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Research article

Engineering

MODEL FOR MIXING PROCESS IMPROVEMENT AT WATER TREATMENT PLANT BY INTEGRATING LEAN MANUFACTURING AND PARAMETER DESIGN

精益制造与参数设计相结合的水处理厂混合工艺改进模型

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Abstract

The aim of integrating lean manufacturing and parameter design is to minimize seven non-value wastes in addition to the traditional waste in clean water production. These additional wastes to be considered are overproduction, waiting, motion, transportation, inventory, overprocessing, and defects. Information obtained from each waste is the input for the parameter design of the mixing process. The result of interaction between these seven types of waste in the lean production of clean water reveals that overprocessing waste is the most influential input in the parameter design of the Taguchi method. In the process of adding the level of concentration of *poly aluminium chloride* coagulant in the mixing process, a turbidity level below 5 nephelometric turbidity units is obtained, which in fact is in accordance with the health standard for clean water. An observation was also made on the behavior of flocs as the effect of Brownian motion due to the attractive force of *poly aluminium chloride* coagulant and colloid particle. The particle was then examined using a scanning electron microscope to find out the dimension of grain-sized flocs as the result of sedimentation in the mixing process. By properly integrating lean manufacturing and parameter design to minimize waste, a quality water meeting the set standard would be produced.

Keywords: Waste, Integration, Mixing, Flocs, Clean Water

摘要 将精益生产与参数设计相结合的目的是，在清洁水生产中，除了传统废物外，还应减少 7 种无价废物。这些额外的废物要考虑的是生产过剩，等待，运输，运输，库存，过度加工和缺陷。从每种废物中获得的信息是混合过程参数设计的输入。在清洁水精益生产中这七种废物之间的相互作用结果表明，在田口方法的参数设计中，过度处理废物是最有影响力的输入。在混合过程中

增加聚氯化铝混凝剂的浓度水平的过程中，获得的浊度水平低于 5 浊度浊度单位，这实际上符合清洁水的卫生标准。由于聚氯化铝凝结剂和胶体颗粒的吸引力，还对絮凝物的行为作了布朗运动的影响进行了观察。然后使用扫描电子显微镜检查颗粒，以找出由于混合过程中的沉降而导致的颗粒状絮状物的尺寸。通过适当地整合精益生产和参数设计以最大程度地减少浪费，可以生产出符合设定标准的优质水。

关键词: 废物，一体化，混合，絮凝物，清洁水

I. INTRODUCTION

Clean water is an essential requirement in a dynamic community life due to the various activities, such as household needs, industry and so on, that require water. Humans are highly dependent on water since their body consists of mostly liquid required for daily activities, hence the availability, quality and continuity of clean water are very important for human life and industry [1]. Maintaining the quality of clean water by following the standard for clean water to satisfy the needs of more than 62 hundred inhabitants is the goal of Water Treatment Plant (WTP), operated by a regional freshwater company in Banjarbaru and Martapura, South Kalimantan. The source of raw water is from the Martapura River specifically the sub-Barito, which has a high turbidity level and production capacity of clean water of, on average, about 250.000 liters per second (m^3/sec).

This specific process at WTP includes water supplied from a river with a very high turbidity level - more than 5 NTU - which therefore needs a process of adding proper coagulants to reduce the turbidity level until it meets the clean water standards [2], [35]. Conventionally, addition of a coagulant variation using a jar test method is performed in the process of reducing turbidity to find the estimation of coagulant dosage [3]. A method of genetic algorithm and artificial neural network is also employed to seek out an approach between the water quality parameter and the more efficient and economical coagulant dosage [4]. Somehow, a suggestion for an improvement method is needed to design the quality of clean water from the beginning with a parameter design adopting the Taguchi method [5] and green approach in the mixing process at various turbidity levels by focusing on waste reduction and minimization [6], [7]. In Indonesia, the source of raw water from the river is different than the same source of water in other countries due to the condition of the forest and environmental factors that highly influence the level of turbidity [8].

Various improvements of the mixing process to obtain an optimal setting are performed using the Green Taguchi approach, which later minimizes waste in production process and reduces the turbidity level until it equals the health standard and flocking behavior which flies during the mixing process. In the mixing process, the coagulation process occurs to reduce turbidity, color, and smell through a chemical process used to remove the colloid particles which may disrupt the environment [9], [10]. Colloid particles cannot precipitate themselves and are difficult to handle physically, and the addition of clean water is an essential requirement in a dynamic community life due to the various activities such as household needs, industry and so on. Humans are highly dependent on water since their body consists of mostly liquid required for daily activities, hence the availability, quality and continuity of clean water are very important for human life and industry. *Poly aluminium chloride* (PAC) coagulant destabilizes the particles so that the micro-flocs are created [11]. Micro-flocs then coagulate into macro-flocs, which then can be precipitated through a flocculation process. The coagulation process depends on time and the slow mixing in the water. Generally, the period of flocculation lasts 10-30 minutes after the coagulation process [12]. The faster the mixing time is, the bigger flocs that will be formed. The characteristics of raw water source, mixing condition, flocculation time, coagulant selected, and the variation of additional coagulation concentration will later influence the performance of coagulation [13], [14].

Small and fine colloid particles are generally negatively charged since river water contains organic or anorganic compounds that cannot be omitted only with the common sedimentation, but by using the positively charged PAC, the attractive force created would cause the coagulation of floc particle [15]. PAC as coagulant purifying drinking water has a good velocity to form new flocs in the mixing process of clean water. As a basic element, alumunium creates multiple units within the long-chain of molecular bond whose charge is positive, high and heavy, with big molecules. It is also able to minimize flocs in the purified water at certain dosages [16]. Thus, PAC combines netralization and the ability to bridge floc particles so that coagulation occurs more efficiently [17]. PAC can easily neutralize the electric charge on the floc surface and cope with or reduce the electrostatic repulsive force between particles up to the smallest size, which enables flocs to move closer (covalent attractive force) and form a bigger coagulation/mass [18].

By integrating lean manufacturing in the form of output of waste, which is highly influential toward the mixing process at WTP, a proper parameter design is then needed to reduce the turbidity level with a variation of coagulant addition. Positively charged coagulant characteristics are used to attract the negatively charged colloid particles to form flocs that will precipitate in the bottom of the canal. The coagulant behavior seizing flying colloid particles into flocs would be then observed and examined using a scanning electron microscope (SEM) to find out the dimension of grain-sized flocs as a sedimentation result of the mixing process with its various compound contents.

II. MATERIAL AND METHODS

A. Lean Manufacturing

Lean manufacturing is a continuous effort to remove waste and increase value added by reducing unnecessary things in the product design (good or service) so that it can contribute consumer value in the exact place, time, and number to achieve perfect work flow that remains flexible (easy to change) in response to changes in condition [19], [20], [34]. Management of lean manufacturing is a strategic philosophy to increase the capability of the company to meet and satisfy the customer need. Lean philosophy is based on Toyota Production System (TPS) principles. The aim of the management system of lean manufacturing is to increase value added and reduce waste through the optimization of standard processes [21]. Also, attention is given to the minimization of the seven conventional wastes (over-production, waiting, unnecessary motion, transportation, unnecessary inventory, over-processing, and defects) and its relationship with the performance rate for certain selected operations (throughput, productivity, efficiency, time cycle, work in process, quality process, leveled and balanced schedules) [22].

Lean manufacturing emphasizes the creation of value added and reduces waste. Minimizing waste means reducing production cost and increasing the quality of the end product, even though it is unlikely to minimize all wastes (zero waste). In a rigid operation system and efficient waste that has been minimized (even though waste is part of the function), it is necessary to understand the relationship and interaction of waste to minimize the level of waste as much as possible. In lean manufacturing, seven wastes have been identified as follows: over-production, waiting, unnecessary motion, transportation, unnecessary inventory, over-processing, and defects [23], [24]. The conceptual development of an integration model structure based on lean manufacturing and parameter design for clean water to minimize waste and optimize the model of mixing process as it can be seen in Figure 1 below.

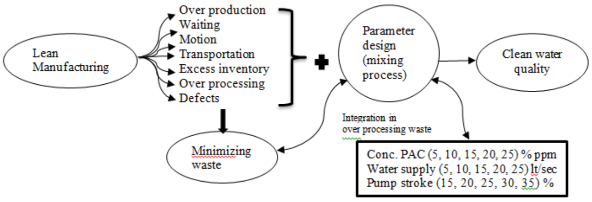


Figure 1. The model of integration of lean manufacturing and parameter design in the process of mixing

B. Colloid Particle (Flocs)

In parameter design, coagulation is used to remove and separate suspended solid (SS) and colloid particles. SS is from natural organic minerals such as loam, mud, and any results of decomposition of plants or animals. Another colloid is a smaller SS as a particle that cannot precipitate naturally and has a diameter of less than 1 mm giving color and turbidity. These particles attract each other, in an interaction known as van der Waals force, and repulse each other, called as zeta potential force which has the same charge of mass coagulating to form flocs. The attractive force tends to enable aggregation while the repulsive force causes the stability of colloid dispersion. The stable characteristic of the colloid can be removed with the addition of coagulant dosage in which its electrolyte charge is against the colloid charge. Coagulation is a process of stability breakage by the addition of coagulant that is followed by quick mixing to neutralize the colloid charge and to enable coagulation, forming significant precipitation [10].

According to [17], coagulation is a physical chemistry process which adds coagulants in the process of mixing with quick stirring, causing interaction between positive and negative ions. The difference between the positive and negative ions causes the formation of an electrostatic field. This potential determines the motion of the colloid and interaction between the colloid. This particular potential is known as zeta potential. Figure 2 given below shows the attractive force between the positively charged coagulant and colloid particle forming negatively charged flocs.

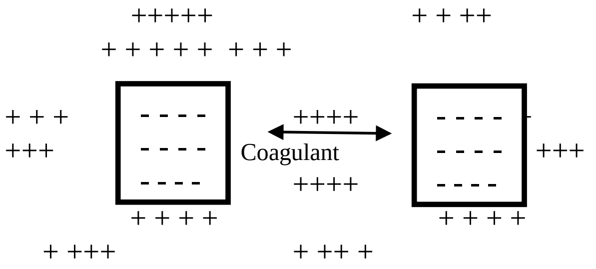


Figure 2. Attractive force of coagulant and colloid (flocs)

The colloid particle is generally negatively charged in the water, which causes the particles to attract the positively-charged ions and decreases into sedimentation to remove. Positive ions form a layer close to a certain particle surface surrounded by negative ions fusing little by little with positive ions, until neutral particles are formed. The layer of positive ion is known as stable layer or stern layer, while the negative ion dispersed around the stable layer is called as diffused layer formed by ions easily in motion. This diffused layer exists on the sliding surface which is the border of the opposite ion attracted to the particle surface. Colloid can be said as stable if the repulsive force between particles is bigger than the attractive force of the mass, thus at some time, there is no aggregation. To remove the stable condition, changing the force of interaction between particles by adding positively charged coagulant is done in order to make the attractive force bigger thus the destabilization of negatively charged particle occurs due to the positive charge. The addition of coagulant percentage is done using Taguchi technique to obtain the optimum estimation of coagulant and to get the quality clean water in accordance with the standard set [16].

C. Experimental Design Taguchi Method

According to [25] explains that the strength of Taguchi method compared to other experimental design is because of its more efficient experiment inclusive to many factors but with a relatively small number of experiment units needed, a more consistent product, and a less sensitive (robust) towards variability caused by uncontrolled factors (noise).Objective function of Taguchi method for a sturdy and noiseproof design is derived from the measurement of product quality by applying the quadratic loss function in a wider notion of definition to produce optimal design or parameter design. Signal to ratio (SNR) in this system design of experimental method gives a comparison of quantitative value for a variation of response. To maximize the result of SNR, minimization of variation of response and performance of a sturdy parameter design in accordance with target is made for the best quantification from mean squared deviation (MSD) on the performance of mixing process.

The most significant expectation of the sturdy design of the Taguchi method, especially the parameter design, is to examine the effect of variability in the factorial and experimental levels, using statistical tools as an auxiliary. To assist with the full factorial experiment, which is large, highly complex, time-consuming and costly, Taguchi suggests the employment of orthogonal arrays (OA) to represent the stretch the experiment is likely to conduct. After doing the experiment, all al dataexperiment are evaulated using analysis variant (ANOVA) to determine the optimum setting parameters [26], [27].

III. RESEARCH METHODOLOGY

Partial Least Square (PLS) is developed using the PLS Regression (PLS-R) and PLS Path models, which have a reflective model of indicators – often called as the main factor of the model – where the covariance of the indicator measurement is influenced by Laten, which constructs or reflects the variation of Laten construction. In the reflective model, an n-dimensional construction is depicted by an elliptical shape with arrows from construct to indicator. This model is the hypothesis, detecting changes in Laten construction that would influence the change of indicator. The indicator of the reflective model is needed to define internal consistency, because all standard indicators are assumed as valid. Therefore the two measurement indicators with the same reliability are interchangeable, although the reliability (Cronbach's alpha) of certain construction would be low if one of the indicators is removed [28], [29]. The PLS approach aims to obtain waste with the largest effect toward clean water production in the process of mixing. With that minimum of information, the process of the Taguchi method with parameter design can be done.

The Taguchi method used for parameter design and integration of output of waste is significantly influential in improving the quality of clean water product, reducing the turbidity level with a variation of coagulant dosage, and optimizing the mixing process. The aim of this method is to make the clean water noise-insensitive, hence it is called a robust design [30]. The concept is below:

1. The quality of clean water needs to be designed from the beginning, not only investigated.
2. The best quality is achieved by minimizing the deviation from the target, hence the product

needs to be designed so that it is robust towards the uncontrolled environmental factor.

3. The cost of quality needs to be measured as the function of deviation from a certain standard, and the loss needs to be measured at all product stages.

This method is to find out the factors influencing a certain response that is optimum for its characteristics. The quality characteristic of "The Smaller The Better" (STB) indicates that the smaller the quantity of a parameter characteristic, the better the quality. "The Larger The Better (LTB)" indicates that the larger the parameter characteristic is, the better its quality will be. Meanwhile, "Nominal The Better" (NTB) is the concept that the quality increases only as it gets closer the nominal (target) value set by the parameter design and response for clean water with its variation of concentration and level [31].

IV. RESULT AND DISCUSSION

Methods of validating reflective indicators are the correlation between item score and construct score. Reflective indicator measurement models show the change in a certain indicator in a certain construct only when another indicator in the same construct changes (or is expelled from the model). This research applies a reflective indicator as an appropriate tool for measuring observation. The indicator used in this research is valid or has met the criteria of convergent validity. A linearity test was taken using X6 and Y1, which are both non-value-added. The ANOVA model, shown in Table 1, points out the relationship between variables X6 and Y1, showing how the variables meet the linearity assumptions, since the F-test for linearity shows that the degree of confidence used is 0.05, if the calculated F value is greater than the F table value, the alternative hypothesis states that all independent variables simultaneously have a significant effect on the dependent variable.

Table 1.
Linearity assumption for X6 and Y1 with table ANOVA

	Sum of squares	**df**	**Mean square**	**F**	**Sig.**
Y1 * X6 Between Groups(Combined)	58.655	6	9.776	1.692	.141
Linearity	45.215	1	45.215	7.826	.007
Deviation from linearity	13.440	5	2.688	.465	.800
Within Groups	306.195	53	5.777		
Total	364.850	59			

The hypothesis was tested using the bootstrapping method developed by Geisser and Stone. Bootstrapping is one of the resampling methods researchers use to produce results with a small number of samples. The determination of this method establishes the validity of freely distributed data so that no assumption of normal distribution is required. The hypothesis test was conducted to find out the effect of research variables on one another. The test used a *P* =0.048, meaning if the results of the test had a *P* value of less than 5%, then the results would be significant. In contrast, if the results of the test had a *P* value of greater than 5%, then the results would be insignificant. In Table 2 below, the path value of overprocessing for the purpose of minimizing waste is positive and significant as the value of the path coefficient 3.987 and the *P* value is greater than 0.05.

Table 2.
Test of direct effect toward waste minimization

Waste	**Path coef. to minimize**	**P value**	**Validity**
Defect	1,995	0,047	Significant
Motion	1,829	0,068	Significant
Waiting	2,247	0,025	Significant
Over	3,987	0,000	Significant
Processing	1,981	0,048	Significant
Over	0,913	0,362	No
Production	0,543	0,587	Significant
Transportation			No
Inventory			Significant

A test on the data of water supply turbidity was run to obtain the characteristic qualities and contents. The information was taken at the optimum time in the mixing process to capture the changing concentration levels (ppm) of PAC using the specifications shown in Table 3 below.

Table 3.
Specification of liquid PAC

PAC liquid	**Spesification**	**Indicator**
	Al_2O_3 (%)	10,3 ± 0,3
	Fe (%)	Max0,006
	As (ppm)	Max 0,5
	Mn (ppm)	Max 10
	Cd (ppm)	Max 0,3
	Pb (ppm)	Max 1,0
	Hg (ppm)	Max 0,1
	Cr (ppm)	Max 1,0
	Basicity (%)	51,0 ± 4,0
	SpecificGravity (25%)	1,204 ±0,004

	pH (25^{0}C)	2,6 ± 0,3
	Viscocity (cp 25^{0}C)	4,0 ± 0,5
	Freezing Point (^{0}C)	-12,0 ± 1,0

Examining the by-products of lean manufacturing, we see that overprocessing, which is most efficient at minimizing waste at the path coefficient of 3.987, is a significant method of waste reduction as shown in Table 3 above. Therefore, it would benefit the mixing process, reducing turbidity, to add the coagulant variation with the parameter design of the Taguchi method, with a low level of 5–10 ppm, a medium level of 11–15 ppm, and a high level of 16–20 ppm as shown in Table 4 below [32].

Table 4.
Level factor

Parameter	**Code**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Conc.alum	A	5	10	15	20
Water supply	B	5	10	15	20
Pump stroke	C	15	20	25	30

The concentration level of PAC coagulant can be set at low level, medium level, or high level with the setting of the water supply and pump stroke. The turbidity level will decrease as the coagulant concentration level rises, spreading positive ions. The positive and negative ions will show the effect and response of variable concentration, water supply, and pump stroke as shown in Figure 3 and Table 5 below. The effects plot for S/N ratio will indicate the parameter design's optimum mixing processes at the various concentration levels [33].

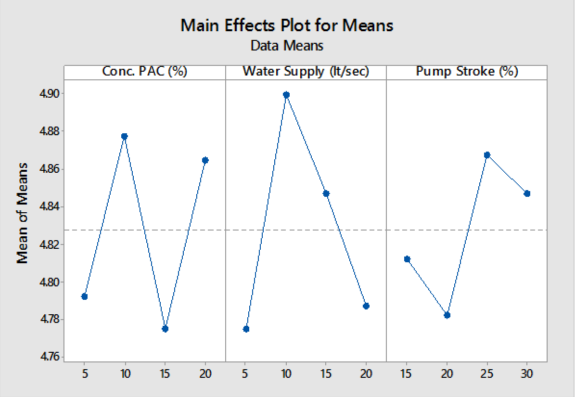


Figure 3. Main effect and response table variable conc. PAC, water supply and pump stroke

Table 5. Response table for means

Level	**Conc. PAC**	**Water supply**	**Pump stroke**
1	4.793	4.775	4.813
2	4.877	4.900	4.782
3	4.775	4.848	4.868
4	4.865	4.787	4.848
Delta	0.102	0.125	0.085
Rank	2	1	3

Parameter design conducted in mixing process, as shown in Figure 4 below, shows that the turbidity value of water supply is above 5 NTU (nephelometric turbidity unit) - which is the standard value for clean water. With a medium level of concentration (11–15 ppm), the decrease level of turbidity ranged from 4–5 NTU at pH 7.1. The turbidity values of the water supply when the mixing process can also be seen in the contour plot in Figure 5, which presents the dispersion of turbidity values with a more detailed range level at each change of PAC concentration.

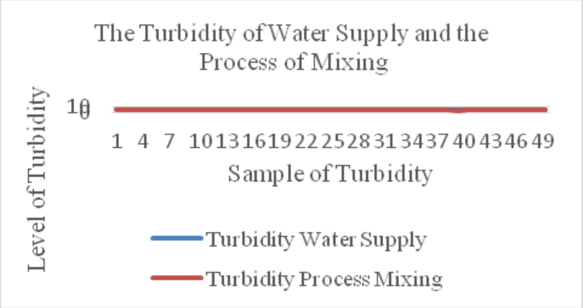


Figure 4. The level of turbidity of water supply and mixing process

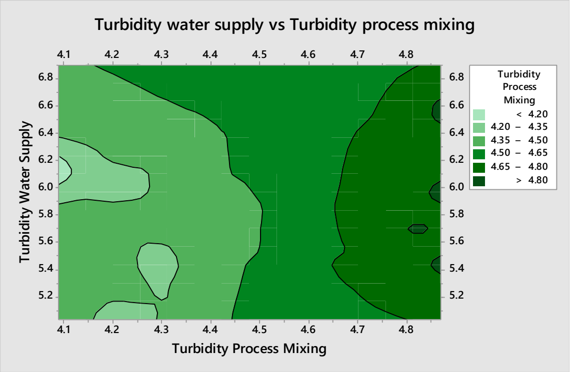


Figure 5. Contour plot of turbidity of water supply and turbidity of mixing process

The turbidity level of the water supply was, on average, 5.8 NTU, and the average decrease of turbidity level in the mixing process was 4.5 NTU when the addition of medium level in coagulant concentration. However, the fluctuation approximates the normal distribution, as shown in Figure 6 below. The variation of turbidity in the water supply was influenced by the condition of downstream river, weathering organic and the environment erosion. The decrease of turbidity in the mixing process was due to the coagulant setting. As the ppm of coagulant increased, the turbidity reduced until reaching the optimal concentration Level 5-7 at the medium level in the water supply: 5–7 NTU.

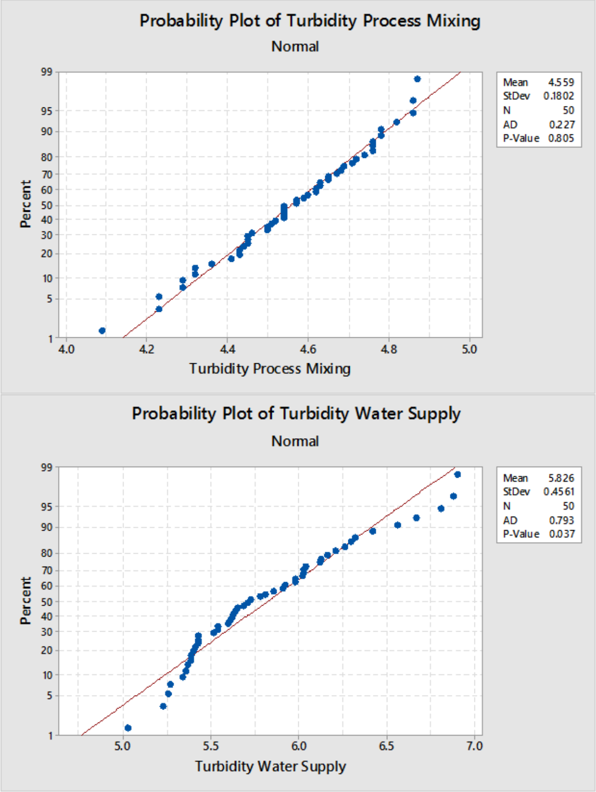
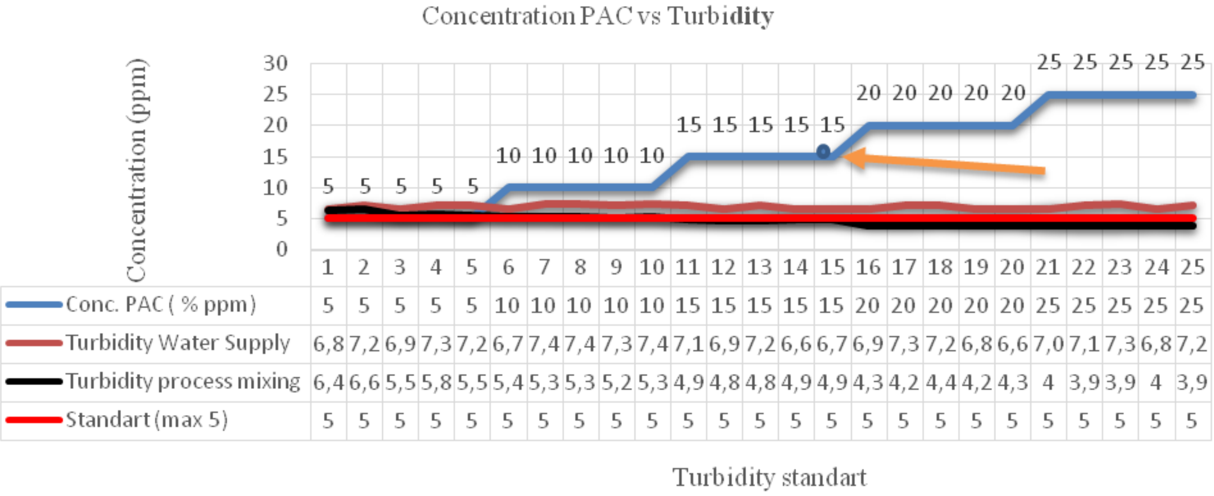


Figure 6. The normality of turbidity of water supply and process mixing

By examining the fluctuation of water supply turbidity on the mixing process, the model of mixing process can be predicted at the medium level of coagulant (14 and 15 ppm). On average, the model of mixing process prediction collects the maximum coagulant at the medium level (15 ppm) under the condition of 5–7 NTU.

Optimal mixing process = 15% ppm conc. PAC + 15 lt/sec + 15% pump stroke

The optimal model can fluctuate with change concentration of turbidity in a 2-point range (e.g., 5–7 NTU, 7–9 NTU). Every change in ppm concentration, water supply, and pump stroke can be seen in Figure 7 below. At the medium level 11-15, it can be seen that the turbidity of the mixing process is at 4.8 NTU and 4.9 NTU, which are close to the health standard turbidity (below 5). The higher % ppm of PAC causes the turibidity to decrease and the water color to turn transparent. The use of a high concentration of PAC would not typically be harmful to the human body, but with continuous, excessive doses over a long time, it could cause side effects via toxin buildup within the body digestive tract.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Conc. PAC (% ppm)	5	5	5	5	5	10	10	10	10	10	15	15	15	15	15	20	20	20	20	20	25	25	25	25	25
Turbidity Water Supply	6,8	7,2	6,9	7,3	7,2	6,7	7,4	7,4	7,3	7,4	7,1	6,9	7,2	6,6	6,7	6,9	7,3	7,2	6,8	6,6	7,0	7,1	7,3	6,8	7,2
Turbidity process mixing	6,4	6,6	5,5	5,8	5,5	5,4	5,3	5,3	5,2	5,3	4,9	4,8	4,8	4,9	4,9	4,3	4,2	4,4	4,2	4,3	4	3,9	3,9	4	3,9
Standart (max 5)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Figure 7. The variation of PAC concentration at each level

Each change in PAC concentration causes changes in water turbidity, colloid behavior, and floc formation in the mixing process. PAC would attract a negatively charged colloid; this is termed the van der Waals force. A sufficient addition of coagulant concentration would reduce the zeta potential repulsive force in the colloid; as a result, there would be more positive ions than negative ions, which facilitates a faster floc formation process. With the sedimentation process and floc filterization, sediment would gravitationally sedimentate at the bottom surface and ultimately be discarded, as the sedimentation is considered a waste product in the clean water industry.

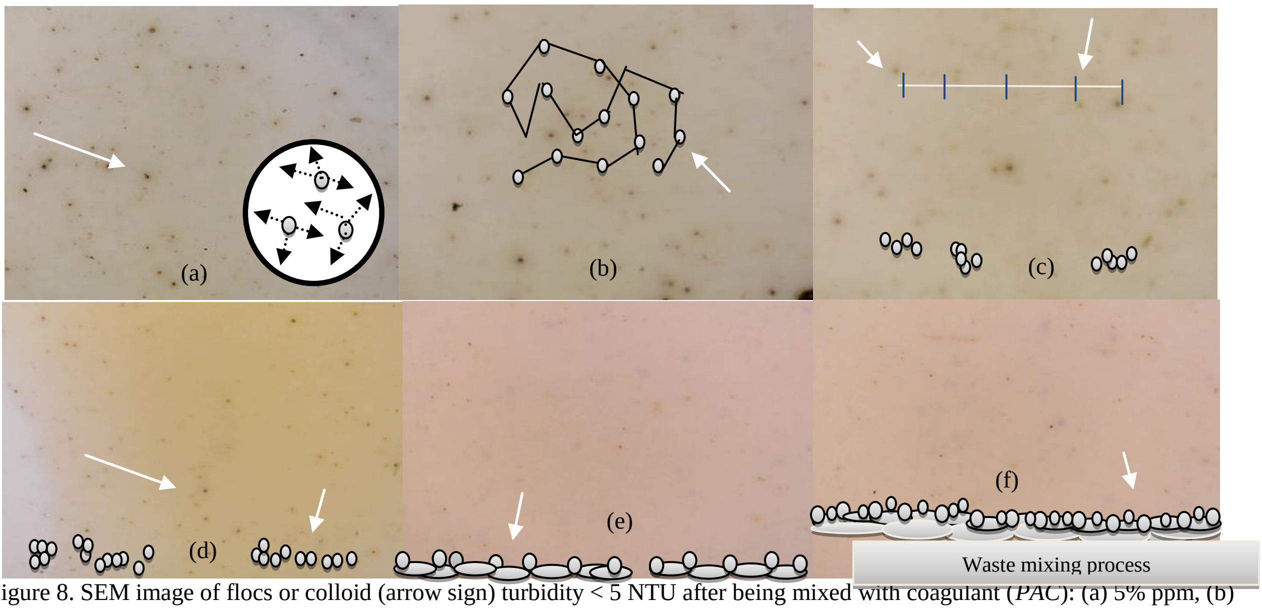


Figure 8. SEM image of flocs or colloid (arrow sign) turbidity < 5 NTU after being mixed with coagulant (*PAC*): (a) 5% ppm, (b) 10% ppm, (c) 15% ppm, (d) 20% ppm, (e,f) 25% ppm

In the mixing process, each variation of water supply, ppm PAC and % pump stroke was influential at the turbidity level due to the addition of a coagulant that is positively charged. With the increase of coagulant and pump stroke in the form of pump velocity (rpm), process mixing would fasten the process of floc formation. Figure 8a represents the large-grain flocs in which the effect of the van der Waals force is visible. The large attractive force from the coagulant attracts a negatively charged floc. Micro photo with SEM magnification 1200x digital camera was required observe the Brownian motion, which is in the form of a zig-zag line or straight line and gradual, as seen in the molecular kinetic flocs in Figure 8b. In Figure 8c, the distance between flocs increases along with rpm; then, the colloid flies slowly to the bottom in groups due to gravity. Moreover, as seen in Figure 8d, flocs start to sedimentate downward closing by the plat basis, together with coagulation and flocculation. In Figure 8e, the colloid and flocs are not visible since the pump rpm of the mixing process is concentration 20% ppm and 25% ppm in experiment. It can be seen that the small visible flocs are close to a void between large flocs filled by liquid where viscosity is smaller; hence, they follow the large floc pattern by continuously clinging onto and uniting with large flocs. In Figure 8f, the group of flocs is visible except for on the basic floor with larger grains and precipates covering almost its entire surface.

V. CONCLUSION

By integrating the result of interaction among seven waste in the lean manufacturing of clean water, it was determined that the most influential cause of seven waste is overprocessing with 3.987 significance at the path coefficient to minimize as an input of information at the parameter design of the Taguchi method (Table 2). The optimal mixing process is at a medium concentration PAC of 14% and 15% ppm and a turbidity of 4.8 and 4.9 NTU (close to the health standard, which is 5 NTU). A decrease in turbidity occurs if the coagulant concentration level is raised gradually from a low concentration 5-10 ppm or medium concentration 11-15 level to a high level, where at each level increase of level, there would be a strong attractive force of positive ions towards the negative ions in the colloid. At a low level of coagulant concentration, the attractive force between coagulant and colloid is not so great, but at the medium and high levels, the attractive force of coagulant is strengthened due to coagulant or PAC positive ions. Conversely, the effect of the Brownian motion decreases as the % ppm of coagulant increases since water tends to have translucent color. If the coagulant concentration is increased with the proper rpm and time, then flocs would gravitationally precipitate at the basic plat in the form of waste sediment channeled to the waste processor before being discharged to an environmentally friendly waste treatment facility. Eventually, the result of integrating lean manufacturing and parameter design represents and describes waste from overprocessing used to obtain optimal mixing process = 15% ppm conc. PAC + 15 lt/sec + 15% pump stroke at 14% and 15% ppm to bring the turbidity level below 5 NTU in accordance with health standards.

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