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Flow Dynamics in the Equalization and Retention Units of a Textile Company's Effluent Treatment Plant (ETP): Implications for Removal Efficiencies and Biodegradability Index

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Abstract

Radioactive tracer (RT) residence time distribution (RTD) technology and conventional effluent quality techniques have been respectively applied to assess the performance (flow dynamics) of the effluent treatment plant (ETP) and effluent quality [Removal Efficiencies (RE) and Biodegradability Index (BI)] of a textile printing company in Ghana. The RTD investigation focused on the process flow anomalies (dead volumes, stagnant zones, channeling, and short-circuiting or by-passing of waste-water flow) in two (2) sedimentation tanks (T1 & T2) of the Equalization and Retention Unit (ERU) of the ETP. RTD established an experimental Mean Residence Time (MRT) of 60.7 mins (T1) and 122.7 mins (T2) respectively; these were higher than the design MRTs of 46.3 mins (T1) and 35.7 mins (T2), signifying the existence of dead volumes in the tanks. The fluid dynamics in T1 and T2 modelled with an International Atomic Energy Agency (IAEA) developed RTD analysis software revealed that the *Perfect Mixers in Series with Exchange (PMSE)* model best described the flow regime in T1. PMSE model description equations conceptualized T1 as consisting of two perfectly mixed tank systems in series with exchange having an active volume of 46%, stagnant volume of 26% with a complete dead volume of 28%. The *Perfect Mixers in Parallel (PMP)* model best described the flow structure in T2. Flow model parameters analysis conceptualized T2 was as consisting of four (4) compartments arranged in parallel with total active volume of 93.1% and dead volume of 6.9%. The mixing efficiency in T2 (estimated variance of 9.02469×10^5) was better than TI (estimated variance of 4.77730×10^5). Effluent quality parameters assessed generally compared favorably with the World Health Organization (WHO) and Ghana's Environmental Protection Agency (EPA-Ghana) recommended values, though color and turbidity were above recommended levels. The RE for effluent quality parameters were comparatively (with literature data) low except total suspended solids (TSS). Consequently, there is a need to improve influent treatment to enhance effluent quality. Calculated BI of 0.33 indicates a slowly biodegradable influent; necessitating the incorporation of a biological treatment unit into the ETP to boost biological degradation.

Keywords: radioactive tracer, residence time distribution; effluent quality, effluent treatment plant, hydrodynamics, and parametric investigation, mean residence time.

1. Introduction

The textile and apparel industry, which generated approximately US$2.4 trillion in revenue in 2019 [KJT, 2021], is the third-largest manufacturing sector worldwide. More than 300 million people are employed across the industry's value chain, from fibre producers to manufacturers and content suppliers. Clothing consumption has increased by 60% in the last 15 years. In Ghana, the textile industry was once a leading player, employing approximately 30,000 workers and contributing around 6% of the country's GDP. While the industry has experienced a decline in recent years, it continues to serve local, regional, and international markets, particularly in the United States, by promoting traditional fabrics to niche markets. The textile printing industry consumes significant amounts of water in their operations, resulting in the production of wastewater that requires treatment before it can be discharged into nearby water sources. To eliminate or reduce undesirable substances in the wastewater, Effluent Treatment Plants (ETPs) are utilized, as depicted in Fig 1 for the textile company under study. The performance of ETPs can be suboptimal due to anomalies in process flow, such as stagnant zones, dead volumes, channelling, and short-circuiting; as they are complex systems with multiple phases (solid, liquid, or gas) that coexist, their efficiency is determined by their multiphase flow structures and corresponding RTDs. These hydrodynamic characteristics, such as MRT, Variance, and flow structure, can be obtained from RTD data using the Radioactive Tracer RTD principle, which involves injecting a tracer into the ETP at an inlet, measuring its concentration-time curve at the corresponding outlet with a detector, while marking time-zero with another detector at the inlet. The resulting RTD after data treatment can be used to understand flow processes and identify the pre mentioned system anomalies (Fernández & Coarasa, 2004). Regarding the assessment of resulting effluent quality, measuring key water quality parameters is important but not the only aspect. Estimating the RE[2] and BI[3] of the ETP are also crucial.

1.1 Objectives

The goal of the study was to use radioactive tracer residence time distribution (RRTD) to investigate the hydrodynamics and parameters of a textile manufacturing company's Effluent Treatment Plant (ETP) and to determine its impact on the quality of the effluent.

Specifically; to assess the Hydrodynamics of the treatment units (mean residence time [MRT] of materials and the Variances [$\boldsymbol{\sigma}^2$] using the Moments method), appraise the flow non-idealities in the units, and Predict/Model the Flow Pattern in the units of the plant, to evaluate the Removal Efficiencies (%RE) and Biodegradability Index (BI) of the influent-effluent wastewater using conventional water quality methods, and, to estimate the overall performance of the ETP.

1.2 Wastewater treatment at the studied ETP

ETPs generally follow one principle; physico-chemical treatment finalized with polishing treatments (Sand filtration, adsorption-activated charcoal treatment, chemical oxidation-ozonation, ultra-filtration, reverse osmosis, and evaporation) in complicated systems where all the processes happen [E.W.P., 2021]. The studied ETP mainly uses sedimentation process to remove most of the contaminants. It couples the sedimentation process with equalization, coagulation, filtration, and adsorbents use. First, the influent is directed into a primary gutter

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[2] RE: Removal Efficiency, measures an ETP's proficiency in removing or reducing contaminants and information on RE assists in improving ETP design.

[3] BI: Biodegradability Index, data helps in selecting appropriate treatment methods and enhancing effluent treatment methods for maximum RE, resulting in a significant impact on the ETP's efficiency.

and screened through a metal mesh to remove large particles. Then, the wastewater is directed into retention tanks where it undergoes neutralization, flocculation, and coagulation. The wastewater is sent to sedimentation tanks where gravity is used to carry the dosed wastewater, and retention aids improve effluent retention for continuous coagulation and settling of coagulated flocs. The effluent then overflows into a carbon filter bed where activated carbon and stones filter out heavy metals, odour, colour, and suspended flocs. Finally, the wastewater is transferred to maturation ponds for further biological treatment and secondary settling before being discharged into the receiving media (Fig 1.1)

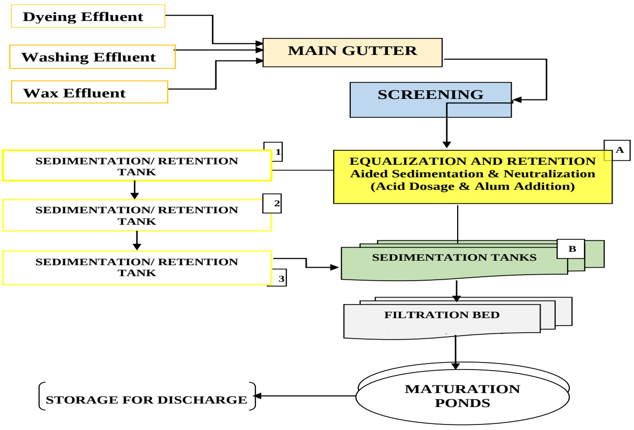


Fig. 1.1 Layout of the studied textile company ETP

2. METHODOLOGY

The research was allotted into two main components (Fig 2.1), the performance efficiency of the ETP evaluated using radiotracer RTD and a range of analytical techniques used to assess the Removal Efficiencies (RE) and Biodegradability Index (BI) of the ETP from important textile industry effluent quality characteristics that were analysed using water quality analysis methods. illustrates the investigation process.

The equalization and retention unit (ERU) of the ETP were utilized for RRTD study, which essentially consists of three tanks for alum dosing and neutralization purposes. Two of these tanks, as shown in Fig 2.1 were chosen for the experiment and were connected in series to allow the outflow of the first tank to serve as the inflow of the sec ond tank.

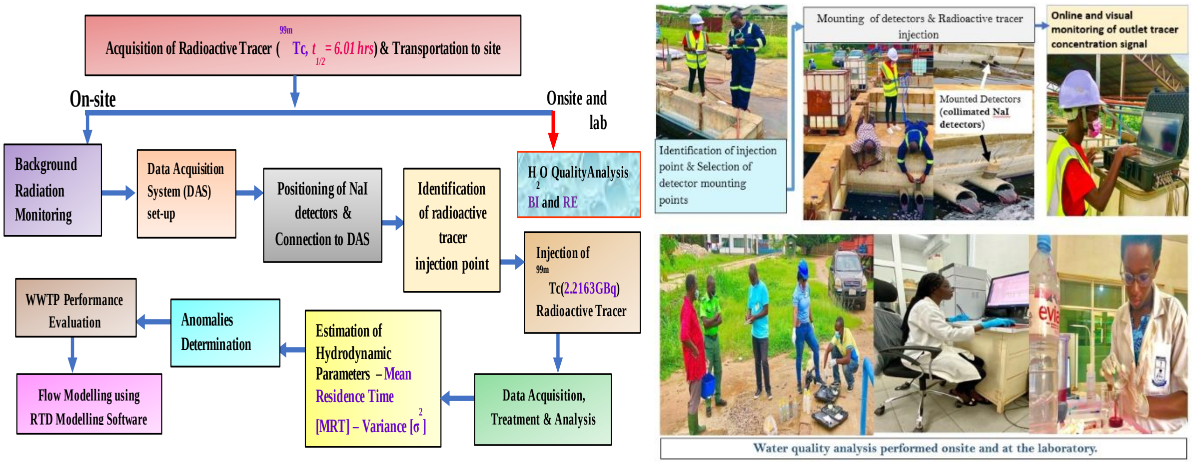


Fig. 2.1 *Schematic and pictorial representation of the analytical work*

2.1 RRTD study data treatment and modelling

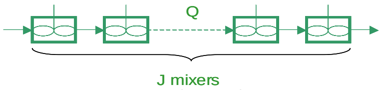
The first step involves measuring background radiation levels and monitor the radiation dose levels of researchers and staff. Radiotracer injection point was selected and NaI detectors were mounted at the inlet and outlet of the tanks to detect the radiotracer trajectory. The radiotracer was injected at the appropriate point in the tank, and the concentration-time curve of its trajectory was monitored for the period of the study.

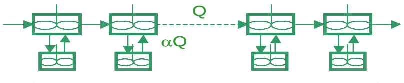
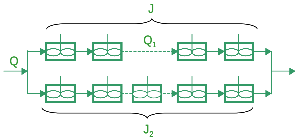
There were several adjustments that needed to be made to the experimental data to obtain an accurate RTD curve. The data collected from the experiment was corrected for background radiation, decay, and normalized to remove noise and variables that affect the curve's area but not its shape. The IAEA radiotracer RTD model software was used to model the RTD curve with theoretical functions of different flow patterns. A collection of elementary flow models and an optimization technique to fit the model response with the tracer experiment data was done. Three non-ideal models were used to construct a systemic model: the perfect mixers in parallel (PMP), perfect mixers in series (PMS), and perfect mixers in series with exchange (PMS) models. Relevant equations used for calculations and modelling processes are detailed in the suceeding (IAEA, 2008; 2011).

RTD Data Treatment and Analysis

Correction for background radiation $C_{bc}(t) = C_{exp}(t) - C_{bkg}$ Equation 2.1 Where: $C_{bc}(t)$= background-corrected count rate; C_{bkg} = background count rate; C_{exp} = experimental count rate	***Decay correction*** $n_c(t) = n_m(t)\text{Exp}(\lambda t)$, where $\lambda = \frac{0.693t}{T_{\frac{1}{2}}}$ Equation 2.2 $n_c(t) = n_m(t)\text{Exp}(\frac{0.693t}{T_{1/2}}t)$, Equation 2.3 Where: $n_c(t)$ = decay corrected count, $n_m(t)$= measured count rate, t = time, $t_{1/2}$ = half-life, λ= decay constant.
Normalisation of counts $E(t) = \frac{n_c(t)}{\sum nci\Delta t}$ Equation 2.4 Where: $n_c(t)$ = count, $n_{c,i\,=}$ corrected count rate at time $_i\Delta t$.	***Mean residence time (MRT)*** The normalized count was used in finding the experimental MRT (Equation 3.5) using moments method as; $\tau_{exp} = \frac{\int_0^\infty tE(t)}{\int_0^\infty E(t)dt} = \int_0^\infty tE(t)dt$ Equation 2.5 Where: $\boldsymbol{\tau_{exp}}$ = the MRT; **t** = the time the fluid spends in the system and; $\mathbf{E}(\boldsymbol{t})$ = the normalized RTD function.
The theoretical MRT ($\boldsymbol{\tau_{TH}}$) was calculated using: $\tau_{TH} = \frac{V}{Q}$ Equation 2.6 Where: V = Volume of the tank, which was estimated from calculation in the case of the ETP under study; Q = volumetric flow rate measured.	***Variance*** Variance which expresses extent of mixing in the tanks was also found by the second moment(Equation. 3.7): $\sigma^2 = M_2 - M_1^2 = \int_0^\infty (t - \tau_{TH})^2 tE(t)dt$ Equation 2.7 Where: M_1 = First moment; M_2 = Second moment around the origin.

RTD Data Modelling

Perfect Mixers in Series (PMS) Model The perfect mixers in series model is made up of perfect mixing cells that are placed progressively.	The RTD function is written as shown in Eqn. 2.1. (IAEA, 2011); $E(t) = \left(\frac{J}{\tau}\right)^J \frac{t^{J-1}\exp\left(-\frac{Jt}{\tau}\right)}{(J-1)!}$ MRT = τ. Equation 2.8 Where **J** represents the number of cells (shown in) for this model  ***Fig. 2.2*** *Conceptual scheme for perfect mixers in series model.*

Perfect Mixers in Series with Exchange (PMSE) Model The PMSE model used in RTD applications involves a series of perfect mixers through which the main flow rate passes, exchanging flow rate with other mixers.	Has four independent parameters, evaluated using equation Equation 2.9 to determine the mean residence time, time constant, and relative volume of the stagnant zone. $\tau = \frac{JV_1}{Q}, t_m = \frac{V_2}{\propto Q}, k = \frac{V_2}{V_1}$ and J. Equation 2.9  ***Fig. 2.3:*** *Perfect mixers in series with exchange model conceptual framework*
Perfect Mixers in Parallel (PMP) Model The PMP model is a parallel configuration of two sets of mixers in series that divides the total flow rate Q into Q1 and Q2, which flow through J1 and J2 mixers, respectively, in series; each set with a total volume of V_1 and V_2, respectively.	Total mean residence time (MRT) can be calculated using Equation 2.10 as provided in the guidelines; t_1 and t_2 are the MRTs of systems 1 and 2 respectively $\overline{t} = \frac{Q_1}{Q}\overline{t_1} + \frac{Q_2}{Q}\overline{t_2}$ Equation 2.10 ***Fig. 2.4*** *Perfect mixers in parallel model* 

2.2 Water Quality Analysis

For the water quality analysis of influent and effluent samples at the textile ETP, 1L samples were collected from different processing units in the ETP and labelled accordingly for onsite and laboratory analysis. Relevant water quality (WQ) parameters with relation to textile effluent were considered. Some parameters were determined in situ, while others were repeated in the lab for quality assurance. In situ analysis was done using the Oakton PCSTestr 35 Waterproof Multi-parameter Tester for the parameters of pH[4],electrical conductivity (EC)[5], total disolved solids (TDS)[6], Salinity[7] and Temperature; while laboratory analysis was carried out for parameters such as biological oxygen demand (BOD)[8], chemical oxygen demand (COD)[9], Alkalinity[10], Total hardness[11], Chloride[12], Calcium, Turbidity, Total Suspended Solids, and Color[13]. The relvant equations used are shown below.

The BOD was calculated as follows (Bruckner, 2021): $DO[DO_1 \,\&\, DO_5]\left(\frac{mg}{L}\right) = \frac{Titre}{V_{sample}}.101.6$ Equation 2.11 BOD = DO_1 - DO_5 Equation 2.12 Where: DO_1 = Dissolved Oxygen measured on first day of experiment, DO_5 = Dissolved Oxygen measured five days after first DO (DO_1) measurement.	***COD*** The chemical oxygen demand was calculated by: COD $= \frac{(\mathrm{A}-\mathrm{B}) \times \mathrm{M} \times \mathrm{DF} \times 8000}{\text{Volume of sample }(\mathrm{mL}) - 10\, mL}$ Equation 2.13 Where: DF = Dilution Factor (if applicable), M = Molarity of standardized Ferrous Ammonium Sulfate solution, B = Volume consumed in titration with blank preparation, A = Volume consumed in titration with sample preparation.

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[4] pH : of wastewater measures the acidity or alkalinity of the water. It was measured using the Oakton PCSTestr 35 Waterproof Multi-parameter Tester, calibrated using standard pH buffers of acetic acid-sodium acetate and borax-sodium hydroxide, with instrumental washing between each test.

[5] Textile conductivity measures electrical current flow based on the presence of ions, their valences, mobility, concentration, dissociation, migration in the electric field, and temperature (Islam, 2020). The tester was calibrated at 25 °C using a 1413 µS/cm 0.01 M KCl standard solution and the electrode was washed with distilled water after each reading for accuracy.

[6] TDS: The TDS of the wastewater indicates the level of dissolved inorganic and organic substances, including harmful chemicals, minerals, and salts that require proper treatment to prevent environmental damage, measured in ppm or mg/L.

[7] Salinity: Salinity in wastewater refers to the amount of dissolved minerals and salts.

[8] BOD: was determined using the Winkler method, which measures dissolved oxygen in the effluent. Reagents used in the process included manganese sulphate, alkali-iodide-azide, sulfuric acid, starch solution, and sodium thiosulfate.

[9] COD: measures the amount of pollution in water after wastewater treatment, with higher values indicating greater organic contamination. The procedure involves oxidizing organic constituents in the water sample with potassium dichromate, sulfuric acid, silver sulfate, and mercury sulfate to produce carbon dioxide and water.

[10] Alkalinity, was determined by titrating a water sample with a known concentration of acid and using stoichiometry to calculate the concentration of alkalinity based on the number of moles of acid required to reach the endpoint.

[11] Total hardness: a solution of EDTA and Eriochrome Black-T indicator was used to titrate the sample, and the volume of EDTA needed to reach the endpoint was recorded and used to calculate the total hardness.

[12] Chloride: 100mL of the sample is titrated with standard silver nitrate solution using potassium chromate as an indicator, and the volume of silver nitrate required is recorded and used to calculate the chloride concentration.

[13] The HACH DR 900 Portable Colorimeter was used to measure TSS, color, and turbidity of water samples, calibrated with stock solutions and each sample's readings were confirmed and recorded.

Alkalinity was calculated using the formula below:

$$\text{Alkalinity} = \frac{\text{Titre x 0.02 x 50000}}{\text{Volume}_{\text{sample}}} \qquad \text{Equation 2.14}$$

Total hardness was calculated as:

$$\text{Total Hardness} = \frac{1000\ V_1}{V} \qquad \text{Equation 2.15}$$

Where: V_1= Volume of EDTA used, V = Volume of prepared sample

Chloride was calculated by:

$$\text{Chloride (mg/L as Cl}^-) = \frac{(A-B)N \cdot 35450}{V} \qquad \text{Equation 2.16}$$

Where; A = Volume of $AgNO_3$ for sample titration, B = Volume of $AgNO_3$ for blank titration, N = Normality of $AgNO_3$, V = Volume of water sample taken

Biodegradability Index (BI)

Biodegradability index can be calculated in two ways; as a ratio of COD:BOD or BOD: COD. The Biodegradability Index was calculated as a ratio of the influent BOD to the COD values.

Percentage Removal Efficiency; for the WQ parameters including EC, TDS, TSS, Turbidity, Color, Cl^-, Ca^{2+}, BOD, and COD were calculated using Equation 2.16, which compared their concentration in effluent (C_{eff}) to their concentration in influent (C_{inf}).

Where: C_{eff} = the pollutant concentration in treated wastewater (effluent) and; C_{inf} = the pollutant concentration in unprocessed wastewater (influent)

$$\text{RE} = 100\left(1 - \frac{C_{eff}}{C_{inf}}\right)\% \qquad \text{Equation 2.17}$$

3. DISCUSSED RESULTS AND CONCLUSIONS

Results from RRTD experiment are shown in Figs 3.1-3.8 and Tables 3.1 & 3.2.The results developed were compared with global standards and scientific literature, while also applying governing theoretical principles to the obtained data.

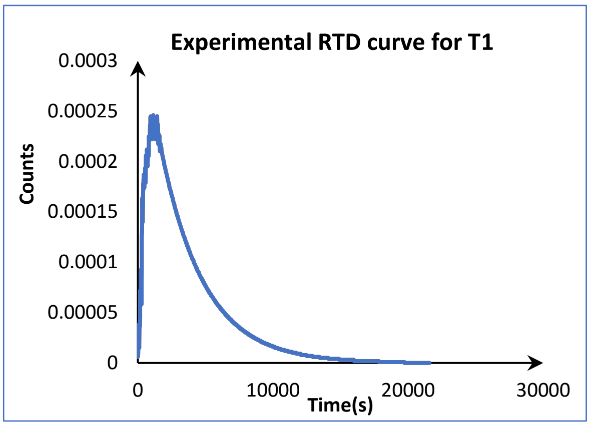

Fig. 3.1 *Experimental RTD curve for Tank 1 (T1)*

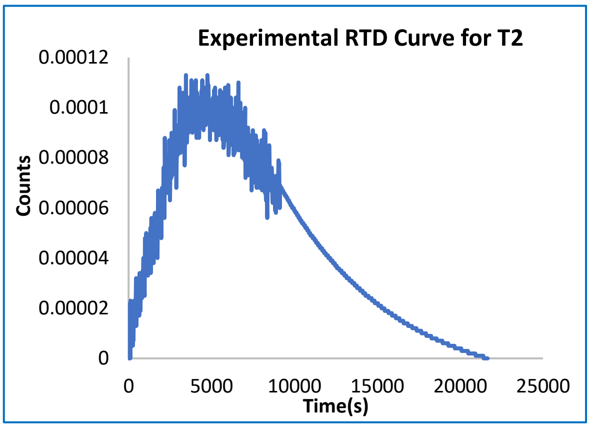

Fig. 3.2 *Experimental RTD curve for Tank 2 (T2)*

Table 3.1: RTD parameters measured and calculated for the studied ERU sedimentation tanks

MEASURED PARAMETERS	Theoretical (V,m^3)	Flow Rate (Q ,m^3/s	Theoretical MRT (min)	Exp MRT (min)	Variance
Tank 1 (T1)	**38.9**	**0.014**	**46.3**	**60.7**	**4.77730 x 10^5**
Tank 2 (T2)	**30.0**	**0.014**	**35.7**	**122.7**	**9.02469 x 10^5**

Table 3.2: RTD Models and their theoretical functions as applied in the modelling

ST	τ_{exp} (min)	Perfect Mixers in Series Model		Perfect Mixers in series with Exchange Model				Perfect Mixers in Parallel Model				
		τ_m (min)	J	τ_a (min)	J	Tm	k	τ_1 (min)	J1	τ_2 (min)	J2	Q1/Q
T1	**60.7**	**55.5**	**1.6**	**37.9**	**2.3**	**24.2**	**0.6**	**265.7**	**2.3**	**74.9**	**0.3**	**1.98**
T2	**122.7**	**131.2**	**2.6**	**17.0**	**2.9**	**3.1**	**6.6**	**131**	**2.7**	**44.6**	**1.1**	**1**

Where: ST = Sedimentation tank, τ_{exp} = Experimental MRT, τ_m, τ_a, τ_1, and τ_2, = Flow model MRT, J = Number of mixing tanks, J1 = Number of mixing tanks for the first set of tanks, J2 = Number of mixing tanks for the second set of tanks , k = Relative volume , Tm = Relative time constant

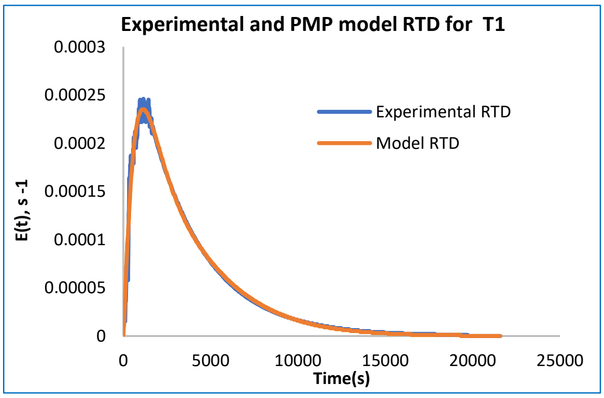

Fig. 3.3 *PMP model & experimental RTD for Tank 1*

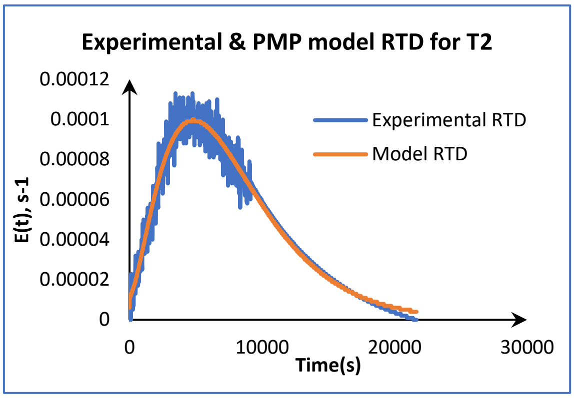

Fig. 3.4 *PMP model & experimental RTD for Tank 2*

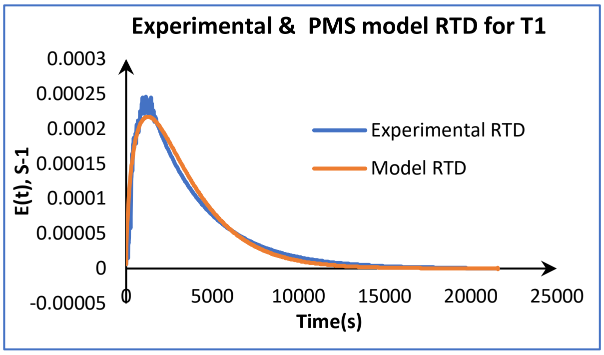

Fig. 3.5 *PMS model & experimental RTD for Tank 1*

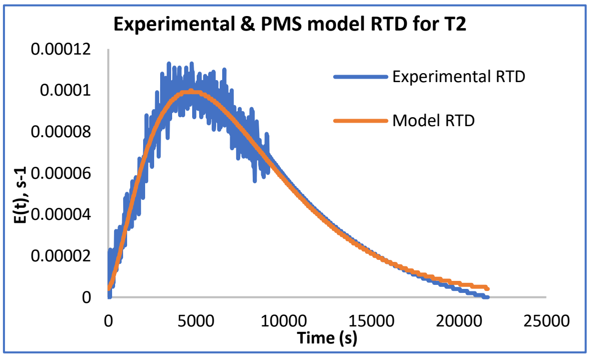

Fig. 3.6 *PMS model & experimental RTD for Tank 2*

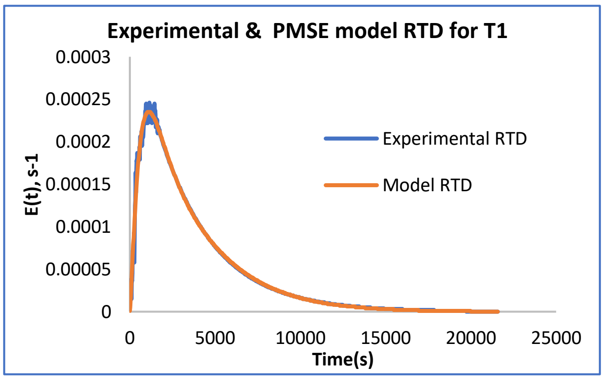

Fig. 3.7 *PMSE model & experimental RTD for Tank 1*

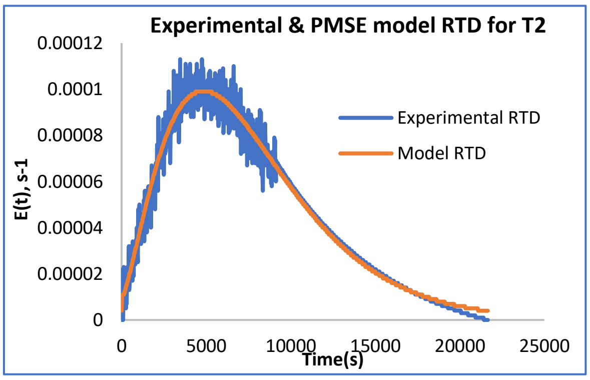

Fig. 3.8 *PMSE model & experimental RTD for Tank 2*

The curve does not show multiple distinct peaking, meaning there was absence of channeling, bypassing and parallel flow paths in the tank. T1 has a narrower peak than T2, suggesting a smaller mixing efficiency (IAEA, 2008; 2011). The RTD curves obtained exhibited tailing effects an the experimentally determined Mean Residence Time (MRT) of the studied sedimentation tanks of the ETP's Equalization and Retention Unit (ERU) were higher than the Theoretical MRTs. These observations suggested the presence of dead volume in the tanks. The study revealed a variance of 4.77730×10^5 for sedimentation tank T1 and 9.02469×10^5 for sedimentation tank T2; signifying efficient mixing (performance) in T2 compared to T1. Residence Time Distribution (RTD) modelling (using IAEA-developed RTD Analysis Software) of the experimentally generated data showed that the model that best described the fluid dynamics in sedimentation tank T1 was Perfect Mixers in Series with Exchange (PMSE); while Perfect Mixers in Parallel (PMP) best described fluid dynamics in sedimentation tank T2. The PMSE model conceptualised sedimentation tank T1 as consisting of two (2) perfectly mixed tanks with an active volume of 46% and a stagnant volume of 26% with about 28% of the water in T1 completely dead. The PMP model described the flow regime in sedimentation tank T2 as consisting of four (4) compartments arranged in parallel with total active volume of 93.1% and dead volume of 6.9%. The dead volumes [T1 =28% and T2 = 6.9%] could be described to the sludge accretion from the alum addition, coagulation and sedimentation of debris or suspended matter in the influent.

Results of the physico-chemical quality analysis of the sampled wastewater from the textile industry along the Influent-Effluent points of the ETP is shown in Tables 3.3 and 3.4

Table 3.3: Measured Influent – Effluent WQ Levels

Parameters	**Determined levels in Ranges**		
	Influent	**Effluent**	**Removal Efficiencies (%)**
pH	10.1 - 10.2	9.2 - 9.4	
Temp. (°C)	25	25	
EC (µS/cm)	535 -633	657 - 725	(-14.5) - (-22.8)
Salinity (g/L)	1.0 - 1.2	0.4 - 0.7	41.7 - 60.0
Color (TCU)	350 - 385	231 - 260	32.5 - 34.0
Turbidity (NTU)	215 - 293	104 - 230	21.5 - 51.6
TDS (mg/L)	287 - 316	109 - 188	40.5 - 61.0
TSS (mg/L)	141 - 183	24 - 38	79.2 - 83.0
TH (mg/L)	38 - 58	16 - 24	57.9 - 58.6
Alkalinity (mg/L)	10 - 12	3 - 7	41.7 - 70
COD (mg/l)	20 - 39	14 - 16	30 - 59
BOD (mg/L)	7 - 12	3 - 5	57.4 - 58.3
Cl^- (mg/L)	33 - 50	22 - 25	33.3 - 50.0
Ca^{2+} (mg/L)	13 - 24	5 - 9	61.5 - 62.5

Table 3.4: Determined WQ levels compared with WHO & EPA-Ghana

Parameters	**Determined Levels in Ranges**		**Recommended Guidelines**	
	Influent	**Effluent**	**EPA (Ghana)**	**WHO**
pH	10.1 – 10.2	9.2 – 9.4	6 -9	6.5 – 8.5
Temp. (°C)	25	25	<3 °C above ambient	
EC (µS/cm)	535 – 633	657 - 725	750	400
Salinity (g/L)	1.0 – 1.2	0.4 – 0.7		
Color (TCU)	350 – 385	231 – 260	100	200
Turbidity (NTU)	215 – 293	104 – 230	75	75
TDS (mg/L)	287 – 316	109 – 188	1500	1000
TSS (mg/L)	141 – 183	24 – 38	50	50
TH (mg/L)	38 – 58	16 – 24		
Alkalinity (mg/L)	10 – 12	3 – 7		
COD (mg/L)	20 – 39	14 – 16	250	250
BOD (mg/L)	7 – 12	3 – 5	50	50
Cl^- (mg/L)	33 – 50	22 – 25		
Ca^{2+} (mg/L)	13 – 24	5 – 9		

The pH of influent from a textile manufacturing plant was moderately alkaline due to the use of alkaline solutions in the production process[14]. Acid dosing was performed during treatment to ensure the effluent's pH fell within acceptable limits. Effluent's pH was within the recommended range, making it safe for aquatic life. The electrical conductivity of the influent and effluent indicated the presence of dissolved substances. Effluent's EC increased due to the release of ions from alum dosing during treatment[14]. Although the effluent's EC exceeded the WHO's recommended level, it met the Ghana EPA's limit. The influent had higher salinity than the

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[15] (Osamau, 2020).

effluent, possibly due to dilution in the maturation pond before discharge. Salinity reduction is important to prevent harm to the ecosystem. Effluent salinity levels were below the recommended limits[15]. Effluent showed a reduction in colour due to the application of activated carbon in the treatment process. However, the effluent's colour levels were slightly above the recommended limits. Turbidity levels decreased in the effluent due to coagulation, sedimentation, and filtration in the treatment process[16]. The removal efficiency for turbidity was moderate. TDS levels were reduced in the effluent through coagulation, biological processes, and adsorption. The effluent's TDS met the recommended levels. TSS levels highly decreased in effluent due to filtration, sedimentation aids, and adsorption. The ETP's treatment process reduced total hardness levels in the effluent greatly. Measured alkalinity levels in the influent and effluent of the textile company were 10-12 mg/L and 3-7 mg/L respectively, with a reduction attributed to acid dosing during equalization and retention processes[17]; chloride levels in the effluent ranged from 22 to 25 mg/L, with a removal efficiency of 33.3-50% likely due to adsorption by activated carbon; calcium ion levels decreased from 13-24 mg/L in the influent to 5-9 mg/L in the effluent, resulting in a removal efficiency of 61.5-62.5% through adsorption[18]; and the influent COD levels were 20-39 mg/L, reduced to 14-16 mg/L in the effluent with a removal efficiency of 30-59% attributed to aeration[19], while BOD levels decreased from 7-12 mg/L in the influent to 3-5 mg/L in the effluent with a removal efficiency of 57.4-58.3% possibly due to natural microbial decomposition

Generally, apart from the TSS whose removal efficiency (RE) was appreciably high, the RE for other determined parameters were comparatively low; signifying the need for improvement in WW treatment by the textile manufacturing company. The effluent quality parameters assessed generally compared favorably with EPA-Ghana and WHO recommended values; notwithstanding some parameters (Color and Turbidity) were above the recommended levels. Calculated Biodegradability Index (BI) of 0.33 showed that the influent is slowly biodegradable, thus, there is the need for the incorporation of a biological treatment unit into the textile company's ETP in order to enhance biological degradation.

4. RECOMMENDATIONS

From the conducted study, results obtained (experimentally and calculated), and conclusions drawn; the under-listed recommendations are proffered to both the Textile Printing Company, EPA-Ghana, Ghana's Department of Factories Inspectorate, and the Research Community.

a. The Textile Printing Company should incorporate intermittent/regular descaling of the sedimentation tanks of the ETP's ERU to improve its performance. The Environmental Protection Agency of Ghana (EPA-Ghana) and Ghana's Department of Factories Inspectorate are encouraged to include Annual Performance Evaluation/Appraisal of Textile Company's ETP using Radiotracer Technology in addition to the effluent quality analysis being undertaken.

b. The Textile Company should implement measures, such as proper dose spreading and adequate aeration, to enhance the mixing efficiency of sedimentation tank T1, which is crucial for effective equalization, coagulation, and subsequent sedimentation in the equalization and retention unit, as recommended by Nemerow (2007), and also adopt hybrid treatment system that combines sophisticated , and incorporate a concise biological treatment system for efficient biological degradation of the biodegradable influent; to aid dye removal and subsequent color reduction in generated effluent.

c. Further study is recommended on: (i) the type of biological treatment best for textile influent; (ii) the treatment system best for removing dye/color from textile effluent; and (iii) the breakthrough effluent treatment methodology that will enhance pH reduction to near neutral.

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[15](Krayer et al., 2017). [16] (Soros, 2019). [17](Tom Fernandez, 2021). [18](Hammes et al., 2003). [19](Edokpayiet al., 2017).

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