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Multiphase flow meter case study using artificial neural network in petroleum industry

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Abstract

An Artificial Neural Network (ANN) method can provide estimation product especially to design and analyze multiphase flow smart control in the petroleum industry. The conventional measurement of multiphase flow is very difficult due to mixing flow rate total that are complicated in output inlet and outlet pressure Separator (FSB – V – 04) Foxtrot well Platform, *Pertamina Hulu Energi* (PHE) West Java Indonesia. Based on the problem, this study aimed to estimate Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) over 2012 and 2013. The observation data was taken from Department of Engineering Construction *Pertamina Hulu Energi* (PHE) Offshore North West Java (ONWJ) Indonesia in eight-month observation. The Multilayer Perceptron (MLP) was used in ANN architecture to obtain training result. Multi-input and multi-output (MIMO) structure and Levenberg Marquardt (LM) algorithms are suggested to process the data. The result showed the Root Mean Square Error (RMSE) value of output estimation reached 6.33E10 and 98.8 % of Variance Accounted For (VAF) during training section.

Keywords: Artificial Neural Network (ANN), *Pertamina Hulu Energi* (PHE) Offshore North West Java (ONWJ) Indonesia, Multiphase flow meter and Separator

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1. Introduction

The multiphase flow rate is a phase of substance and can be described into three groups which are liquid, solid and gas [1]. The refinery crude oil companies used separator system to find the flow rate gas, oil and water over Indonesia is *Pertamina Hulu Energi* (PHE) Offshore North West Java (ONWJ). The conventional separator systems have a weakness whereby it assumed the flow rate gas (F_g) variable to be steady [1]. However, measurement of multiphase flow rate gas is not steady due to imprecision measurement of flow rate for gas, oil and water. Hence, this work is aimed to estimate multiphase meter variable over 2012 to 2014 in Separator (FSB – V – 04) Foxtrot well Platform PHE – ONWJ, Indonesia.

In the current study of a multiphase flow meter, Zhou and Michael [1] found that the simulation flow rate pipe based on numerical scheme performed with Total Variations Diminishing (TVD) logarithm gave poor results due to numeric and computation time process. The iteration of simulation was unsuccessful. However, in their next study, the authors used Godunov numerical method that resulted in successful simulation [2]. Meanwhile, Seraj et al [3] have studied venturi flow meter application for flow measurement with added radioactive to find the ratio of flow rate gas, oil, and water. The relative venturi ratio reached (10:1) for maximum and minimum flow rate measurement. Georg Zangl et al [4] has studied the multiphase flow rate estimation using simple regression method (MLR) and a back-propagation Artificial Neural Network (ANN) where they found that ANN was a better estimation method with relatively good results.

In this work, the input parameters of multiphase flow meter were estimated using ANN. The seven layers architecture with Levenberg Marquardt (LM) algorithm was suggested in this work. In order to obtain estimation result, the four parameters input such as Flow Rate Total USM (Q_T), Pressure inlet (P_1), Temperature inlet (T), and Pressure Outlet (P_2) from separator (FSB – V – 04) Foxtrot well platform was collected. The Eight-month observation data (September, December (2011), March, April, June, August, October (2012) and January 2013) was selected to estimate the output variable of a multiphase flow meter.

2. Methodology

2.1. Data and location

Pertamina Hulu Energi (PHE) Offshore North West Java (ONWJ) Indonesia is an offshore oil company in the North West Java, Indonesia with a vision become a world

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class oil company. To realize the vision, we estimated multiphase flow meter variation using the measurement data on Separator (FSB – V – 04) Foxtrot well platform. In this work, the selected parameters such as Flow Rate Total USM (Q_T), Pressure Inlet (P_1), Temperature (T), Pressure Outlet (P_2), Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) were used in this work (See fig. 1).

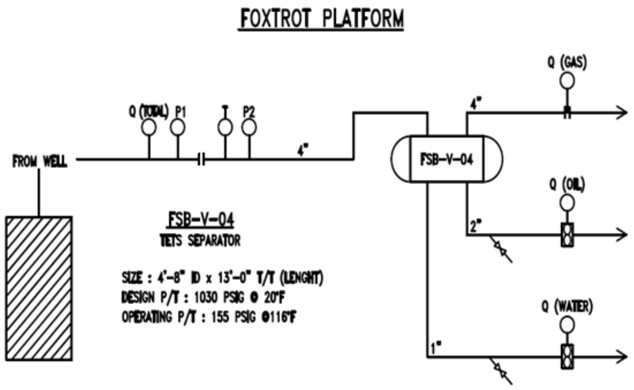

Fig. 1. Process Flow Diagram (PFD) Separator (FSB – V – 04) Foxtrot well Platform in PHE – ONWJ

2.2. Data Processing

The data obtained from Department of Engineering Construction PHE ONWJ Indonesia in Separator (FSB – V – 04) Foxtrot well Platform (see fig.2) over eight-month observation was sorted and cleaned using MATLAB program. We used four inputs (from outlet well) and three outputs (from outlet separator) data with interval observation of 6 to 7 hours (7am, 14pm, 20pm).

PERTAMINA PHE ONWJ — PERTAMINA HULU ENERGI FOXTROT WELL PLATFORM

DATA SEPARATOR (FSB-V-04)
FOXTROT WELL PLATFORM - 1L
BULAN : SEPTEMBER 2011

NO	WAKTU		OUTLET WELL (FSB-01L)				OUTLET SEPARATOR (FSB-V-04)		
	Tanggal	Pukul	Q (Total) BBL/Day	P1 (PSI)	P2 (PSI)	T (deg F)	Q (Gas) MMSCFD	Q (Oil) BOPD	Q (water) BWPD
			FQI-FSB-01	PI-FSB-01A	PI-FSB-01B	TI-FSB-01	FQI-FSB-V-04A	FQI-FSB-V-04B	FQI-FSB-V-04C
1	01-09-2011	07.00	1121.40	280.00	275.00	111.04	1.39	432.96	26.05
		14.00	1121.40	280.00	275.00	111.04	1.39	432.96	26.05
		20.00	1121.90	279.00	274.00	109.01	1.39	436.24	25.10
2	02-09-2011	07.00	1122.40	279.00	275.00	110.00	1.39	434.14	26.07
		14.00	1121.40	280.00	275.00	111.04	1.39	432.96	26.05
		20.00	1122.40	279.00	275.00	110.00	1.39	434.14	26.07

Fig. 2. Data record of measurement from Separator (FSB – V – 04) Foxtrot well Platform

In order to estimate the multiphase flow meter output variable, the four variables such as Flow Rate Total USM (Q_T), Pressure Inlet (P_1), Temperature Inlet (T), and Pressure Outlet (P_2) while targeted to Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w). Furthermore, the normalization (Scaling) was performed for input and target/output parameter data while the missing data were replaced by not a number (NaN) in the MATLAB program. Figure 3 showed flowchart processing data using ANN Levenberg Marquardt (LM) algorithms. In this work, the ANN-LM algorithms were used to estimate Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w). The selection of input and output parameter was used to develop estimation model. In order to design ANN architecture, the statistical analysis was used to obtain the R-squared value of input and output parameter. Furthermore, the maximum epoch 1000 with I ~ IV layers were applied in ANN architecture using LM algorithm. The setting minimum error was applied in the training process. Moreover, the estimation result was validated with 20% of RAW data to find estimation error.

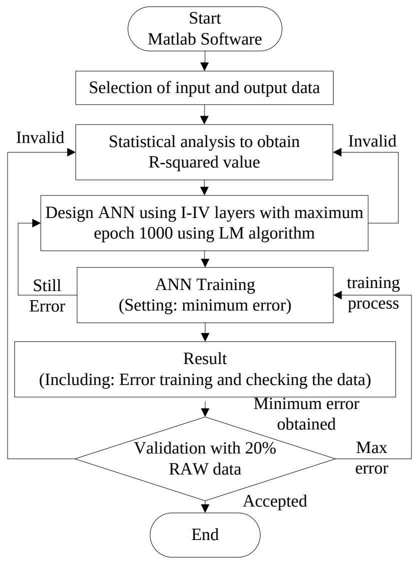

Fig. 3. Flowchart processing data using ANN-LM

2.3. Mass conservation law in the Separator

The separator is a primary device in the oil refinery unit. This device is used to separate the crude oil with pressure and temperature. The equation of liquid mass conservation in crude oil separator was given as [5]:

$$\frac{\mathrm{AdhL}}{\mathrm{dt}} = QL,in - QL,out \quad (1)$$

$$VG\frac{\mathrm{dP}}{\mathrm{dt}} = RT\frac{dn\mathrm{G}}{\mathrm{dt}} - P\frac{dVG}{\mathrm{dt}} \quad (2)$$

$$VG\frac{\mathrm{dP}}{\mathrm{dt}} = RT\frac{\rho\mathrm{G}}{\mathrm{MrG}}(QG,in - QG,out) - P\frac{dVG}{\mathrm{dt}} \quad (3)$$

$$Qg,out = Qin - \frac{\rho\mathrm{liq}}{\rho\mathrm{g}}Qliq,out \quad (4)$$

$$Vg = Qg,out = \frac{\mathrm{dhg}}{R\mathrm{g}} \quad (5)$$

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where Q_{in}, Q_{out} are the flow rate input and output respectively and Q_g, Q_L are the flow rate gas and liquid phase respectively.

2.4. Levenberg Marquardt logarithm

In order to obtain estimation result, the Levenberg Marquardt logarithm was proposed to develop estimation model. This logarithm is usually adopted to obtain hessian matrix [6]. This matrix is a second differential function for each bias and weight component [6] thus Levenberg Marquardt logarithm is designed to approach the second differential training velocity without calculating the Hessian matrix value. With the equation given as:

$$H = J^T J \quad (6)$$

And gradient as follows,

$$g = J^T e \quad (7)$$

$$X_{k+1} = X_k - [H + \mu I]^{-1}.g \quad (8)$$

The advantage of using Levenberg Marquardt logarithm is that it is able to solve the existing problems in both methods such as gradient descent and Gauss-Newton method for ANN training data, with two combination logarithms. This logarithm is considered as one of the most efficient training algorithm [6].

2.5. Artificial Neural Network (ANN)

The Artificial Neural Network architecture in this study was used feed-forward back propagation method and training function *Levenberg Marquardt* algorithm. The *binary sigmoid* activation function was performed for each neuron. The architecture of ANN using Multilayer Perceptron (MLP) structure is shown in Figure 4.

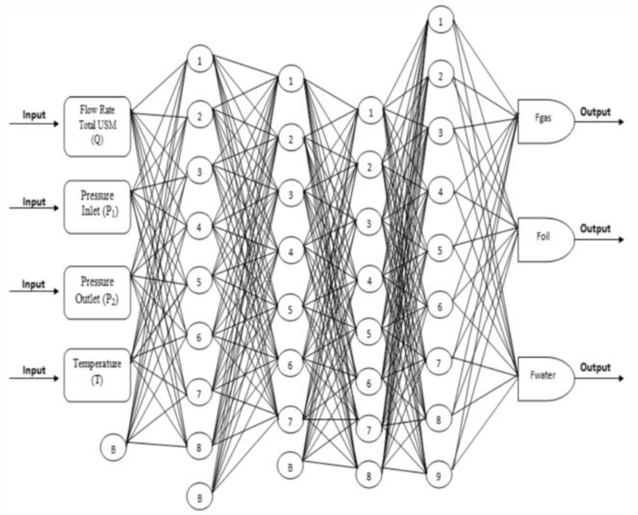

Fig. 4. Flowchart processing data using ANN-LM

In this study, the ANN-LM were suggested to obtain the estimation result using combination layer I ~ IV with node VII ~ VIII.

3. Result and Discussion

In order to obtain the estimation result, Figure 5 showed the pattern of normalization data input e.g. Flow rate, Pressure inlet I, Pressure inlet II, and Temperature inlet. We obtain flow rate total USM (Q) was decreased from 540 data until data 720 (August, October (2012) and January 2013). This indicated that the flow rate total production of crude oil has decreased including that of Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w). However, the maximum value of temperature has increased on January 2013 (near 713 data). The temperature is anti-correlated with pressure inlet 1 (P_1).

Moreover, the maximum value of pressure inlet 2 (P_2) occurred near data 176. Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) variation. Here, the Flow Rate Oil (Q_o) has decreased on August 2012, October 2012 and January 2013. This indicated that the Flow Rate Total USM (Q_T) is anti-correlated with Flow Rate Oil (Q_o). Furthermore, the minimum value of Flow Rate Water (Q_w) was in the middle of October 2012 and January 2013. Flow Rate Gas (Q_g) was also found to be decreasing where the Flow Rate Total USM (Q_T) of crude oil production has decreased for four months (June, August, October (2012) and January 2013).

As can be seen in the Figures, the observation data in the middle of September 2011 to April 2012 (30 to 300 data) showed the Flow Rate Total USM (Q_T) to increase due to steady pressure and temperature in the crude oil well. The result showed output value of Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) from separator were increased. Figure 6 showed the performance of training process, where the blue line colour is training data with MLP architecture using Levenberg Marquardt (LM) logarithm while green line colour is a result of validation data with training process data and red line colour is test result between training - validation data.

The Mean Square Error (MSE) value was obtained *3.29 × E-10*. It is showed the convergence between training and test results have an error value of over *3.29 × E-10* at 1000 epoch (iteration). In another hand, the maximum layer for this study was seven – eight layers where the overfitting results were obtained if seven layers are used in ANN - LM. In order to obtain precision of the estimation model, the validations were suggested to compare estimation model to find minimum estimation error. The comparison result between validation and output data showed in figure 7.

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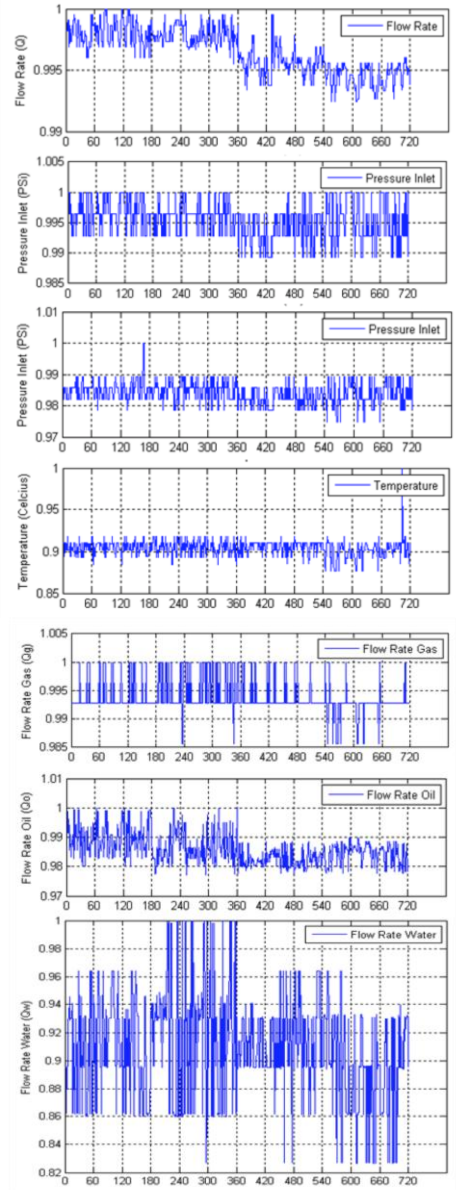

Fig. 5. Normalization input and output data

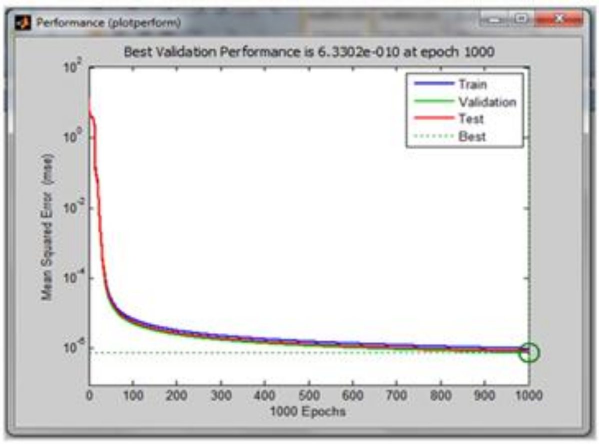

Fig. 6. The performance of training process

Here, the strongest result in this work was obtained where the estimation model followed the RAW data pattern. In terms of validation for the estimation model, 20% data (180 RAW data) was used to compare the estimation model with data observation. Here, we found that the weight iteration for output target e.g. Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w). The RMSE result is obtained *6.33 × E-10* during training section. The estimation model showed the ANN method has successfully estimated the multiphase flow meter variable using MLP architecture. The Variance Accounted For (VAF) in this work was reached 98.8%. The value indicated very small error and the estimation model performed has high precision.

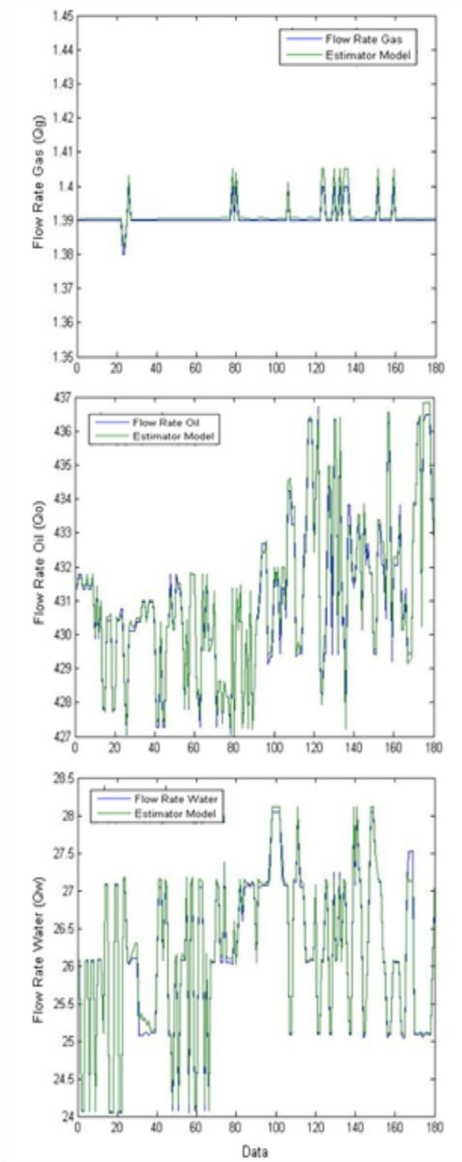

Fig. 7. The comparison of estimation model and validation using measurement data (RAW data)

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4. Conclusion

The estimation Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) in 2012 to 2013 in *Pertamina Hulu Energi* (PHE) Offshore North West Java (ONWJ) Indonesia in Separator (FSB – V – 04) Foxtrot well Platform were successful. The ANN application was performed in this study using Multilayer Perceptron (MLP) and Levenberg Marquardt (LM) algorithms. The result showed that the total production of crude oil including Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) has decreased in August 2012, October 2012 and January 2013. We found that the maximum value of temperature has increased in January 2013 (near 713 data).

Estimation model using four inputs and three output targets gave good results. The results are compiled in Figure 8. The maximum estimation value of Flow Rate Oil (Q_o) was reached at 436.74 m^3/hr in October 2012. The Root Mean Square Error (RMSE) and Variance Accounted For (VAF) value of three output targets were $6.33 \times E\text{-}10$ and 98.8%, respectively. The Flow Rate Total USM (Q_T) increased when Flow Rate Gas (Q_g), Flow Rate Oil (Q_o) and Flow Rate Water (Q_w) increased the temperature decreased in September and December 2011.

For future work, the estimation model based on ANN would be developed into multiphase flow meter system. This allowed the conventional multiphase flow meter to change into smart multiphase flow meter without separator plant and at the same time, help to minimize cost for separator installation.

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