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Cogent Engineering (2020), 7: 1785756
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Abstract: Wastewater from oil refinery industries has major pollution potentials with mutagenic and toxic compounds. Due to water scarcity in South Africa, oil refinery industries are compelled to find appropriate technology to treat their wastewater for reuse. With regards to this, most of the chemo-physical treatment processes are inadequate and are faced with major environmental and economic challenges. Therefore, this study aimed to find replaceable and cost-effective coagulants to the conventional coagulant for the treatment of a local South Africa oil refinery wastewater using dissolved air flotation (DAF) Jar tests. Three polymeric coagulants for the removal of turbidity, total suspended solids, chemical oxygen demand, and soap oil and grease (SOG) were investigated. At defined experimental conditions of recycle ratio (10%), air saturator pressure (350 kPa) and pH at 5, each coagulant was evaluated from a dosage of 10 mg/L to 50 mg/L. Above 80% of the aforementioned oily pollutants were removed at the coagulant dosage of 50 mg/L. Among the coagulants evaluated, PASS was found as the most suitable alternative coagulant to alum, to enhance and aggregate the air bubble–oil droplet interface.

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PUBLIC INTEREST STATEMENT

To improve water quality, conventional inorganic coagulants (aluminium and iron-based) used in the water and wastewater settings for coagulation treatment are being associated with major environmental and health challenges. These shortcomings have engendered the search for alternative coagulants, which are bio-based, eco-friendly and cost-effective. This research presented bench-scale to real-life application of polymeric coagulants (PCs) for the treatment of a local South Africa oil refinery wastewater. The most suitable alternative coagulant to aluminium and iron-based for pre-treatment of industrial wastewater is highlighted. The merits of PC which make it a better option for industrial wastewater treatment, owing to its low impact on human health, low amount of sludge generation and cost estimation are discussed. The economic prospects of developing natural PCs such as starch, chitosan and moringa for wastewater treatment were introduced for future research.
for easy separation by the DAF. From the results, PASS is foreseen as promising and economical for pre-treatment of industrial wastewater, which is due to its lower cost and easy degradability.

**Subjects:** Chemical Engineering; Waste & Recycling; Water Engineering

**Keywords:** Alum; coagulation; dissolved air flotation; oil refinery wastewater; polyaluminium silicate sulfate (PASS)

1. **Introduction**

The rise of industrialization and extensive utilization of petrochemical products (oil-related fuels), makes the processing of crude oil a major pollution potential by generating large volumes of wastewater posing a threat to human health and the ecosystem (Sun et al., 2020). In a crude oil refinery, some hydrocarbons are fragmented into different components, which are then blended into useful products (Petrol, diesel) (Ghodbane et al., 2020; Shahriari et al., 2018; Yargholi et al., 2020). Due to the complexity of the crude and the high concentration of the oil (>1000 mg/L) in the waste streams along with high content of recalcitrant pollutants, the treatment of oily wastewater is difficult (Farid et al., 2006; Shahriari et al., 2018). In South Africa, the demand for freshwater supply outpaces its availability and is being faced with several sanitation problems. Interfering with the crude oil processing can lead to enormous human health risk and economic deformation (Kweinor Tetteh et al., 2017; Shikwambana & Kganyago, 2020; Tetteh et al., 2020). To curb this issue as an effort of achieving the united nations (UN) sustainable development goal of clean water and sanitation for all before 2030 (UN, 2018), the treatment of oil refinery wastewater (ORW) for reuse therefore comes in handy (Sharma et al., 2020; Sun et al., 2020).

Generally, the oil refining sector produces the most important products that have helped alleviate the living standard in every modern society (Karhu et al., 2014; Naidoo, 2018; Tetteh & Rathilal, 2019). However, due to the increase in global energy demand, it has been estimated that the world oil demand is expected to rise to 107 million barrels per day by 2030, which accounts for 32% of the worlds’ energy supply (Farid et al., 2006; Jarao et al., 2019; Shahriari et al., 2018; Wu et al., 2015). According to El-Naas et al. (2014), oily wastewater produced by petrochemical industries during refinery operations is 0.4–1.6 times the amount of the crude oil processed. This oily wastewater contains waste streams of recalcitrant pollutants, such as waste oil, grease, phenols, aromatics group (Benzene, Toluene, Xylene) and hydrocarbons (Fernando & Trujillo, 2014; Javodi et al., 2020; Sharma et al., 2020; Y. Wang et al., 2016). This makes the processing of petroleum products to be complex by generating large volumes of wastewater, which can end up deteriorating the water quality as well as affecting human health (Gunawardena et al., 2017; Houngbo, 2018; Sun et al., 2020; De Villiers, 2007). Thus, oily wastewater with high organic matter and complex products of chemical reaction with unpleasant colour and odour without proper treatment can cause cancer in humans and reduce the dissolved oxygen content in aquatic life, when discharged into water bodies (US Environmental Protection Agency, 2016; Sohani et al., 2020; B. Wang et al., 2015).

Conventionally, processes applied in most wastewater treatment plants (WWTPs) are classified as primary (physical and chemical) and secondary (membrane, disinfection, advanced oxidation process) treatment processes (Hoseinzadeha et al., 2020; Khouni et al., 2020; Sharghi et al., 2020; Tetteh & Rathilal, 2019; Q. Wang et al., 2017). This includes coagulation/floculation, electrocoagulation, flotation, sedimentation, filtration, reverse osmosis, bioreactor and photocatalytic processes (Hoseinzadeha et al., 2020; Kanakaraju et al., 2018; Liebetrau et al., 2019; Tetteh & Rathilal, 2019; Q. Wang et al., 2017). Coagulation as a chemo-physical process stands out as the first step in WWTPs, where inorganic coagulants play a vital role in the agglomeration of the smaller particles into larger aggregates (Sun et al., 2020; Bensadok et al., 2007; Duan & Gregory, 2003). However, some of these technologies for the treatment of ORW remain unsatisfactory due to the complexity of
the oily wastewater pollutants, which can transform from one medium to another (Diya'Uddeen et al., 2011; Khouni et al., 2020; Sabour & Shahi, 2018; Sharghi et al., 2020).

This makes the treatment of recalcitrant pollutants by downstream processes to be energy-intense and costly (Kariman et al., 2019; Sabour & Shahi, 2018; Yu et al., 2017). For instance, biological systems are faced with the challenges of disposing the large volumes of sludge it generates, its high hydraulic retention time and a large working volume (Aliff Radzuan et al., 2016; Bahrekazemi & Hekmatzadeh, 2017; Frena et al., 2014; Khouni et al., 2020; Sahu & Chaudhari, 2013; Sharghi et al., 2020). Biological methods require large area, long treatment time, and low efficiency when applied as a single treatment system, likewise with physicochemical systems such as dissolved air flotation (DAF) (Bahrekazemi & Hekmatzadeh, 2017; Tetteh & Rathilal, 2020). The DAF is a promising technology, which is gaining prominence to enhance chemical pretreatment processes in various wastewater settings (Atamaleki et al., 2020; Tetteh & Rathilal, 2020).

Subsequently, coagulation and gravity separation of oil droplets from the ORW is one of the most important steps in the primary treatment process (Veréb et al., 2017; Q. Wang et al., 2017). Integration of coagulation-dissolved air flotation (CDAF) technology has gained much interest in the industrial applications as a clarification technology for separating low-density particles such as oil droplets from oily waste (Atamaleki et al., 2020). The CDAF configuration usually applied in the WWTPs involves a coagulation-flocculation step followed by the DAF (Aliff Radzuan et al., 2016; Diya'Uddeen et al., 2011; Karhu et al., 2014; Kyzas & Matis, 2016). In the CDAF process, the addition of the coagulants enhanced the agglomeration of the flocs, while inducing micro-bubbles to promote buoyancy by decreasing the oil droplet weight to enhance the separation efficiency (Aliff Radzuan et al., 2016; Atamaleki et al., 2020).

The application and selection of coagulants (coagulation) depend on the hydrodynamic interaction and the surface chemistry with the oil droplets which varies with ORW source, composition, and density, which may significantly affect the subsequent treatment process (Atamaleki et al., 2020; Tetteh & Rathilal, 2020; Tetteh & Rathilal, 2019). Iron and aluminium-based coagulants have been the most widely used coagulants with active charge ions on their surface (Boaventura et al., 2000; Ukiwe et al., 2014). Their addition destabilizes the water molecules and causes the negatively charged ions, to consequently neutralize and agglomerate into larger flocs (Boaventura et al., 2000; Nasir & Daud, 2014; Tak et al., 2015).

Iron and aluminium-based coagulants have high positive charges and their respective coagulation mechanisms are very complicated with a large number of mono- and polymeric hydroxyl complexes (Boaventura et al., 2000; Tetteh & Rathilal, 2019; Ukiwe et al., 2014). This phenomenon results in generating extra sludge and residual metals in the treated water via under dose or overdosing of the coagulant (Boaventura et al., 2000). This has become a public concern concerning the technical, economic, environmental and health-related problems (Boaventura et al., 2000; J. Wu et al., 2018). In this regard, to select an appropriate coagulant for highly contaminated water treatment (thus ORW), the operational conditions, type of coagulant and dosage must be considered (Tetteh & Rathilal, 2019). Ideally, there are natural (chitosan, Moringa oleifera), inorganic (ions, and iron-based) and organic (polymer-based) coagulants that exist (Sun et al., 2020; Tetteh & Rathilal, 2019). Polyaluminum chloride (PACI) has been reported to be more effective than other conventional coagulants based on their low alkalinity, extensive temperature and pH tolerance (Demirbas & Koby, 2017; Sahu & Chaudhari, 2013; Younge, 2014).

Recently, researchers are focused on developing new and more cost-effective coagulants as an alternative to overcome the challenges and drawbacks associated with aluminium and iron-based coagulants (Boaventura et al., 2000; Sun et al., 2020; Tetteh & Rathilal, 2019). In addressing such drawbacks, this study aimed to investigate three different polymeric coagulants viz. poly aluminium chloride (PAC-10 LB), Polyferric sulphate (PFS) and Polyaluminium silicate sulphate (PASS) for
the treatment of a local South African ORW to an acceptable discharge limit of 50 mg/L. From the authors’ previous studies, there is still limited knowledge on the use of these locally manufactured coagulants for the treatment of industrial wastewater with high content of oily waste and organic matters (Tetteh & Rathilal, 2020; Sun et al., 2020). This study was carried out on a lab-scale by evaluating and comparing the treatability performance for the removal of turbidity, total suspended solids (TSS), chemical oxygen demand (COD) and soap oil and grease (SOG) from the ORW. The materials, experimental setup and protocols used in this are presented in section 2. Section 3 presents the results obtained with discussions, while the conclusions are in section 4.

2. Materials and method

2.1. Wastewater sample
This study was carried out at Umgeni Process Evaluation (PEF) centre, Wiggins in the Kwazulu Natal Province, South Africa (Figure 1). The ORW is a mixed source of ship slops, oil refinery off-spec and waste streams of the petrochemical industries. A sample was obtained from the inlet sample point of a local South Africa oil refinery wastewater treatment plant DAF unit, whose characteristics over three months are presented in Table 1. Acceptable sampling, storage and characterization was done according to the South African Bureau of Standards Method 1051.

Figure 1. Map of South Africa showing KwaZulu-Natal Province and South Durban Basin Adapted from Shikwambana and Kganyago (2020)
Table 1. Characteristics of oil refinery wastewater sample

| Parameter          | Range       | Average ± SE  |
|--------------------|-------------|---------------|
| Turbidity (NTU)    | 1770–2753   | 2430 ± 15.36  |
| TSS (mg/L)         | 867–1035    | 984 ± 4.56    |
| COD (mg/L)         | 11810–12173 | 12115 ± 21.32 |
| SOG (mg/L)         | 1100–1320   | 1230 ± 18.54  |
| pH                 | 6.5–7.5     | 6.8 ± 1.45    |

*SE—standard error

2.2. Coagulants
Table 2 indicates the polymeric coagulants used, which were supplied by Zetachem (Pty) Ltd, South Africa. The respective 1 L stock solution was prepared in accordance with the method by Kweinor Tetteh et al. (2017) and Younge (2014). This was stored under a temperature of 20°C, whereby after a week fresh stock solutions were prepared.

2.3. DAF jar test
A batch DAF jar test (Model DBT6, EC Engineering, and Edmonton, Alberta, Canada) was used in this study. This experimental setup is equipped with six 1 L plus 300 ml suspension space rectangular Perspex beakers, steel mixers and an 8 L air-water saturator vessel (Kweinor Tetteh et al., 2017). In each assay, a volume of 1 L of ORW sample was fractionated into each beaker. The pH of the samples was adjusted and maintained at 5 by using H₂SO₄ and NaOH. The coagulants were dosed (10–50 mg/L) in a sequential interval of 10 mg/L. After the dosage to ensure effective agglomeration of the oil droplets, the samples were firstly agitated at 320 rpm for 1 min. As shown in Figure 2, the DAF was operated at a rapid mixing rate of 250 rpm for 2 minutes followed up with slow mixing at 30 rpm for 15 minutes and flotation time of 15 minutes (Tetteh & Rathilal, 2018). The dissolved water in the air saturator vessel under a saturation pressure of 350 kPa was released into the beakers by regulating

Table 2. Physiochemical properties of polymeric coagulants

| Coagulant type | Common name | Properties |
|----------------|-------------|------------|
| PAC 10 LB      | Polyaluminium chloride Al₂(OH)₃Cl₂ | 10–11% Al₂O₃ or 20–23% w/w PACl |
|                |             | * SG 1.18  |
|                |             | * 50% basicity |
|                |             | * 10.5% w/w Cl |
|                |             | * 245 g/L |
| PASS           | Polyaluminium | 10% Al₂O₃ or 5.3% |
|                | Silicate sulphate | w/w Al |
|                | Al₂(OH)₁.₂₄Si₀.₁(SO₄)₁.₅₈ | * SG 1.34 |
|                |             | * 54% basicity |
| PFS            | Polyferric sulphate | 12.2% w/w Fe(III) or 43.7% w/w |
|                | Fe₂(OH)₀.₆(SO₄)₂.₇ | Fe₂(SO₄)₃ |
|                |             | * SG 1.54 |
|                |             | * 10% basicity |
|                |             | * 673 g/L |

*SG—Specific gravity
the pressure valve at 10% vol/vol of air–water ratio for 3 seconds. After the 15 minute flotation, 500 mL samples were collected from each beaker for analysis. The percentage removal was calculated using Equation (1).

\[
\%_{\text{removal}} = \left(\frac{C_0 - C}{C_0}\right) \times 100\%
\]  

(1)

where \(C_0\) and \(C\) represent the initial and final concentration of COD, TSS, turbidity and SOG, respectively.

2.4. Analysis

All protocols outlined in the standard methods for measuring wastewater were duly followed to measure before and after treatment of the ORW samples collected (APHA/AWWA/WEF, 2012). The COD was measured with a Hanna HI 83,099 COD and a multi-parameter photometer at a wavelength of 430 nm for high range (up to 1500 mg/L). Turbidity was measured with a Hach 2100 N turbidity meter. The Hach DR890 portable colorimeter, with 25 ml sample test cells was used to measure the TSS. The SOG test was performed by the extraction (Dichloromethane) and dry out moisture (Sodium sulfate) technique by the South African Bureau of Standards (SABS) method 1051 (Kweinor Tetteh et al., 2017).

3. Results and discussion

3.1. DAF performance

DAF being a separation process works on the following principles: (i) air bubbles encapsulating the insoluble particles, (ii) agglomeration of air bubble–insoluble particles to form flocculent structures and (iii) chemical adsorption of the air bubbles to the insoluble particles (Atamaleki et al., 2020; Tetteh & Rathilal, 2020). In this case, attachment of the air bubbles to the oil droplet caused the specific gravity to be less than that of water. This influenced the separation by inducing the agglomerated oil droplets to rise in an upward direction (Atamaleki et al., 2020). The occurrence of this rising velocity was due to the addition of the coagulant, which engineered the change in density difference (Lins et al., 2017; Varjani et al., 2019). In this case, three polymeric coagulants (PAC-10 LB, PFS, and PASS) were investigated to select the best coagulant for the treatment of the local South Africa ORW. The treatability performance of each coagulant was determined based on the optimum dosage (Section 3.2). Follow up is the comparative and cost-effective index study (Section 3.3) of the coagulants at an optimum dosage, whereby the best coagulants among them
were recommended for further studies and large-scale application. Furthermore, the Stoke’s principle expressed in Equation (2) can be used to compute the DAF velocity and performance (Karhu et al., 2014).

\[
V_t = \frac{gD^2(\rho_a - \rho_b)}{18 \mu}
\]  

(2)

where \( V_t \), \( g \), \( D \), \( \rho \) and \( \mu \) represent the terminal rise velocity of the agglomerate (cm/s), gravitation constant (980 cm/s²), the diameter of the agglomerate (cm), viscosity and density of the aqueous phase, respectively.

### 3.2. Effect of coagulant dosage

The effect of dosage on the ORW treatment was studied, where each of the aforementioned coagulants (10–50 mg/L) were examined for COD, TSS, SOG and turbidity removal. Due to variation of the water pollutants, coagulant dosage becomes an essential factor in the water treatment settings. Thus, the degree of their monomeric and polymeric species can cause alkalinity consumption and a parallel pH, which can affect the water quality. Also, overdose or under dose of coagulants can jeopardize the treatability efficiency and chemical cost (Kariman et al., 2019; Nasir & Daud, 2014). As many scholars have reported, high amount of ions from Al and Fe based coagulants can hunt the hydroxyl radicals, thereby affecting the pollutant structure, adsorbsents properties and kinetic pathways (Diamadopoulos et al., 2007; Sahu & Chaudhari, 2013; Sun et al., 2020; Tetteh & Rathilal, 2019). Also, pH as a determinant factor is essential in coagulation of ORW to enhance destabilising and agglomerating the oil droplets (Tetteh & Rathilal, 2020; Sun et al., 2020; Tetteh & Rathilal, 2018). This study confirms previous studies where the treatment of ORW with most of the aforementioned coagulants were found to be effective under an acidic medium limited to be around a pH of 5 to 6 (Tetteh & Rathilal, 2020; Sahu & Chaudhari, 2013). Noticeable from the results obtained (Figure 3–6), increasing the coagulant dosage increased the hydrolytic effect which produced high cationic charged species (\( \text{Al}^{3+} \) and \( \text{Fe}^{3+} \)) for the contaminant adsorption (Atamaleki et al., 2020; Sahu & Chaudhari, 2013; Sun et al., 2020).

Figure 3 shows the removal efficiency of turbidity with an increase in the polymeric coagulant dosage until a maximum efficiency is reached. With the initial turbidity concentration of 2430 ± 15.36 NTU, at optimum dose of 50 mg/L the order of removal efficiency of the coagulants were PASS > PFS > PAC-10LB corresponding to 95%, 85%, and 83%, respectively. As observed in the trends, there is a progressive increase among the coagulants except PAC-10LB, where a slight
reduction was seen at the 50 mg/L dosage. This might be due to overdose, which caused the restabilization of the insoluble particles, thereby resulting in the low efficiency (83%) (Atamaleki et al., 2020; Sun et al., 2020).

Figure 4 presents the removal efficiency of TSS by increasing the coagulant dosage. At low coagulant dosage, the trend of PASS efficiency was seen to be very low as compared to the other coagulants. However, at the dosage of 50 mg/L, PASS was found to be the most effective among them with 85% TSS removal from the initial concentration of 984 ± 4.56 mg/L. Whereas PAC-10LB and PFS were 75% and 74%, respectively. The order of preference in selecting the best polymeric coagulant for the removal of TSS remains PASS > PAC-10LB > PFS.

Figure 5 shows the removal efficiency of COD by adding the polymeric coagulants. This reveals that increasing the dosage (10–50 mg/L) increased the COD removal until a maximum plateau peak was attained before it decreased. This phenomenon is due to restabilization of the colloids which was caused by an overdose resulting in the decrease of treatment efficiency (Kariman et al., 2019; Sun et al., 2020). At dosage of 50 mg/L, the initial COD concentration of 12,115 ± 21.32 mg/L was significantly reduced by PASS > PAC-10LB > PFS, respectively, for 91%, 90% and 83%. The PASS was found to be the best coagulant among them.
Figure 6 displays the impact of increasing the dosage of the coagulants on the removal efficiency of SOG. Remarkably, the initial SOG content of 1230 ± 18.54 mg/L decreased with increasing the coagulant dosage. Whereas reducing the pH (5) of ORW to acidic medium enhanced rapid hydrolysis, which resulted in the precipitation of the oil droplets (Tetteh & Rathilal, 2020; Sun et al., 2020). The dosage of 50 mg/L for all the coagulants had a significant effect on the SOG removal. The PASS, PAC-10LB and PFS efficiency were 93%, 88% and 84%, respectively. Their order of influence was found to be similar to that of COD removal (Figure 5) as PASS > PAC-10LB > PFS. This confirms that the amount of cationic species in polymeric coagulants can enhance the rate of neutralization, precipitation, and agglomeration of oil droplets (Sun et al., 2020; Tetteh & Rathilal, 2019). Unfortunately, the reduction in the electrostatic force of attraction between the oil droplets, as seen by the use of PFS, affected SOG agglomeration (Sun et al., 2020). This reduced PFS degree of coalescing and rising velocity of the oil droplets as established by the Stoke’s law (2), hence retarded its efficiency (Karhu et al., 2014).

### 3.3. Comparative and economic study

Figure 7 shows the results obtained by the coagulants at the dosage of 50 mg/L for the removal of the contaminants. Comparatively, with a reference performance above 80% removal of the pollutants (Table 1), PASS was found to be the best coagulant among them. Subsequent economic studies based on the estimated cost of dosage and the final treated water quality results obtained is presented in Table 3. Based on the unit price and optimum dosage (50 mg/L), ordering the
Table 3. Coagulant economic analysis and performance

| Coagulant   | PAC-10 LB | PASS  | PFS  |
|-------------|-----------|-------|------|
| Price (*ZAR/500 g) | 775       | 670   | 825  |
| Cost per dose (*ZAR/mL) | 80        | 70    | 85   |
| Average performance (%) | 86        | 90    | 84   |

After treatment:

|          | Turbidity (NTU) | TSS (mg/L) | COD (mg/L) | SOG (mg/L) |
|----------|-----------------|------------|------------|------------|
|          | 340.2           | 137.9      | 1693.1     | 172.2      |
|          | 243             | 98.5       | 1211.5     | 123        |
|          |                 |            | 1938.4     |            |

* South African Rand [18.42 ZAR = 1 US Dollars] (Accessed on 04/05/2020)

estimated dosage cost from the lowest to the highest was ZAR70 < ZAR80 < ZAR85 for PASS < PAC-10LB < PFS, respectively. Economically, PASS in this study is justified as the most cost-effective and efficient coagulant for the treatment of ORW (Hoseinzadeh et al., 2020).

Despite the coagulants addition to the DAF, results obtained (Table 3) do not meet the acceptable discharge limit of the SOG (50 mg/L) to the environment. However, the performance of PASS outsmarted the rest of the coagulants, which is a good indicator for its usability to enhance the DAF treatability on a large scale (Atamaleki et al., 2020; Tetteh & Rathilal, 2020; Sun et al., 2020). Thus, PASS has high cationic and hydrolytic species which makes it possible to neutralise the negative charged oil droplets for effective destabilization (Boaventura et al., 2000; Khouni et al., 2020; Sharghi et al., 2020). According to Khouni et al. (2020), agglomeration and bridging of the oil droplets following large aggregate formation with air bubble–water interface can effectively be separated by the DAF.

In Table 4, some studies of coagulation coupled with DAF for the treatment of various ORW are presented. This study shows a noticeable improvement of the water quality, as well as the biodegradability index (COD/BOD < 2.5) with respect to the COD and SOG reduction (Khouni et al., 2020; Lins et al., 2017; Sharma et al., 2020; Young, 2014). In fact, taking into account the high content of SOG, the result obtained (Table 4) by PASS is more acceptable than that of the alum (Tetteh & Rathilal, 2020). This is because alum is reported to be associated with large

Table 4. Studies of coagulation-DAF process for the treatment of oil refinery wastewater

| Coagulant type        | Dosage (mg/L) | Influent SOG (mg/L) | % removal | Reference                  |
|-----------------------|---------------|---------------------|-----------|----------------------------|
| Aluminium sulphate    | 50            | 500                 | 93        | Megid et al., 2014         |
|                       | 50            | 1218                | 91        | Kweinor Tetteh et al., 2017|
| Poly–aluminium chloride | 30          | 100.9               | 90        | Karhu et al., 2014         |
| DAF only              | 10            | 300                 | 73        | Aliff Radzuan et al., 2016 |
| Alum +DAF             | 10            | 300                 | 86        | Aliff Radzuan et al., 2016 |
| *Alum +DAF            | 50            | 1230                | 90        | *This study                |
| *PASS +DAF            | 50            | 1230                | 93        | *Under this study          |

*Under this study
volumes of sludge generations, together with health risk (Atamaleki et al., 2020; Sun et al., 2020). Many researchers have reported on the use of iron or aluminium based salts with highly charged cations can augment the destabilisation of an oil-water emulsion when applied with DAF (Ghodbane et al., 2020; Sharghi et al., 2020; Sharma et al., 2020). Therefore, to safe guard the environment and improve the ORW quality, the use of PASS is very promising to be used as pre-treatment of ORW prior to post-treatment systems.

4. Conclusion
In this study, application of a coagulation–dissolved air flotation system was used to investigate three different types of polymeric coagulants, as an alternative to alum for the treatment of oil refinery wastewater. The results show ORW with high content of organic loads (SOG, COD, TSS and turbidity) will require a post- treatment system apart from the coagulation-DAF process to reach the acceptable discharge limit of SOG < 50 mg/L. From the experimental designed space, the optimum dosage of the coagulants was found to be 50 mg/L at the pH of 5. At this condition, above 80% treatability performance of the coagulants was achieved in the following order as: PASS < PAC-10LB < PFS for the removal of COD (82–90%), SOG (84–93%), TSS (72–83%) and turbidity (81–92%). This exhibited a good correlation between the treatment efficiency and the increase in the coagulant dosage. Among the polymeric coagulants, PASS was found to be readily available, produces less amount of sludge, and is cheap, biodegradable and eco-friendly. This makes PASS suitable and the best alternative coagulant to the conventional alum. Therefore, to improve the industrial wastewater quality and protect the environment, the future of PASS as a coagulant seem very promising. Future research of developing natural coagulants such as starch, chitosan and moringa for wastewater treatment is economical viable.

Acknowledgements
The authors wish to thank the Durban University of Technology (DUT), FFS Refiners and Umgeni Process Evaluation (PEF) center, Wiggins in the Kwazulu Natal Province for their support. Also, the DUT, Directorate for Research & Postgraduate Support for sponsoring the article open access charges.

Funding
The authors received no direct funding for this research.

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Cover image
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Citation information
Cite this article as: Evaluation of different polymeric coagulants for the treatment of oil refinery wastewater, E. K. Tetteh & S. Rathilal, Cogent Engineering (2020), 7: 1785756.

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