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System Dynamic Modeling for Behaviour Pattern on Process and Operation of Water Treatment Plant

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ABSTRACT

This research assessed behavior pattern on existing process and operation of Water Treatment Plant (WTP) in order to find affecting factors and formulating its performance improvement. In fact, management aspects of WTP at PDAM (Water Supply Enterprise owned by Local Government) needs support on decision making based on cause and effect relation among variables which affecting its process and operation behavior of water treatment. Therefore, this research is expected to initiate and fill the gap on scholarly aspects, especially on water treatment, and at once as a contribution to give alternatives solution for improving the performance of WTP. The object of this research were Babat I WTP Lamongan and Kedunguling WTP Sidoarjo, East Java, Indonesia. Meanwhile, its scope of works was covering at special observation on water turbidity parameter. Modeling of behavior pattern on process and operation of WTP using system dynamic approach by causal lop diagram, stock and flow diagram method. The result of system dynamic modeling of behavior pattern on process and operation at WTP showed a clear description on cause and effect relation among variables which could give influence the performance of WTP.
KEY WORDS: Water Treatment Plant, turbidity parameter, system dynamic modeling, causal loop, stock flow

INTRODUCTION

The main basic of the background of this research is that most of Water Treatment Plant (WTP) that managed by PDAM (Water Supply Enterprise owned by Local Government) has not been operated with the optimal process and operation. Therefore, a research which particularly analyze about the behavior of WTP process and operation related to all influencing factors, and optimization on each treatment unit is necessary. Considering that water treatment process itself has patterned series which the effluent from the first stage becomes the influent on the next stage, thus the integrated optimization is required on entire stages in order to produce the best final effluent.

The goal of this research is to improve the efficiency and effectivity of the process production of drinking water so that will provide a significant contribution to the PDAM management especially in production efficiency. The objects of this research are Babat I WTP at PDAM Lamongan, and Kedunguling WTP at PDAM Sidoarjo in Indonesia. The similarities of both WTP on their conventional treatment system along with the differences on both source of raw water and the typical of plant construction were the reason to choose both of those WTP.

This research conducted optimization of the coagulant dosage in coagulation-flocculation process, and duration of backwashing in filtration units as well. As reference, the result of optimization is water quality standard that also provide feedback on the process and operation performance. For the planning, operation and maintenance factors of WTP are based on relevant Indonesian National Standards (SNI). It is also focused on to analysing the behavior pattern of process and operation of WTP in order to obtain a description of affecting factors that the performance enhancement efforts can be formulated. In this case, it is conducted by system dynamic modeling approach.

Raw water is treated using chemical compounds that make small suspended particles stick together and settle out of the water. Based on many articles which discuss about optimization of water treatment plant, their researches have given us the basic scientific information. The previous object research on water sector, particularly in WTP as follow. Rietveld *et al*. [1] reported that in water treatment, it is particular importance to determine the water quality indicators for good operation. In the reported research the objective was to focus on the target water quality parameters and direct indicators for the performance. In the

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operational practice of drinking water treatment, however, derived indicators are often used. Banff *et al.* [2] defined optimization of conventional water treatment plant means to attain the most efficient or effective use of the water treatment plant which consist of some principles, there are; achievement of consistently high quality finished water on a continuous basis; and the importance to focus on overall plant performance, instead of focusing too much on individual processes. Approaches to conventional WTP optimization should be mostly common sense, be organized and get into the facts first. The paper which reported by Worm *et al*.[3] Environmental decision-support systems (EDSSs) were used as a blueprint for this simulator because the integration of different models is common in EDSSs. Models are an essential part of the simulators since they represent the behavior of the treatment plant's processes. Four models run simultaneously in the simulator, i.e: water quality model, hydraulic model, process control model and a field object model. Especially another researchs on water sector which apply system dynamic approach i.e.: development for suistainable financial policy on water supply and waste water management done by Rehan *et.al.* [4].

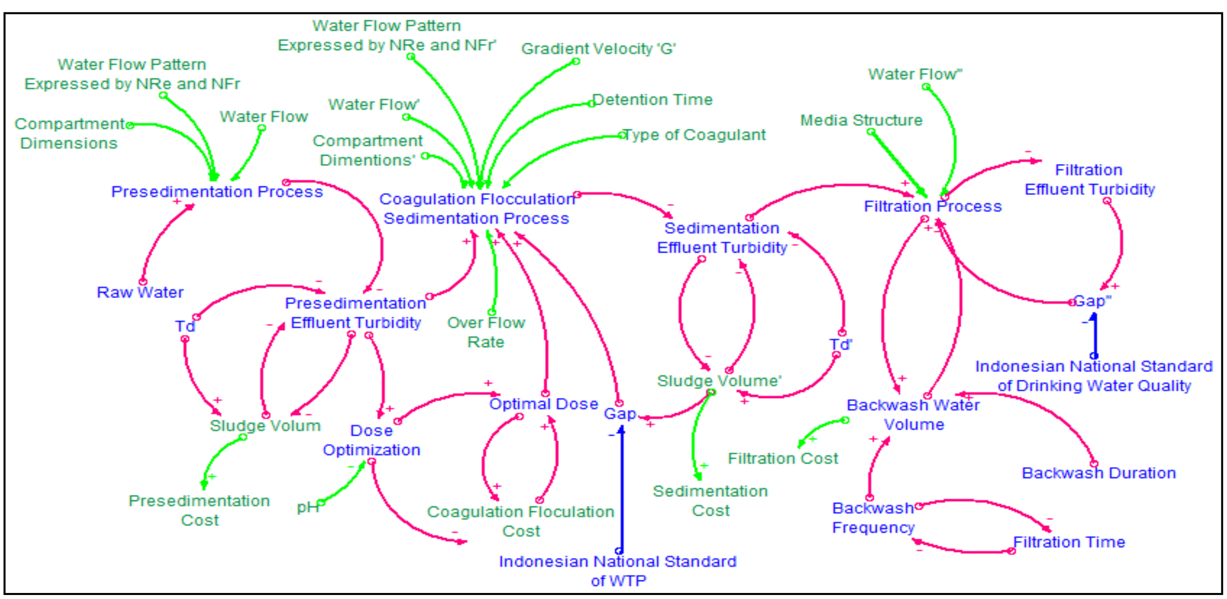
Acording to the previous research , the application of system dynamic modeling approach particularly in WTP were very limited and partially. Thereby, this research aims to fills a gap in the scientific aspects particularly in modeling aprroach of WTP, and also become one of the initiation and contributive alternative solution for improving the WTP process and operation performance. This paper presents an analysis and discussion of behaviour pattern on process and operation of WTP. A proposed method or system dynamic model approach was developed to make more clear of description and to increase accuracy of research result.

METHODS

Model conceptualization of WTP process and operation is represented in causal relationship of each treatment unit, related factors, and association among treatment unit which expected to ease the problem analysis for finding functions the solutireferon to optimize the performance on each unit as well as the overall WTP. Refer on Kirkwood [5], to better understand the *system structure* which cause the patterns of behaviour is illustrated by the diagram. This diagram present relationships that are difficult to verbally describe because normal language present interrelations in linier cause-and-effect chains, while the diagram shows that the actual system there are circular chains of cause-and-effect.

In the other hand, about *system thinking* Barry.R [6] defined that the process of thinking, communicating and learning contitute an interpendent system, or at least have the potential as such. The first step toward realizing the potential synergies is to clearly visualize how each process works in relation to the other. In this research, causal relationship on entire system of behavior pattern of operation and process are represented in Causal Loop Diagram (CLD) form

Figure 1. Causal loop Diagram of WTP



Causal Loop Diagram of WTP

Each unit or stage treatment in WTP has an input (effluent) and output (effluent) of water which is influenced by process and operation factors. This problem formulation is focused on system dynamic modeling include the related matters that represent:

a. Interrelation among sub-models that describes about the process and operation of presedimentation, coagulation–flocculation- sedimentation, and filtration unit.
b. Iterrelation among variables of each sub-model, in particularly the affecting factor of each unit process and operation.
c. Simulation model of optimization result on coagulant dosage and duration of backwash

The causal relationship of entire process and operation behavior pattern as scope of research are shown in Causal Loop Diagram (CLD). It is also shows the causal relationship among the variables which is indicated by arrows. The positive (+) arrow shows the proportional relationship where adding value to this variable can make an added value to affected variable. There is also a variable that serves as examiner gap achievement for determining next loop direction, as known as Indonesian National Standard (SNI) and water quality standard. The Causal Loop Diagram shown in Figure 1.

The description of the red, blue, and green arrows in CLD are: red arrows describe the variable that the data were included in the running simulation of system dynamic modeling, blue arrows describe the standard reference variable, green arrows describe the variable that the data were not included in the running simulation of system dynamic modeling, but still used as analysis supporter.

The process and operation of presedimentation are influenced by flowrate and quality of raw water (influent), compartmen dimension of presedimentation tank, and water flow pattern which are expressed by Reynold's Number (NRe) and Froude's Number (NFr). Those numbers will affect the laminar flow of the water and provide the deposition capabilities of discrete particles that caused the turbidity. On the other hand, the presedimentation process will also affect the settling time of particles, sludge volume, and efluent's turbidity level. The faster particles get settled, the settling time will be smaller, the sludge volume will be higher thus the turbidity level of the effluent will be lower. This causal relationship can be seen by the (+) and (-) notation on the arrows.The effluent from presedimentation process will become the influent of coagulation-flocculation unit.

The CLD of coagulation-flocculation and sedimentation process and operation which it influenced by flowrate and quality of raw water (influent), compartmen dimension of presedimentation tank, and water flow pattern which are expressed by Reynold's Number (NRe) and Froude's Number (NFr). Those numbers will affect the laminar flow of the water and provide the deposition capabilities of discrete particles that caused the turbidity. Coagulation-flocculation and sedimentation process are influenced by the optimization result of coagulant dose and influent's tubidity level. While the operation are influenced by: compartment dimension, flowrate, gradient velocity (G) (in coagulation process) and flocculation process. The operation of sedimentation process is influenced by over flow rate (OFR), Nre, and NFr. Those numbers refer to Indonesian Water Treatment Plant Plan Standard (SNI 6774:2008).The result of sedimentation operation and process (effluent) also influenced by flocs settling time. The effluent's turbidity is mutually influence with sludge volume. This effluent would become influent of filtration unit.

The process and operation of filter is affected by media structure, quality and flowrate of influent, filter backwashing, especially which related to filter-running time. Backwashing process itself is affected by duration and frequency which will affect to the volume of water use. Performance of operation and process on filter will affect the effluent's turbidity which adjusted to Water Quality Standard of Ministry of Health of Indonesia(No.492/MENKES/PER /IV/2010).

Variable Indentification

Variable identification is necessary as introduction of system that will be modelled. In this research, variable identification was used to variables inventory that will be used in modelling. Variables that used in system dynamic models formulation of WTP patterns and behavioral processes and operations among others, as follows: As *Sub modul* are: process and operation of presedimentation unit, process and operation of coagulation-flocculation-sedimentation unit, process and operation of filtration unit. As *Stocks* are: turbidity's content of influent, turbidity's content of effluent on each WTP unit (Presedimentation, coagulation-floccluation-sedimentation, and filtration). As *Flows* are all process and operation of each WTP unit. As *Converters* are all variable that affected to operation & process of water treatment plant

According to system identification of this research as shownin Figure 1 where CLD of WTP process and operation is a conceptual model, thus the causal relationship among variables were formulated in dynamic system model structure which covers: stock as counted variables, flows as determinant variables, and converters as data input that compiled into one flow system.

In terms of turbidity parameter in WTP process and operation, system dynamic modelling formulation will be divided into 3 sub models, there are: Presedimentation Submodel, Cogulation-flocculation-sedimentation submodel, and Filtration submodel.

Stock and Flow Simulation Model on WTP

According to dynamic system model formulation of each modul, by using system dynamicsoftware application the simulation models can be described as Figure 2 below:

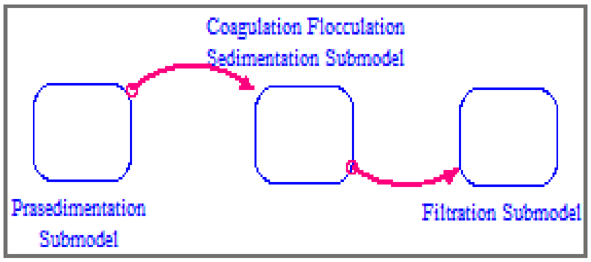


Figure 2. Main Model of WTP System

This figure can be described that presedimentasion submodel, coagultion-flocculation-sedimentation submodel, and filtration submodel have a series connection, in this case, the input and output of each submodel will give a sequentially impact. Input of presedimentation submodel in real system is raw water intake, while the output is effluent which become the input of coagulation-flocculation-sedimentation submodel. As well as the output of coagulation-flocculation-sedimentation submodel would become input of filtration submodel. The complete of stock and flow diagram on WTP process and operation model will be shown in Figure 3, with the description as follow.

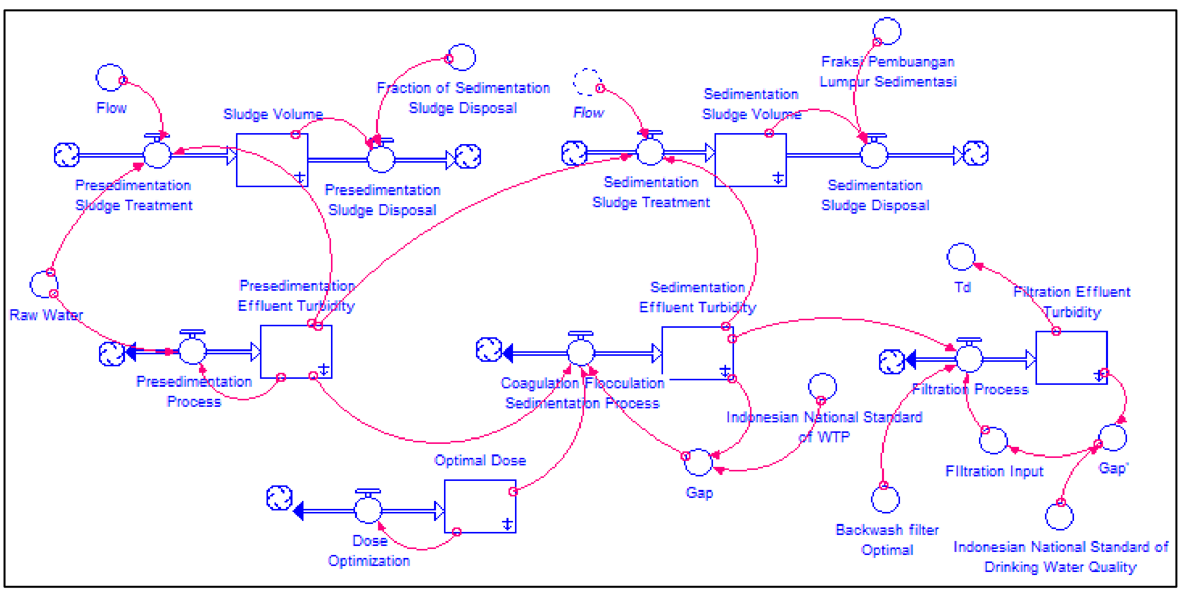


Figure 3. Stock and Flow Diagram of WTP

RESULTS AND DISCUSSION

Presedimentation Submodel

Presedimentation submodel aims to recognize the settling process of suspended matters or discrete particles which can be settled by their own weight. In this process, the turbidity removal percentage is influenced by several factors, such as water flowrate and sedimentation tank dimension which represented by the value of *Over Flow Rate*

(OFR) and Reynold's Number (Nr). Those numbers will determine the water flow pattern that will affect to sludge settling velocity (td) in sedimentation unit.

In order to get the value of removal percentage in simulation model variable of presedimentation sludge volume and variable of sedimentation's effluent turbidity are needed as *stock* variable. Sludge settling, sludge disposal, presedimentation process and operation and output are as *flow* variable. Presedimentation's effluent turbidity, sludge settling time (td) e, sedimentation's effluent (high or low turbidity) are as *converter* variable.

In presedimentation submodel, simulation process were started from particle settlement that affect turbidity in raw water. The particle settlement will result sludge volume which then accumulated at the bottom of the tank to be disposed periodically. The sludge settling process also related to turbidity level of effluent from presedimentation process. The turbidity level of effluent is used to determine the the efficiency percentage of turbidity removal on prsedimentation's influen. The turbidity level of effluent which was used as converter variable will be used as the input of simulation process on coagulation-flocculation-sedimentation submodel.

Coagulation–Flocculation–Sedimentation Submodel

Coagulation–flocculation-sedimentation submodel aims to recognize the behavior pattern of coagulation-flocculation-sedimentation process. In this stage, turbidity removal percentage is affected by several factors, such as optimum coagulant dosage, prsedimentation's effluent turbidity, and sludge settling time in sedimentation unit. Optimum dose of coagulant was resulted from other analysis through optimization process of coagulant dose which generates the lowest effluent's turbidity. Franceschi *et al*. [6] reported that in some cases in most water treatment plants, the minimal coagulant concentration and the residual turbidity of the water are determined by the Jar-Test technique, and a systematic study of the influence of raw water quality and operating conditions on the effectiveness of the coagulation-flocculation process using aluminium sulphate is presented.

In order to get removal percentage of simulation model sedimentation's sludge volume variable and sedimentation's effluent turbidity are needed as *stock* variable. Sludge settling, sludge disposal, coagulation – flocculation - sedimentation process and operation and output are as *flow* variable. *Converter* variables are sedimentation's effluent turbidity variable, sludge settling time (td), optimum coagulant dose, sedimentation's effluent variable (whether in high or low turbidity). Simulation process of this submodel were started by using the converter variable of presedimentation's effluent turbidity as the input. In this submodel, there was a separately simulation process which is the coagulant dose optimixation process with some dosage varieties (45 ppm, 50 ppm, 55 ppm, 60 ppm, 65 ppm, and 70 ppm) for Babat 1 WTP and (50 ppm, 55 ppm, 60 ppm, 65 ppm, 75 ppm and 80 ppm) for Kedunguling WTP.

The sedimentation process was started by using flocs settling with those dosage variation and settling velocity (td) that will generates sludge volume. The sedimentation process can be correlated to the value of sedimentation's effluent turbidity which affected by coagulant dose optimization in coagulation process. Sedimentation's effluent turbidity was used as *stock* variable which then be used as input in filtration submodel.

Filtration Submodel

Filtration submodel aims to recognize the behavior of filtration operation and process. Reffer on Huisman [7] , duration of backwash for fiter media depends on influent turbidity, filter run and maximum headloss provide. Headloss may be defined by observing the water level above the media of filter. In this stage, removal percentage are affected by filter's influent (sedimentation's effluent), filter operation time (which related to backwash frequency), and duration of backwash. The optimum backwash duration is resulted from backwash optimization analysis which generates the lowest effluent turbidity. Variation of backwash duration (3 mins, 5 mins, and 7 mins) are used as *converter* variable. In order to get the removal percentage in simulation model, filter's effluent turbidity variable is needed as *stock* variable while filtration process variable is as *flow* variable.

Simulation process in filtration submodel was started by using *stock* variable of sedimentation's effluent turbidity as filter's input or influent. The sedimentation's efluent turbidity will affect optimization process of backwash duration (3mins, 5mins, and 7mins). Backwash optimization process is related to process simulation that generates effluent turbidity and turbidity removal percentage which then be modeled as *stock*. The simulation of filter reactor was conducted by considering influent as *converter*. Filter's effluent is compare to water quality standard and if it meets, then the gap will be zero (0), but when it doesn't, then reprocess and follow up will be necessary.

Figure 2 shows the series relationship between presedimentation submodel, coagulation-flocculation-sedimentation submodel, and filtration submodel. It is described in stock and flow diagram (SFD) as simulation model of WTP process and operation (Fig 3) which represents connection of input and output of each submodel. Generally, the output of presedimentation submodel will become the input of coagulation-flocculation-sedimentation submodel and so as for the next stage.It is relevance to the real system of WTP where the input and output of each unit are gradually related to each other.

Submodel simulation of presedimentation process shows the influent correlation on turbidity variety as the input (*converter*) with settling time variable *(converter)*, the sludge settlement as process *(flow)*, and the effluent's turbidity *(converter)* as output. The output of presedimentation will sequentially become input in cogulation-flocculation-sedimentation submodel process simulation.

Cogulation – flocculation - sedimentation submodel process simulation represents the simulation series which covers; simulation of coagulant dose optimization in several different influent turbidity level *(converter)*, simulation of coagulation-flocculation-sedimentation in optimum condition of coagulant as process *(flow)*, and the sedimentation effluent turbidity as result which considered as output *(stock)*. The output of sedimentation will sequentially become the influent in simulation of filtration submodel.

Simulation of filtration submodel represents the simulation of filter backwashing time optimization in several different filter's influent turbidity level *(converter)* before and after backwashing as the input. The result of filtration simulation process in optimum backwash time was efluent filter *(stock)* which was considered as output. The quality of filter's effluent turbidity refers to Water Quality Standard.

CONCLUSION

There are conclusions of simulation model on behavior patern of process and operation on WTP: Causal Loop Diagram (CLD) and running model simulation result by system dynamic aprroach on all process and operation of WTP and also on each unit as sub model shows the relationship of cause and effect (positive and negative) inter variables, especially on related with turbidity removal effectiveness. Even some of variables on CLD related with operation of WTP (G,td, Nre,NFr,OFR) were not include on simulation process by system dynamic modeling, but they can also present the patern hidraulic aspect or typical flow of water which have impact on process of treatment. System dynamic modeling on process and operation of WTP that shows the relationship of spesific variables (*flow*, *converter,* and *stock)*, gives the information and consideration for making strategic decision in order to improve its performance.

Whereas in order to make this research more complete and comprehensif that covered all aspect and variable related to improve performance of WTP , there are recomendation for developing the follow up research that shoud be perform. The similar research which completed by all quality parameter of water (phisychal, chemical, and biology); the research by using hydraulic simulation system ; and the research which use optimization method approach include with operation and maintenance cost aspect**.**

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