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Prototype of Heat Exchanger Cooler Type Shell And Tube Counter Flow Model as ATrainer for Temperature using Neuro-Fuzzy Control (ANFIS)

(First Project)

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***Abstract*— Heat transfer equipment which uses fluid to another fluid is water heater – charger – boiler is open (open feed – water heater), but more commonly used are heat exchangers where the fluid is separated from another fluid by a wall or bulkhead that is traversed by the heat, a recuperator type heat exchanger is a pipe-shaped heat exchanger inside the pipe.in this prototype is using lm35 for temperature sensor, flowmeter sensor and two pump, first pump to pumping oil and second pump to pumping water.**

Prototype heat exchanger using hot oil cooler which is cooled using a water flow direction of the water and oil counter flow based on empirical calculations that showed a decrease of hot oil temperature of 60 degrees Celsius to 24 degrees Celsius, the water flowrate of 10 L / min. based on the actual data from the sensor there is a temperature error on the incoming oil that should be 60 to 65 degrees Celsius. from the input and output data used for training on anfis by utilizing matlab software, the error plant there is still a big error so it still has to be done training and testing so that the response of the plant can be better and the error that happened can be as small as possible

Keywords—Heat exchanger, sensor, anfis

I. INTRODUCTION

Heat transfer equipment which uses fluid to another fluid is water heater – charger – boiler is open (open feed – water heater), but more commonly used are heat exchangers where the fluid is separated from another fluid by a wall or bulkhead that is traversed by the heat, a recuperator type heat exchanger is a pipe-shaped heat exchanger inside the pipe.

There are various ways to improve the effectiveness of heat exchange devices, according to mechanical engineering, by increasing the convection heat transfer coefficient, increasing the heat exchanger surface area and increasing the temperature difference to reach the specified temperature.

The second way to achieve the desired temperature is to use a control method, with fluid temperature input, pump speed shell, cooling fan speed and expected output is the desired fluid temperature. The technique used in this research is MISO (multi input single output), with neuro fuzzy control method to get the desired temperature.

The unavailability of teaching medium in the form of Heat Excanger shell and tube trainer in Mechatronics Laboratory, so that the learning process is not optimal, with the design prototype of Heat Excanger counter counter flow model can improve the role of students and lecturers in doing research, especially the application of control techniques so that lecturers in performing the function colleges especially research can be done in the laboratory itself.

II. LITERATUR REVIEW

A. previous research

Budiarto,Hairil, in his research said that long variations of static twisted tape and variation of hot oil fluid discharge have a real effect on pressure drop in oil cooler type counter flow, the result in research is the longer static twisted tape installed in the inner tube of the heat exchanger and with the increasing flow of heat fluid flow, in each test with the same variation of heat oil fluid flow will increase the pressure drop, and effectiveness.[1].

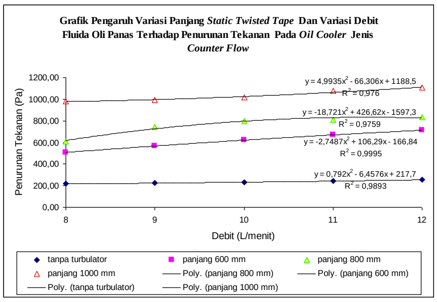

Figure 1. Graph of influence of static twisted tape length variation and variation of fluid flow of hot oil fluid to pressure drop.

The best static twisted tape length is at 1000mm pipe length with its heat transfer rate of 366.40 Watt and causes a pressure drop of 1106.98 Pa

Hidayat, Rohmat, in a final event conferens entitled fuzzy logic application for tuning PID control parameters on temperature setting of shell and tube heat 1xchanger fluids. The design of the hardware uses the LM35 temperature sensor, DC servo motor used to drive the valve, a 300 watt with Alternatimg Current and microcontroller sources that serve as the control center and PC, reference testing with fixed input.[5]

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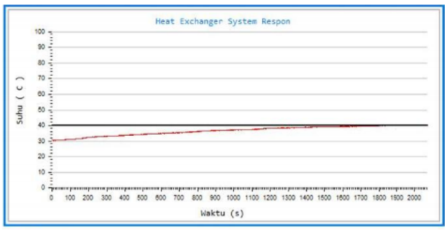

Figure 2. System response method Fuzzy PID

In the research, the result of fuzzy logic control is used, it can generate PID parameter according to error system and can generate stable control signal and system response, good sensor readings with error value 0,08oC, test with set point up or down, control signals can follow the given set of points.

Ekasari, Fatimah. Fathimah Ekasari [2014], In her research entitled fluid temperature controller on heat excanger using predictive control model algorithm (MPC), concludes that predictive control model (MPC) belongs to the category of design concept of proces-based controller, with the result of highly controller design depending on the validity of the approach model used, the most suitable MPC is to use 20 horizon predictions and 4 horizon controls and the steady state time takes 70 seconds.[4]

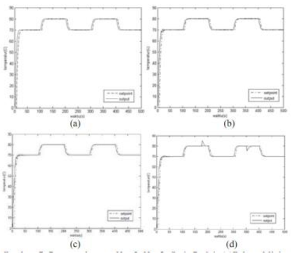

Figure 3. Response with Hp = 5, Hc = 2, Q = 1, R = 0.1 (a) minimal load (b) Nominal load (c) maximum load (d) load changed.

Control of the linear approximation of the plant with the MPC controller can produce a stable response without overshoot and corresponds to the desired set point value of 70oC at either fixed or load loading which varies about 20% of the nominal load with a steady state time of 35 seconds.

Padhee, Subhransu, in his research entitled Controller design for temperature control of heat 2xchanger system in simulation studies, focusing his research on performance analysis of several controller techniques that would be applied to regulate temperature in heat 2xchanger, and from the simulation it was found that internal model control has a higher performance value than feedback- and feedback plus-feedforward controller, the implementation using PID controller shows a high degree of overshoot at the same 2xchange time.[6]

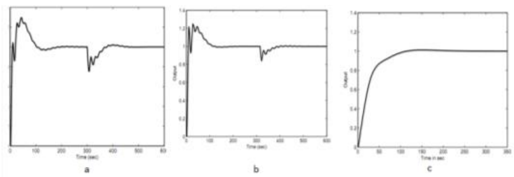

Figure 4. Set point and load disturbance response using (a) PID controller (b) feedback plus feedforward controller (c) internal controller model

Ramadoni Syahputra, in the simulation study of heat 2xchanger temperature control using adaptive neuro-fuzzy technique, it is found that the result of control using feedforward is relatively better than using feedback especially in speed toward stable state this is because computing feedforward relatively smaller.[7]

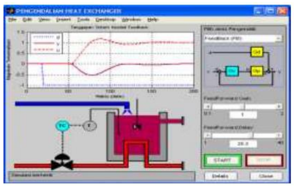

Figure 5. Model heat exchanger temperature system with feedback control

In the simulation with combined feedforward and feedback control, it was found that the system response was better than the control using feedforward or feedback only. The system is stable at the 20th second.

Heat energy is one form of energy that can move from one system to another as a result of the difference in temperature. In steady fluid flowing in a channel where there is one inlet and one outlet, the flow rate of the incoming fluid mass will be equal to the rate the mass flow of the outflow fluid or $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$, if the fluid does not work then the amount of heat energy transferred will be equal to the energy changes contained in the system.

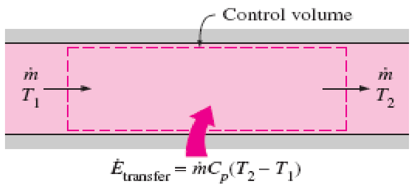

Figure 6. Heat energy transfer on a system with volume control

The amount of heat energy in the system can be expressed by the following equation :

$$\dot{Q} = \dot{m}C_p \,\Delta T \qquad (1)$$

The heat transfer can be defined as the transfer of energy from one system to another as a result of the temperature difference, this energy transfer always occurs from a high temperature system to another lower temperature system and will stop after both systems reach the same temperature, the temperature difference is the main condition for the occurrence of the displacement of the system. If the two systems have the same temperature then there will be no heat transfer in the second

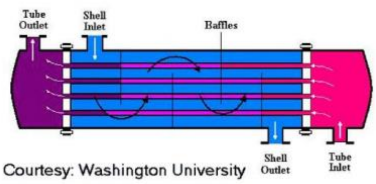

Figure 7. Heat Exchanger Type Shell and Tube

The rate of conduction heat transfer is given by J.B.J. Fourier in 1822 was the magnitude of the rate of displacement of the heat of conduction proportional to the surface area of heat, the temperature difference, and the thermal conductivity of the material, but inversely proportional to the thickness of the surface passed by the heat.

$$\dot{Q}_{cond} = -kA\frac{(T_2-T_1)}{\Delta x} \qquad (2)$$

The heat transfer of convection is the mechanism of heat transfer through the fluid layer, be it liquid or gas fluid. The faster the fluid movement will be the greater the rate of heat transfer convection.

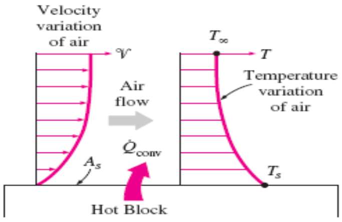

Figure 8. The heat transfer of convection from a hot surface blown by cold air.

If a fluid of a certain viscosity flows in a pipe then the fluid flow will form a velocity boundary layer and a thermal boundary layer. The fluid velocity profile flowing in the pipe will form from the zero velocity on the pipe surface to reach the maximum speed at the center of the pipe. In the fluid temperature profile, if the surface temperature of the pipe wall is greater than the fluid temperature, the fluid temperature in the transverse direction will change from the Ts temperature on the surface of the pipe wall to a minimum at the center of the pipe.

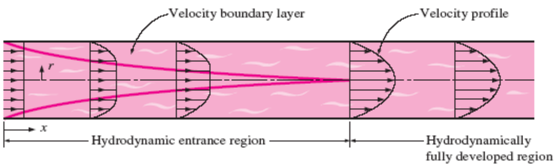

Figure 9. Hydrodynamic boundary layer

whereas if the surface temperature of the pipe wall is less than the fluid temperature then the fluid temperature in the transverse direction will change from Ts on the surface of the pipe wall to the maximum at the center of the pipe.

Fuzzy logic is one of the control methods that are part of the artificial intelligent control (AI). The term fuzzy was first introduced by Lotfi A Zadeh in July 1964. The fuzzy control structure uses two inputs ie error and delta error.

Figure 10. Fuzzy Control Structure.

Fuzzification is a process in fuzzy control that serves to map the data input crisp into the fuzzy set into the fuzzy value of some input linguistic variables. The regenerator base consists of a database and a rule base, the database defines the fuzzy set of input space and output spaces.

The rule base contains the rules of the fuzzy control rule used for process control, the specified rule is used to connect between variable input variables and output variables.

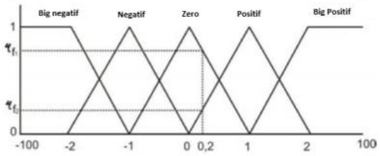

Figure 11. Fuzzyfication process

The most popular neuro-fuzzy method is often known as ANFIS (adaptive neuro fuzzy inference system). ANFIS is an adaptive network based on fuzzy logic inference system, with the implementation of fuzzy logic inference system on adaptive network can be used to adapt the inference system, ANFIS parameter is divided into two, namely the antecedent parameter and consequence parameter or so-called learning process or training, the often used training process for ANFIS is backpropagation and hybrid (the combined back propagation and least square estimation, LSE).

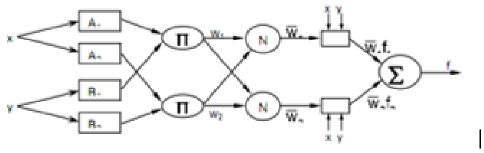

Figure 12. ANFIS architecture sugeno model in general.

III. METHOD AND RESULT

In this research, we can use experimental method. The prototype of heat exchanger is made as in figure 13.

Figure 13. Prototype Heat Exchanger

We also using 2 pump and peltier to keep the water temperature remains at 25 degrees Celsius, flow sensors used to determine the flow of water and oil. Valve dc control to cover the flow of water and oil,shown in figure 14.

Figure 14. Peltier, flow sensor and DC valve control.

Calculation of Prototype Heat Exchanger Analysis :

a) amount of water that passes flow sensor water 10 L/min
b) $T_{cold,in}$ (temperature cold of water) = 25°C
c) $T_{hot,in}$ (temperature hot oil) = 60°C

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Model prototype heat exchanger, following the model staggered tube bank, as in Figure 15.

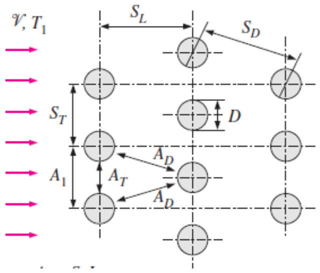

Figure 15. Staggered Tube bank

Known :

S_L = 0,02 m; D = 0,004 m; S_T = 0,02 m; $Q_{pump\ water}$ = 10 L/min.

The assumed mean temperature :

$$T_{mean} = \frac{60+25}{2} = 42{,}5 \ \approx 40^oC \tag{3}$$

Evaluated the water at T_{mean} 40°C

Refers to the thermodynamic table A-9 table in the heat transfer heading book, then the value of:

K = 0,631 W/m.°C   ρ = 992,1 Kg/m³.

C_p = 4179 J/Kg.°C. P_r = 4,32

μ = 0,653 x 10^{-3} Kg/m. S

Figure 16. Properties of thermodynamic

$$S_D^2 = S_L^2 + \left(\frac{1}{2}.S_T\right)^2 \tag{4}$$

S_D = 0,022 m.

For 1 liter = 1 dm3 = 10-3. M3, then the next step is to find the value of water velocity of the pump (v), then:

$$Q = \frac{10x10^3(m^3)}{1\ min.\frac{60\ s}{1\ min}} \tag{5}$$

$$Q = v\ xA \tag{6}$$

$$v = \frac{1{,}67x10^{-4}\frac{m^3}{s}}{\frac{\pi}{4}(0{,}01)^2 m^2} \tag{7}$$

$$v = 2{,}13\,\frac{m}{s}$$

The next step is to find vmax, by entering a value of v in the previous equation, then:

$$v_{max} = \frac{S_T}{2(S_D-D)}x\ v \tag{8}$$

$$v_{max} = 1{,}18\,\frac{m}{s}$$

Next step is looking reynold number, to find that the flow is laminar or turbulance.

$$R_e = \frac{\rho\ .v_{max}\ .D}{\mu} \tag{9}$$

$$R_e = 7171{,}08$$

With the value of the reynold number above 2500 then the flow of water in the shell pipe is turbulent, the range of reynold numbers between 1000 s / d 2x105, then the number of nusselt number follows the equation:

$$N_{uD} = 0{,}35.\left({}^{S_T}/_{S_L}\right)^{0,2}.R_{eD}{}^{0,6}.P_r{}^{0,36}.\left({}^{P_r}/_{P_{rs}}\right)^{0,25} \tag{10}$$

$$N_{uD} = 0.35\ \left({}^{0,02}/_{0,02}\right)^{0,2}\ (7171{,}08)^{0,6}\ (4{,}32)^{0,36}\ \left({}^{4,32}/_{2,99}\right)^{0,25}$$

$$N_{uD} = 133{,}39$$

The next step is to calculate the nusselt number average, by entering the number of rows and columns on the tube according to the design of the heat exchanger prototype made.

$$N_{uD.NL} = F\ .N_{uD} \tag{11}$$

By entering the number of N_L = 6, corresponding to the number of tube rows so that the F value can be searched on the thermodynamic table in table 7-3, so the value F = 0.945

$$N_{uD.NL} = 126{,}05$$

The next step is to find the value of (h), the heat transfer value for all tubes used in the prototype, by entering the value of the nusselt number average, then:

$$h = \frac{N_{uD.NL}\ .K}{D} \tag{12}$$

$$h = 19884{,}39\ {}^{W}/_{m^2.{}^oC}$$

To calculate the heat transfer on the surface area of the tube, it is necessary how many tubes are used, the number of tubes used is N = 31, then the calculation is:

$$A_s = N\ .\pi\ .D\ .L \tag{13}$$

$$A_s = 0{,}389m^2$$

To calculate the mass flow rate in water (water as a cooling medium within the shell), calculated using the equation:

$$M^o = \rho\ .v\ (N_T\ .S_T\ .L) \tag{14}$$

$$M^o = 211{,}32\ {}^{kg}/_{s}$$

The next step is to calculate the oil temperature coming out of the heat exchanger, using the equation:

$$T_{oli(out)} = T_{h(out)} = T_s - (T_s - T_i)\ \exp\left(-\frac{A_s.h}{M^o.C_p}\right) \tag{15}$$

$$T_{oli(keluar)} = 24{,}78\ \approx 25^oC$$

To calculate LMTD (loq mean temperature differense), then use the equation:

$$LMTD = \Delta T_{ln} = \frac{(T_s-T_e)-(T_s-T_i)}{\ln\left[{}^{(T_s-T_e)}/_{(T_s-T_i)}\right]} \tag{16}$$

$$LMTD = \Delta T_{ln} = 35^oC$$

So the rate of heat transfer is:

$$Q^o = h\ .A_s\ .\Delta T_{ln} \tag{17}$$

$$Q^o = 2{,}707\ x\ 10^5\ W$$

The next step is to take the output data from the sensor to compare the calculation results and the real plant data prototype heat exchanger. The steps performed to determine the error value between the calculations and sensor.

Table. 1 Temperature of oil before and after past heat exchanger

Flowrate Oil (L/min)	Temp oil in (C)	Temp oil out (C)
4.92	64.94	24.90
4.91	64.94	25.39
4.92	65.43	25.88
4.75	65.43	26.37
4.74	64.45	26.86
4.75	66.89	25.88
4.57	65.92	28.81
4.58	66.41	27.34
4.57	65.43	28.81
4.41	65.43	29.30
4.41	65.92	29.30

Table 2. Temperature of water before and after past heat exchanger

Flow rate(L/min)	Temp water in (C)	Temp water out (C)
10.51	25.00	45.44
10.51	25.00	44.76
10.50	25.00	45.86
10.52	25.00	44.77
10.50	25.00	45.14
10.49	25.00	45.16
10.51	25.00	45.70
10.34	25.00	46.11
10.32	25.00	46.46
10.34	25.00	46.11
10.32	25.00	46.46

The next step is to test from the prototype by inputting the water temperature and oil temperature and and the flowrate from the water, so that the output data obtained is the temperature of the oil out, as in the table 3.

Table 3. data input and output

Flowrate water (L/min)	Temp water in (C)	**Temp oil in (C)**	**Temp oil out (C)**
7.63	20.02	66.41	29.79
29.49	19.04	65.92	30.76
32.01	20.63	65.92	28.32
32.18	24.41	65.92	30.76
32.35	24.74	66.41	29.79
32.16	22.46	66.89	29.79
32.40	15.23	65.92	28.81
32.21	19.28	65.92	28.81
32.21	19.28	68.36	25.39
32.23	19.74	66.89	26.37
32.21	18.35	66.41	26.37
32.33	20.02	65.43	26.86
32.18	21.21	65.92	29.30
31.87	21.23	64.94	31.74
28.26	22.28	66.89	28.81
13.22	21.48	66.41	29.79
12.89	22.81	66.89	31.25
12.88	21.42	67.87	31.74
12.88	23.44	67.87	32.71
12.89	18.79	67.38	33.20
12.87	19.77	66.89	34.18
12.89	19.74	66.41	33.69
13.05	19.28	67.38	35.64
12.87	19.46	67.38	35.64
12.90	19.72	67.38	36.13
12.88	18.30	67.38	36.13
12.89	20.18	66.89	38.57
13.06	18.42	66.89	37.11
5.09	18.21	68.85	37.60
2.54	18.63	67.87	36.62
4.91	18.14	67.87	37.11
3.73	16.21	67.87	37.11
3.91	16.42	67.38	36.13
3.73	16.86	69.34	35.64
3.73	16.77	67.87	36.62
3.73	16.23	67.87	36.13
3.73	16.28	67.87	35.64
10.35	16.18	68.36	35.16
11.02	17.23	67.87	34.18
11.02	17.58	67.87	35.64
11.00	17.70	66.41	36.62
11.04	18.25	67.87	35.64

by using matlab, then the response of the input-output can be plotted as in Figure 17.

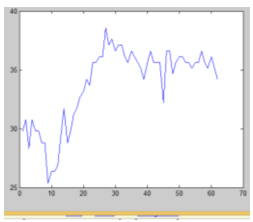

Figure 17. plotting of data

using anfis, the error of the prototype heat exchanger plant as shown in Figure 18.

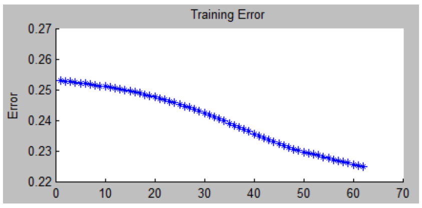

Figure 18. Training Error

The structur of ANFIS, is shown in figure 19.

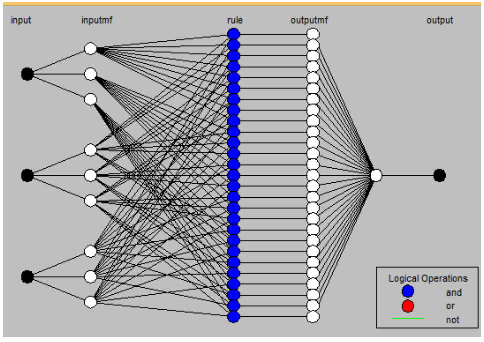

Figure 19. Anfis mode structur

CONCLUSION :

based on mechanical calculations and actual data there are differences in the results, from the empirical data, incoming oil temperature is set at 60 degrees Celsius, oil temperature sensor readings of 65 degrees Celsius, the setting flowrate to the oil and the water was very nice.
for ANFIS training, there is still a great error that still needed models for its fuzzy rule base so that the response can plant as expected or may use other control methods.
Suggestion and recomendation preferably using a temperature sensor other than lm35, using a strong pipe and pump type

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