IMPACT OF COAGULANTS ON THE TSS SEPARATION PERFORMANCE IN CLEAN WATER PRODUCTION: AN EXPERIMENTAL FINDINGS

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ABSTRACT: *This paper reports an experiment conducted with a feed water contained low level total suspended solid (TSS≤ 10 mgL^{-1}). This research aims to investigate a problem to justify whether coagulants is required to filter that feed water to produce required clean water (TSS≤ 1.0 mgL^{-1}). This research has been conducted with combined use of Multi Media Water Filter (MWF) and Micro Filter (MF). The water filtration rate of this experiment was 20.0 m3(d)$^{-1}$. The TSS in product water (PW) was 0.735 mgL^{-1} when the plant was operated with coagulants. When the plant operated without coagulants the TSS content in PW was 0.876 mgL^{-1}. Two sets of experimental data were analysed and tested with paired-samples t-test at a 95% confidence level. The result demonstrated that the P-value was more than 0.05 (>0.05) when compared to the mean difference between the data sets. This finding indicates that the TSS content in PW of these two processes is nearly equal, and there is no significant difference between the two processes. This finding could be a reference to the water industry, engineering professionals and policy implementation agencies relating to the use of coagulants in the WF process. This study concludes that coagulants are not required in the WF process when feed water contains TSS less than 10 mgL^{-1} and the MWF can significantly remove TSS from feed water to produce the required clean water. This study recommends similar further research with various types of feed water to develop a standard model for the WF process to achieve SDG 6, SDG8, and SDG13.*

Keywords: Sustainable Water Supply, Water Filter, Low Pressure Water technology, clean water, Production performance, Economic Sustainability (SDG 8), Environmental Sustainability (SDG13), Sustainable Development Goal (SDG).

1.0 BACKGROUND OF THE STUDY

This paper reports an experiment conducted with a feed water contained low level total suspended solid (TSS≤ 10 mgL^{-1}) by MWF. The experiments were conducted in two phases. At the first phase, MWF was operated with the dosing of coagulants. In the second phase, MWF was operated without coagulants. Historically, the TSS is an integral part of run-off water that arises from land erosion, dissolution of minerals, decay of vegetation, discharges wastewater from residences and industries. All these impurities are required to be removed from feed water stream as it causes the deterioration of product water quality [1, 2]..

The MWF is used as a primary water filter for catering clean water to secondary and tertiary water filtration [3]. Though, MWF is not an advanced water treatment process, it still has a demand in water industries due to economic benefits [4, 5]. The combination of MWF and membrane system (MS) is popular in water industries due to its simple design, higher productivity and easy operations [6-8]. The performance of MWF in producing clean water depends on a few operating factors. The potential factors are the quality of feed water, MWF plant cleaning performance, and optimization of the coagulants dosing rate [9, 10].

MWF with coagulants have been used to increase TSS and pollutant separation efficiency. The coagulants act as a binding agent to combine the small particles of impurities and transform them into larger aggregates flocs that adsorb dissolved organic matter from feed water. Thus, MWF with coagulants contribute to removing impurities from feed water [2].

With this background, this study has undertaken to reveal the operating conditions of MWF to achieve sustainable performance in water filtration (WF) by reducing coagulants dosing rate that may contribute towards achieving economic (SDG8) and environmental (SDG13) sustainability.

1.2 Problem Statement and Research Objectives

Studies on clean water production by the use of MWF have established a relationship between coagulants dosing rate and productivity in clean water production. Research findings demonstrate that the coagulant dosing rate into the feedwater in clean water production by MWF has been playing a vital role in managing the water crisis. It was also reported that the residual coagulants affect quality of the environment, run-off water, aquatic lives and biodiversity. This statement has raised the question of "**Are coagulants always essential for the water filtration process?"** This research project has undertaken to answer the question stated.

1.3 Research Objective

The broad objective of this research is to determine the effect of coagulants on TSS separation performance. Achieving the research goal, the objective of this experiment is divided into three specific objectives:

1.3.1 To determine the TSS separation efficiency when the WF plant operates with coagulants to produce required clean water.

1.3.2 To estimate the TSS separation efficiency when the WF plant operates without coagulants to produce required clean water.

1.3.3 To evaluate the impact of coagulants on the overall performance of the water filtration process in producing required clean water.

2.0 LITERATURE REVIEW ON PERFORMANCE OF WATER FILTRATION

The MWF is a low-pressure driven system widely used in water industry for producing cleane water for residential use, power plant's cooling system, and industries for product processing MWF has been installed at the primary level in the WF process to cater feed water for secondary and tertiary water treatment [11, 12]. A few indicators have been used for measuring the MWF's performance; the indicators are productivity in clean water production, efficiency in separating impurities from feed water, energy consumption rate [kWh(m^{3}-water)$^{-1}$] [13]–[16]. Chemical oxygen demand (COD), Biological oxygen demand (BOD), natural organic materials (NOM) and water-born bacteria separation capability have also been used to measure the performance of MWF [16–19].

2.1 Coagulant in Water Filtration

Coagulants play a vital role in water treatment, and this process has been used since late nineteen century [20]. Coagulants have been used in feed water to address the adjustment of pH, pollutant removal and disinfection [21]. A few chemicals have been used in the coagulation process for separating various pollutant from feed water. Coagulant's type and dosing rate depend on feedwater properties as well. Traditionally, MWF and coagulants have been used to separate TSS, COD, BOD, and NOM from feed water. These are the targeted elements that enquire to be separated from the feed water [22]. Optimizing the size of MWF and coagulants dosing rate could reduce the effect of residual coagulants on the environment [23].

2.2 TSS and Turbidity Removal Efficiency by Water Filter with Coagulants

The MWF efficiency in TSS and turbidity removal depend on impurities loading rate to the WF system, pressure head of feed water, depth of filter media and coagulants dosing rate. The backwash frequency and backwash performance of MWF also plays a vital role in TSS and turbidity removal efficiency. The MWF's performance ranges could be from 50% to 95%. When the output water of MMF passes through the MF, the separation efficiency could be up to 99.9% [3]. The separation performance also depends on the binding of coagulants with the TSS and organic pollutants. Achieving higher separation efficiency of MWF, a homogenous mixing process of coagulant and feed water is essential [24].

2.3 Optimization of Coagulants Dosing Water Filtration

Coagulants dosing rate estimation is a difficult task in the WF, and it is commonly determined using a Jar test technique. The Jar test approach is time-consuming, expensive, involving human errors, and greatly influenced by raw water quality changes. A prediction model has been introduced to address all barriers involved in Jar test procedure [25, 26]. This model is a standalone random forecasting (RF) unit. The hybridized RF with genetic algorithm (GA) has used to optimize coagulants dosing rate [27]. The optimization mode reported by Achite *et al.*, and Sadie *et al.*, would reduce residual coagulants in water treatment, and also able to contribute to achieving economic and environmental sustainability [26, 27].

2.4 Effect of Coagulant on the Water Bodies and Environment

The release of residual coagulants and flocculants has several effects on the water bodies and environmental. The toxicity of the waste residual has appeared as a risk to the natural aquatic environment and would contribute to the higher biodiversity loss.

However, the impact of residual coagulants can be reduced by optimizing the coagulant dosing rate [1, 24]. Environmentally friendly coagulants are available, which would reduce toxic effects on the environment and aquatic lives [28, 29].

2.5 The Economy of Water Filtration

The economy of WF depends on a few factors of plant operations and maintenance. Optimization in plant design, using the consumable, plant backwash performance, preventing maintenance have been playing the potential role in controlling the cost. Coagulation dosing optimization could control cost effectiveness in the WF process. The depth of MWF, and its chemical properties are the driver of the MWF plant economy[2], [30]. Nguyen *et al.* [31] revealed that the operating cost of WF in producing clean water potentially depends on the plant operations. Nguyen et al. [31], Yoo *et al*. [4], Sung [9], and Jamalinezhad et al. [14] concluded that at an optimum plant operating condition, cost would be within 12% of the total water production cost.

This study concludes that coagulants become an essential part of the traditional WF process. But the residual chemicals of coagulants have appeared to be a toxic element for the water bodies and environment. This residual also affects biodiversity loss [28]. This study also confirms the performance and economy of WF depend on process optimisation of MWF and coagulants used. which associates with the sustainable clean water production and supply (SDG 6).

3.0 MATERIALS AND METHODS

3.1 Research Methodology and Experimental Setup

The experiment aims to measure the effect of coagulants on the TSS separation efficiency from the feed water. The experimental setup is presented in Figure 1.0.

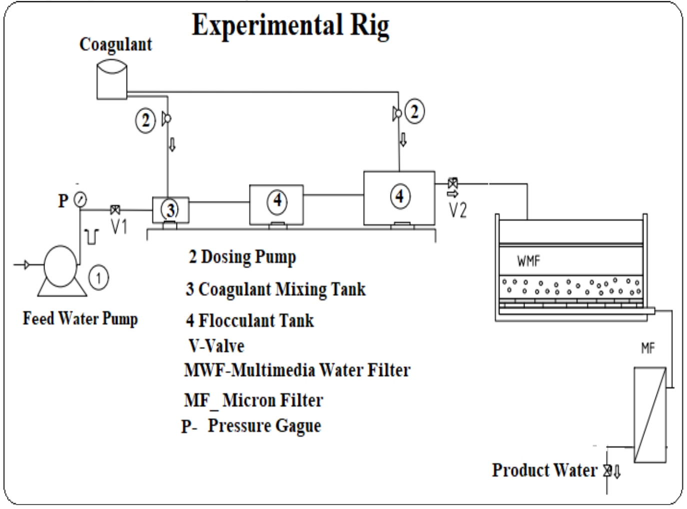

Figure 1: Experimental Set-up with Equipment

The equipment used in the experiment was a coagulant mixture, metering pump for coagulant dosing, feed water pump, pressure indicators and water flow meter.

To achieve the goal of this research, the experimental setup shown in Figure 1.0 has been used. The water consumption rate by the end users was 20.0 m^3 a day. The experimental run (Ø) was 14.0, which performed in 14.0 days. The data collection rate for an experimental run was 1.0 hour and 8.0 $(day)^{-1}$ (from 8:00 am to 16:00 pm). The total time spent for conducting the experiment was 112.0 hours.

In data analysis, statistical techniques SPSS, Excel software and 't statistic was used. Two sets data were recorded from the experiment. The experimental data were analyzed by using paired 't' statistic at 95% confidence level.

3.2 Theoretical Framework for Evaluating TSS Separation Performance

This section contains the required theories and mathamatical models for data analysis..

3.2.1 Estimating Average TSS in Water

Average TSS in water can measure from equation (1):

$$\bar{A}(\mathrm{TSS})_{PW} = \frac{\sum_{1}^{N} TSS_W}{N} \qquad \text{Eq. (1)}$$

Here, $\bar{A}(\mathrm{TSS})_W$ is average in TSS water, N is the no of samples.

3.2.2 Measuring the WF's Performance by Efficiency

Zirehpour & Rahimpour [17], Ramli & Bolong [16], and Yangang et al. [32] have used efficiency model to measure the performance of WF . The separation efficiency (Ƞs) of TSS can be estimated from equation (2) and equation (3):

$$Ƞs = \frac{\mathbf{TSS}_{FW} - \mathbf{TSS}_{PW}}{\mathbf{TSS}_{\mathbf{FW}}} 100 \qquad \text{Eq. (2)}$$

$$\bar{A}(ŋs) = \frac{\sum_{1}^{N} ŋs}{N} \qquad \text{Eq. (3)}$$

Here, 'Ƞs' is the TSS separation efficiency of WF. TSS_{FW} is TSS content in feedwater. TSS_{PW} is TSS content in product water.

3.3 Measuring Impact of Coagulants on TSS Separation Performance

The impact of coagulants in separating TSS can be evaluated from equation (4) and equation (5).

. $\Delta TSSpw = \bar{A}(TSS)wc - \bar{A}(TSS)oc$ Eq. (4)

ΔȠs = [Ƞsoc - Ƞswc] Eq.(5)

Here, 'Ƞ(wc)' is TSS separation efficiency of WF when filtration performs with a coagulant. 'Ƞs(oc)' is TSS separation efficiency which TSS separation performed without coagulants. 'ΔȠs' is difference in TSS separation efficiency between 'Ƞ(wc)' and 'Ƞs(oc). If there is any difference in TSS separation efficiency in WF, it will be an indicator of the coagulant's contribution.

3.4 Significance Test for Evaluating the Impact of Coagulants on TSS Separation Performance

P-value is a measure to test whether the contribution of coagulates in TSS separation from feedwater is significant. If P-value >0.05 at 95% confidence level, it will be an indicator that the contribution of coagulants in TSS separation is not required and vice versa. From a paired-samples t-test, P-value can be derived from the' t score', t-table and normal distribution curve, which is in Figure 2.

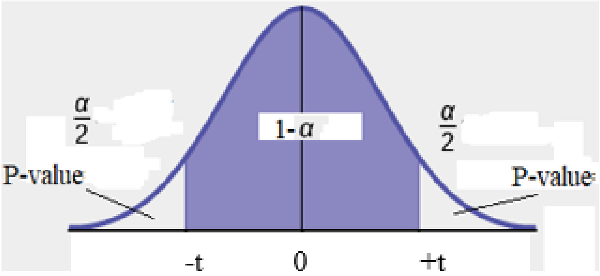

Figure 2: Normal Distribution Curve with t-score

The t-score, pooled standard deviation (Sp) and degree of freedom (df) can be estimated from equation (6), equation (7) and equation (8):

$$t_{st} = \frac{X1 - X2}{Sp\sqrt{\frac{1}{N1} + \frac{1}{N2}}} \qquad \text{Eq.(6)}$$

$$Sp = \sqrt{\frac{(n_1 - 1)s1^2 + (n_2 - 1)S2^2}{N_1 + N_2 - 2}} \qquad \text{Eq.(7)}$$

'df'= N1-N2-2 Eq. (8)

Here, X1-average mean of sample 1. X2- average mean of sample 2. S1-standard deviation of X1. S2-standard deviation X2. N_1 and N2 are the sample sizes.

3.4.1 Hypothesis Test to Evaluate the Significance Level in TSS separation

The null hypothesis and alternative hypothesis tests can be conducted to evaluate the significance of coagulant's contribution in TSS separation performance.

3.4.2 Null Hypothesis

Ho: $\mu 1 = \mu 2$ at 95% confidence level at (P-value > 0.05).

If P-value of mean difference of ΔTSS in WF with and without coagulant is more than 0.05 (P-value > 0.05), it will indicate that the mean of two data sets is almost equal and has no significant difference. This means the coagulant is not required in WF for achieving required water quality (TSS $\leq$ 1.0 mgL^{-1}).

3.4.2 **Alternative Hypothesis**

Ho: $\mu 1 \neq \mu 2$ at 95% confidence level at (P-value $\leq$ 0.05).

If P-value of mean difference of ΔTSS in WF with and without coagulant is less than 0.05 (p-value $\leq$ 0.05), it will indicate that the mean difference of two data sets is not equal and has significant difference. This means coagulant is required in WF for achieving required water quality (TSS $\leq$ 1.0 mgL^{-1}).

4.0 EXPERIMENT AND DATA ANALYSIS

The broad objective of this research is to determine the effect of coagulants on the water filtration performance. For conducting experiments, the mode of WF operation performed in two phases. The first phase is WF operation performed with coagulants, and the second phase is WF operation performed without coagulants.

4.1 Determine the TSS Separation Efficiency when WF Operation Performed with Coagulants

Experimental setup stated in section 3.1 and Figure 1.0 has been used to conduct the experiment. In this experiment MWF operated with coagulant (WC), which is relating to the objective number 1.0 that stated in the section 1.3.1.

Total 14.0 samples have been collected from feed water stream and TSS of these samples were tested. The average TSS ($\bar{A}$TSSwc) of these samples water was obtained from estimating equation (1). Total 14.0 samples also have been collected from the product water stream. Later stage, these samples were tested to evaluate the TSS contents in the product water. The TSS separation efficiency ($ŋ_{swc}$) of MWF is obtained from estimating equation (2). The average TSS separation efficiency $\bar{A}$(ŋswc) is estimated from equation (3). The outcomes of the laboratory tests and estimated values of TSS relating to the objective 1.0 is presented in Table 1.

Table 1.0: MWF Plant Operate with Coagulants

Ø	TSS$_{FW}$ (mgL^{-1})	TSS$_{pw}$ (mgL^{-1})	ŋ$_{swc}$
1	7.8	0.75	0.923
2	7.5	0.8	0.933
3	7.4	0.7	0.932
4	6.5	0.85	0.938
5	7.0	0.75	0.928
6	7.5	0.7	0.946
7	7.4	0.8	0.91.9
8	7.0	0.7	0.928
9	6.8	0.65	0.926
10	7.6	0.7	0.921
11	7.5	0.8	0.933
12	8.0	0.75	0.9375
13	7.8	0.65	0.923
14	7.5	0.7	0.933
Ā	Ā(TSS)Fw=7.25	Ā(TSS)wc= 0.735	Ā(ŋs)wc= 93.03
σ	0.4	0.06	0.07

The characteristics of TSS separation efficiency of MWF is also presented in Figure 3.0.

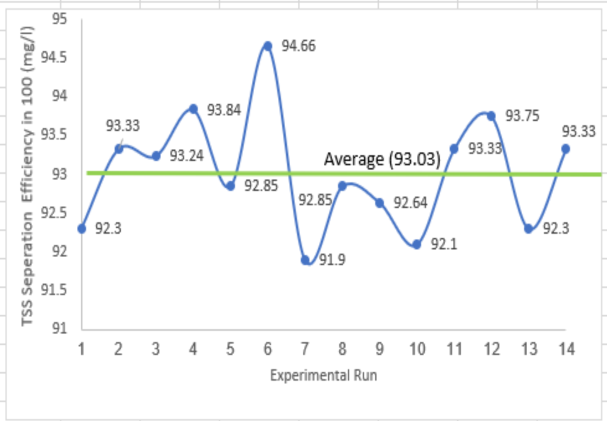

Figure 3: TSS Separation Efficiency

Figure 3.0 and Table 1.0 demonstrate the outcomes of the experiments. The average TSS content in PW is 0.735mgL^{-1}, which is achieved at TSS separation efficiency of 93.03%. The TSS contents in PW is found within the acceptable limit in accordance with the acceptable water quality limit in Malaysia [33].

4.2 Estimate the TSS Separation Efficiency when WF Operation Performed Without Coagulants

The experiment of this section is performed without coagulants, which is relating to the objective number 2.0 that stated in section 1.3.2.

Total 14.0 samples have been collected from feed water stream and TSS of these samples were tested. The average TSS (ĀTSSoc) of these samples water was obtained from estimating equation (1).

Total 14.0 samples have been collected from the product water stream. Later stage, these samples were tested to evaluate the TSS contents in the product water. The TSS separation efficiency (ŋ$_{swc}$) of MWF is obtained from estimating equation (2). The average TSS separation efficiency Ā(ŋswc) is estimated from equation (3). The outcomes of the laboratory tests and estimated values of TSS relating to the objective 2.0 is presented in Table 2.

Table 2: Plant Operation without Coagulant

Ø	TSS$_{FW}$ mgL^{-1}	TSS$_{PW}$ mgL^{-1}	* ŋ$_{soc}$
1	7.6	0.9	0.88
2	7.5	0.85	0.88
3	7.6	0.8	0.89
4	7	0.95	0.863
5	7.3	0.9	0.87
6	7.5	0.85	0.886
7	7.8	0.8	0.897
8	7.5	0.85	0.886
9	7	0.95	0.864
10	7.5	0.85	0.886
11	7.5	0.85	0.886
12	7.8	0.9	0.884
13	7.5	0.95	0.873
14	7.8	0.90	0.884
‘Ā’	Ā(TSS)$_{FW}$ =7.47	Ā(TSS)$_{OC}$ =0.876	Ā(ŋs)oc=0.882
σ	0.06	0.05	0.09

able 2.0 demonstrates the performance of WF when filtration performed without coagulant. The characteristics of TSS separation efficiency is presented in Figure 4.0.

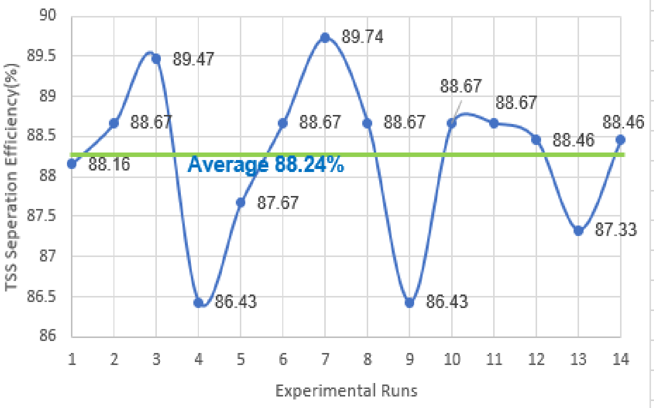

Figure 4: TSS Separation Efficiency

Figure 4.0 and Table 2.0 demonstrate the outcomes of the experiment. The average TSS content in PW is 0.762, which is achieved at TSS separation efficiency of 0.882%. The TSS content in PW is found within the acceptable limit in accordance with the water quality in Malaysia[33].

4.3 Evaluate the Impact of Coagulants on TSS Separation Performance

The impact of using coagulant on the TSS separation performance is measured at 95% confidence level (significance α =0.05). TSS contents in the PW and TSS separation efficiency from the feed water have used to measure the impact of coagulants.

With reference to Table 1.0 and Table 2.0, the TSS level in PW is 0.735 mgL^{-1} at a TSS separation efficiency (ŋ$_{swc}$) of 0.93 when WF performed with coagulant. The TSS level in PW is 0.876 mgL^{-1} at a TSS separation efficiency (ŋ$_{soc}$) of 0.8824 when WF performed without coagulant. The impact of coagulant on TSS separation performance is evaluated by estimating the equation (4) and equation (5).

. ΔTSSpw = Ā(TSS)wc- Ā(TSS)oc

$= (0.87-0.735)\ mgL^{-1} = 0.145 mgL^{-1}$ Eq. (9)

$\Delta \eta s = [\eta soc - \eta swc]$

$= 0.930-0.882= 0.051$ Eq. (10)

The findings present in Eq. (9) and Eq. (10) demonstrate that the differentness of these two processes are positive and coagulants have contributed to increase TSS separation ($\Delta TSSpw$) by $0.145 mgL^{-1,}$ and TSS separation efficiency ($\Delta \eta s$) by 0.051%. The Eq. (9) and Eq (10) demonstrate that the coagulant has made a positive contribution to TSS separation performance. In this regard, the research question is whether the contribution of coagulant is significant?

4.3.1 Hypothesis test to check whether coagulant has a significant impact on the TSS separation performance

To test the hypothesis, models stated in sections 3.4.1 and 3.4.2, have been used. This test involved paired-samples t-test at 95% significant level. Sp is estimated from equation (7).

The estimated value of Sp is: 0.273

Here, from Table T1

S1=standard deviation of sample means 1= 0.06

X1-average of sample mean = Ā(TSS)wc= 0.735

N_1 is sample size = 14.

From Table T2,

S1=standard deviation of sample means 1= 0.05

X1-average of sample mean = $\bar{A}(TSS)_{OC}$= 0.876

N_1 is sample size = 14.

The degree of freedom can estimate Eq. (8) .

df= (N1+ N2–2) = 26.

The 't_{st}' is estimate from Eq. (6).

The estimated value of tst is = 0.019.

From paired-samples t-test and t table, at df 26 and 95% confidence level 'critical value t=2.06 and P-value >0.05((0.5< P-value <1.0). The statistical data is presented in Figure 5.

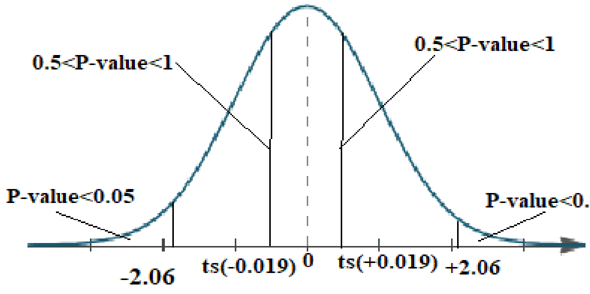

Figure 5: 't' score for Hypothesis test with mean value of TSS in Product Water

Figure 5.0 demonstrates that the estimated 't' value is less than the critical value (α=0.05) and P-value is more than 0.05 (0.5<P-value<1.0). With these findings, the study has enough information for not reject Ho. In other part, Ha is rejected. It indicates that coagulants have not made a significant contribution in removing TSS from the feed water. The finding also demonstrates that coagulant is not required to produce water that contains TSS within 1.0 mgL^{-1} (TSS≤ 1.0 mgL^{-1}). With this finding, study concludes that the impact of coagulant on producing the required clean water is insignificant when TSS in feed water is less than 10.0 mgL^{-1} (TSS≤ 10.0 mgL^{-1}).

4.3.2 Hypothesis test to Check whether coagulant has a Significant Impact on TSS Separation Efficiency

Testing hypothesis, models stated in sections 3.4.1 and model 3.4.2, have been used. This test involved a paired-samples t- at 95% significant level.

The required Sp estimate from Eq. (7):

The estimated value of Sp from Eq. (7) is 0.08

Here, From Table T1.

N_1 is sample size = 14

S1=standard deviation (σs_{oc}) in TSS separation efficiency of sample means 1= 0.07.

N_1 is sample size =14

From Table T2,

S2=standard deviation (σ_{swc}) o) in TSS separation efficiency in sample means 2=0.09.

N2 is sample size =14

The degree of freedom can estimate Eq. (8).

df= (N1+ N2–2) = 26.

The 't_{st}' estimate from Eq. (6).

X1- average sample mean for separation efficiency of TSS Ā(ŋs)oc = 0.882.

X2- average sample mean for separation efficiency of TSS Ā(ŋs)wc = 0.93.

The estimated value of t_{st} from Eq. (6) is = 0.02.

From paired-samples t-test and t table, at df 26 and 95% confidence level 'critical value t=2.06 and p-value >0.05(0.5< p-value <1.0). The statistical data present in Figure 6.

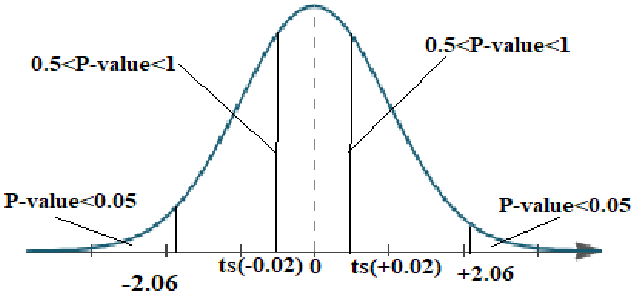

Figure 6: 't' score for Hypothesis test with mean value of TSS Separation Efficiency

Figure 6.0 demonstrates that the estimated 't' value is less than the critical value (α=0.05) and P-value is more than 0.05 (0.5<P-value<1.0). With these findings, the study has enough information for not reject Ho. In other part, Ha is rejected.

It indicates that coagulants have not made a significant contribution to remove TSS from the feed water. This finding demonstrates that coagulant is not required to produce required water quality (TSS≤ 1.0 mgL^{-1}) from the feed water used for this experiment. With this finding, study concludes that the impact of coagulant on TSS separation efficiency in producing the required clean is insignificant when TSS in feed water contains less than 10.0 mgL^{-1} (TSS≤ 10.0 mgL^{-1}).

5.0 Scenario Analysis of Research Findings and Conclusion

Experiments reported in section 4.0 of this paper revealed that water filtration performed by MWF and coagulant has contributed to increase PW quality though the TSS and pollutants content in PW was within the acceptable limit (TSS≤ 1.0 mgL^{-1}).

Statistical analysis proved that the mean difference of TSS in PW produced with and without coagulant is not statistically significant at 95% level (P-value>0.05). Even, the mean difference of TSS separation efficiency was also not statistically significant (P-value>0.05).

This finding suggests that the TSS of PW produced by WF with and without coagulants are within the acceptable limit ($TSS \leq 1.0\ mgL^{-1}$) hence coagulants are not required for this WF process.

This finding also suggests that adding coagulants in low TSS feed water ($TSS \leq 1.0\ mgL^{-1}$) for WF process would increase water production cost and may reduce economic performance and affect SDG8 [22].

Adding coagulants in WF process would also affect the environmental sustainability (SDG13), increase pollution in run-off water and thereby biodiversity loss.

The research outcomes reported in this paper have several implications in the water industry, engineering professions, and policy implementation domains relating to the use of coagulants in WF process. With reference to the research outcomes listed in this paper, it would be concluded that further research shall continue with various impurities in source water to increase the overall performance in WF for achieving sustainable development goal (SDG).

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