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EPANET MODEL CALIBRATION OF CLEAN WATER PIPELINES WITH MODIFIED C VALUE PIPE ROUGHNESS HAZEN-WILLIAMS METHOD

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Abstract

The Epanet model in clean water pipelines is intended for time efficiency in calculating hydraulic behaviour. Calibration of the water pipe network is to compare the simulation results of the model to actual field observations and to see that the model that has been made is truly valid and reliable as a tool to determine the hydraulic behaviour of the network system when a change input into the system is given (e.g. the addition of pipelines and number of customer tapping debits). The pipe roughness coefficient (C) is a number that indicates the amount of energy loss due to friction between the flowing fluid and the pipe wall. The increasing age of the pipe will cause the pipe wall roughness to increase, and the energy loss will be even more significant. This research aims to calibrate the pipe network model by adjusting the C value of the actual pipe roughness coefficient according to the installed age.

An initial simulation model was carried out by entering the standard pipe C value in the Hazen Williams energy loss equation in the Epanet link/pipe properties. Then a simulation is carried out by modifying the value of C according to the pipe's service life. For 600 mm steel pipe, change the C value from 150 to 87 (pipe age >30 years), HDPE 315 mm pipe changes in C value from 140 to 100 (pipe age >10 years) and 25-50 mm PVC pipe from 140 to 100 (pipe age >10 years). From the simulation results of the Epanet model-field observations, the average compressive height was obtained for five observation nodes.of 2 tails was performed paired sample test the pressure height value of the model-observation. Before modifying the value of C, the paired mean difference test results showed a significant difference between the simulation results of the model on field observations with a model significance value of 0.004, which means <0.005. There is a considerable difference between the simulations and observations, and the model is considered invalid. However, after modifying the value of C according to the actual age of the pipe, a paired sample test T average value of the compression model-observation was 0.098 > 0.005), which means that there is no significant difference between the simulation and observation. This means that the model made is quite valid. Product moment correlation between the model simulation height - field observations, the value of R = 0.967, the relationship is robust between the two results.

Keywords: model, calibration, roughness, pipe, compression height, valid.

Introduction

Well-controlled water resources are considered an essential part of development, which reduces poverty and equity (Xiang et al., 2021). One of the water distribution problems in urban areas is the availability of water in sufficient quantities. Some combination of factors such as infrastructure renovation, improved design of new water and sanitation systems, and wider implementation of watershed service management will be required to provide clean water to humans (Sun & Caldwell, 2015). The quantity of water can be measured by hydraulic parameters in the form of high pressure in the pipe network system. The compressive height is expected to meet the minimum requirement of 0.5-1 atm (Permen PUPR No. 18 of 2007).

The model is a prototype or imitation of the actual state of nature, although there is no complex model that can represent an actual reality (Yani et al., 2019). Modelling can provide valuable design information, but the results must be interpreted with care and field experience (Kind, 1986). The use of the model is intended for time efficiency in observing the hydraulic behaviour of the piping network system without disturbing the existing network system.

Calibration compares the results of the process/output of measuring instruments used with standard measuring instruments or measuring objects / certified traceability to national and international standards. The purpose of calibration is to determine the traceability of a measuring instrument, the deviation of the measuring instrument, and to ensure that the measuring instrument has been traced to national and international standards (Wicaksono & Susanto, 2015). Techniques for calibrating pipe roughness in water distribution networks are becoming an essential and valuable tool for water authorities (Simpson et al., 2000). In other words, the calibration of pipelines compares the results of the hydraulic parameter measurement (compression height) simulation in the Epanet program with the actual measurement results in the field (at customer faucets).

The Epanet program has several advantages based on previous research. For example, using the Epanet program, the Sedibeng water distribution system in the Republic of South Africa was modelled and populated with actual free chlorine (Walt et al., 2021) data. In another case, the Epanet program also analyzed the irrigation network of the proposed Taq-Taq dam using hydraulic simulation software to study the distribution of pressure, velocity, and head in the pipeline to ensure the operation of the network (Karim & Sahib, 2019). In the Epanet method, several variables are considered: pipe friction factor (Hazen William Coefficient), nodal consumption, a combination of both and pipe diameter (Jamasb et al., 2008; Travis&May, 2007). For this reason, appropriate input is needed so that the model made can approach the actual condition of the existing network, both input properties of physical facilities (pumps, reservoirs of water sources, pipes, valves and others). As well as the input of water usage loads/tapping demand and distribution zones water load.

So that if in the future there will be network development, the model that has been made is indeed valid and reliable as a tool to determine the hydraulic behaviour of the network system when input changes are given to it (Mays, 1999).

Pipe roughness.

The pipe roughness coefficient is a number that indicates the amount of energy loss due to friction between the flowing fluid and the pipe wall. The pipe roughness is estimated using an optimization algorithm that aims to minimize the difference between the measured pressure and flow and their simulated values (Gao, 2017). This roughness coefficient will increase as the pipe ages, which causes the energy loss to be even greater (Sofia et al., 2015). The older the pipe network, the roughness value will increase which causes energy loss to increase (Subekti & Susatyo, 2017). This means that the model needs to be calibrated so that the C value of the pipe roughness corresponds to the actual age of the pipe so that the value of the energy loss that occurs is in accordance with the actual (the model is more valid) (Kustamar, 2008).

The purpose of this research is to calibrate the pipe network model by adjusting the roughness coefficient C value so that the model made is more valid, which includes:

1. Make a simulation of the water distribution network system model owned by Perumda Tirta Moedal Kec. Mijen Semarang City (simulation).
2. Observing the compression height at the customer node.
3. Comparing the compressive height of the model (simulation) to the results of field measurements (observation).
4. Calibrating the simulation model on observations by modifying the C value of the Hazen-Williams pipe.

The scope of research that will be discussed in this study are

1. Modification of the value of C on the pipe node component in the Epanet model and its effect on changes in the compressive height value of the model.
2. Measurement of the actual compressive height value at 5 customer nodes (the position farthest from the reservoir and the position of the largest height difference) at the peak time of water use, namely morning rush hour (05.00-08.00) and afternoon rush hour (17.00-20.00) at Perumda Tirta Moedal Kec. . Mijen Semarang City

Literature Review

One of the variables that affect the satisfaction of drinking water/clean water customers is the pressure received at the customer's faucet. Not only that, water activity plays an important role in all fields of science (Zanoni et al., 1998). For field pressure, measurements can be made using a manometer (Brater&King, 1996; Sekhri et al., 2019). The magnitude of the compressive height can be calculated using the continuity equation (conservation of mass) and the Energy equation (Bernoulli's equation) (Schäfle & Kautz, 2021).two equations are needed in every pipeline network that forms both loopsclosed .branches (Rishel, 2000) And it takes a very long iteration process to complete the calculation (Hollingshead & Roark, 2007). The Epanet model in clean water pipelines is intended for time efficiency in calculating hydraulic behaviour (BPSDM PU, 2018).EPANET is designed to simplify the task of calculating the discharge value and pressure level at a point in the pipeline (Ingeduld et al., 2008; Lijuan et al., 2012).

The Equation of Continuity

The principle of conservation of mass states that mass can neither be created nor destroyed (Suripin, 2018). Liquid in compressible flows continuously in a pipe with a constant or non-constant cross section, then the volume of liquid passing per unit time is the same for all cross sections (Schild, 2018).

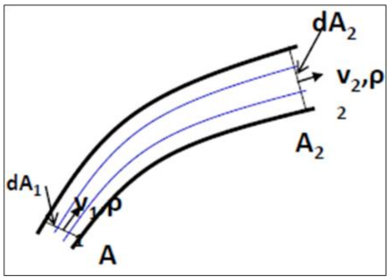


Figure 1 Continuity Equation

Q1 = Q2 ....(1)

A1 . V1 = A2 . V2 ....(2)

The Energy Equation (Bernoulli)

The principle of conservation of energy states that energy can neither be created nor destroyed. This energy conservation principle was developed into the energy equation (Bernoulli) (Qin & Duan, 2017). Bernoulli's equation for the flow of a liquid along a streamline is based on Newton's 2nd law of motion, F = m . a, where the acceleration of an object will be directly proportional to the net force acting on it and inversely proportional to its mass (Smith, 1972). The direction of the acceleration will be the same as the direction of the net force acting on it (Arakeri, 2000). Taking into account the energy loss in the real (viscos) liquid, the energy equation is:

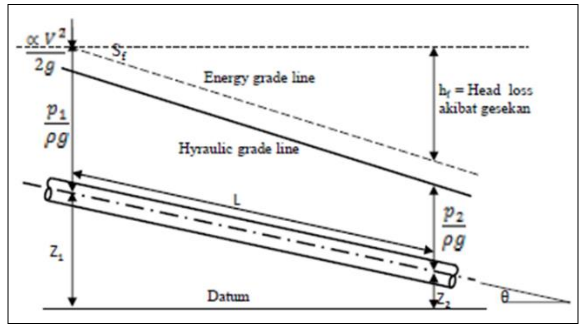


Figure 2. Pressure Line and Energy Line Bernoulli Equation

Energy Loss

Major energy loss is energy loss due to fluid friction (Makawimbang et al., 2017) with the pipe wall which is stated in the equation:

- Hf major Darcy Weisbach = $\frac{\lambda L V^2}{2gD}$................(4)
- Hf major Hazen William = $\frac{10{,}58.L.Q^{1{,}85}}{C^{1{,}85}.D^{4{,}87}}$) ...(5)

Minor energy loss is energy loss due to fluid friction with fittings / connections on pipes (Tuames et al., 2015), turns and valves and other accesories in the network system pipe,

- Hf minor = k . $\frac{V^2}{2g}$ ....(6)

Pipe Roughness Number

The pipe roughness coefficient is a number that indicates the amount of energy loss due to friction between the flowing fluid and the pipe wall (Gindalan, 2010; Nuryani & Santosa, 2020).

Table 1. Roughness C Value (Rossman, 2004)

Material	Hazen William C (unitless)	Darcy Weisbach (feet x 10^{-3})	Manning n (unitless)
Cast Iron	130-140	0,85	0,012-0,015
Concrete or Concrete Lined	120-140	1-10	0,012-0,017
Galvanized Iron	120	0.5	0,015-0,017
Plastic	140-150	0,005	0,011-0,015
Steel	140-150	0,15	0,015-0,017
Vitrified Clay	110		0,013-0,015
Cast Iron or Riveted Steel after some years of use	95-100		
Deterioted Old Pipes PE-PVC	60-100		

For the C value of the Hazen William method which has depreciated due to age, the table of C values can be shown as follows:

Table 2 Hazen-William C value (Mays, 1999)

Pipe Material	Age (years)	Diameter	C
Cast iron	5	>380 mm	120
		>100 mm	118
	10	>300 mm	111
		>100 mm	107
	20	>300 mm	96
		>100 mm	89
	30	>400 mm	87
		>100 mm	75
PVC	Average		140
Asbestos	Average		140

The EPANET Program

The EPANET program is a computer program released by the US Environmental Protection Agency (US EPA) (Rossman, 2004), (Tiruneh et al., 2019). EPANET can simulate hydraulic behavior and water behavior in a drinking water distribution network (S Shihab et al., 2009). A drinking water distribution network consists of pipes, nodes (branches), pumps, water tanks or reservoirs and valves (Susanto et al., 2019).

The steps for modeling the water pipe network in Epanet are as follows:

1. Input pipe table, in the form of pipe number, length, diameter, pipe roughness, upstream and downstream node points.
2. Input point (node) table, in the form of no node, node elevation, demand (demand) on the node, node location coordinates.
3. Input pump characteristics, in the form of head and pump capacity,
4. Input hydraulic option, pattern demand , water usage patterns,
5. Furthermore, a "run analysis" out and the results of the hydraulic calculations in the pipeline network will come out.

Research Methods

1. Primary data collection: network image of reservoir-pump-collector pipe-transmission pipe-distribution pipe

(length, diameter, coordinates, pump characteristic data), water distribution zone, demand pattern (customer water usage pattern),

2. Secondary data collection: measurement of pressure height, flow rate, position coordinates at 5 customer nodes, observations at the farthest position from the reservoir and the highest customer node elevation position (biggest elevation difference to reservoir)
3. Modeling network systems in Epanet and running programs/simulations and displaying hydraulic calculation results
4. Calibrate the results of Epanet's hydraulic calculations against the results of observations at 5 customer nodes.
5. Difference test 2 paired average (paired sample test)

Results And Discussion

Epanet Program Water Distribution Network Simulation

Evaluation of the pipeline network in the field is carried out using Epanet software, a pipe network model that is made to imitate the existing conditions installed in the field.

From the network performance evaluation, the hydraulic calculation results in the form of high pressure, flow velocity, head loss and others will be compared to the results of field measurements (5 customer nodes).

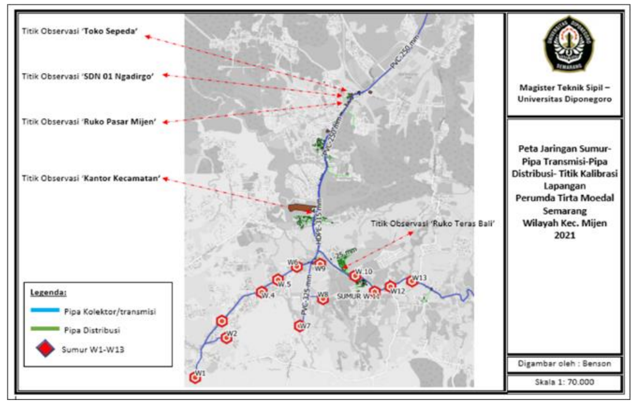


Figure 3. Plot of the Distribution Pump-Pipe Network in Kec. Mijen Semarang City

Next set the 'system default' network characteristics in the form of determining curve rating pump head to discharge) according to the installed pump specifications, water usage patterns/fluctuations (pattern), Hydraulic option (hydraulic calculation method used), and option time/old model will be tested later.

The pattern used is the actual water usage/consumption pattern of customers in the Kec. Mijen is recorded by the company, where the average hourly usage is assumed to be a constant 1, and the fluctuation of hourly usage is divided by the average hourly usage so that the percentage of hourly usage is obtained.

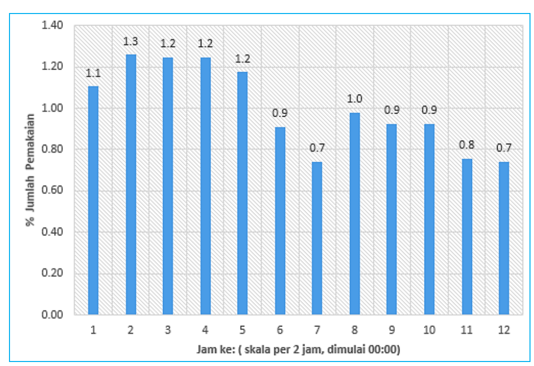


Figure 4a. Customer's 24-hour water usage pattern in Kec. Mijen

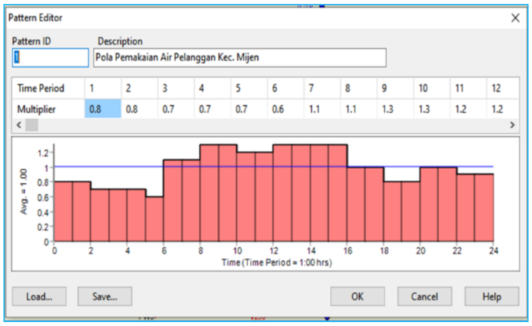
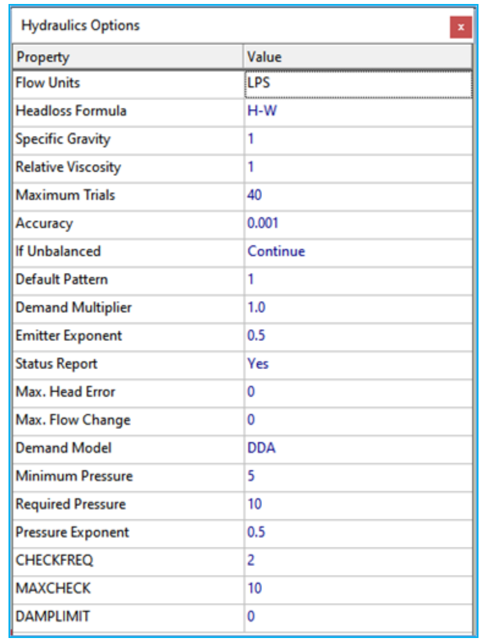


Figure 4b. Customer's 24-hour water usage pattern in Kec. Mijen

In 'hydraulic options', flow units are selected using LPS (liters per second/ liters per second).equation headloss used to calculate the major energy loss in the pipe (head loss) was chosen using the Hazen-Williams equation because this equation does not need to take into account the viscosity due to extreme temperature changes, in other words it is suitable for clean water distribution networks. Meanwhile, if you use the Darcy Weisbach formula, it will take into account the Reynolds number (laminar/turbulent flow type) and temperature/viscosity which is more complex, more suitable for raw water.


Hydraulics Options

Property	Value
Flow Units	LPS
Headloss Formula	H-W
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	1.0
Emitter Exponent	0.5
Status Report	Yes
Max. Head Error	0
Max. Flow Change	0
Demand Model	DDA
Minimum Pressure	5
Required Pressure	10
Pressure Exponent	0.5
CHECKFREQ	2
MAXCHECK	10
DAMPLIMIT	0

Figure 5. Hydraulic Options in Epanet

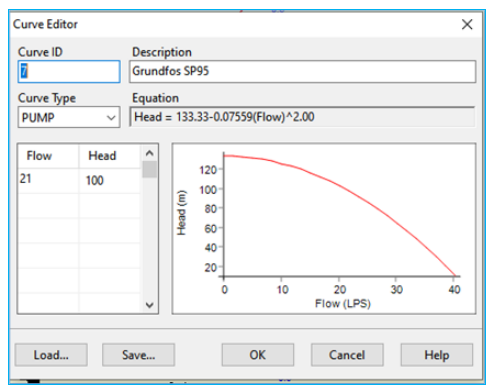


Figure 6. Pump Curve Editor in Epanet

Next, draw a pipeline starting from entering the actual coordinate values of the field into the Epanet model as node points, connecting between nodes with pipes/pumps/valev, entering reservoir/wells water sources, so that all become a complete network, starting from the reservoir/ borehole W1-W9, pumps 1-9, node-junction, transmission-collector pipes (Ø600 mm and 315 mm), primary distribution pipes Ø 250 mm and pipelines secondary distribution/reticulation 25-50 mm to customer faucets. The C value in the initial model uses the standard C value according to the Hazen William equation (table 1).

Pipe PipaTokoSepeda

Property	Value
*Pipe ID	PipaTokoSepeda
*Start Node	42
*End Node	TokoSepeda
Description	
Tag	
*Length	191.93
*Diameter	50
*Roughness	140

Figure 7. Bicycle Shop Pipe Input Default C Value

Next, after the network description is complete, it is continued to fill in the properties of both nodes/pipes/junctions/reservoirs/poma with the actual characteristics of the field.

At the node/junction, fill in the amount of demand tapping/ required water intake (lps) obtained from the pattern of water use in the Kec. Mijen. For the pipe/link/ component, the data entered is pipe dimensions and pipe roughness coefficient. For the reservoir node, input the total head /energy height obtained from the dynamic water level elevation or water elevation in the borehole, and for the pump/pump curve value (discharge-head) and entered customer water usage patterns are

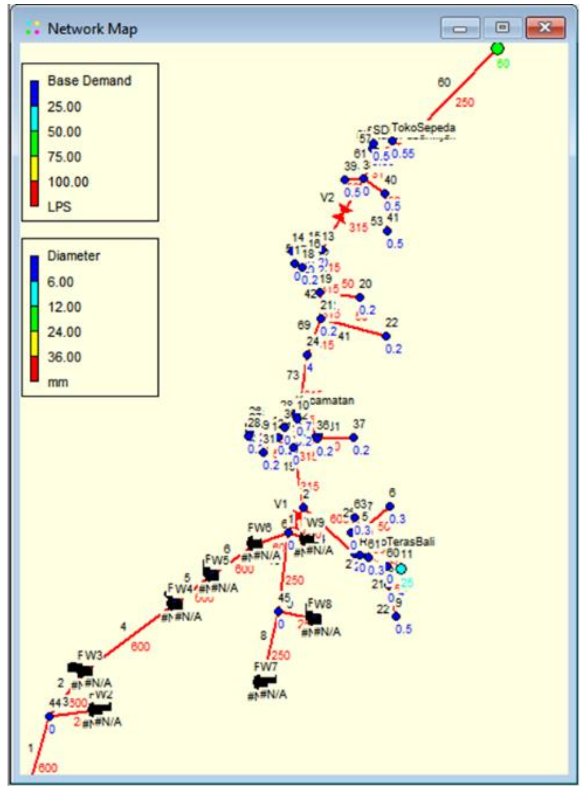


Figure 8. Pump-Pipe Network Model in Kec. Mijen on Epanet

Simulation-Observation Results of Standard Pipe C Value

The Epanet program output displays hydraulic calculations that occur at the Node/junction/point as well as on the pipe/link. At the node, the hydraulic calculation results will appear in the form of: head , total energy height (m), high pressure (m), elevation (m), and water demand/demand (lps). While on the pipe/link shown: flow velocity (m/s), discharge (lps), energy loss/head loss (m/km).

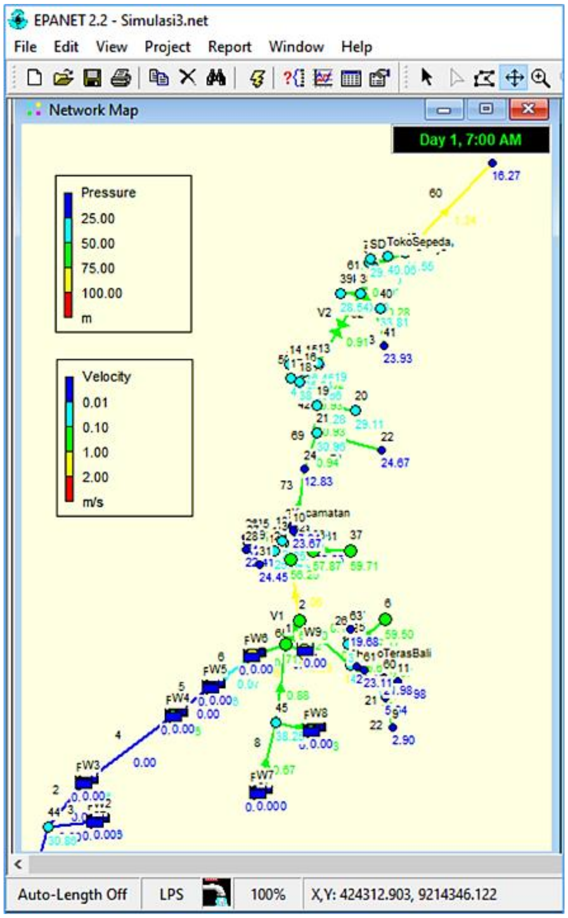


Figure 9. Epanet Run Analysis Results

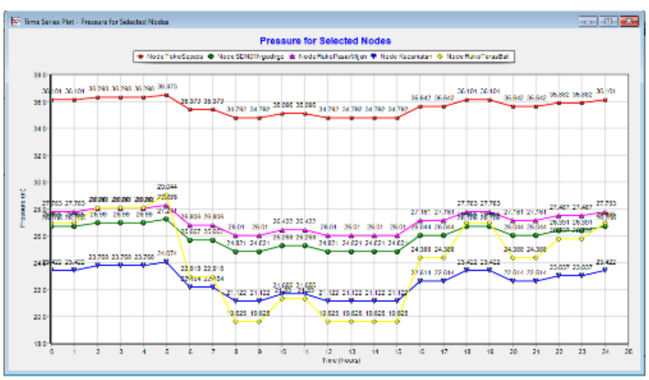


Figure 10. Simulation of high pressure Epanet at 5 customer nodes for 24 hours with a standard C value

In Figure 10, it can be seen that the simulation results of a high pressure Epanet model at 5 customer nodes for 24 hours. The average compressive height (m) of each customer node, both the results of the Epanet simulation and the results of field measurements are shown in the table below.

Table 3. Results of Average Compression Height (m) in 5 Simulation Nodes Standard C Value – Observation

Measurement Node	Simulation	Observation
Toko Sepeda Abo	35.61	31.00
SDN01 Ngadirgo	26.08	19.75
Ruko Pasar Mijen	26.56	20.00
Kantor Kecamatan	22.75	13.25
Ruko Teras Bali	24.55	12.75

.paired sample T test was performed on the above-simulation-observation compression height, using the paired t-average difference test. This test is used to determine whether there is a difference from the average of 2 paired samples or not (Ismiyati, 2011). The t test was chosen because the sample was <30 (sample 5 nodes), and the data was paired (uniform) because the data came from the same node, but there were 2 data, namely simulation - observation. Previously, we first determined the hypothesis for the paired T-test (Paired Sample t-Test),

1. Ho : there is a significant difference between the simulation pressure and the observation, if the significance value (2 tailed) < 0.05.
2. H1 : there is no significant difference between the observation-simulation

pressure, if the significance value (2 tailed) > 0.05.

Then the results of the paired sample T-test are obtained as follows:

Table 4. Paired sample test The value of C Default model

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Observasi - Simulasi	-7.76	2.86167	1.27978	-11.3132	-4.20677	-6.06	4	0.004

The significance value of the model (coefficient of pipe roughness using the default C value) for observations is 0.004 ... meaning < from 0.005, it can be said that the two results of the simulation vs. observation mean compression height have a significant difference. In other words, the Epanet model built using standard C values is not valid enough.

Simulation Results-Observation of Modified C Value

For this reason, Hazen William's C roughness coefficient is modified according to the age of the pipe (refer to table 2.1-2.2).

Table 5. C Value Modified Pipe Age (adjusting to table 1)

No	Type, Size and Installation year of Pipe	C Initial Model	C Modified
1	Steel pipa Transmisi 600 mm – 1982	150	87
2	HDPE Pipa Distribusi primer 315 mm – Year 2008	140	100
3	PVC Distribusi Sekunder-Retikulasi 50 mm – Year 2008	140	100

Then input the modified C value for each pipe property in the network system according to the type and age of the pipe.

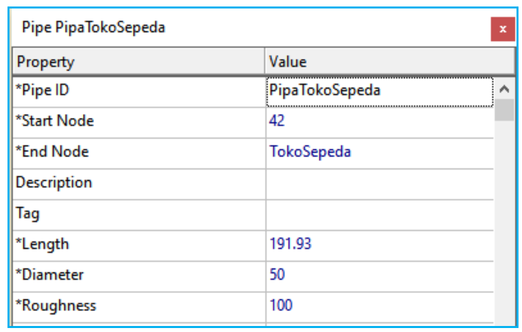


Figure 11. Example of Modified C Value Input in PVC Pipe model 50 mm

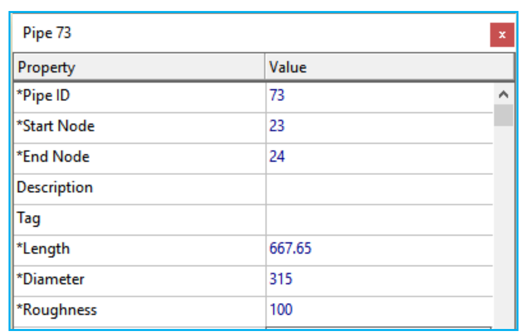


Figure 12. Example of Modified C Value Input in PVC Pipe model 315 mm

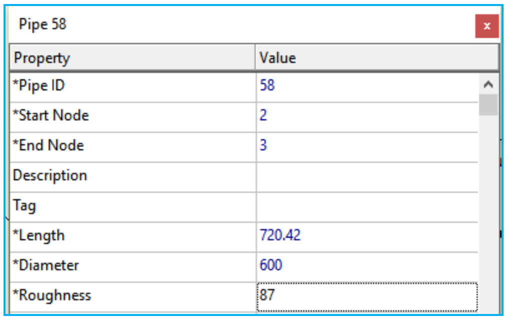


Figure 13. Example of Modified C Value Input in the Steel Pipe model 600 mm

Then obtained a graph of the simulation height for 24 hours at 5 customer nodes,

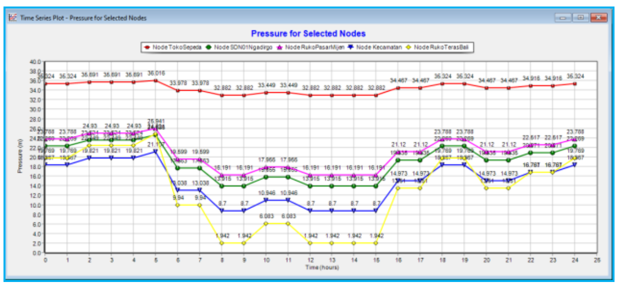


Figure 14. Graphics of Simulation High press 24 hours Modified C Value

From the simulation results of the Epanet program and field observations, it can be concluded that at all nodes, the highest pressure level occurs at 05.00, which is the quiet hour for water usage, and the lowest pressure level is at 08.00-15.00 during peak water usage (peak water usage). Which means that the greater the use of water/ tapping demand , the smaller the value of the high pressure. Vice versa, the smaller the demand for water use, the greater the pressure that occurs.

The average compressive height (m) of each customer node, both the Epanet simulation results and the results of field measurements with the Hazen-William modified C value, is shown in table 6 below.

Table 6. High Press Simulation-Observation with Modified C Value of 5 Customer Nodes

	Rerata Tinggi Tekan (meter) Simulasi vs Observasi									
	Toko Sepeda		SDN 01		Pasar Mijen		Kantor Kecamatan		Ruko Teras Bali	
Jam :	Simulasi	Observasi	Simulasi	Observasi	Simulasi	Observasi	Simulasi	Observasi	Simulasi	Observasi
5	36.02	30.86	24.00	20.00	25.50	20.00	21.00	14.86	25.00	13.71
6	33.90	32.29	17.50	19.14	19.64	19.67	13.00	14.57	15.00	13.43
7	33.90	32.00	17.50	18.29	19.60	18.67	13.00	9.71	15.00	10.29
8	32.90	30.00	13.80	19.43	16.20	19.33	9.00	10.29	9.50	9.71
17	34.40	31.14	19.30	19.71	21.00	19.00	14.90	10.86	17.00	10.57
18	35.30	30.86	22.20	19.43	23.00	19.33	18.30	12.00	22.00	10.29
19	35.30	31.43	22.20	19.71	23.00	20.00	18.30	14.86	22.00	12.86
20	34.40	30.57	19.30	19.71	20.00	19.33	14.90	15.71	17.00	14.00

Furthermore, the average value of compression height at 5 customer nodes is displayed, both model simulation - actual customer observation,

Table 7. Results of average compression height (m) in 5 Simulation Nodes, Modified C value – Observation

Measurement Node	**Simulation**	**Observation**
Toko Sepeda Abo	35	31.5
SDN01 Ngadirgo	19.64	19.75
Ruko Pasar Mijen	21.39	20
Kantor Kecamatan	15.32	11.75
Ruko Teras Bali	18.25	13.25

The results of the simulation height vs. observational compression height, then a validation test is carried out, namely in the form of a product moment to see how big the relationship between the two compression height results is. Correlation analysis is used to analyze the relationship between 2 or more variables that are quantitative. The calibration feature is found in Epanet by inputting the compression height data in the field which will be compared to the simulated compression height in the program.

From the calibration results (see Figure 15) it is obtained that there is a strong relationship between the high value of the simulation vs. observation pressure with a value of R = 0.967. From these results, it can be stated that the simulation results of the valid model can be accepted.

Calibration Report - Pressure

Statistics | Correlation Plot | Mean Comparisons

Calibration Statistics for Pressure

Location	Num Obs	Observed Mean	Computed Mean	Mean Error	RMS Error
TokoSepeda	8	31.50	34.55	3.340	4.033
SDN01Ngadirgo	8	19.75	19.64	2.408	3.067
RukoPasarMijen	8	20.00	21.39	2.546	3.188
Kecamatan	8	11.75	15.32	3.895	4.819
RukoTerasBali	8	13.25	18.25	5.789	6.975
Network	40	19.25	21.83	3.596	4.642

Correlation Between Means: 0.967

Figure 15. Model-Observation Calibration at Epanet

Next, paired sample test (T) (Herlina, 2019) differs from the above simulation-observation pressure heights, to see if there is a significant difference between the two results. with the following results:

Table 8. Paired Sample test Value C Modified Model

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	observasi - Simulasi	-2.1	2.18375	0.977	-4.81	0.61148	-2.15	4	0.098

The model significance value (coefficient of pipe roughness using a modified C value) for observations is 0.098...meaning > from 0.005, it can be said that the two results of the simulation vs. observation mean compression height do not have a significant difference. In other words, the Epanet model made by modifying the pipe C number according to the age of the pipe is in accordance with the existing field conditions / is valid.

Conclusion

1. Based on the results of the compressive height (m) of the model simulation on field observations, it was found that the C value factor determines the amount of energy loss and the compressive height. By using the Hazen-Williams equation, the smaller the value of C (the longer the age of the installed pipe), the greater the energy loss/head loss that occurs.
2. The results of the model calibration using the modified C value on the actual field observations are valid with a significance number of 0.098 (meaning > 0.05) or > 5% significance and the correlation value of R = 0.967, a very strong relationship.
3. The highest compressive height (m) is reached at 05.00 during the low hour of water usage, the lowest pressure level occurs at 08.00 at the peak hour of water usage.

Suggestion

For further research, it is possible to measure the value of C on pipes of various sizes and other materials.

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