

SIMULATION MODEL DEVELOPMENT FOR FIRE WATER PIPING NETWORK WITH NEWTON-RAPHSON ITERATION

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Abstract

The oil and gas industry is an industry that possesses various risks. The most significant risk in this sector is fire. To support the oil and gas production activities, it is necessary to install permanent and non-permanent fire extinguishers to prevent and deal with fire accidents. The firewater network system has a role in supplying flow rates with a certain pressure to protect the production process in a fire. The flow rate and pressure must be able to preserve the process area. Therefore the performance of firewater network system must be monitored. Over time, the performance degradation of the firewater network system is unavoidable. This decrease is due to scaling or leak minor at pipe and the decreasing performance of the diesel fire pump.

This research aims to create a model of simulation fire water network system using newton-raphson iteration. The simulation model that is formed will be used to vary the flow rate against pressure. Based on iteration show the flow rate at platform 4 is 198.9 m³/h. The discharge variation is carried out to see the pressure on platform 4, the variation of the discharge of 2,000 m³/h gives a pressure of 150.45 psig, the variation of the discharge of 1,500 m³/h gives a pressure of 130.85 psig, and the variation of the discharge of 500 m³/h gives a pressure of 24.26 psig. The results of the discharge variation are used to see the performance of the fire water network system. Performance with a discharge of 2,000 m³/h decreased by 9.74%, and performance with a discharge of 1,000 m³/h decreased by 8.81%.

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1. Introduction

The firewater network system consists of a series of piping, fire canons, and diesel fire pump to prevent or deal with fire accidents. The firewater network system has a role in supplying flow rates with a certain pressure to protect the production process in a fire. The pressure distributed must be able to protect the entire production process. The performance of firewater network system must be monitored. Over time, the performance degradation of the firewater network system is unavoidable. This decrease is due to scaling or leak minor at pipe and the decreasing diesel fire pump performance.

The presence of hydrocarbon or hazardous gas release cannot be avoided. In oil and gas production activities, installing permanent and non-permanent fire extinguishers is necessary to prevent and deal with fire accidents. These facilities are crucial and need attention to protect the company's assets for the effective operation of the oil and gas production. There are three-term levels in fire hazards (Kurniawan, 2010). A Low-level fire hazard is a type of fire with low occupancy and flammability, which has intense fire spread. A moderate-level fire hazard is a type of fire that has a moderate amount of occupancy and flammability. In addition, a high-level fire hazard is a type of fire with a very high number of occupancy and flammability, which means that the spread of fire is very high and fast.

A Company engaged in oil and gas is classified as a high-level fire because its production process contains high-pressure explosive gases. Newton – Raphson can be used as a method to analyze the complex piping network. Newton – Raphson method can perform a simulation with more variables directly and more complex data (Stoecker, 1989). So can be used to see the performance of firewater network system with variation of flowrate.

Fernando (2020) conducted a gas turbine performance analysis based on the Newton-Raphson iteration method. Based on the simulation results, in 2017, it produced a net power of 17.52 MW, and in 2018, it produced a net power of 19.86 MW, and later in 2019, it was 20.58 MW. The simulation data compares with the average annual net power generated, namely in 2017 of 18.25 MW, in 2018 of 19.05 MW, and in 2019 of 21.55 MW, which has a minimal difference of around 4%. From the net power data, the thermal efficiency produced in 2017 was 22.58%, in 2018, it was 31.01%, and in 2019 it was 23.15%.

Waluyo and Laksana (2012) created a simulation model of the gas pipeline network using the Newton-Raphson method in a case study of the Pertamina Gas pipeline design for the Semarang-Gresik line. The simulation was carried out by entering arbitrary values and would then reach convergence quickly (less than ten iterations). In the simulation results with variations in the pipe size, the effect of pipe size was not substantial on the pressure changes, but the larger pipe size resulted in a significant increase in flow rate.

Simulations with variations of the compressor location were carried out at 50 KM intervals; the simulation results showed that the area of the compressor that was farther away from the ORF will result in an increase in the flow rate at Tambak Lorok PLTGU and a decrease in the flow rate at the Gresik PLTGU. After the simulation was accomplished, the optimal location of the compressor station was obtained at a distance of 130 Km from the ORF (Onshore Receiving Facility). This reveals that the simulation model can be used for gas pipeline network optimization. This simulation model can accommodate major and minor losses in piping.

Khakim (2015) research proposed a modified Newton-Raphson method as a simulation development for a three-phase active distribution system. The modified Newton-Raphson method is formed by changing the linear equation of power into a linear current equation to produce a convergent power flow value in a radial distribution system. The determination of DG location and the injected capacitor bank in the system is calculated through the loss of sensitivity factor. The reduction in power loss in the system reaches 50.01% from the initial state.

2. Methodology

This study conducted in a field owned by a private gas company located in Kutai Kartanegara, East Kalimantan, Indonesia. The primary goal of this research is to create a fire water network simulation model, validate the simulation model created, and perform simulations to see the effect of flow rate on pressure. Hopefully, by making a model of a system, it will be easier to carry out the analysis. This is a modeling principle that asserts that modeling aims to facilitate its research and development. Therefore, the steps are as follow:

1. Collecting data in the field (this data covers 5 platforms, fire water platform, platform 1, platform 2, platform 3, platform 4, and platform 5).
2. Modelling the fire water network equation.
3. Solving by using Newton Raphson iterations to obtain a convergent value.
4. Validating iteration data with field comparison data.
5. Predicting the effect of flow rate on the pressure.
6. Conducting results analysis and giving suggestions.

The basic equation will be created from the data collected in the field. The data includes the pressure on each platform and also the flow rate on each platform. After that, there will be simulations by the Newton - Raphson method using the basic equation from these equations as shown in equation (Chapra, et al., 2010).

$$X_{i+1} = X_i - \frac{f(X_i)}{f'(X_i)} \quad (1)$$

Based on equation (1), i denote it as the iteration i . So, the iteration value will be continued until a certain amount desired reaches a convergent value.

3. Results and Discussions

The primary data was taken for each platform using digital and manual gauges. The preliminary data used in equations on the firewater platform is the pump outlet pressure (P_2) with the flow rate from the diesel fire pump (W_1). On platform 1, three main parameters can be used in the formation of the equation model, the pressure on platform 1 (P_A), the flow rate on platform 1 (W_A), and also the flow rate that goes to the next platform (W_2). W_2 is subtracting the fire water pump flow rate (W_1) with the flow rate on platform 1 (W_A). On platform 2, there are three main parameters used, the pressure on platform 2 (P_B), the flow rate on platform 2 (W_B), and also the flow rate that goes to the next platform (W_3). W_3 is the result of subtracting the flow rate of W_2 with the flow rate on platform 2 (W_B).

On platform three there are three parameters, namely, the pressure on platform 3 (P_C), the flow rate on platform 3

(W_C), and also the flow rate that goes to the next platform (W_4). W_4 is the result of subtracting the flow rate of W_3 with the flow rate on platform 3 (W_C). Platform 4 is the last platform. On this platform, there are only two parameters, namely pressure on platform 4 (P_D) and flow rate on platform 4 (W_D).

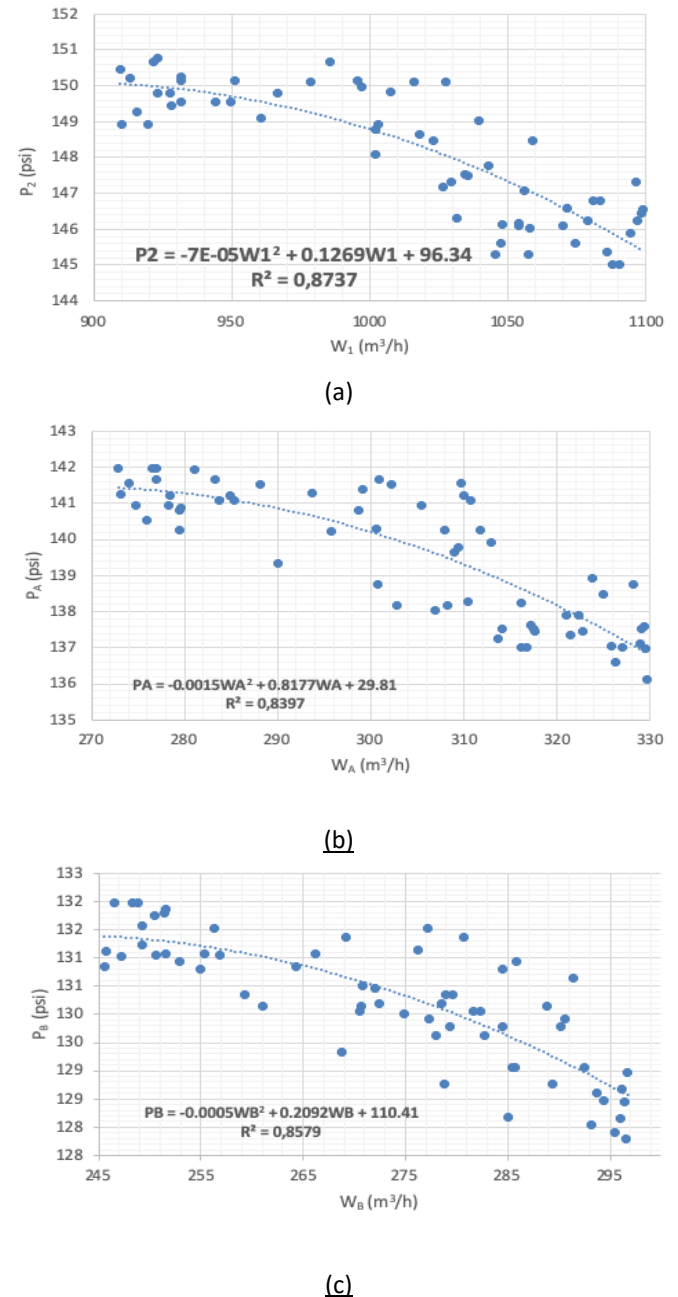


Figure 1. Correlation parameters between flow rate and pressure of each platform: (a) P_2 and W_1 , (b) P_A and W_A , (c) P_B and W_B , (d) P_C and W_C , and (e) P_D and W_D

Based on data as plotted in Figure 1, correlation parameters between flowrate and pressure for each platform can be expressed by following equations:

$$P_2 = -0.000007W_1^2 + 0.1269W_1 + 96.34 \quad (2)$$

$$P_A = -0.0015W_A^2 + 0.8177W_A + 29.81 \quad (3)$$

$$P_B = -0.0005W_B^2 + 0.2092W_B + 110.41 \quad (4)$$

$$P_C = -0.0013W_C^2 + 0.5278W_C + 68.69 \quad (5)$$

$$P_D = -0.0003W_D^2 + 0.0747W_D + 117.72 \quad (6)$$

Based on Kirchoff's Current Law (KCL), the first is the mass flow rate of the incoming fluid (W_{in}) and the mass flow rate of the fluid coming out (W_{out}) from each branch must be zero, then the equation can be formed:

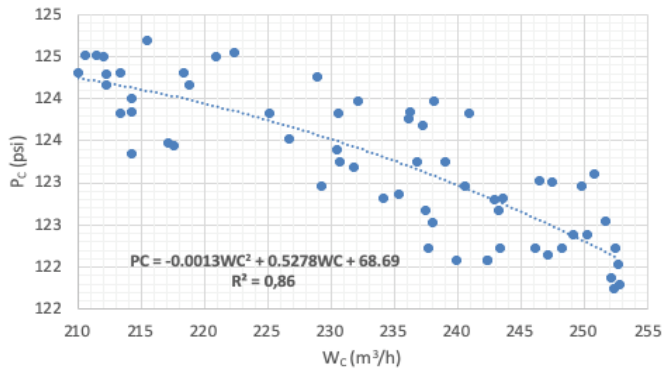
$$W_1 - W_A - W_2 = 0 \tag{7}$$

$$W_2 - W_B - W_3 = 0 \tag{8}$$

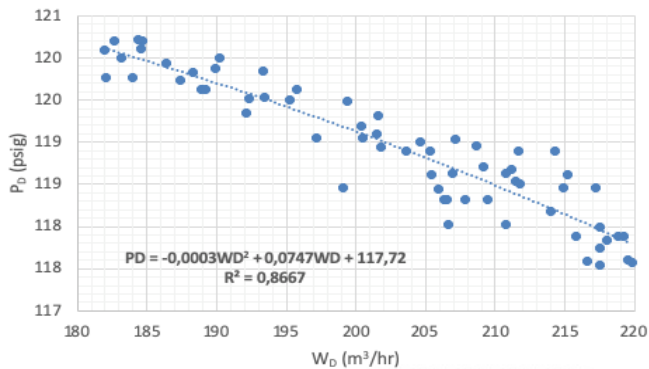
$$W_3 - W_C - W_4 = 0 \tag{9}$$

$$W_4 - W_D = 0 \tag{10}$$

$$W_1 - W_A - W_B - W_C - W_D = 0 \tag{11}$$



(d)



(e)

Based on the existing equations, initial values will have to be found, for it will be used as the first step in the analysis phase with the Newton - Raphson method. Some unknown variables that will be searched for the initial values include P1, P2, PA, PB, PC, PD, W1, W2, W3, W4, WA, WB, WC, and WD. Determination of the initial value is conducted by initial guess with a value that is close to the system (Chapra and Canale, 2010). Newton – Raphson method can be used to find a solution and it can converge quickly if the initial value of the iteration close to the actual solution (Bakari, et al., 2016). Table 1 shows the initial value that had been chosen for the iteration.

Table 1. Initial value of the iteration

unknown variable	initial value	unknown variable	initial value
P1	0,5	W2	700
P2	150	W3	400
PA	90	W4	200
PB	105	WA	500
PC	114	WB	300
PD	120	WC	200
W1	1000	WD	190

Those initial values were employed as the starting value for Newton – Raphson Method. Table 2 shows the iteration result of the Newton – Raphson method. Based on the table, the convergence result was achieved at the fifth iteration, and the value of W_D shows a stable value of 198.9 m^3/h .

Table 2. W_D Iteration of fire water network

itr	P1	P2	PA	PB	PC	PD	W1	W2	W3	W4	WA	WB	WC	WD
0	0.5	150.0	90.0	105.0	114.0	120.0	1,000.0	700.0	400.0	200.0	500.0	300.0	200.0	190.0
1	0.5	201.0	423.0	336.0	326.0	266.0	-171.5	-392.1	-792.7	62.1	223.0	125.0	477.0	452.0
2	0.5	112.0	113.0	28.6	99.0	53.0	-803.2	1,222.1	2,068.8	1770.9	152.0	423.0	112.0	62.0
3	0.5	436.0	251.0	258.0	258.0	159.0	2,425.9	-427.5	1,014.8	1107.2	476.0	366.0	366.0	236.0
4	0.0	153.1	142.0	132.0	114.3	120.7	1,011.4	708.0	434.9	202.3	321.0	278.0	225.0	199.7
5	0.1	153.1	139.0	130.0	123.0	119.0	1,011.4	708.0	434.9	202.3	305.0	271.0	231.0	198.9
6	0.1	153.1	139.0	130.0	123.0	119.0	1,011.4	708.0	434.9	202.3	305.0	271.0	231.0	198.9
7	0.1	153.1	139.0	130.0	123.0	119.0	1,011.4	708.0	434.9	202.3	305.0	271.0	231.0	198.9
8	0.1	153.1	139.0	130.0	123.0	119.0	1,011.4	708.0	434.9	202.3	305.0	271.0	231.0	198.9
9	0.1	153.1	139.0	130.0	123.0	119.0	1,011.4	708.0	434.9	202.3	305.0	271.0	231.0	198.9

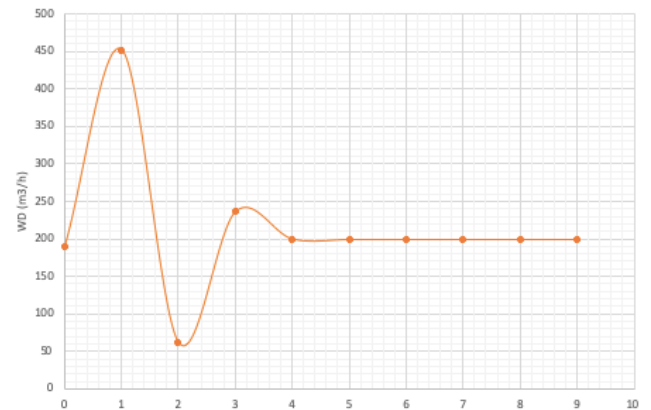


Figure 2. Iteration result of W_D

A. Validation

The validation process compares the W_D values obtained from the simulation results and the average W_D values from 30% of the field data. W_D which will be used as a comparison is 203.7 m^3/h .

$$\text{discrepancy} = \frac{(W_{D \text{ on field}} - W_{D \text{ simulation}})}{W_{D \text{ on field}}} \times 100\% \tag{12}$$

Based on the calculation, the discrepancy value or the difference from the simulation results between W_D in the field and W_D simulation results using the Newton-Raphson method shows a value of 2.39%.

B. Predicting the Effect of Flow rate on Pressure

In predicting the effect of flow rate on pressure, variations of the flow rate value will be employed and then the value of P_D , which is the farthest point, or pressure on platform four will be observed. The variations of the flow rate values are 2000 m^3/h , 1500 m^3/h , and 500 m^3/h .

Table 3. Iteration parameter at 2,000m³/h

Iteration	P1	P2	PA	PB	PC	PD
0	0.5	250	225	200	175	150
1	0.5	415.26	380.41	356.58	295.26	24.26
2	0.5	80.26	110.59	40.26	30.56	320.26
3	0.5	200.26	185.65	179.26	164.55	151.01
4	0.5	191.23	189.55	178.56	165.88	150.45
5	0.1	191.23	189.55	178.56	165.88	150.45
6	0.1	191.23	189.55	178.56	165.88	150.45
7	0.1	191.23	189.55	178.56	165.88	150.45
8	0.1	191.23	189.55	178.56	165.88	150.45
9	0.1	191.23	189.55	178.56	165.88	150.45

In the variation of flow rate 2,000 m³/h and 1,500 m³/h, the P_D value is quite large, namely 150.45 psig and 130.85 psig. This shows that the pressure at the end of platform 4 is quite large, and sufficient to meet the needs of firewater network pressure in the event of an emergency, in this case, a fire. However, when the flow rate variation was set to 500 m³/h, the P_D value showed 24.26 psig; with this pressure, the firewater canon was not sufficient to protect the platform area 4.

Table 4. Iteration parameter at 1,500m³/h

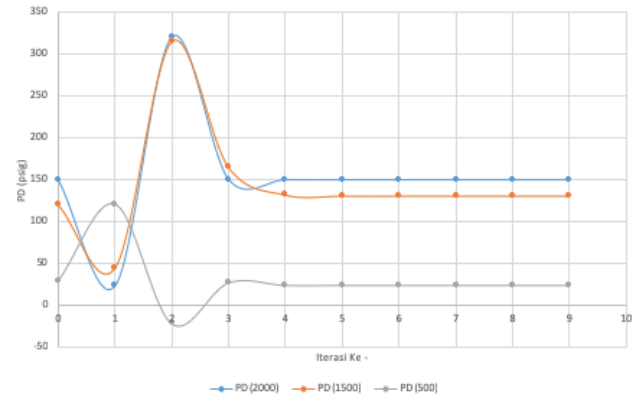
Iteration	P1	P2	PA	PB	PC	PD
0	0.5	200	180	160	140	120
1	0.5	400.26	315.26	264.54	210.26	45.26
2	0.5	90.56	70.26	10.26	40.26	315.24
3	0.5	201.56	198.54	110.25	80.56	165.24
4	0.5	163.54	160.74	153.26	143.54	132.11
5	0.1	162.33	160.22	154.23	142.36	130.85
6	0.1	162.33	160.22	154.23	142.36	130.85
7	0.1	162.33	160.22	154.23	142.36	130.85
8	0.1	162.33	160.22	154.23	142.36	130.85
9	0.1	162.33	160.22	154.23	142.36	130.85

Table 5. Iteration parameter at 500m³/h

Iteration	P1	P2	PA	PB	PC	PD
0	0.5	150	125	100	75	30
1	0.5	350.26	201.56	210.36	115.26	120.59
2	0.5	21.03	120.36	110.24	240.26	-21.26
3	0.5	102.25	81.23	60.12	31.98	27.19
4	0.1	101.23	80.32	60.65	31.22	24.26
5	0.1	101.23	80.32	60.65	31.22	24.26
6	0.1	101.23	80.32	60.65	31.22	24.26
7	0.1	101.23	80.32	60.65	31.22	24.26
8	0.1	101.23	80.32	60.65	31.22	24.26
9	0.1	101.23	80.32	60.65	31.22	24.26

Figure 3 shows the iteration become convergence for each variation of flowrate. Variation of 2,000 m³/h become convergence in fourth iteration, variation of 1,500 m³/h become convergence in fifth iteration, and variation of 500 m³/h become convergence in fourth iteration.

During platform 4 facilities construction performance test were done to fire water network system. The result of the test were become the baseline value. The test were done with the debit variation of 1,000 m³/h and 2,000 m³/h



without resistance in pressure control valve. Pressure generated in

Figure 3. Iteration result for each variation flowrate

1,000 m³/h was 130.5 psig and on 2,000 m³/h, generated pressure 166.75 psig.

The performance test is done by comparing the data from simulation at 2,000m³/H and 1,000m³/h to the initial project data. The variable being compared is pressure at platform 4 (P_D).

$$\text{discrepancy} = \frac{(P_{D \text{ initial}} - P_{D \text{ simulation}})}{P_{D \text{ initial}}} \times 100\%. \quad (13)$$

The calculation found that performance with a flow rate of 2,000 m³/h decreased by 9.74%, and performance with a flow rate of 1,000 m³/h decreased by 8.81%.

4. Conclusion

In this research, a simulation model of a firewater network system has been developed, which can be used to see the flow rate variation against pressure. This simulation model can also be used to compare the performance of a firewater network system. Processing the data with the newton-raphson method can help simulate large data and various equations with faster iteration. This can help to simulate if there are additional platforms in the future.

Nomenclature

- P1 atmospheric pressure (psig)
- P2 pressure outlet pump (psig)
- PA pressure at platform 1 (psig)
- PB pressure at platform 2 (psig)
- PC pressure at platform 3 (psig)
- PD pressure at platform 4 (psig)
- WA flowrate at platform 1 (m³/h)
- WB flowrate at platform 2 (m³/h)
- WC flowrate at platform 3 (m³/h)
- WD flowrate at platform 4 (m³/h)
- W1 flowrate at platform fwp (m³/h)
- W2 flowrate at between platform 2 (m³/h)
- W3 flowrate at between platform 3 (m³/h)
- W4 flowrate at between platform 4 (m³/h)

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