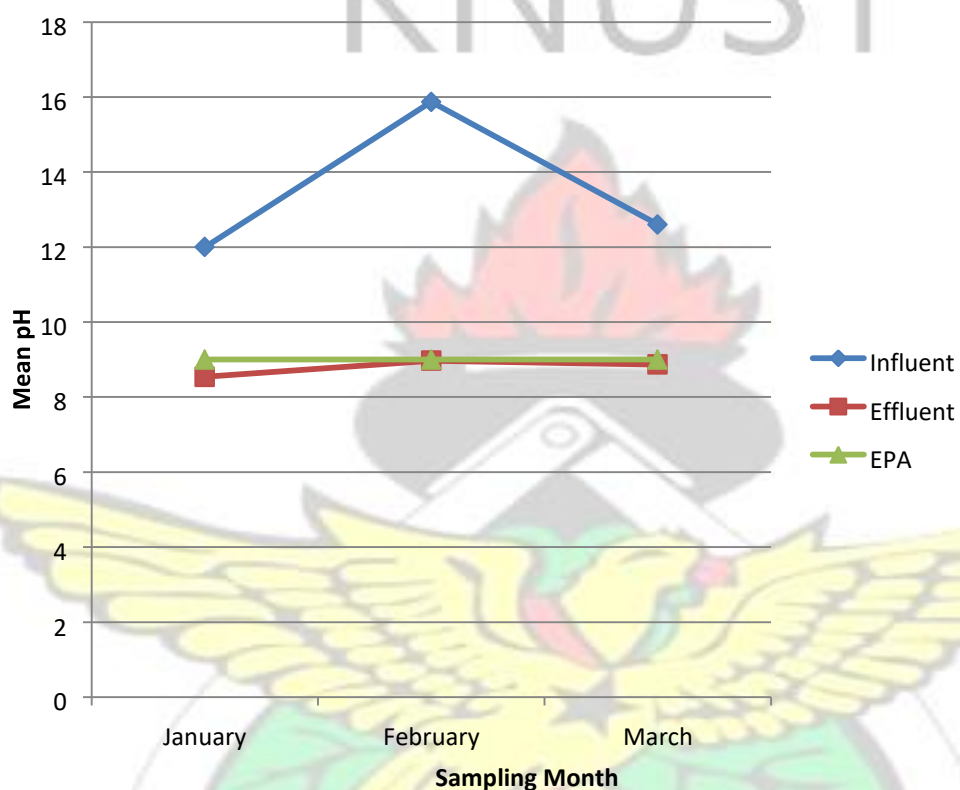


FIG. 1: Mean pH in the wastewater from both effluent and influent

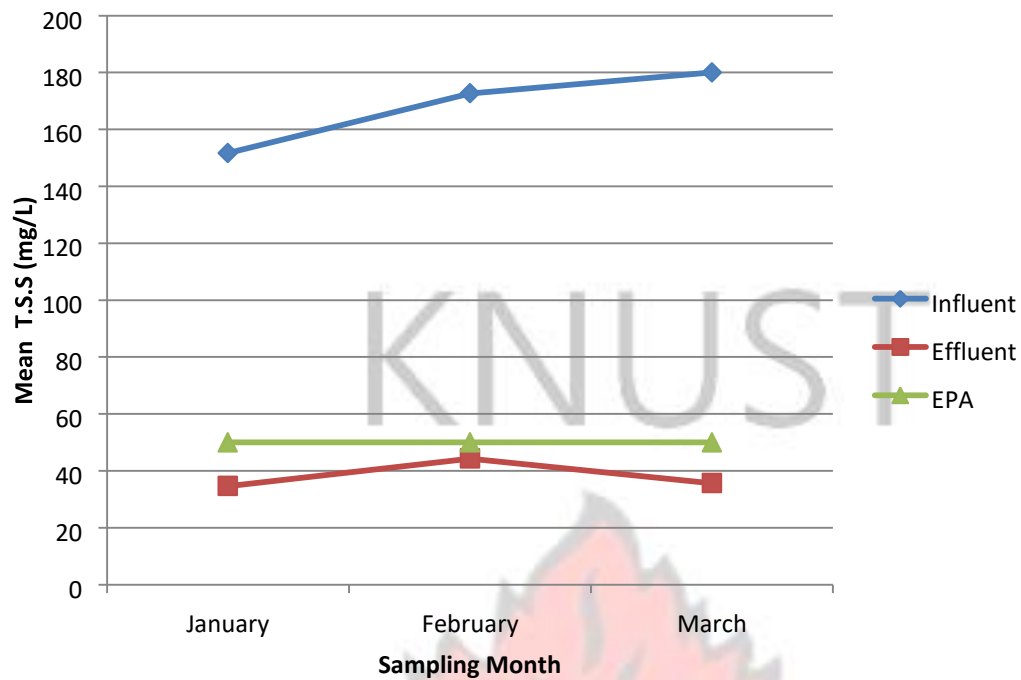


FIG. 2: Mean TSS in the wastewater from both effluent and influent

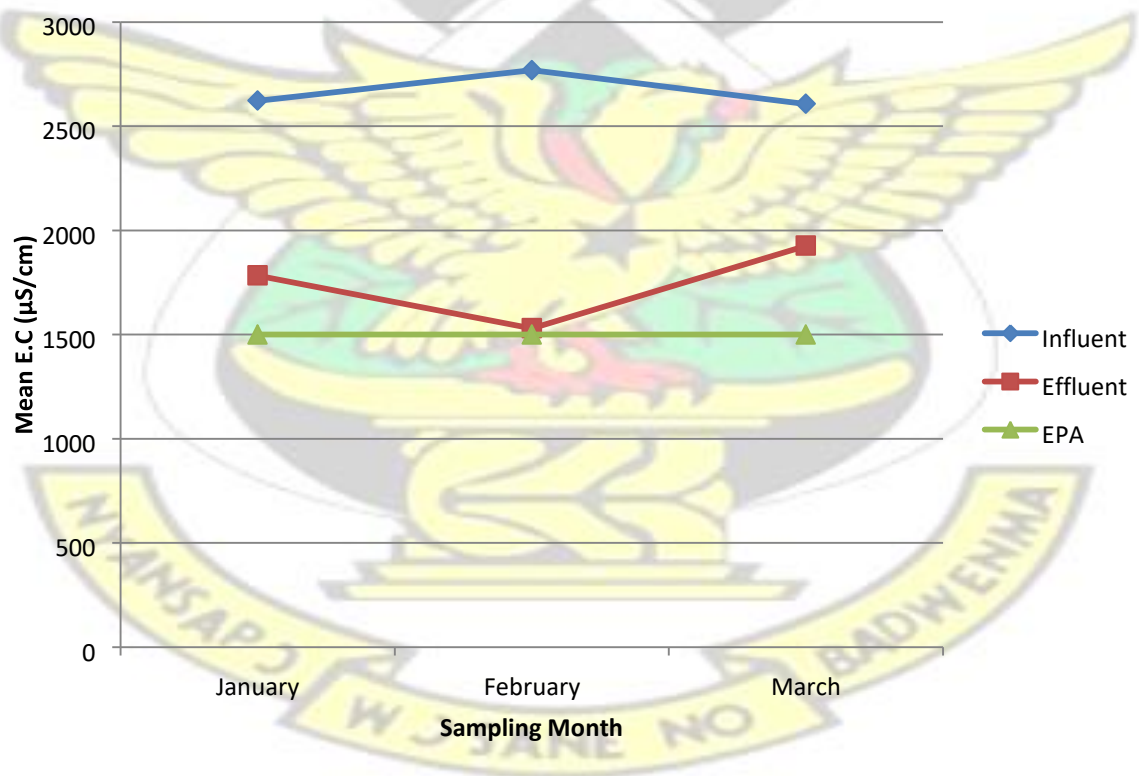


FIG. 3: Mean Electrical conductivity ($\mu\text{S}/\text{cm}$) in the wastewater from both effluent and influent

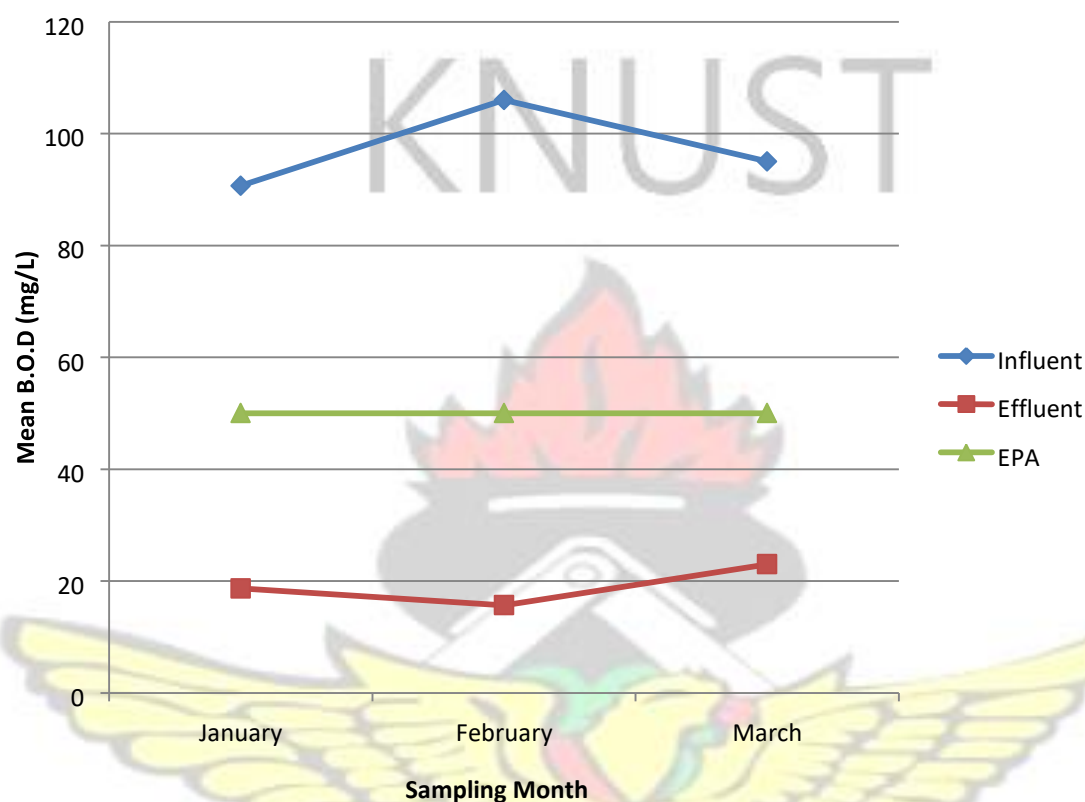


Fig.4: Mean B.O.D (mg/L) in the effluent and influent wastewater.

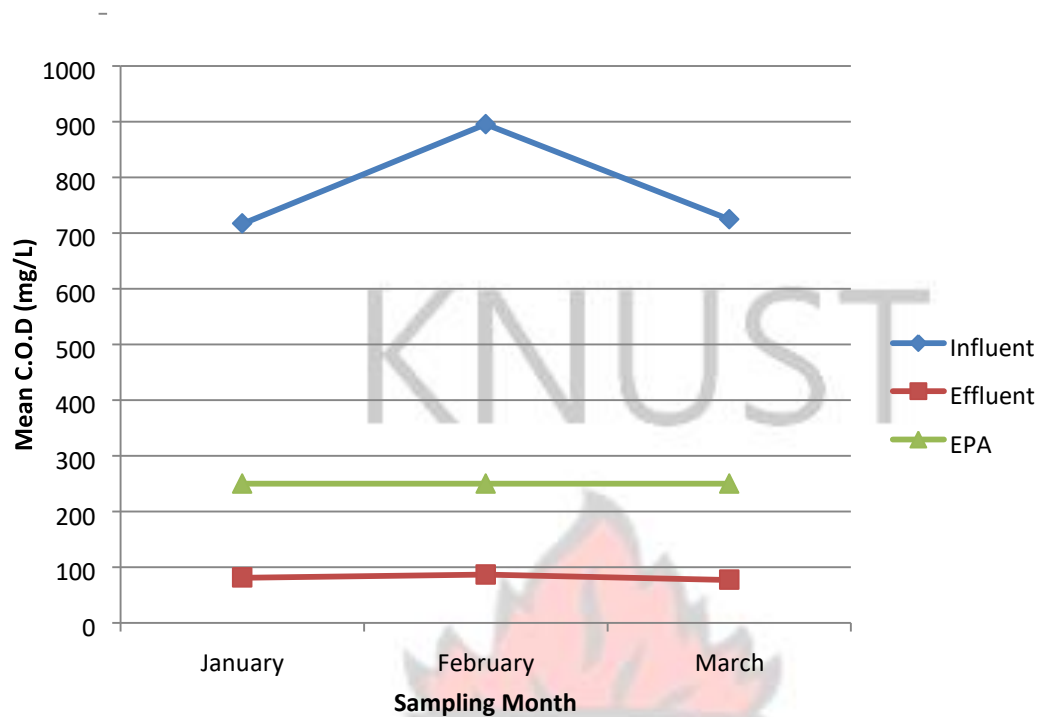


Fig.5: Mean C.O.D (mg/L) in the effluent and influent wastewater.

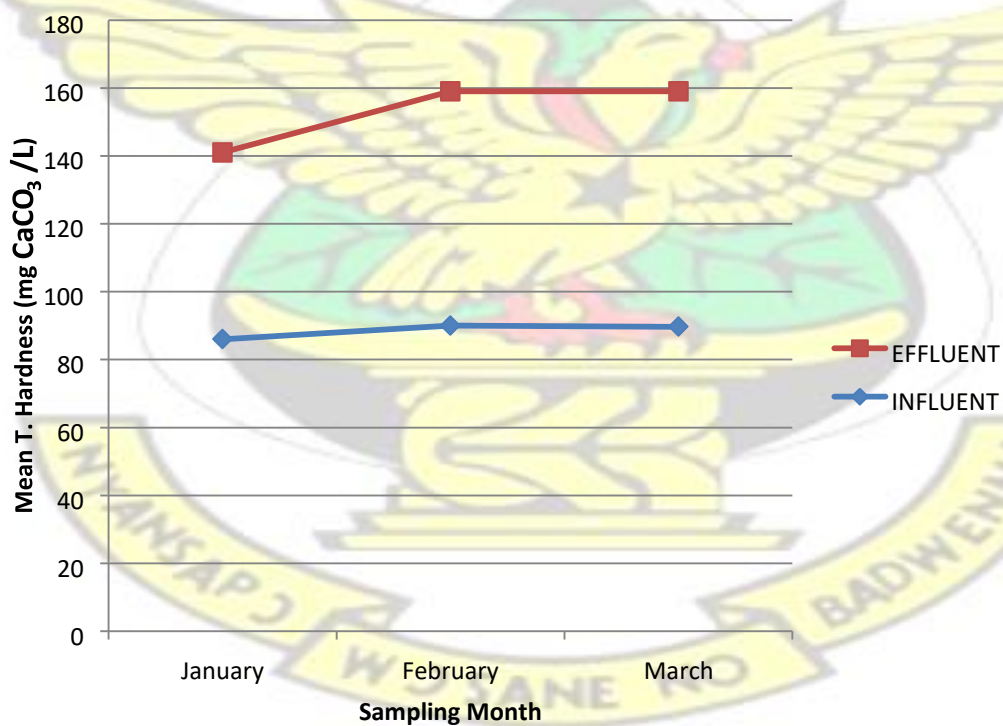


Fig.6: Mean Total Hardness (mg CaCO₃/L) in the effluent and influent wastewater.

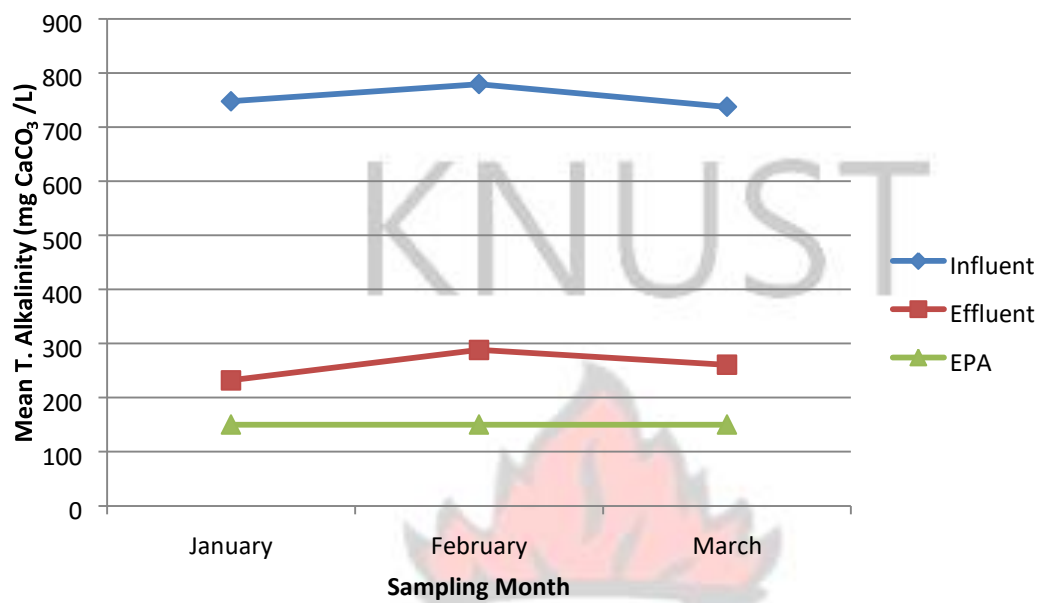


Fig 7: Mean Total Alkalinity (mg CaCO₃/L) in the effluent and influent wastewater.

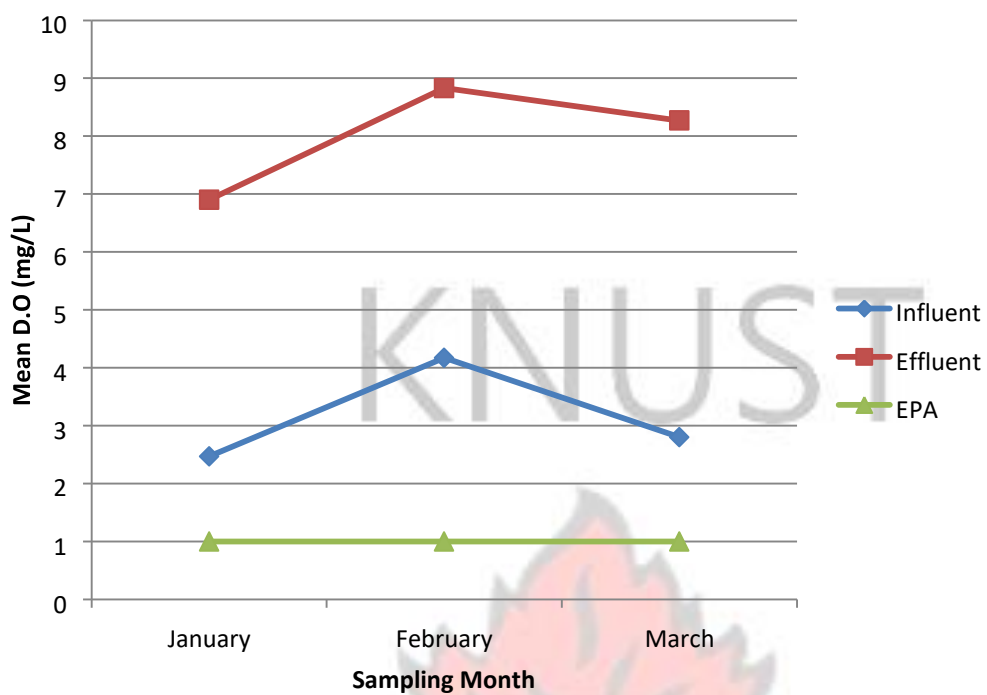


Fig.8: Mean D.O (mg /L) in the effluent and influent wastewater.

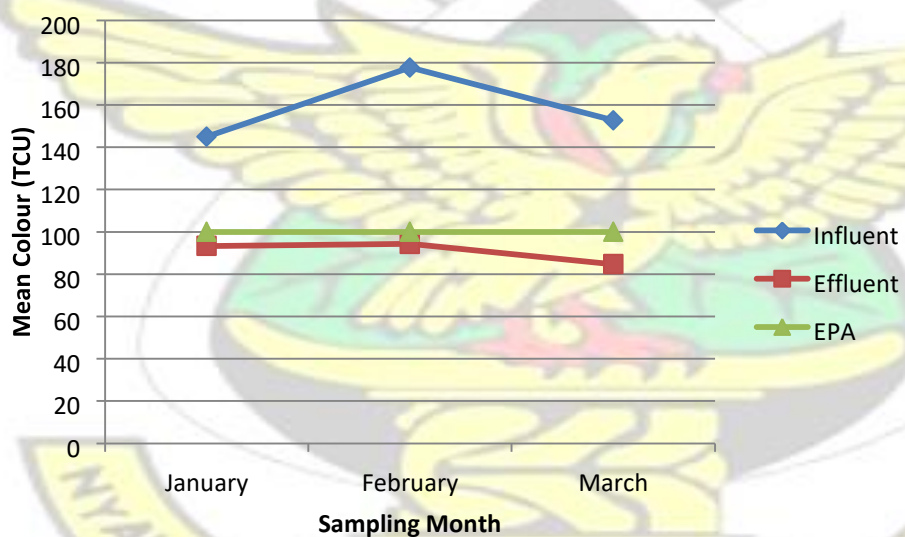


Fig.9: Mean Colour (TCU) in the effluent and influent wastewater.

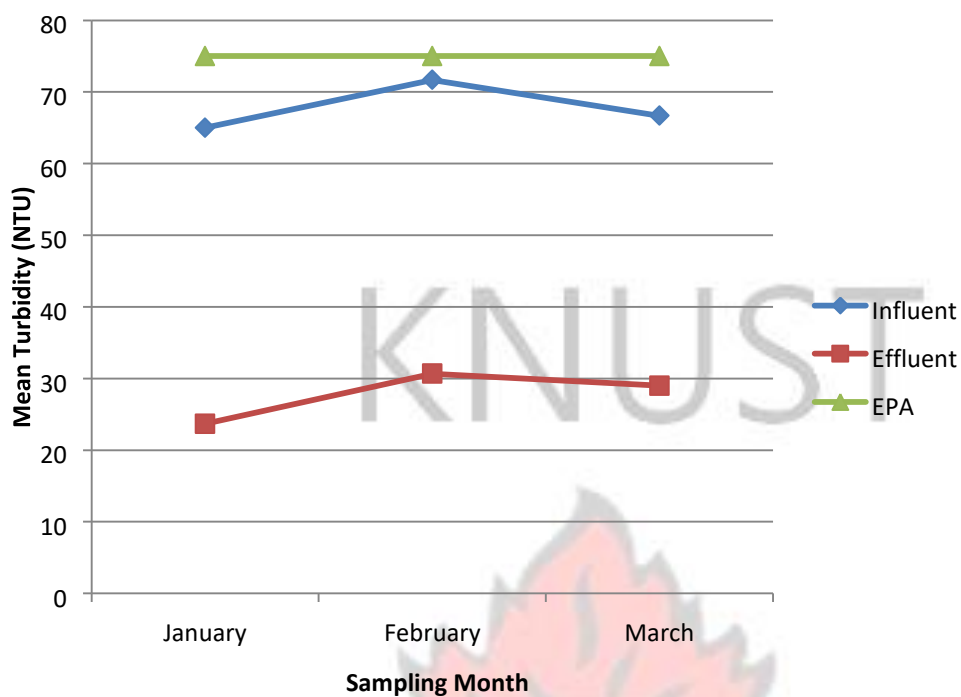


Fig.10: Mean Turbidity (NTU) in the effluent and influent wastewater.

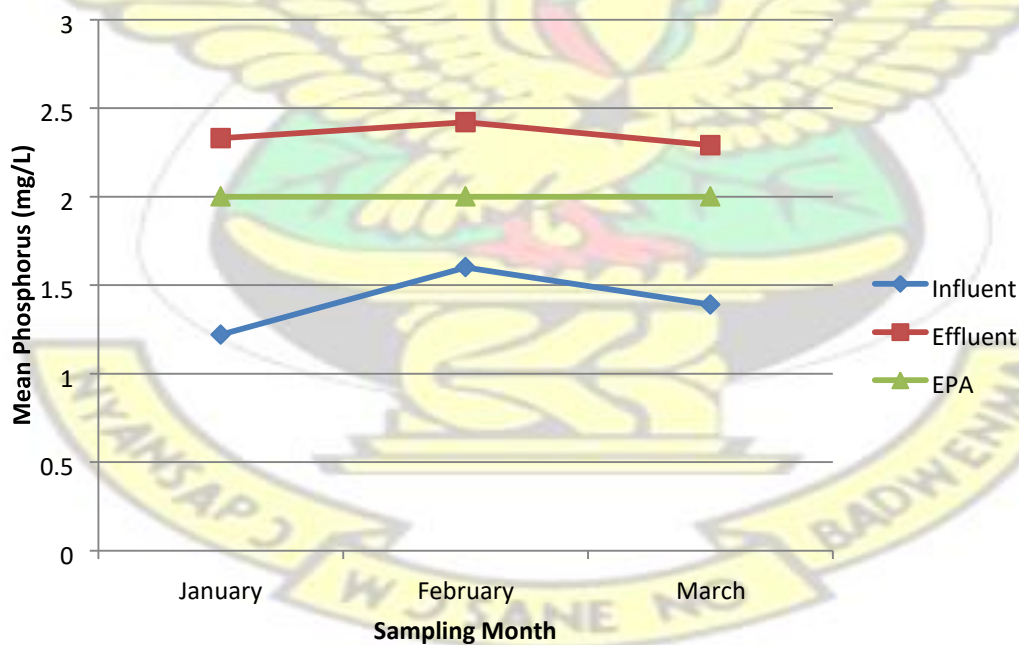


Fig.11: Mean Phosphorus (mg/L) in the wastewater effluent and influent.

MEAN METAL CONCENTRATION IN BEVERAGE WASTEWATER

INFLUENT AND EFFLUENT

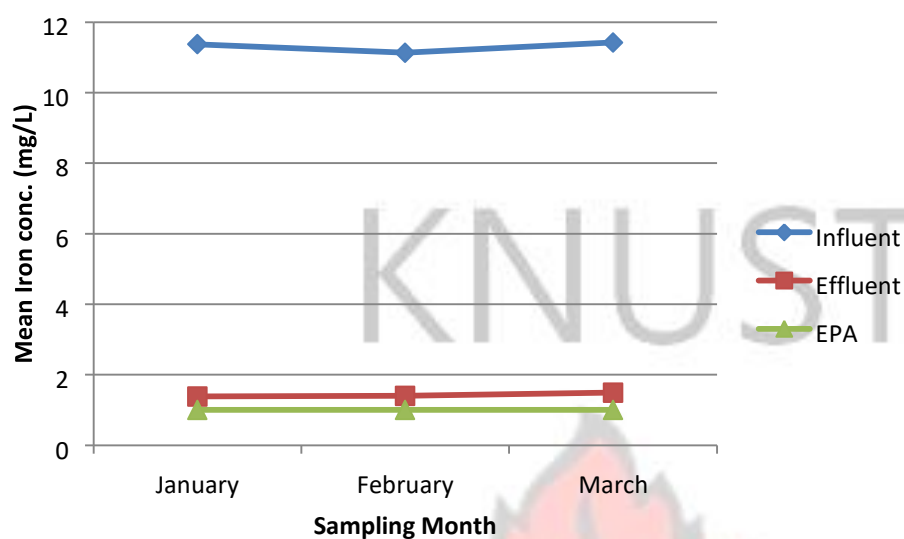


Fig.12: Mean Iron (mg/L) in the effluent and influent wastewater.

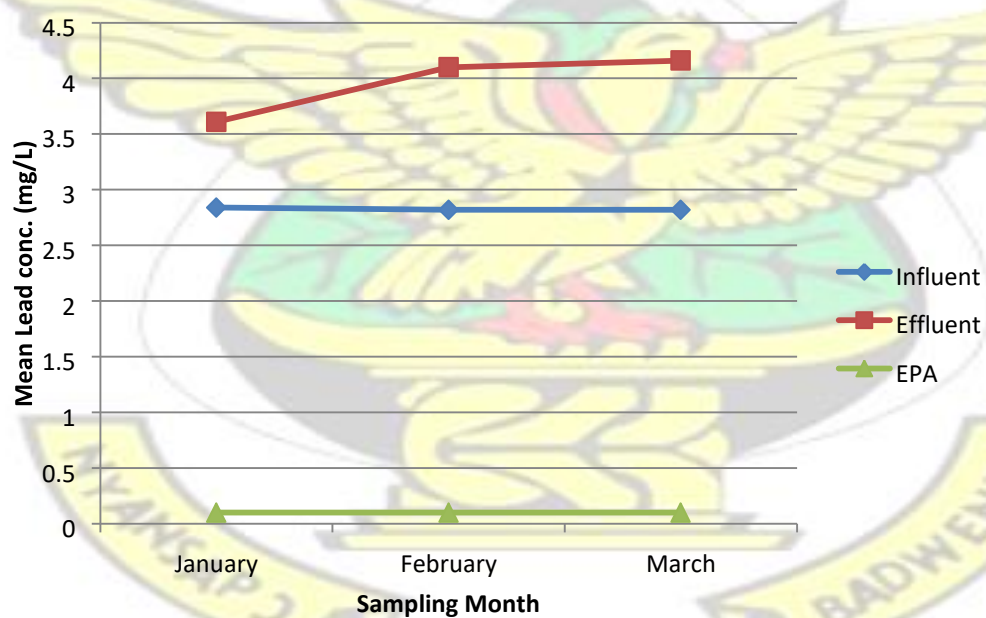


Fig.13: Mean Lead (mg/L) in the effluent and influent wastewater.

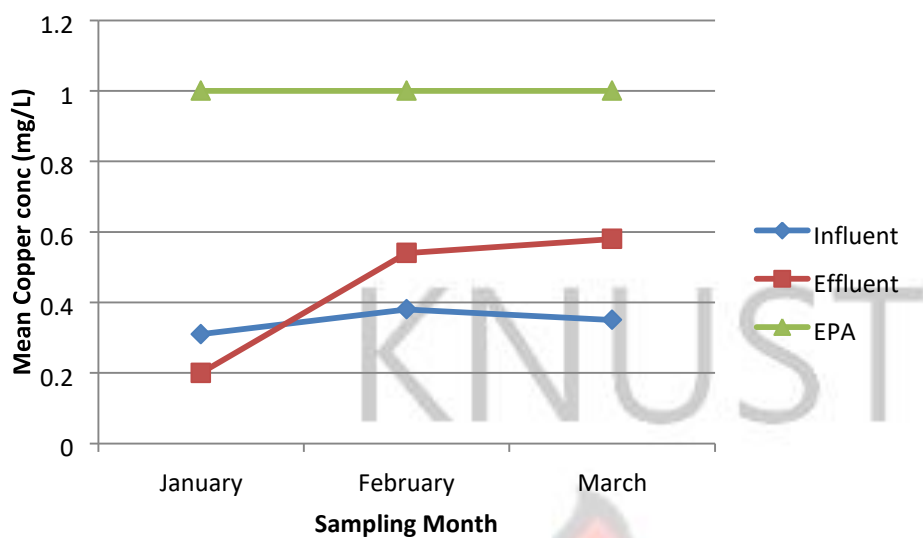


Fig.14: Mean Copper (mg/L) in the effluent and influent wastewater.

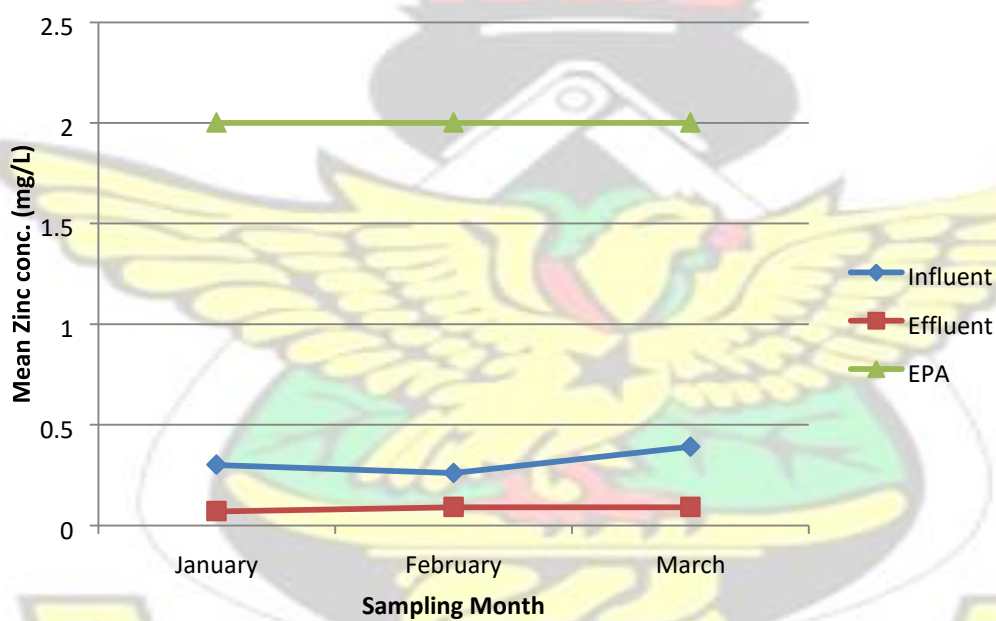


Fig.15: Mean Zinc (mg/L) in the effluent and influent wastewater.

MEAN BACTERIAL LOADS IN INFLUENT AND EFFLUENT WASTEWATER

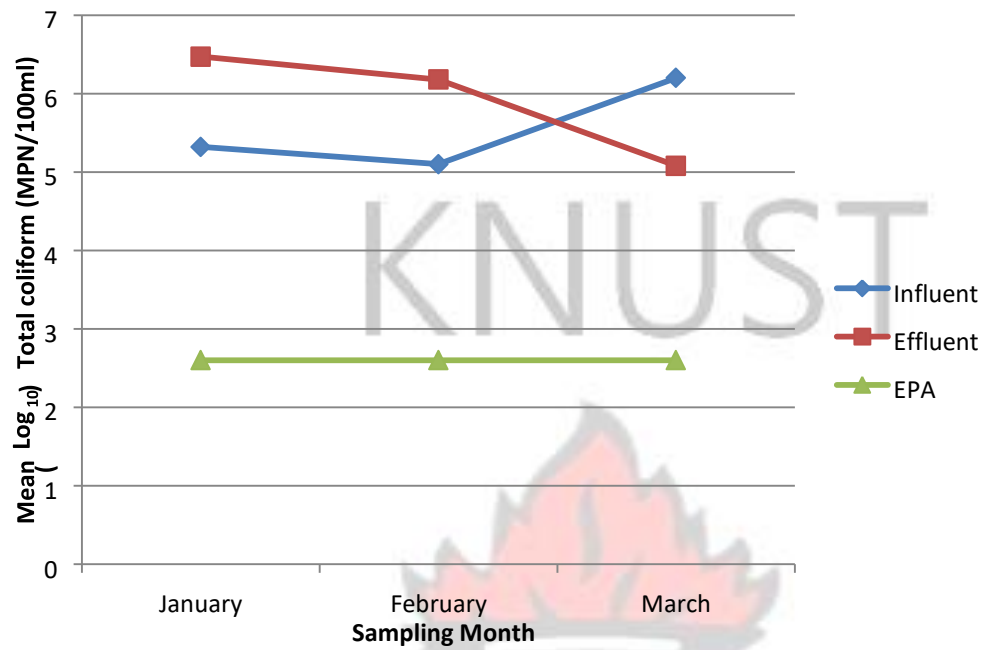


Fig.16: Mean ($\log_{10}$) Total coliform levels (MPN/100ml) in the effluent and influent wastewater.

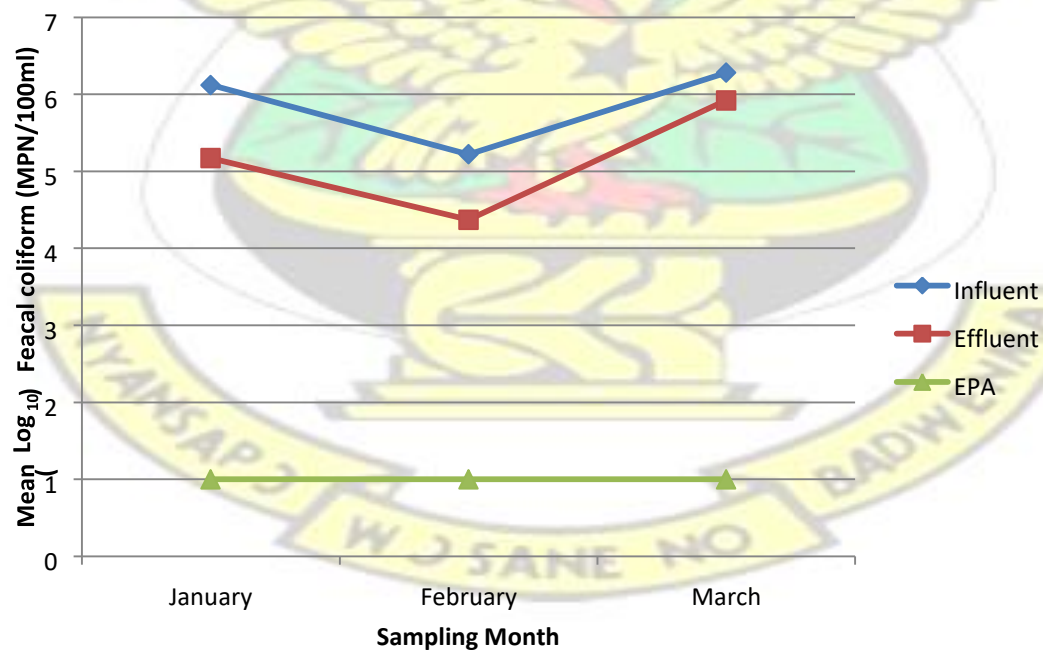


Fig.17: Mean (Log₁₀) Feacal coliform levels (MPN/100ml) in the effluent and influent wastewater.

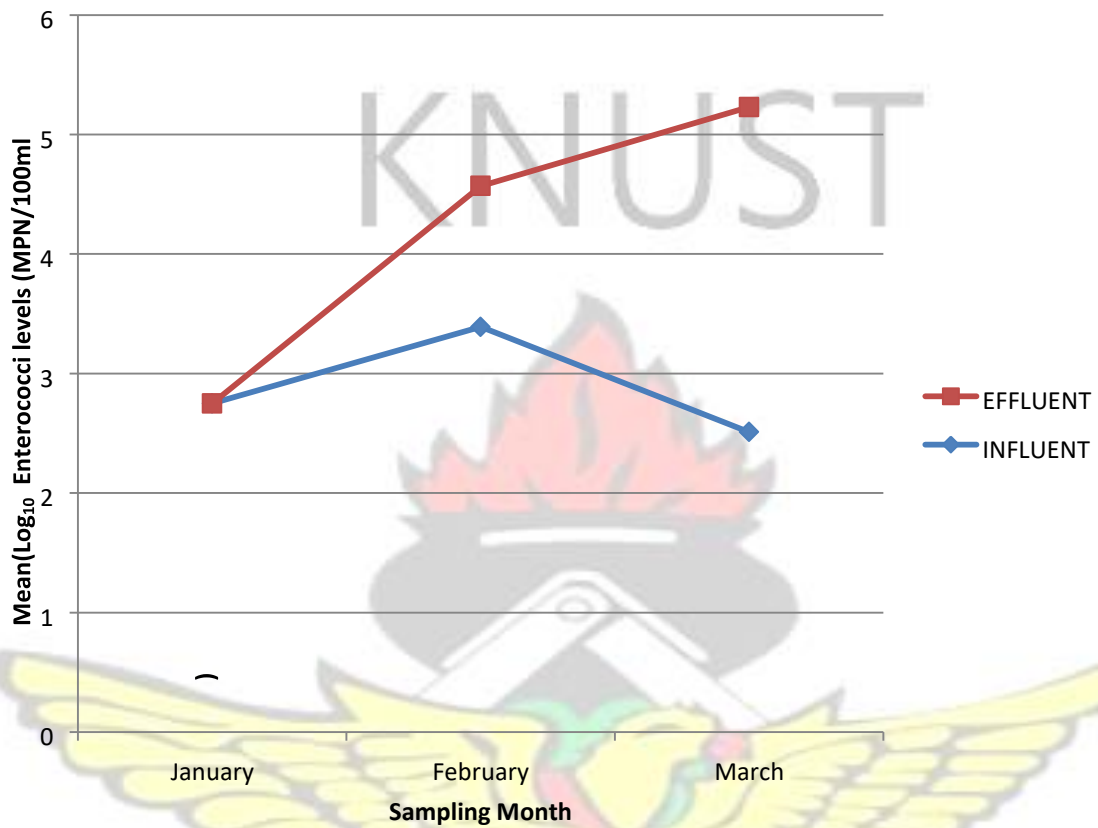


Fig.18: Mean(Log₁₀) *Enterococci* (MPN/100ml) in the effluent and influent wastewater.

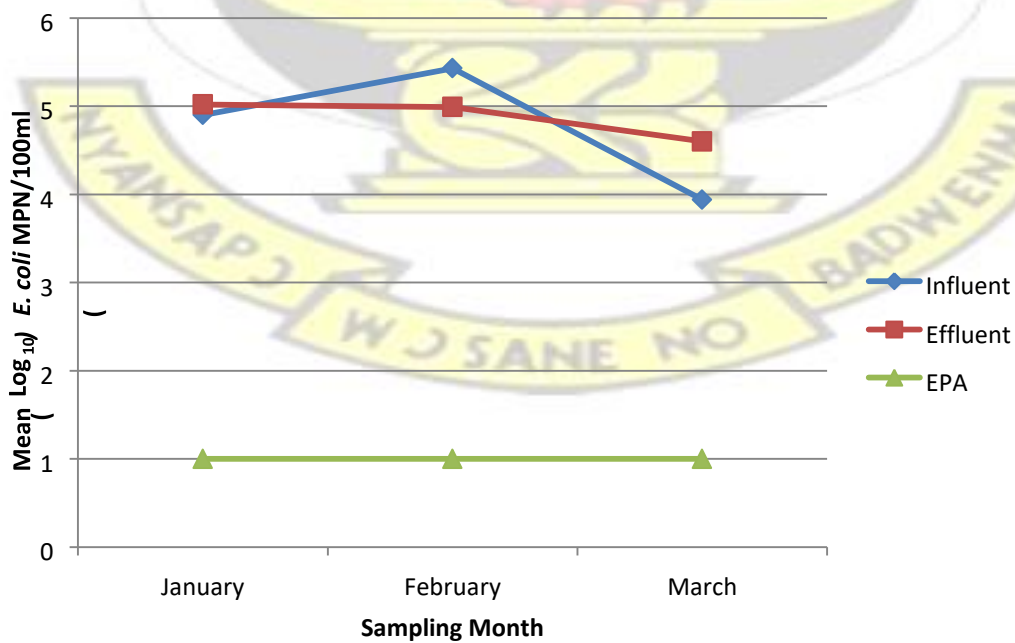


Fig.19: Mean (Log₁₀) *E. coli* (MPN/100ml) in the effluent and influent wastewater.

MEAN PHYSICOCHEMICAL RESULTS OF WASTEWATER DURING FLAVOUR CHANGE OVER AND PLANT SHUTDOWN

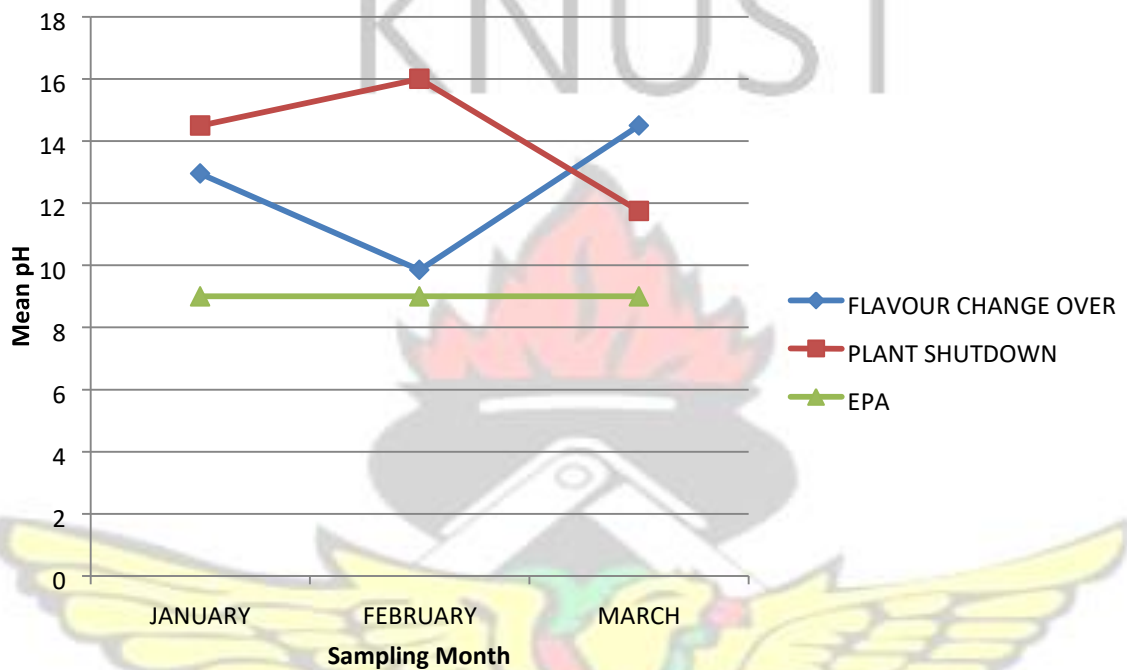


Fig. 20: Mean pH of wastewater during Plant Shutdown and Flavour Change Over.

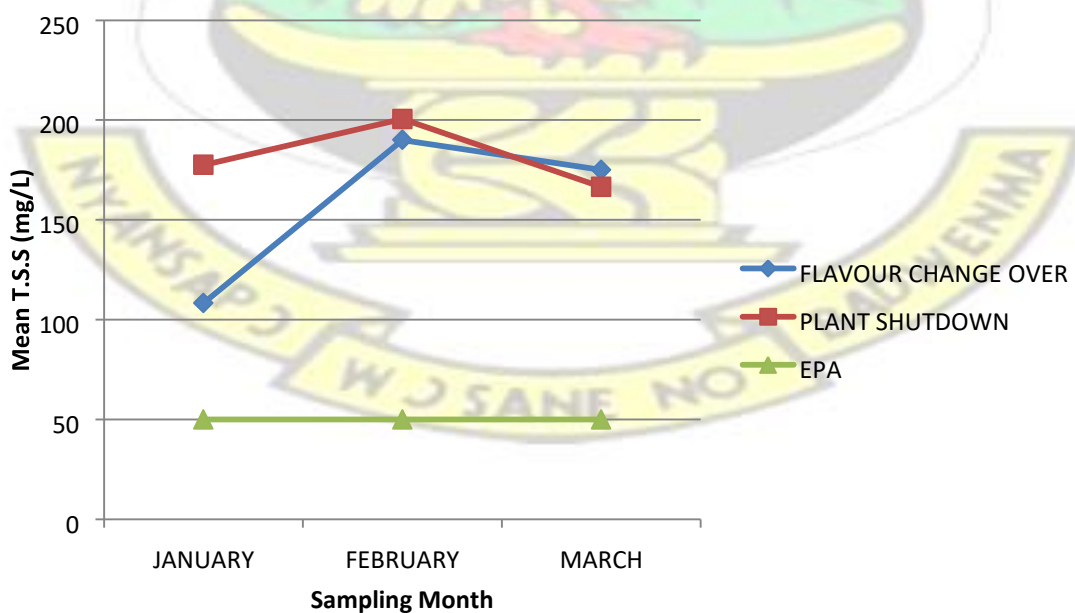


Fig. 21: Mean TSS (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

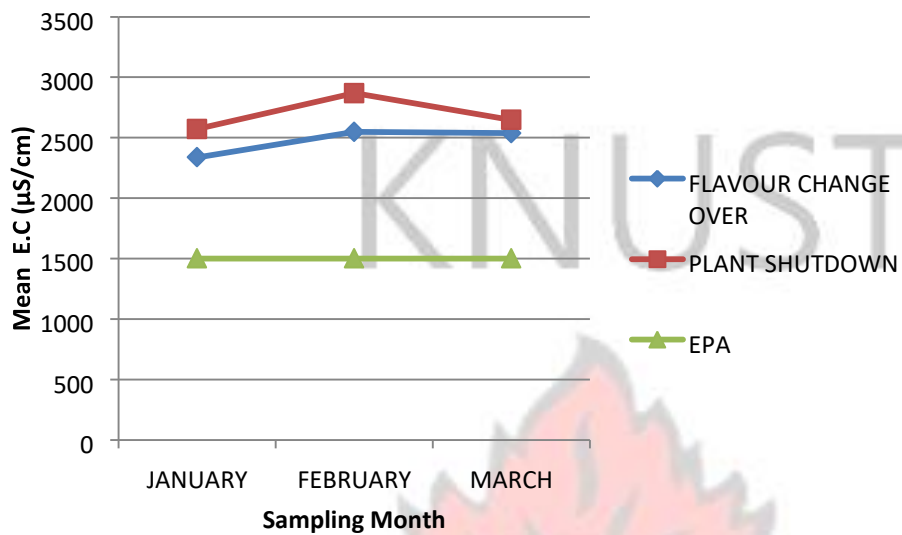


Fig. 22: Mean Electrical Conductivity ($\mu\text{S/cm}$) of wastewater during Plant Shutdown and Flavour Change Over.

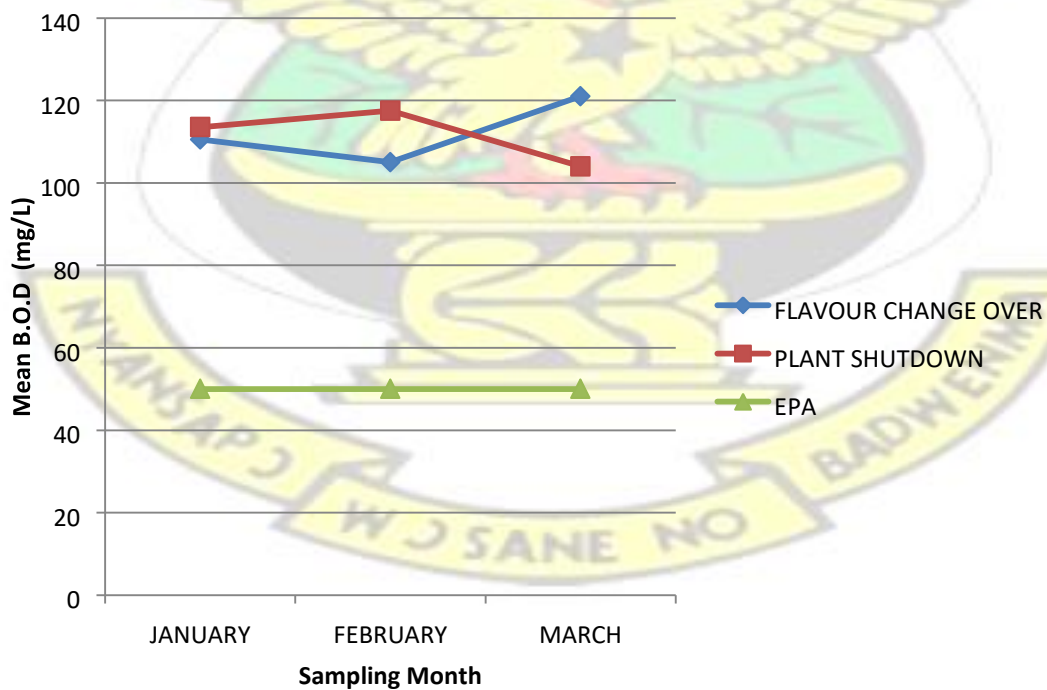


Fig. 23: Mean B.O.D (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

KNUST



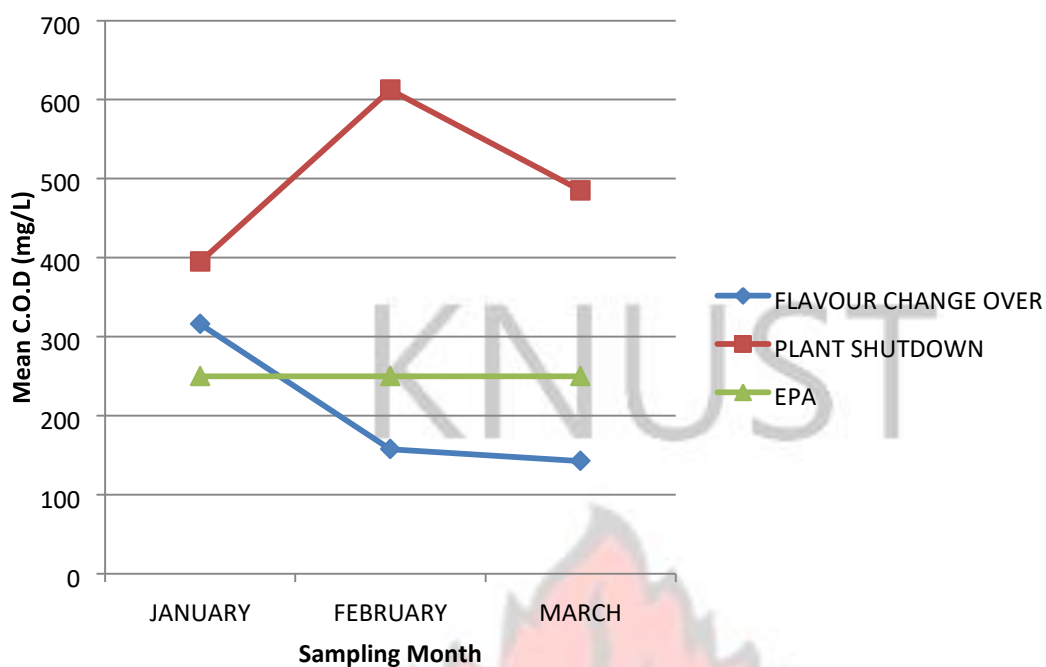


Fig. 24: Mean C.O.D (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

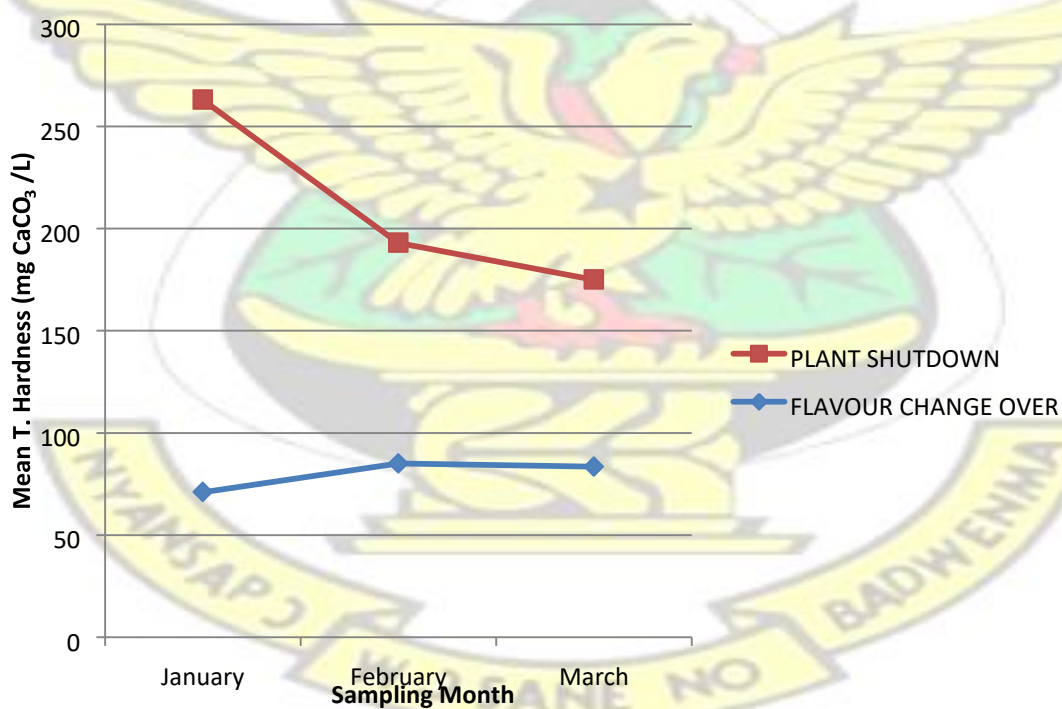


Fig. 25: Mean Total Hardness (mg CaCO₃ /L) of wastewater during Plant Shutdown and Flavour Change Over.

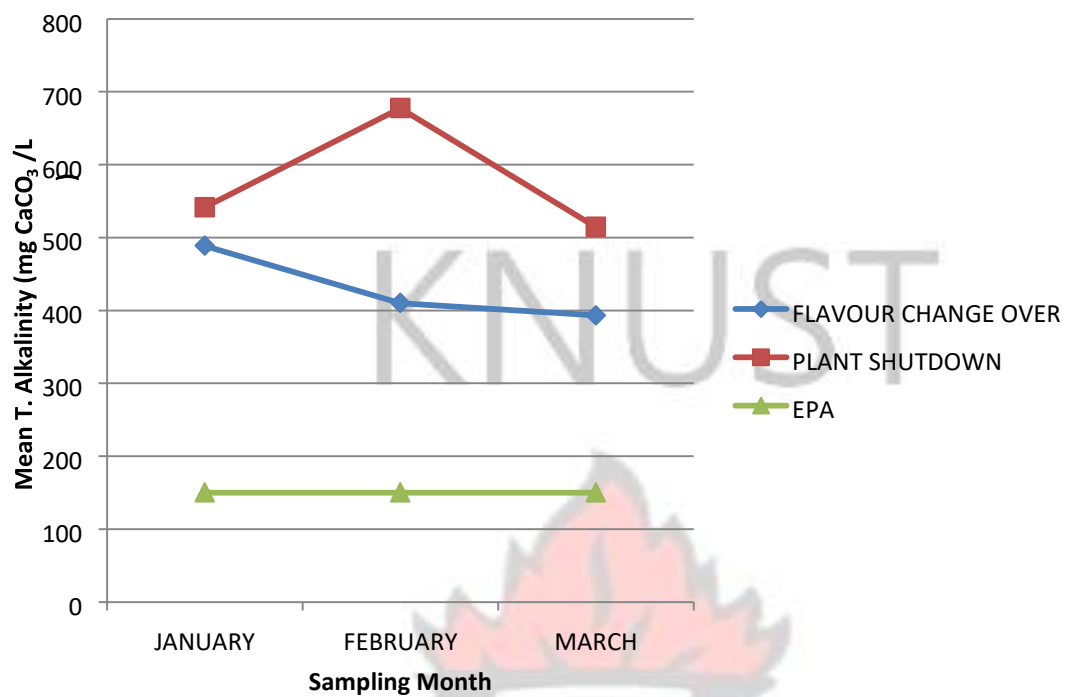


Fig. 26: Mean Total Alkalinity (mg CaCO₃/L) of wastewater during Plant Shutdown and Flavour Change Over.

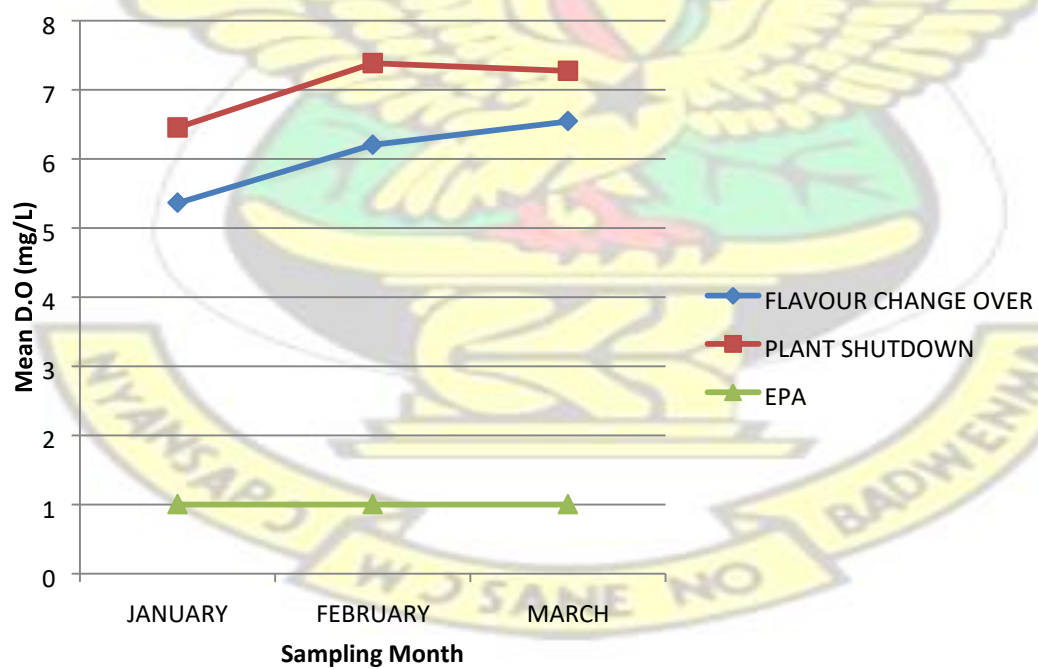


Fig. 27: Mean D.O (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

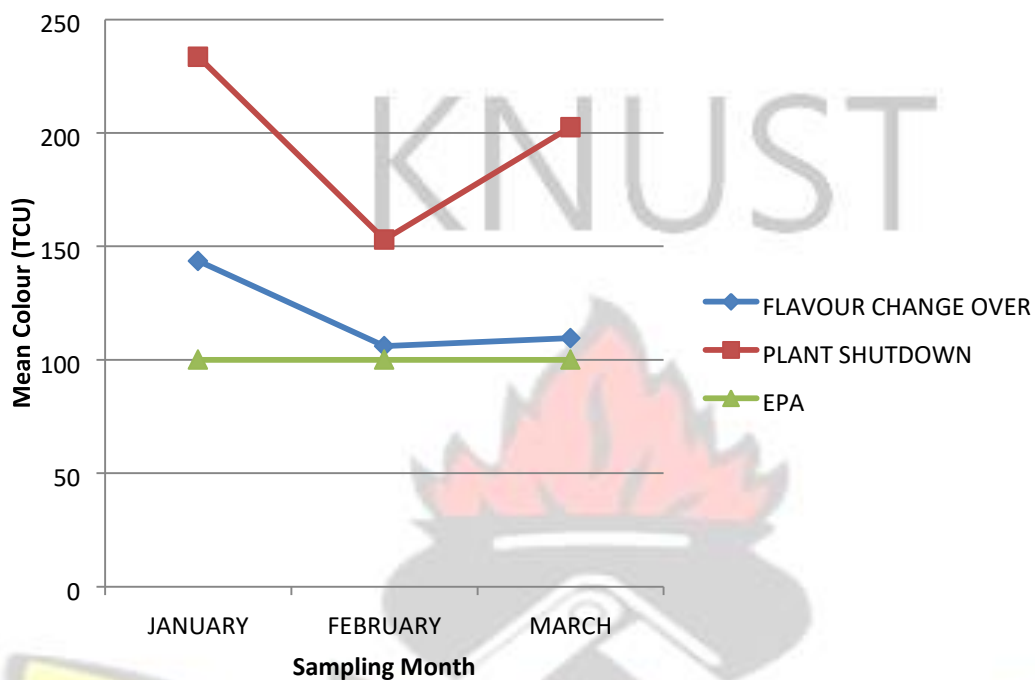


Fig. 28: Mean Colour (TCU) of wastewater during Plant Shutdown and Flavour Change Over.

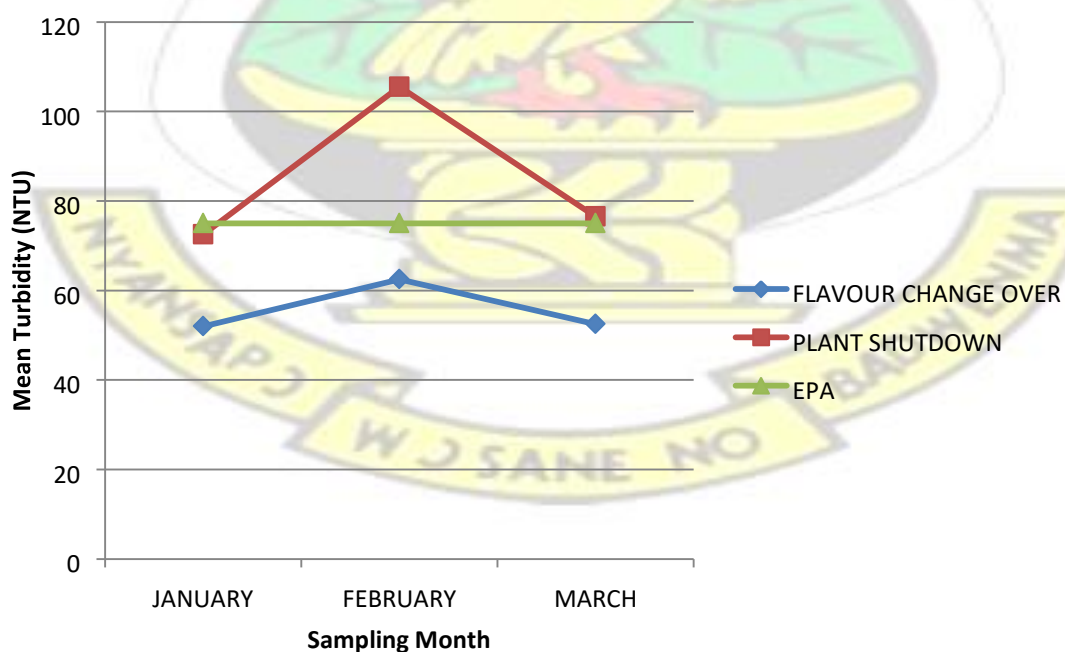


Fig. 29: Mean Turbidity (NTU) of wastewater during Plant Shutdown and Flavour Change Over.

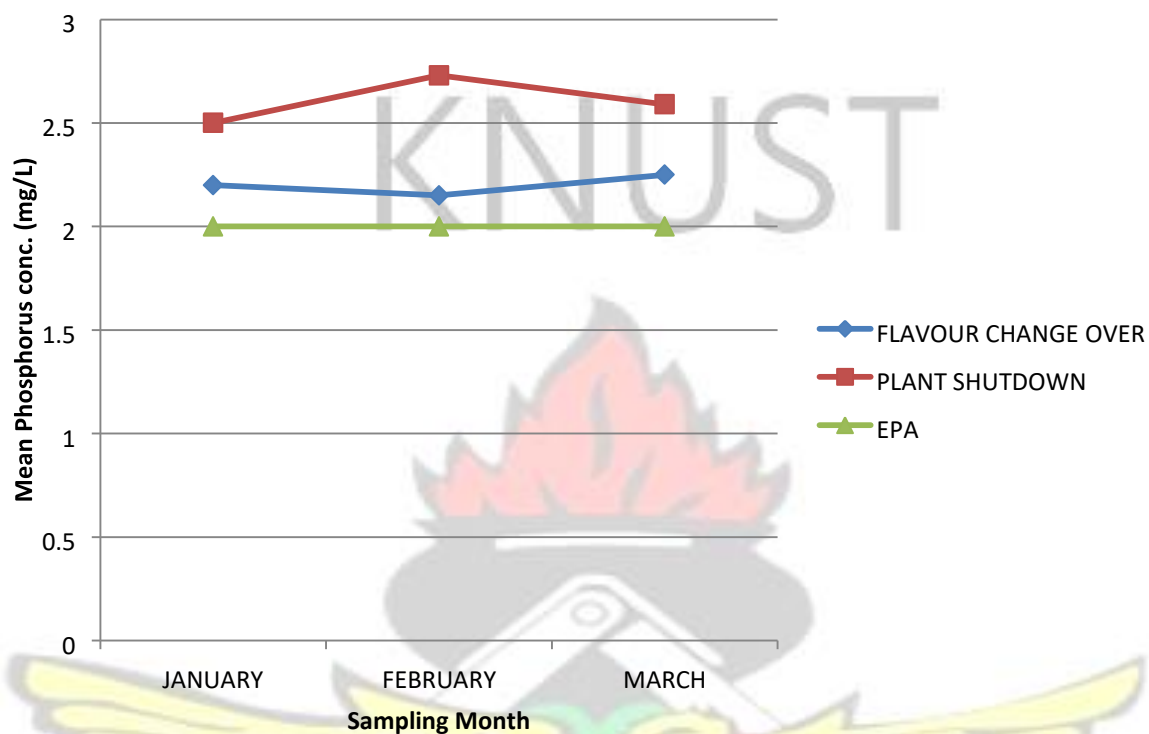


Fig. 30: Mean Phosphorus (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

MEAN METAL CONCENTRATION IN WASTEWATER DURING FLAVOUR CHANGE OVER AND PLANT SHUTDOWN.

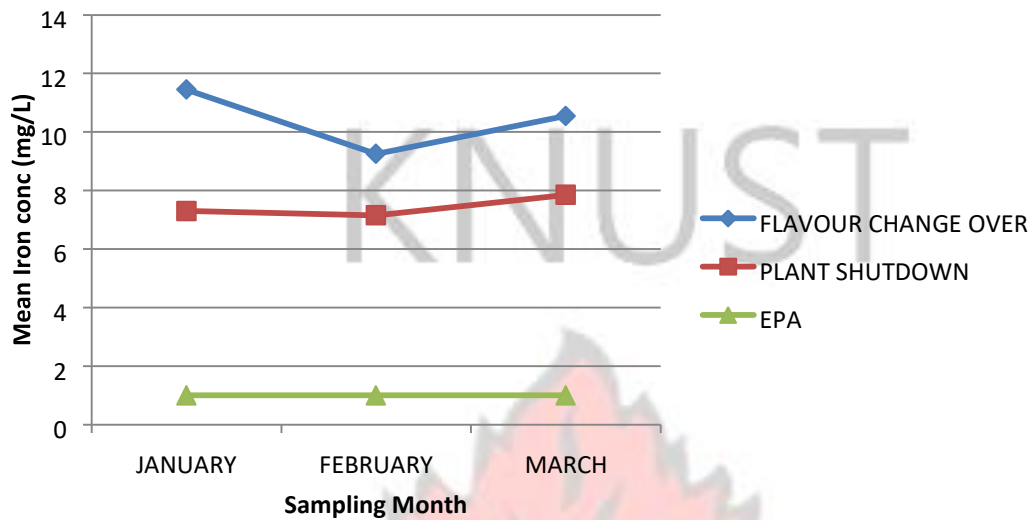


Fig. 31: Mean Iron (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

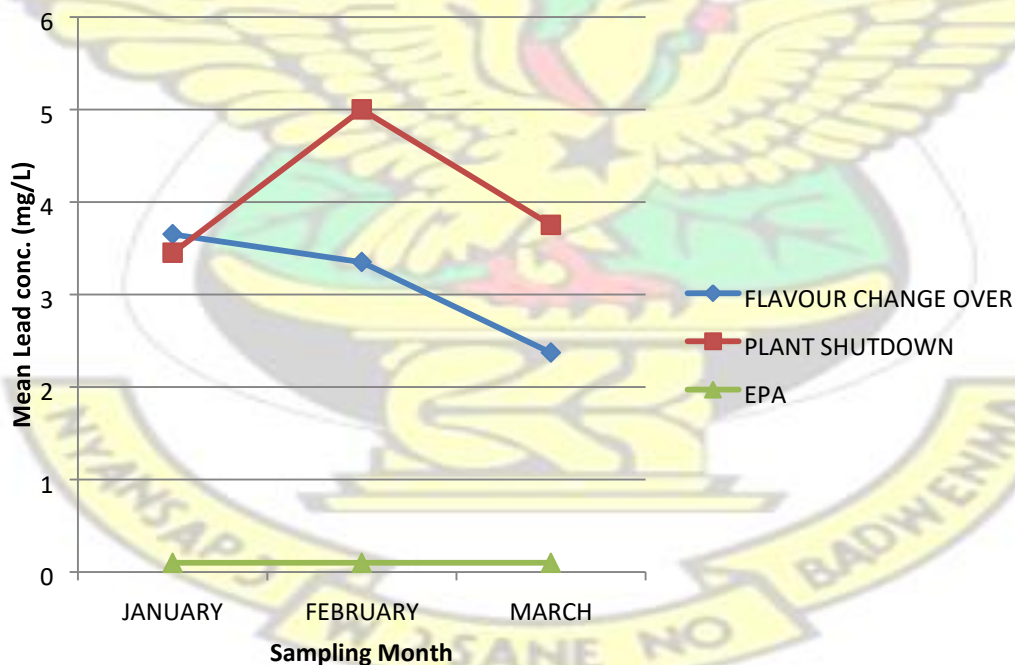


Fig. 32: Mean Lead (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

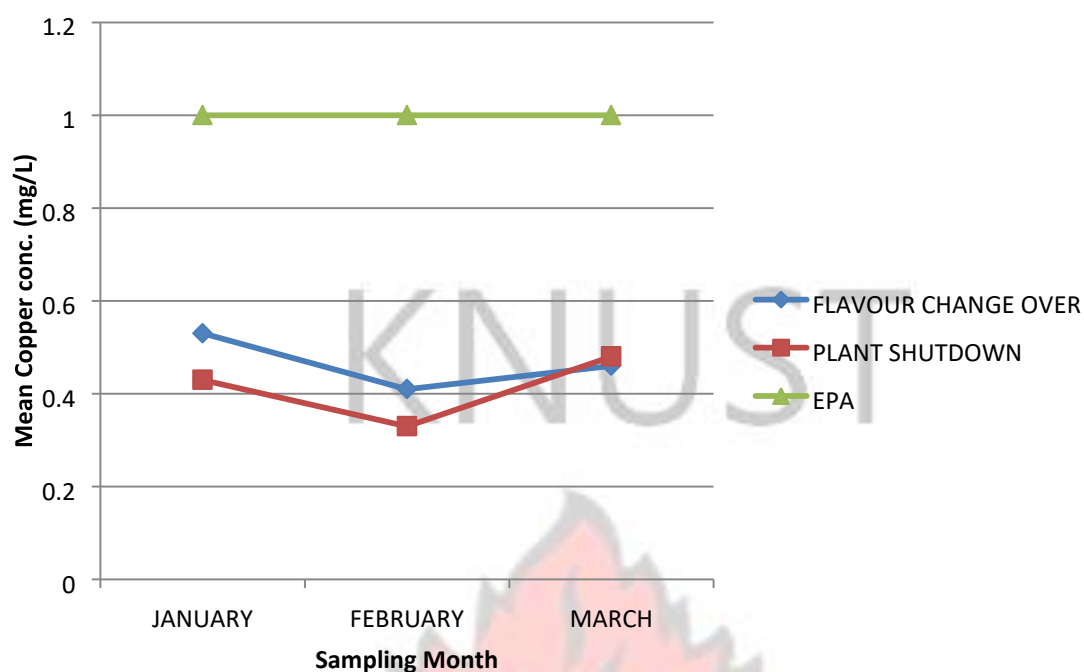


Fig. 33: Mean Copper (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

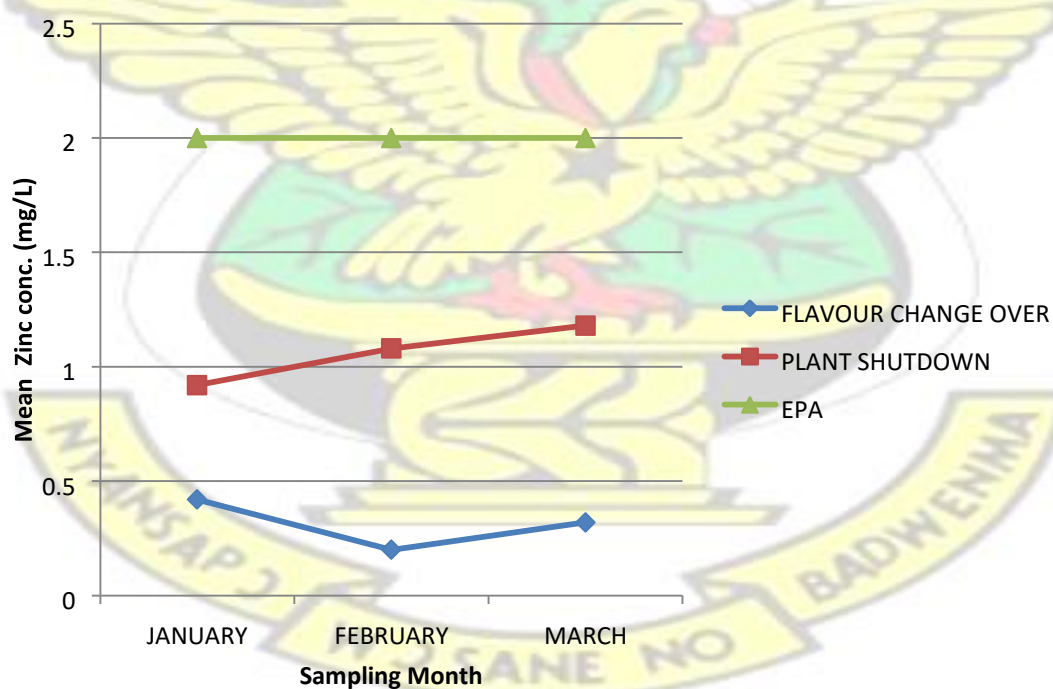


Fig. 34: Mean Zinc (mg/L) of wastewater during Plant Shutdown and Flavour Change Over.

MEAN BACTERIAL LOADS IN WASTEWATER DURING FLAVOUR CHANGE OVER AND PLANT SHUTDOWN.

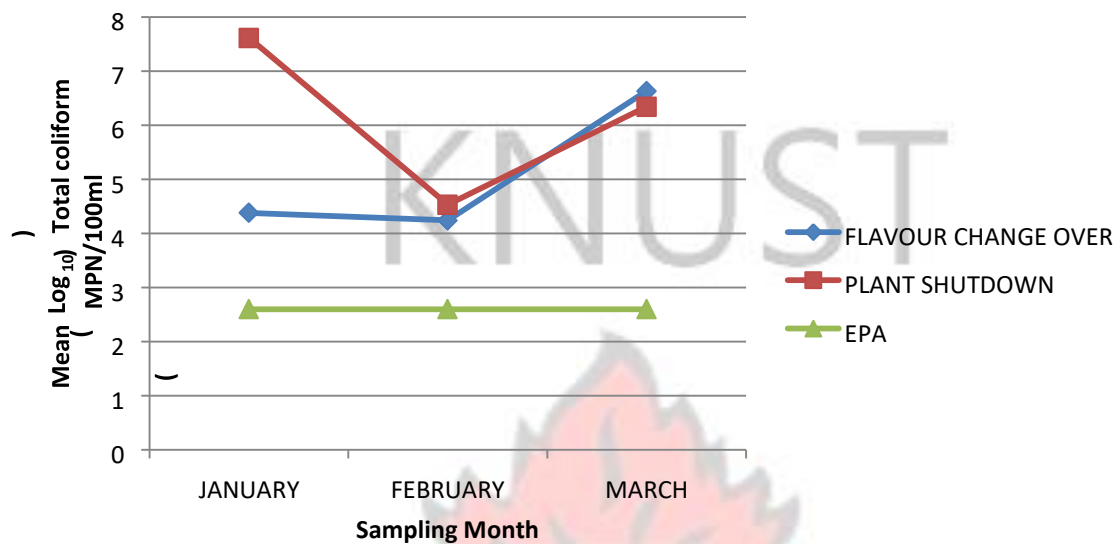


Fig. 35: Mean ($\log_{10}$) Total coliform (MPN/100ml) of wastewater during Plant Shutdown and Flavour Change Over.

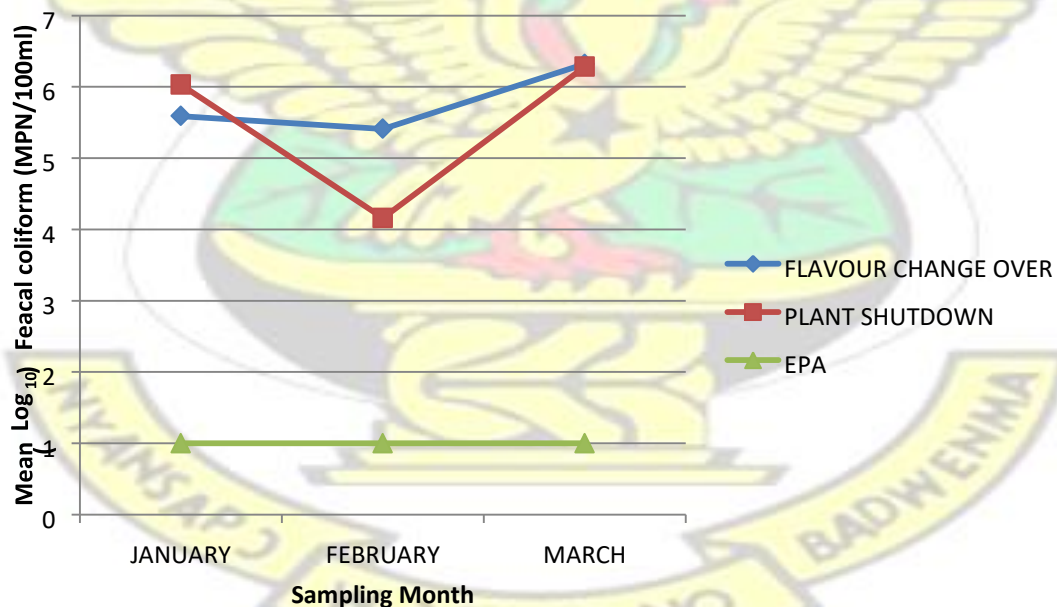


Fig. 36: Mean ($\log_{10}$) Faecal coliform (MPN/100ml) of wastewater during Plant Shutdown and Flavour Change Over.

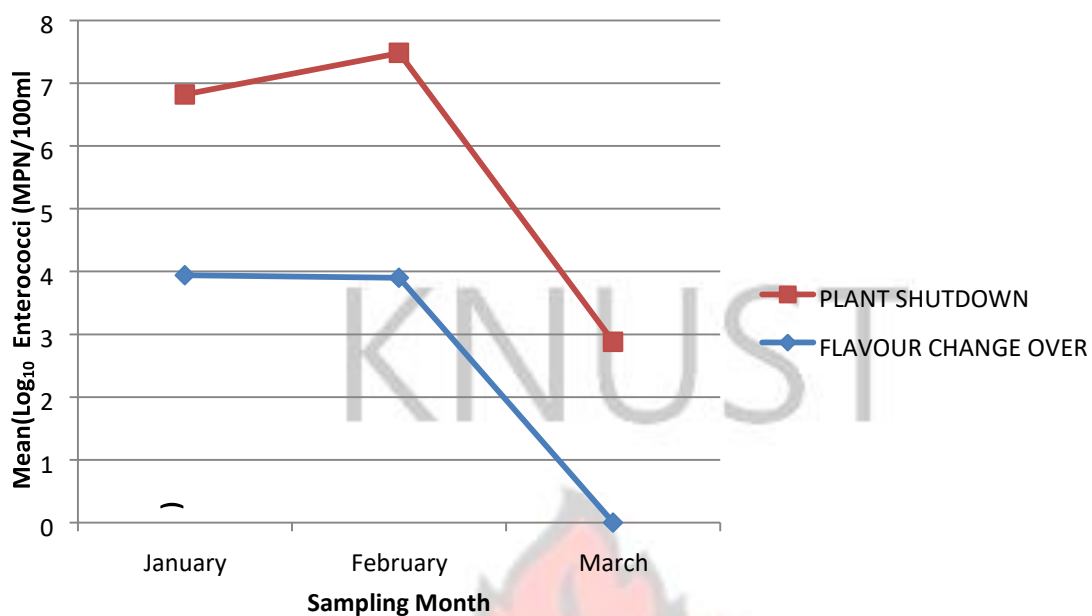


Fig. 37: Mean (Log₁₀) *Enterococci* (MPN/100ml) of wastewater during Plant Shutdown and Flavour Change Over.

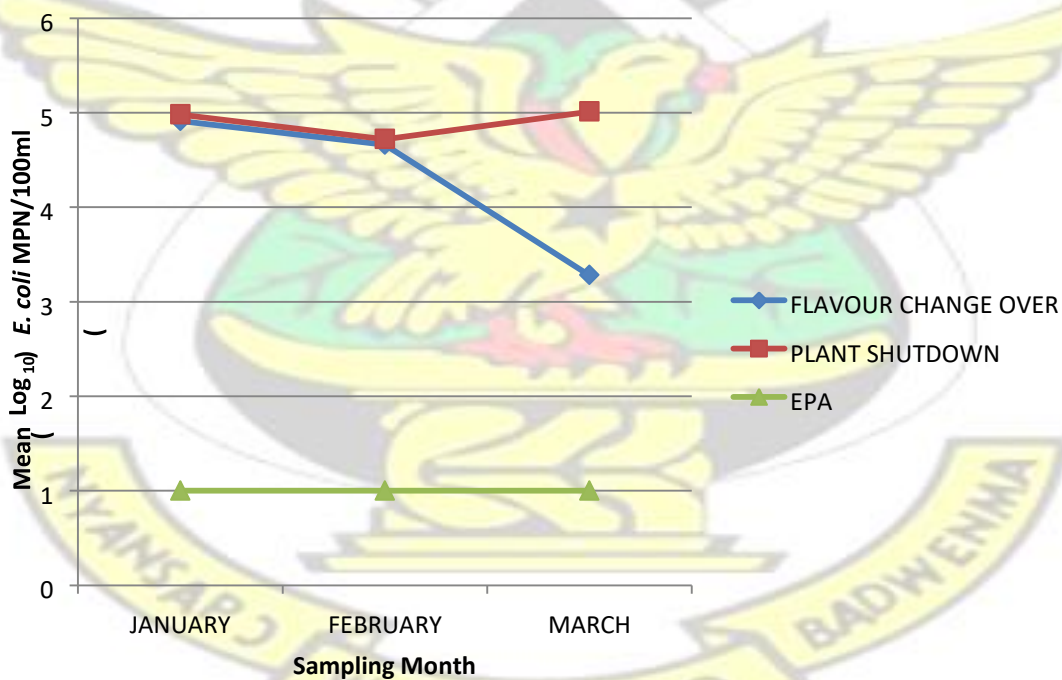


Fig. 38: Mean (Log₁₀) *E. coli* (MPN/100ml) of wastewater during Plant Shutdown and Flavour Change Over.