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**Abstract:** Indiscriminate discharge of raw wastewater resulted in pollution of aquatic environments and loss of biodiversity along Mukuvisi Stream. The aim of this research was to monitor wastewater quality parameters against ZINWA Effluent Standards after incorporation of a chemical treatment process into the existing physical treatment process at National Foods. The methodology was divided into Wastewater Treatment and Wastewater Quality Analysis. Alum, Alsa Floc and Lime were used for treatment and standard methods for analysis. One Sample T-tests were done in SPSS. Most results showed a positive kurtosis meaning that they were close to ZINWA effluent standards. Parameters under investigation varied significantly (p < 0.05) with ZINWA effluent standards. The mean concentrations in mg/L were found as TDS: 906, chlorides: 271, FOG: 2.39, phosphates: 0.94 and pH of 6.9 at 21.6°C which were below maximum permissible limits. It was recommended that treated wastewater be used for general cleaning, coal dust suppression and watering lawns.

Key words: physico-chemical monitoring, flocculation, coagulation, sedimentation

## 1. Introduction

The challenge of effectively managing process wastewater seems to cross geographical boundaries and individual food product classifications with equal ease [1]. With discharge standards tightening and haul-out costs escalating by the year, many food processors have found an attractive alternative in treatment systems that can be installed and operated on-site to produce clear, sewerable water and a residual sludge that in most cases is locally landfillable [2]. Contaminants from processing industries, where the most typical contaminants are monitored by municipal regulatory agencies, include TSS (Total Suspended Solids), BOD (Biological Oxygen Demand), sulphates, phosphates and Fats, Oils and Grease (FOG). Ordinarily, water in the food waste stream is subjected to pH adjustment and chemical or physical processes that cause the pollutants to agglomerate or form a floc for subsequent removal [2]. Crude oils, particularly soybean oil, contain significant quantities of organic phosphorus in the form of phosphatides. These compounds are removed to a large extent from the oil phase in the refining process [3]. Treatment of this wastewater includes processes involving separation of colloidals which is achieved by the addition of chemicals which can either be coagulants or flocculants. These chemicals change the physical state

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of colloids retaining them to a stable state, creating colloids and flocs with settling properties. Wastewater treatment and subsequent recycling and reuse by industries can contribute significantly to reduction in the demand of clean water from local authorities. It is against this background that this research assessed the pH, temperature and concentrations of FOG, phosphates, chlorides and total dissolved solids against ZINWA standards in treated industrial wastewater after incorporation of physico-chemical wastewater treatment processes in Aspindale Oil Plant – National Foods.

## 2. Literature Review

Physico-chemical treatment processes are used to remove inorganics primarily by oxidation and precipitation. Occasionally chemical treatment will be used to remove organics particularly those that are not, or are resistant to biodegradation [4]. Physicochemical precipitation is a process whereby some or all of a substance in a solution is transformed into a settleable solid-phase by chemical means [5]. It is based on alteration of chemical equilibrium relationships affecting the solubility of inorganic species. Removal of metals as hydroxides and sulphides is the most common precipitation application in wastewater treatment. Lime or sodium sulphide is added to wastewater in a rapid mixing tank along with flocculating agents. Certain anionic species such as phosphate, sulphate, chloride and fluoride can be removed by precipitation. Organic compounds may form organometallic complexes with metals which could inhibit precipitation [2]. Cyanide and other ions in wastewater may also complex with metals making treatment by precipitation less efficient [6].

The theory of chemical precipitation reactions is very complex with numerous side reactions in wastewater taking place. These aspects can be divided into three, namely: nature of particles in wastewater, surface charge, and particle aggregation [7]. There are two general types of colloidal solid particle dispersions in liquids which determine the nature of particles in wastewater. When water is the solvent, these are called hydrophobic and hydrophilic colloids. These two types are based on the attraction of the particle surface for water. Some water molecules will generally adsorb on the typical hydrophobic surface, but the reaction between water and hydrophilic colloids occurs to much a greater extent. An important factor in the stability of colloids (resistance to settle) is the presence of surface charge. It develops in a number of different ways, depending on the chemical composition of the medium (wastewater in this case) and the colloid. Regardless of how it is developed, this stability must be overcome if these particles are to be aggregated (flocculated) into larger particles with enough mass to settle easily. Surface charge develops most commonly through preferential adsorption, ionization and isomorphous replacement. For example, oil droplets, gas bubbles or other chemically inert substances dispersed in water will acquire a negative charge through the preferential adsorption of anions particularly hydroxyl ions [8]. To bring about particle aggregation, steps must be taken to reduce particle charge or to overcome the effect of this charge. This effect can be overcome by:

The addition of potential-determining ions, which will be taken up or will react with the colloidal surface to lessen the surface charge, or the addition of electrolytes which have the effect of reducing thickness of the diffuse electric layer and thereby reducing the zeta potential.

The addition of long-chained organic molecules (polymers), whose subunits are ionizable and are therefore called polyelectrolytes, which bring about the removal of particles through adsorption and bridging [9].

Depending on whether their charge when placed in water is negative, positive or neutral, polyelectrolytes are classified as anionic, cationic and non-ionic respectively. The addition of polyelectrolytes can be divided into two general categories according to Ref. [9];

(a) Polyelectrolytes act as coagulants that lower the charge of wastewater particles. Because wastewater particles are negatively charged, cationic polymers are used for this purpose.

(b) Polyelectrolytes can be used for inter-particulate bridging; in this case anionic or non-ionic polymers are used. The size of the resulting three-dimensional particles grow until they can be removed easily by sedimentation.

## 2.1 Flocculation and Coagulation Principles

Charge-neutralized solids can he further agglomerated by using flocculants. Flocculation is the agitation of chemically treated water to induce coagulation. Flocculation is a principal mechanism in removing turbidity from water [10]. It is caused by differences in settling velocities of particles, resulting in heavy particles overtaking and coalescing with slower ones and velocity gradients within the water producing collisions among particles. Flocculants can be thought of a sort of a "high-tech rope" tying particles together, thereby increasing particle size. Flocculants come in various charges, charge densities, molecular weights, and forms. The beneficial results are that particles grow into faster-settling floc sweeping smaller and slower particles from suspension. Flocculation is applicable to aqueous waste streams where particles must be agglomerated into larger more settleable particles prior to other types sedimentation or of treatment. Precipitation is non-selective in that compounds other than those targeted may be removed [11]. Both precipitation and flocculation are non-destructive and generate large volumes of sludge which needs to be properly managed [7]. Chemical addition must be adjusted with compositional changes of the wastewater being treated. Two types of flocculants based on charge include:

(a) Cationic Flocculants

Mostly based on copolymers of AETAC (N,N-Dimethyl aminoethyl Acrylate Methyl Chloride Quaternary) or METAC (N,N-Dimethyl aminoethyl Methacrylate Methyl Chloride acrylamide. These products can perform a dual function by both coagulating with their positive ionic charge and flocculating with their high molecular weight.

## (b) Anionic Flocculants

Mostly based on copolymers of acrylamide and acrylic acid, anionic flocculants possess a negative ionic charge and work by binding with residual cationic charges on coagulants adsorbed to coagulated colloids.

Coagulation involves the addition of chemicals to alter the physical state of dissolved and suspended solids [9]. This facilitates their removal bv sedimentation and filtration. Another result of chemical addition is a net increase in Total Dissolved Solids (TDS) in the wastewater [7]. Common primary coagulants are alum, ferric sulphate and ferric chloride. Alum is mildly hazardous with similar health effects and corrosion characteristics as diluted sulfuric acid. Alum is manufactured as a liquid, and the crystalline form is dehydrated from the liquid. Alum is one of the most commonly used water treatment chemicals in the world. Ferric chloride is generally the least expensive inorganic coagulant, because it is generated as a waste material from steelmaking operations. However, it is by far the most corrosive and hazardous inorganic coagulant, and its use is limited to facilities equipped to handle it safely. Additional chemicals that can be added to enhance coagulation include active silica, which is a complex silicate made from sodium silicate and charged organic molecules which include large molecular-weight polyacryl-amides, dimethlydiallylammonium chloride, polyamines and starch. Coagulation may also remove dissolved organic and inorganic compounds if polymers are used [12]. The hydrolysing metal salts may react with organic matter to form a precipitate or they may form aluminium hydroxide or ferric hydroxide floc particles on which

organic molecules adsorb. The organic molecules are then removed by sedimentation and filtration. Flocculation is purely a physical process in which the treated water is gently stirred to increase inter-particle collision and thus promoting the formation of large particles [1]. The process of sedimentation involves the separation from water by gravitational settling of suspended particles that are heavier than water. Coagulation, flocculation, sedimentation and filtration will remove many contaminants. Perhaps most important is the reduction of turbidity. This treatment yields water of good clarity and enhances disinfection efficiency. If particles are not removed, they harbour bacteria and make final disinfection more difficult [12].

Most of the suspended solids are colloidal in nature such as metal oxides, proteins and micro-organisms. These particles are extremely small (< 1  $\mu$ m) and hence have negligible settling velocities. All tend to be negatively charged, so colloidal particles generally repel each other preventing aggregation and settlement [6]. Coagulants are used to induce agglomeration. Selection of a suitable coagulant depends on the nature of the particles especially their affinity to absorb water and their electrical charge. Particles are generally negatively charged making them stable, i.e., (remain in suspension). Altering their charge destabilises the particles so that they agglomerate and settle [11]. The mechanisms of coagulation are complex including adsorption, neutralisation of charges and entrapment within the coagulant matrix. The coagulant is added to wastewater and rapidly mixed for 20 to 60 seconds to produce a microfloc [11]. The mixture is then gently agitated to achieve flocculation where the microfloc grows to form a floc that will readily settle. Often coagulants alone are not adequate enough to promote satisfactory floc formulation. Coagulant aids which are polyelectrolytes that include a wide range of synthetic organic polymers such polyacryamide, as

polyethylene oxide and polyacrylic acid are added to wastewater after as aids to coagulants [13].

Hydrophilic particles (organic residues. macromolecules such as proteins, starch and detergents) have high affinity for water and their stability is due to bound water layers that prevent particle from coming into close contact. They also have weak charges from the ionisation of attached functional groups (e.g., carboxyl, hydroxyl groups etc.) [14]. Metal salt coagulants react with the alkalinity in the water to produce insoluble metal hydroxide precipitation that enmesh the colloidal particle in water and adsorb other material including dissolved organic matter present. The hydroxide flocs carry a small positive charge that attracts negative particles in water. Polyelectrolytes used as coagulant aids are available with either a positive or negative charge and are used to optimise flocculation.

The most widely used coagulant is aluminum sulphate (alum)  $(Al_2(SO_4)_3.14H_2O)$  but it is highly corrosive and requires careful handling and storage. Alum reacts with alkalinity in wastewater to produce insoluble aluminium hydroxide floc  $[Al(OH)_3]$  according to the equation:

$$Al_2(SO_4)_3.14H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$$
(1)

Where alkalinity is insufficient in the water, lime in the form of calcium hydroxide is added.

 $\begin{array}{l} Al_2(SO_4)_3.14H_2O+3Ca(OH)_2\rightarrow 2Al(OH)_3+3CaSO_4\\ +\ 14H_2O \end{array} \tag{2}$ 

(a) For each coagulant, there is an optimum range of pH values for good flocculation which depends not only on the coagulant but also on the quality of wastewater. For any particular water, the pH range for best coagulation may be only 0.3 units above the initial wastewater pH value [13]. The temperature of water also alters the degree of coagulation obtained, larger doses of coagulant being required at low temperatures. Another factor influencing the degree of coagulation is the timing of the additions and the order of addition if more than one reagent is used [14]. The

optimum conditions of coagulation should be discovered by laboratory tests.

Sometimes even a coagulated solid is slow to settle. Such light flocs can often be made to settle out more quickly by "weighting" them with some inactive but relatively dense material [11]. For this reason ground chalk or clays such as bentonite are sometimes added to wastewater with or just before the coagulant. Bentonite is clay (hydrated aluminium silicate) which forms colloidal solution capable of effecting coagulation. It is effective in the pH range 2-10 so that control of pH value is not necessary [12]. Coagulation and flocculation can reduce colour, turbidity, odour, bacteria, radioactive nuclides, phosphates, solids, trace organics and FOG from wastewater [11].

## 2.2 Sedimentation Theory

Gravity settling is the most common physical process for removing suspended solids from wastewater. Sedimentation can be classified into two types [13].

(a) Plain sedimentation which refers to impurities being separated from the suspended fluid by gravitational and natural aggregation.

(b) Sedimentation with coagulation refers to the addition of chemical substances (coagulants) to increase the aggregation and settling of finely divided suspended and colloidal matter.

Discrete particles are those particles which do not change their shape, size and weight while settling down in a fluid [15]. The suspended impurities in wastewater consist of discrete particles such as inorganic solids having specific gravity of about 2.65 and organic solids of specific gravity of 1.40 [12]. The particles having specific gravity more than 1.20 readily settle down at the bottom of the tank due to the force of gravity. This phenomenon of settlement is known as hydraulic subsidence. Every particle has its own hydraulic subsidence value, but the lighter particles cannot settle down due to the force of gravity. Such particles are converted to settleable size by the application of some coagulants in wastewater. While settling down the floc attracts more and more suspended impurities and thus the size of the floc goes on increasing and ultimately the surface area of the floc becomes sufficiently wide to arrest colloidal, organic matter and some amount of bacteria.

Suspended matter and characteristics of particles are classified into three sedimentation processes which depend on their concentrations. These types are discrete, flocculants and zonal and compression settlement. Where particles are dispersed or suspended at low solids concentration then discrete and flocculants settlements occur. Zonal and compression settlement only occur when the solids concentration has increased to such an extent that the particle forces or particle contact affects normal settlement processes. During settlement, it is common to have more than one type of settlement occurring simultaneously.

Particles in relatively dilute solutions do not act as discrete particles but coalesce or flocculate with other particles during gravitational settlement resulting in flocculants settling. Subsiding particles coalesce with small particles falling at lower velocities to form larger particles which then settle faster than the parent particle. The degree of flocculation is dependent on the opportunity for particle contact, which increases as the depth of the settling tank increases. So the removal of suspended solids depends not only on the clarification rate but also on depth of the clarifier or settling tank, which is a major difference between discrete and flocculants settlement.

In dilute suspensions particles settle freely at their terminal velocity until they approach the sludge zone when the particles decelerate and finally become part of the sludge. In concentrated suspensions (more than 2000 mg/L), hindered settlement occurs. Owing to the high concentration of particles there is a significant displacement of liquid as settlement occurs which moves up through the interstices between particles reducing their settling velocity and forming an even more concentrated suspension. The particles are close

enough for interparticulate forces to hold them in fixed positions relative to each other so that all the particles settle as a unit or blanket. A distinct solid-liquid interface at the top of the blanket with the upper liquid zone relatively clear and free from solids is formed.

## 2.3 Phosphate Removal

Phosphorus is present in wastewater as orthophaspate ( $PO_4^{3-}$ ,  $H_2PO_4^{-}$ ,  $HPO_4^{2-}$  and  $H_3PO_4$ ), polyphosphates and organic phosphate. Polyphosphates undergo hydrolysis in aqueous solutions and revert to orthophosphate forms; this hydrolysis is usually quite slow [1]. Lime is used less frequently because of its substantial increase in the mass of sludge produced as compared to metal salts and the operating and maintenance and occupational health problems associated with the handling, storage and feeding of lime. Due to the reaction of lime with the alkalinity of the wastewater, the quantity of lime required will in general, be independent of the amount of phosphate present and will depend primarily on the alkalinity of the wastewater. The quantity of lime required to precipitate phosphorous in wastewater is typically about 1.4 to 1.5 times the total alkalinity expressed as CaCO<sub>3</sub>. When lime is added to raw wastewater, or to secondary effluent, pH adjustment is usually required before subsequent treatment or disposal [13].

Orthophosphates can be determined by directly adding a substance, such as ammonium molybdate, that will form a coloured complex with the phosphate [5]. The polyphosphates and organic phosphates must be converted to orthophosphates, using an acid digestion step, before they can be determined in a similar manner. Phosphate concentration in water and wastewater can be determined by the following methods: Vanadomolybdophosphoric Acid Colorimetric Method, Stannous Chloride Method, Ascorbic Acid Method and Flow Injection Analysis for Orthophosphate [16, 17].

## 2.4 Fats, Oils and Grease (FOG)

The term oil represents a wide variety of substances ranging from low to high molecular weight hydrocarbons. Grease represents high molecular weight hydrocarbons and all glycerides of animal and vegetable origin. They are normally removed from wastewater using fat traps which is based on decanting principle. The fatty acids occur principally in a precipitated form as calcium and magnesium soaps [15]. As such, they are insoluble in many solvents. Samples are acidified [8] with a mineral acid for instance HCl to a pH of about 1.0 to release the free fatty acids for analysis. The reaction involved may be represented by the following equation:

 $Ca(C1_7H_{35}COO)_2 + 2H^+ \rightarrow 2C_{17}H_{35}COOH + Ca^{2+} (3)$ 

For liquid samples, three methods of FOG determination are present: Partitioning-Gravimetric Method, Partitioning-Infrared Method and Soxhlet Method [16, 17].

- Partitioning methods are designed for samples that might contain volatile hydrocarbons that otherwise would be lost in the solvent removal operations of the partitioning procedure.
- The Soxhlet Method is the method of choice when the levels of non-volatile greases may challenge the solubility limit of the solvent. Also for low levels of FOG (< 10 mg/L), the Soxhlet Method is of choice because gravimetric methods do not provide the needed precision.

According to Ref. [8], hexane is currently the standard solvent of choice for FOG determination because it is a good solvent for all the materials normally associated with the term grease and has a minimum solvent power for other organic compounds.

## 2.5 Chlorides

In oil purification, degumming of crude oil which involves use of Brine Solution  $(NaCl_{aq})$  is the main

source of chlorides in wastewater. Since conventional methods of wastewater treatment do not remove chloride to any significant extent, higher than usual [Cl<sup>-</sup>] can be taken as an indication that the water body is being used for wastewater disposal and hence this research seeks to solve such gaps in wastewater treatment.

There are four methods for the determination of chloride in water and wastewater. The first two are similar in most respects and selection is largely of personal preference.

(a) Argentometric Method is suitable for use in relatively clear waters.

(b) Mercury Nitrate Method is easier in that the end point of titration is very easy to detect.

(c) Potentiometric Method is suitable for coloured or turbid samples in which colour-indicated end points might be difficult to observe. Automated Ferricyanide Method is an automated technique which is faster than all other methods mentioned above [16, 17].

## 3. Research Methodology

Wastewater was passed through a fat trap and then chemically treated with lime, alum and alsa floc polymer using the method adopted from the American Water Works Association Manual and wastewater quality parameters assessed against ZINWA Effluent Standards.

## 3.1 Physico-chemical Wastewater Treatment

- a) The wastewater pH was adjusted to between 4 and 6 units. This was the optimum pH range in which Aluminium sulphate could start the agglomeration and flocculation process. This was be achieved by either adding concentrated sulphuric acid or lime slurry depending on the water's initial pH.
- b) 40% aluminium sulphate was added while mixing the effluent to allow even mixing.
- c) 20% Sodium Hydroxide was added to adjust the pH to between 6.8 and 7.5.
- d) 0.3 m<sup>3</sup> Alsa Floc Polymer was added and the

wastewater was circulated for 30 minutes to allow thorough and even mixing.

- e) The wastewater was allowed to settle for at least 12 hours (overnight)
- f) The sludge was drained in the sludge pit and water samples taken for laboratory analysis before discharge of water to the municipal sewer.

#### 3.2 Sampling & Sample Preservation

A 3 litre composite sample of treated wastewater was taken from the effluent plant using clean glass containers cleaned with distilled water, soap and rinsed with nitric acid. The initial 3 litre sample was taken at the sampling point prior to treatment so as to determine the amounts of chemicals required to treat the effluent. The last 3 litre sample taken after treatment was analysed to check for the success of the treatment process and compare the results with the specifications in the effluent standards and other environmental regulations on effluent quality.

A 1 litre sample was taken from the 3 litre composite sample, acidified to pH around 2 with concentrated  $H_2SO_4$  (10 ml) and stored in a refrigerator at 4°C as a preservation method since first priority was given to those tests which required immediate analysis.

Another 1 litre sample of wastewater was taken from the composite sample for the determination of chlorides, pH, TDS and temperature which were done immediately within the first 30 minutes from sampling. The remaining 1 litre was filtered immediately with a filter paper to obtain a filtrate with dissolved phosphorous in the form of phosphates which would also be kept in a refrigerator before analysis.

## 3.3 Determination of Chlorides

Argentometric Method was used because the apparatus and reagents required to carry out this test are cheap and locally available. No special preservative was done since the sample was analysed soon after sampling. Apparatus were properly cleaned

and rinsed with distilled water both before and after use to eliminate interference from contaminants.

## 3.4 Determination of Wastewater pH, Total Dissolved Solids and Temperature

100 ml of wastewater were used for the determination of pH soon after sampling using the Electrometric Method with a glass electrode rather than a hydrogen electrode. The advantage of the glass electrode over the hydrogen one was that the glass electrode is relatively free from interference from colour, turbidity, colloidal matter, oxidants and reductants. TDS concentration was determined using a TDS meter. No special preservation was required since the sample was analysed immediately. The wastewater sample temperature was determined soon using Mercury-filled after sampling Celsius Thermometer. The thermometer used had a scale marked for every 0.1°C.

# 3.5 Determination of Phosphates, Fats, Oils and Grease

The Vanadomolybdophosphoric Acid Colorimetric Method was used for the determination of phosphates. The method was used because it is most useful for routine analysis in the range of 1-20 mg/L of phosphates. The calibration curve was prepared using different standard phosphate solutions and the sample was analysed together with the standard to determine the curve closest to that of the sample under study. The Soxhlet Method was used for the determination of Fats, Oils and Grease (FOG) using the 1 litre acidified composite sample.

## 4. Results and Discussion

Physico-chemical precipitation removed the inorganic forms of phosphate (a cause of eutrophication) by addition of coagulants since the concentrations of parameters under investigation were within the required limits. Only FOG and chlorides concentration were not close to the ZINWA standard as shown by their negative kurtosis as shown in Table 1.

	N		Minimum	Maximum	Mean		Kurtosis
Parameter	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
pH	30	5.0	9.5	6.880	0.1788	2.037	0.833
Temperature	30	19.6	25.2	21.597	0.2424	1.048	0.833
TDS	30	500	1800	906.33	64.541	0.297	0.833
Chlorides	30	60.5	440.0	270.617	23.2563	-1.190	0.833
Phosphates	30	0.50	1.09	0.9427	0.03031	1.092	0.833
FOG	30	1.21	3.14	2.3787	0.09671	-0.907	0.833
Valid N (list wise)	30						

 Table 1
 Mean concentrations of parameters under investigation.

Lime addition removed calcium ions as well as phosphorous from wastewater along with any other suspended solids. The lime  $(Ca(OH)_2)$  reacts first with the natural alkalinity in the wastewater to produce calcium carbonate (part of sludge) which is primarily responsible for enhancing suspended solids removal as shown by Eq. (4).

 $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$  (4) After the alkalinity is removed calcium ions combine with the orthophosphate present under alkaline conditions (pH 10.5) to form insoluble and gelatinous calcium hydroxyapatite  $[Ca_5(OH)(PO_4)_3]$  which will settle to the bottom of the settling tank as shown in Eq. (5).

 $5Ca^{2+}+4OH^{-}+3HPO_{4}^{2-}\rightarrow [Ca_{5}(OH)(PO_{4})_{3}]\downarrow +3H_{2}(5)$ 

Similarly to as established by Ref. [13], chemical precipitation using aluminum or iron coagulants is effective in phosphate removal. Although coagulation reactions are complex and only partially understood, the primary action appears to be the combining of

orthophosphate with the metal cation. Polyphosphates and organic phosphorous compounds are probably removed by being entrapped or adsorbed in the floc particles. Alum or hydrated aluminum sulphate [Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>.14.3H<sub>2</sub>O] precipitate phosphates as aluminum phosphate (AlPO<sub>4</sub>) which will also settle as sludge in the sedimentation tank as shown by Eq. (6). Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>.14.3H<sub>2</sub>O + 2PO<sub>4</sub><sup>3-</sup>  $\rightarrow$  2AlPO<sub>4</sub> $\downarrow$  + 3SO<sub>4</sub><sup>2-</sup> + 14.3H<sub>2</sub>O (6)

Reaction (6) causes a reduction in the pH and release of sulphate ions into the wastewater. Although the natural alkalinity accounts for some of the coagulant, the dosage rate of alum is the function of the degree of phosphorous removal required. The efficiency of coagulation falls as the concentration of phosphorous decreases. This study showed that greater alum dosage is necessary to precipitate phosphorous from wastewater. One of the competing reactions, which accounts in part of the excess alum requirement, is with natural alkalinity.

 $Al_{2}(SO_{4})_{3}.14.3H_{2}O + 6HCO_{3}^{-} \rightarrow 2Al(OH)_{3}\downarrow + 3SO_{4}^{2-} + 6CO_{2} + 14.3H_{2}O$ (7)

TDS was reduced by Alsa Floc polymer which also behaves as coagulants that lower the charge of wastewater by precipitating ions such as sulphates, chlorides and others which will subsequently settle down if they gain enough weight by adsorption onto the polymer matrix and aggregation. FOG was within the desired range of below 7.5 mg/L and hence this proves that the treatment was also successful in removing FOG. Oil droplets and other inert particles dispersed in water acquire negative charge through preferential adsorption of anions. These particles will then be removed from suspension by polymers and coagulants resulting in a reduction of FOG and phosphates in wastewater as also established by Ref. [8].

 Table 2
 One sample t-tests for the parameters under investigation.

	Test Value = 6.5										
	т	df	Sig. (2-tailed)	Maan Difference	95% Confidence Interval of the Difference						
	1			Mean Difference	Lower	Lower					
pН	2.123	29	0.042	0.3797	0.014	0.745					
	Test Value = 9										
	Т	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference						
					Lower	Lower					
pН	-11.856	29	0.000	-2.1203	-2.486	-1.755					
	Test Value = $40^{\circ}$ C										
	Т	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference						
					Lower	Lower					
Temperature	-75.914	29	0.000	-18.4033	-18.899	-17.908					
	Test Value = 1500 mg/L										
	Т	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference						
					Lower	Lower					
TDS	-9.198	29	0.000	-593.667	-725.67	-461.67					
Test Value = 400 mg/L											
	т	df	Sig. (2-tailed)	Maan Diffananaa	95% Confidence Interval of the Difference						
	1			Mean Difference	Lower	Upper					
Chlorides	-5.563	29	0.000	-129.3833	-176.948	-81.819					
	Test Value = $3 \text{ mg/L}$										
	Т	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference						
					Lower	Lower					
Phosphates	-67.871	29	0.000	-2.05733	-2.1193	-1.9953					
	Test Value = 7.5 mg/L										
	Т	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference						
					Lower	Lower					
FOG	-52.957	29	0.000	-5.12133	-5.3191	-4.9235					

Table 2 shows the results of One Sample T-test which were done in SPSS for the parameters under investigation. Parameters under investigation varied significantly (p < 0.05) with ZINWA standards and were below the maximum permissible limits. This proves that physico-chemical treatment of wastewater resulted in more desirable results which were below maximum permissible limits in wastewater.

## 5. Conclusion and Recommendations

Chemical precipitation and coagulation can be used to treat industrial effluents such that water discharges will have minimal negative impacts on the environment. The results demonstrate that chemical monitoring of industrial wastewater can be very useful in environmental monitoring and evaluation, closing the water cycle in an eco-friendly manner whilst enjoying low water tariffs due to reuse of treated wastewater onsite and this is the key to environmental protection and sustainability. This all saves fresh water for more vital uses elsewhere such as human consumption. The quality of water to be used in industry depends on the service the water should perform. Treated effluent can be used for the following purposes to yield other economic benefits thereby converting the wastewater challenge into a business opportunity:

(a) Coal dust suppression at boiler section. Water does not need to be of high quality but instead is used to avoid air pollution through emission of coal dust which is attributed to diseases mostly suffered by boiler operators such pneumoconiosis (black lung).

(b) General cleaning of plant equipment and surfaces thereby improving the aesthetics of the oil plants with minimal financial costs incurred by the company.

(c) Watering lawns and flowers by low sprinkling since effluents containing dissolved salts up to 2000 mg/L are suitable for most of the plants except the salt sensitive ones of which lawns are not among the sensitive plants. Water will be discharged to the soil

which also enhances sanitization of water before it reaches the aquatic environment through treatment by natural UV light in the lawn beds and predation by other soil micro-organisms.

(d) Used in the cooling towers. On average water from solvent plants will have temperatures of up to 60°C good enough to destroy pathogenic micro-organisms.

(e) Used to flush human excreta in toilets within the oil plant after disinfection with chlorine.

(f) In the event that there is a fire within the company, treated effluent can be used as a fire extinguisher using pressurized hoses.

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