Impact Analysis and Ranking of Potential Pollutants in Wastewater Systems

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Cambridge
Scholars
Publishing

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This book first published 2026

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-0364-6590-2
ISBN (Ebook): 978-1-0364-6591-9

This book is dedicated to the Almighty God and
His Son Jesus Christ, the Saviour of mankind.

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ABSTRACT

Wastewater was treated to Nigerian Federal Environmental Protection Agency (FEPA) discharge limits using the concept of substrate-limited thermophilic anaerobic digestion with physical adsorption. The percentages of pollutants removed from the wastewater indicate that the treatment efficiency was approximately 100% and the percentage error was approximately 0%. The concentration of Total Suspended Solids (TSS) in the wastewater was found to be the most potential among the pollutants in the wastewater for having a coefficient of variation of 0.998 (99.8 %) followed by Biochemical Oxygen Demand (BOD); Total Dissolved Solids (TDS); Total Hydrocarbon Content (THC); Concentration of oil and Grease (COG); negative of the logarithm of Hydrogen ion concentration (pH) and concentration of Volatile Suspended Solids (VSS) with Coefficients of Variation 0.93; 0.709; 0.38; 0.331; 0.087 and 0 respectively. This indicates that the concentration of Total Suspended Solids (TSS) in the wastewater deviates the most from the Nigerian FEPA discharge limit, and is therefore the greatest contributor to the pollutant load of the wastewater. More so, most suspended solids in the wastewater are the most toxic and therefore the major aspect in the treatment of wastewater is the efficiency in the removal of suspended solids, whether by filtration or adsorption. Wastewater must therefore be treated to remove the Total Suspended Solids, Biochemical Oxygen Demand, Total Dissolved Solids, Total Hydrocarbon Content, Oil and Grease, pH, and Volatile Suspended Solids to the discharge limits recommended by the Nigerian Federal Environmental Protection Agency (FEPA) before discharge into the environment (land and/or water bodies) to safeguard the environment and ecosystem. It was found that treating 5,000 litres per day of wastewater at a thermophilic temperature under substrate-limited anaerobic digestion could yield 4.5137 m^3 per day of biogas, equivalent to 4,513.7 Litres per day of biogas. This shows that 1 m3 of wastewater could yield 0.9 m3 or 900 Litres per day of biogas for a hydraulic retention time of 5 days. Biogas, being a renewable energy source and a better substitute for natural gas, anaerobic digestion of wastewater could enhance the realization of Nigeria's quest for self-sufficiency in renewable energy.

Keywords: Wastewater; Total Suspended Solids; Federal Environmental Protection Agency; Discharge Limits; Potential Pollutant; Coefficient of Variation.

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ACKNOWLEDGEMENT

The Author is grateful to Mr. Peter Onu of Prelyn Printing Press, Urualla Mile 1, Port Harcourt, Nigeria for sacrificing his time to provide professional expert typesetting.

ABBREVIATIONS

Abbreviation	**Meaning**
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
CV	Coefficient of Variation
COG	Concentration of Oil and Grease
DF	Dilution Factor
FDL	FEPA Discharge Limit
FEPA	Federal Environmental Protection Agency
FID	Flame Ionization Detector
GC	Gas Chromatography
N	Number of Items
PAHs	Polycyclic Aromatic Hydrocarbons
PFRP	Processes to Further Reduce Pathogens
TDS	Total Dissolved Solids
THC	Total Hydrocarbon Content
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VSS	Volatile Suspended Solids
WEF	Water Environment Federation
WWTP	Waste Water Treatment Plant

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Wastewater is the undesired liquid end product or by-product of municipal, agricultural and industrial activity or unit operation (Dana 2011:1 & Ellis 2017:2). These liquid wastes, which are toxic and hazardous, causing diseases, are usually discharged into water drainage systems that are linked to the Wastewater Treatment Plant (WWTP).

Rabah (2018:3) defined industrial wastewater as water which has been used for industrial purposes and has been mixed with suspended and/or dissolved solids. Wastewater needs to be treated so as to remove these solids, hydrocarbons, oil and grease and other toxic and hazardous substances present in the wastewater.

The Nigerian Federal Environmental Protection Agency (FEPA) (2002:1123) provides discharge limits for treated industrial wastewater, which is to be discharged into the environment (land or water bodies). In Nigeria, the treatment of industrial wastewater to the discharge limits stipulated by FEPA imposes a major challenge to the oil and gas industry. The contribution of each pollutant in the wastewater to the toxicity of the wastewater needs to be known so that their removal can be targeted to enhance optimum results. To know the target pollutants, an impact analysis is necessary.

Impact analysis is defined as the recording, examining and evaluating the results of a process operation. Impact analysis is a method of measuring outcomes to know their effects. Impact analysis helps determine which among several alternatives is the most effective approach. It is important to address impact evaluation as part of an integrated monitoring, evaluation and research plan.

1.2. Statement of the Problem

Dana (2011: 2) stated that pollutants in wastewater that run into streams, rivers or lakes can have serious effects on aquatic life, plants, animals and humans, possibly leading to the extinction of the inhabitants of these environments. Hence, wastewater needs to be treated to remove these pollutants to the discharge limits stipulated by the Nigerian Federal Environmental Agency (FEPA) before it can be discharged into the environment (land and/or water bodies). In Nigeria, the treatment of wastewater to the discharge limits stipulated by FEPA imposes a major challenge to the oil and gas industry. This is the result of a lack of knowledge of the target pollutants and their impact on the environment.

1.3. Aim of the Study

This study aims to find the most potent pollutant in wastewater by carrying out an impact analysis using statistical methods based on the Nigerian Federal Environmental Protection Agency (FEPA) discharge limits.

1.4. Objectives of the Study

The objectives of this study are considered to be:

1. Carry out a review of the related literature by other researchers as part of chapter one of this book to enhance knowledge of the subject matter, as well as make up the chapter volume, being a book, not a Dissertation.

2. Examine the key pollutants in the wastewater, among others.

3. Find the most potential among the key pollutants in wastewater by carrying out an impact analysis using statistical analysis based on the Nigerian Federal Environmental Protection Agency (FEPA) discharge limits.

1.5. Significance of the Study

This research is important because the relevant industries and environmental agencies will use the data provided to identify the most significant pollutants in their wastewater. This will enable knowledge of the pollutants to target more in their wastewater treatment plants, so as to enable quicker attainment of the FEPA discharge limits, efficient and effective treatment of the wastewater.

1.6. Scope and Limitations of the Study

This study examines the pollutants in wastewater, but the impact analysis using statistical methods based on FEPA discharge limits will only be carried out for key pollutants: Biochemical Oxygen Demand, Total Hydrocarbon Content, Concentration of Oil and Grease, pH, Total Suspended Solids, Total Dissolved Solids and Volatile Suspended Solids.

1.7. Limitations of Other Researchers (Research Gap)

Tychobanoglous, G., Dana, A., Ellis, T.G., Rabah, F., Perry, R.H. and other researchers conducted studies on the pollutants in wastewater. These researchers did not use dispersion measures from an assumed mean to find the most potent pollutant in the wastewater under substrate-limited thermophilic anaerobic digestion treatment of the wastewater with physical adsorption.

1.8. Current Work

Under substrate-limited thermophilic anaerobic digestion treatment of the wastewater with physical adsorption, this research book studies the effects of the key physico-chemical parameters of wastewater treatment, e.g. Biochemical Oxygen Demand (BOD), Total Hydrocarbon Content (THC).

Concentration of Oil and Grease (COG); Negative of the logarithm of Hydrogen ion concentration (pH); Concentration of Volatile Suspended Solids (VSS); Concentration of Total Suspended Solids (TSS), and Concentration of Total Dissolved Solids (TDS), to determine by statistical analysis the most potential among them based on discharge limits stipulated by the Nigerian Federal Environmental Protection Agency (FEPA).

1.9. Expected Outcome

This research is expected to produce procedures, formats and equations for the treatment of wastewater, pollutant measurement and removal. The most potential among the pollutants in the wastewater will be determined using a statistical procedure based on FEPA discharge limits and recommendations made.

1.10. Types of Wastewater

Ellis (2017:2) defined wastewater as the undesired liquid product or byproduct of municipal, agricultural and industrial activity.

Generally, Industrial wastewater can be divided into:

i. Inorganic Industrial Wastewater
ii. Organic Industrial Wastewater

1.10.1. Inorganic Industrial Wastewater

Inorganic industrial wastewater is wastewater produced mainly in the coal and steel industry, non-metallic minerals industry and commercial enterprises and industries for surface processing of metals (iron, picking works and electroplating plants). These wastewaters contain a large proportion of suspended matter, which can be eliminated by sedimentation, often together with chemical flocculation through the addition of iron and aluminium salts, flocculation agents and some kinds of organic polymers.

The purification of warm and dust-laden waste gases from blast furnaces, converters, cupola furnaces, refuse and sludge incineration plants and aluminium works results in wastewater containing mineral and inorganic substances. Wastewater from rolling mills contains mineral oil and requires additional installations such as skim boards and skim off apparatus for retention and removal of mineral oils.

Residues of emulsified oil remaining in the wastewater also need chemical flocculation. In many cases, wastewater is produced in addition to solid substances and oil and also contains extremely harmful solutes. These include blast-furnace and gas welding wastewater containing cyanide, waste from the metal processing industry containing acids or alkaline solutions (mostly containing non-ferrous metals and often cyanide and chromate), and wastewater from eloxial works and from the waste gas purification of aluminium works, which in both cases contain fluoride

a. Petroleum Wastewater

The petroleum industry, also known as the oil industry or oil patch, includes the global processes of exploration, extraction, refining, transporting (often by oil tankers and pipelines), and marketing of petroleum products. The largest volume products of the industry are fuel oil and gasoline (petrol).

The petroleum industry is an industry which produces crude oil and natural gas. The crude oil, natural gas and petroleum wastewater exist together in the natural gas well with natural gas in abundance or in the petroleum crude oil well with crude oil in abundance.

This mixture is separated in a settling column into natural gas at the top, crude oil, and petroleum wastewater at the bottom according to their densities.

It is stated in EPA (2018:5) that oil and gas exploration and production (E&P) activities generate a variety of waste materials requiring management. These waste materials include produced waters, spent drilling fluids, used drilling muds and drill cuttings. Produced water is the fluid (often called brine brought up from hydrocarbon-bearing strata during the extraction of oil and gas, and includes, where present, formation water, injection water, and any chemicals added downhole or during drilling, production or maintenance processes.

This wastewater (mixed with oil, solids, Hydrocarbons, etc) from several gas wells and petroleum oil wells in the Ebocha oil field, Omoku, Rivers State, Nigeria, is flushed into a reserve pit. This reserve pit stores all the wastewater from Agip oil wells and gas wells in the Ebocha oil field.

The gas at the top is routed to a gas processing plant, which extracts Natural Gas Liquids (NGL): Ethane, Propane, Butane, Isobutane, Pentane, and

Pentane Plus by cryogenic expansion.

Natural Gas Liquid is a feed for a petrochemical olefins plant, which pyrolyses or cracks these heavy hydrocarbons to lighter ones, which are feed for the resins fabrication industries. Crude petroleum oil is a feed for petroleum refineries, which produce gasoline, kerosene, diesel, etc.

The petroleum wastewater from the reserve pit, which stores all the petroleum wastewater from Agip crude oil wells and natural gas wells in the Ebocha oil field, is a kind of inorganic industrial wastewater called petroleum industrial Wastewater.

1.10.2. Organic Industrial Wastewater

These are wastewaters that contain organic industrial waste flow from the chemical industries and large-scale chemical works, which mainly use organic substances from chemical reactions (Dana, 2011:2). The effluents contain organic substances having various origins and properties. These can be removed by pretreatment of the wastewater followed by biological treatment. Organic wastewater can be generated by the pharmaceutical, cosmetics, organic dye, glue, adhesive, soap, synthetic detergent, pesticide, tannery and leather industries. The treatment of petroleum wastewater covers the mechanisms and processes used to treat waters that have been contaminated in some way by anthropogenic industrial or commercial activities before its release into the environment and its re-use.

Dana (2011:2) classified wastewater into:

i. Domestic wastewater
ii. Industrial wastewater

Dana (2011:2) defined domestic wastewater as wastewater produced by acts of living, such as using the bathroom, doing laundry or washing dishes. Domestic wastewater is wastewater originating from activities such as restroom usage, washing, bathing, food preparation and laundry. Industrial wastewater is process water originating from manufacturing, commercial businesses, mining, agricultural, production, processing and wastewater from the clean-up of petroleum and chemical contaminated sites. All wastewater that is not defined as domestic wastewater is considered industrial wastewater. Industrial wastewater that discharges to domestic wastewater or a reclamation treatment facility must be regulated under the industrial pre-treatment program (USEPA, 2019a:1).

1.11. Constituents of Wastewater

Perry & Green (2007:25-60) stated that wastewater characteristics vary widely from industry to industry. Obviously, the specific characteristics will affect the treatment technique chosen for use in meeting discharge requirements. Because of the large number of pollutant substances, wastewater characteristics are not usually considered on a substance-by-substance basis. Rather, substances of similar pollution effects are grouped into classes of pollutants or characteristics.

Tchobanoglous *et al.* (2004:29) characterise wastewater in terms of its physical, chemical and biological composition. The principal physical properties and the chemical and biological constituents of wastewater are interrelated. For example, temperature is a physical property, but it affects both the amounts of gases dissolved in the wastewater and the biological activity in the wastewater. Secondary treatment standards for wastewater are concerned with the removal of biodegradable organics, total suspended solids and pathogens. Many of the more stringent standards that have been developed recently deal with the removal of nutrients, heavy metals and priority pollutants. When wastewater is to be reused, standards normally include additional requirements for the removal of refractory organics, heavy metals and in some cases, dissolved inorganic solids.

Tchobanoglous *et al.* (2004:32) gave a list of wastewater contaminants and the reasons that they are of concern. This is explained as follows.

a. Biodegradable Organics

Oxygen-consuming organic matter or biodegradable organics are composed principally of proteins, carbohydrates, and fats. Biodegradable organics are measured most commonly in terms of BOD and COD. If discharged

untreated into the environment, their biological stabilisation can lead to the depletion of natural oxygen resources and to the development of septic conditions. The Federal Environmental Protection Agency (2002:17) recommended a BOD of 10 mg/L as a discharge limit for treated wastewater into inland water bodies.Biodegradable Organics can be removed by the following unit operations and processes: Aerobic suspended growth variations; Aerobic attached growth variations; Anaerobic Suspended growth variations; Anaerobic attached growth variations; Lagoon variations; Physical–chemical Systems; chemical Oxidation; Advanced oxidation; Membrane filtration.

b. Suspended Solids

Suspended solids can lead to the development of wastewater deposits and anaerobic conditions when untreated wastewater is discharged into the aquatic environment. The Federal Environmental Protection Agency (2002:11) recommended 30 mg/L of total suspended solids as a discharge limit for treated wastewater that is to be discharged into inland water bodies.

Suspended Solids can be removed using unit operations as follows:

Screening; Grit removal; Sedimentation; High rate clarification;

Floatation; Chemical precipitation; Depth filtration; Surface filtration.

c. Nutrients

Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater. Federal Environmental Protection Agency (2002:11) recommended a discharge limit of 20 mg/L for the discharge of nitrate into surface water, which is within 15 millimetres of rainfall and 5 mg/L for the discharge of phosphate into surface water, which is within 15 millimetres of rainfall.

d. Priority Pollutants

Priority pollutants are organic and inorganic compounds selected on the basis of their known or suspected carcinogenicity, mutagenicity, teratogenicity or high acute toxicity. Many of these compounds are found in wastewater. Owabor & Owihiri (2011:124) gave the priority pollutants to be naphthalene, phenanthrene and anthracene. Refractory organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols and agricultural pesticides.

e. Pathogens

Pathogens are disease-causing organisms. Communicable diseases can be transmitted by the pathogenic organisms in wastewater. Diseases such as typhoid, dysentery and other intestinal disorders are caused by disease pathogens present in wastewater. Tests for total coliform and faecal coliform are used to indicate the presence of pathogenic bacteria. Pathogens are destroyed by the addition of chlorine compounds, chlorine dioxide, ozone,

Ultraviolet (UV) radiation. Federal Environmental Protection Agency (2002:12) recommended 50 MPN/100 mL as the permissible limit of faecal coliforms in bio-solids for land application and 400 MPN/100 mL for discharge into water bodies.

f. Dissolved Inorganics

Inorganic constituents such as calcium, sodium and sulphate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is to be reused. Dissolved inorganics is an expression for the combined content of all inorganic substances contained in wastewater in molecular, ionised or microgranular suspended form.

Dissolved solids pass through a fine mesh filter. Settling or floatation can remove solids, but cannot remove dissolved solids. High total dissolved solids indicate the presence of toxic minerals. A constant level of minerals is necessary for aquatic life; hence, the total dissolved solids level should be monitored. The Federal Environmental Protection Agency (2002:11) recommended that the concentration of total dissolved solids in treated wastewater for discharge onto land and water bodies should not exceed 2,000 mg/L.

1.12. Inorganic Chemical Characteristics

The following are the main inorganic materials present in wastewater:

a. Nutrients

Dana (2011:2) defined Nutrients as life-supporting nitrogen and phosphorus. Nutrients in wastewater are the cause of eutrophication. Eutrophication is a condition of excessive growth of algae and other aquatic plants in a water body. This causes deterioration of water quality. Nutrients stimulate excessive growth of algae and other aquatic plants. They are always present in domestic wastewater and are not removed during conventional primary and secondary treatments. Removal is accomplished by processes in addition to normal wastewater treatment or tertiary treatment when specific reuse requirements require it.

Tchobanoglous *et al.*(2004:60-64) stated that Free Ammonia ($NH4+$); Organic nitrogen (Org N); Total Kjeldahl nitrogen

(TKN (org N + $NH4+$ - N); Nitrites ($NO2$); Nitrates ($NO3-$); Total nitrogen (TN); Inorganic Phosphorus (Inorg P); Total Phosphorus (TP); Organic phosphorus (org P) are used as a measure of the nutrients present and the degree of decomposition in the wastewater. The oxidised forms can be taken as a measure of the degree of oxidation. The Federal Environmental Protection Agency (2002:11) recommended a nitrate and phosphate concentration of 20 mg/L and 5 mg/L, respectively, as maximum concentrations allowed for the discharge of treated wastewater into surface water.

b. pH

The hydrogen-ion concentration is an important parameter in both natural waters and wastewaters. It is a very important factor in the biological and chemical analysis of wastewater. The negative of the hydrogen ion concentration indicates that the wastewater is neutral if it is equal to 7, alkaline if it is greater than 7 and acidic if it is less than 7.

Tchobanoglous *et al.* (2004:57) defined pH as the negative of the logarithm of hydrogen ion concentration.

$$pH = -\log 10[H+] \qquad (1.1)$$

The concentration range suitable for the existence of most biological life is quite narrow (between 6 and 9). Wastewater with an extreme concentration of hydrogen ions is difficult to treat by biological means. If the pH is not increased before discharge, it may increase the acidity of water bodies to which the treated wastewater is discharged. For treated effluents discharged to the environment, the allowable pH range usually varies from 6.6 to 8.5. The hydrogen ion concentration in the wastewater has a relationship with the extent of dissociation of the wastewater molecules. Wastewater dissociates into hydrogen ions and hydroxyl ions as follows:

$$H2O \rightarrow H+ + OH-$$

Applying the law of mass action:

$$[H+][OH-]$$