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Analyze Performance of Heat Exchanger by using Manual Calculation and Cfd Simulation

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ABSTRACT

In this research would be planned to optimize the utilization of boiler exhaust gas by adding a heat exchanger to the chimney to heat the incoming water to the boiler. The types of heat exchangers are very diverse and each is designed to meet specific needs, but the shell and tube type is by far the most widely used type due to its relatively simple construction and reliability because it can be operated with several types of working fluids. Optimization of the design of this heat exchanger was done by full factorial method using four independent variables, namely diameter, length, distance between pipes and pipe angles with three levels of experimentation so that 81 calculated data were obtained. The result of full factorial optimization obtained the highest value of design displacement coefficient (Ud) of 354 W/m^{2o}K.This condition is obtained at the outer diameter of the pipe 0.0127m, the arrangement of pipes 45^o, the distance between the pipes is 1.25 and the length of the pipe 1.2 m. This heat exchanger has a maximum heat transfer capacity of 64.8 kW with a water mass flow rate of 0.1761 kg/second, an average temperature difference of LMTD 109.3 ^{o}K and has an effectiveness of 26.41 %. Thermal validation of manual and CFD calculation results did not show a significant difference. Manual calculation of water output temperature is in the range of 80.5 ^{o}C and the result of CFD 76 ^{o}C and exhaust gas calculation is 110 ^{o}C and CFD 114 ^{o}C.

Keywords: Heat Exchanger, Calculation, Simulation, Boiler

I. Introduction

Background

In the spray coating process of PT.XYZ located in the KIIC Area of Karawang West Java, there are three processes of pretreatment that require a heating process that uses steam from the boiler. The exhaust gas is still at a high temperature and is directly released into free air. Utilization of the exhaust temperature from the boiler for the feedwater heating source in this boiler process is one form of energy saving optimization. The heat required by the boiler feed water comes from the heat balance between the exhaust gas from the LNG combustion/oxidation process with the water entering the heat exchanger. Another advantage is that the temperature of the exhaust gas has decreased so it is safer for the environment. Heating of boiler feed water using boiler exhaust gas occurs by convection and also by conduction. Hot gas from the boiler is channeled through the pipe and by convection heat flows from the exhaust gas to the outside of the pipe and by conduction heat flows from the outer wall of the pipe to the inner wall of the pipe and finally heat energy flows convection from the inside of the pipe to the water. It is expected that the exhaust gas from this baking oven can heat the feed water from a temperature of 29^{o}C (ambient) to a greater than 50^{o}C.

The utilization of this exhaust gas requires a heat exchanger. Shell and Tube type heat exchanger is one of the most widely used types of heat exchangers today. One fluid flows through the inside of the tube, while the other fluid is pushed through the shell and through the outside of the tube. The selection is made by considering the advantages of the shell and tube type of heat exchanger compared to other types of heat exchanger.

- Has a small shape and volume, so it can configure larger surface area.
- Has a good mechanical layout, and is well -shaped and strong enough to operate at fairly high pressures.
- Using quite high technological fabrication methods so that it is easy to disassemble and reassemble, operate and clean.
- It can be made from various materials by adjusting to the operating conditions, namely temperature and pressure.
- The planning procedure is highly structured with over 100 years of experience.
- The constructions can be separated from each other and are not a complete unit, making it easier to transport

Research Purpose

- Analyze performance of the shell and tube type heat exchanger with hot fluid in the form of exhaust gas from the boiler (waste gas) and cooling fluid in the form of water.
- Analyze the overall heat transfer coefficient, heat transfer area, and effectiveness of the heat exchanger has already been planned.
- Simulation of the flow and temperature distribution of the heat exchanger using CFD.

II. Research Method

Research Location

The research was carried out in January, 2021 in the metal painting industry that uses a boiler as a pre-treatment process heater located in the Karawang Industrial Estate and in the Laboratory of the Faculty of Engineering, Pancasila University, Jakarta.

Data Analysis

The data taken in this study were the temperature and flowrate of the water entering the boiler as well as the temperature and flowrate of the boiler exhaust gases. The measurement data can be seen in table 1.The data that has been obtained is then used as input data in optimizing the design using experimental manual calculations and the optimization results were carried out by thermal analysis using CFD software(Ansys Fluent).

The layout of the boiler that will be used for optimization can be seen in Figure 1 and Figure 2. Feed water is supplied from the softner for mineral content in the water so that the potential for scaling can be reduced. Between the water softener there is a silo that serves to temporarily accommodate before the water enters the boiler. The temperature and water discharge are measured from the output of the water softener. The temperature and flue gas flow rate are measured at the boiler control hole and the flow rate is measured at the boiler. This study uses the method of observation, process design, optimization and analysis of the heat exchanger using the full factorial experimental design method of thermal analysis using CFD.

Observations and data collection are carried out directly in the boiler area which has the following specifications:

Equivalent Evaporation : 500 kg/hour

Heating surface : 4.99 m^2

Max working pressure : 10 kg/cm^2

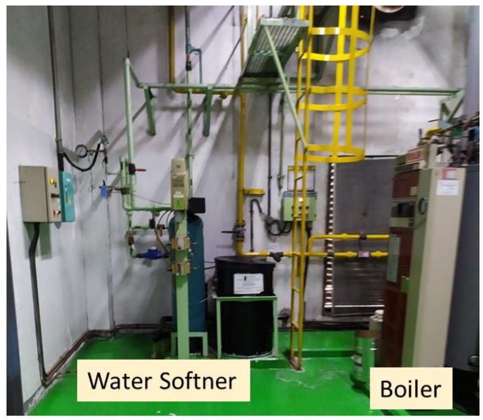

Figure 1. Boiler and Softner Layout

Figure 2. Location of Exhaust Gas Discharge Measurement.

Table 1. Results of Temperature and Flow Rate Measurements

Month	Boiler Number	Data			
		Output exhaust gas		Input feed water	
		Temperature (°C)	Q (kg/s)	Temperature (°C)	Q (kg/s)
April - June	Boiler 1	224	0.326	29	0.1761
April - June	Boiler 2	169	0.326	29	0.1761

Research Stages

In general, the stages of this research can be described in a flow chart as below.

Research Flow

In designing, there are several independent variables used, namely the outer diameter of the pipe (m), the length of the pipe (m), the distance between the pipes and the arrangement of the pipes. To obtain research results that are relevant and in accordance with research procedures, a research flow chart is made. This research diagram is explained in steps as shown in Figure 3.

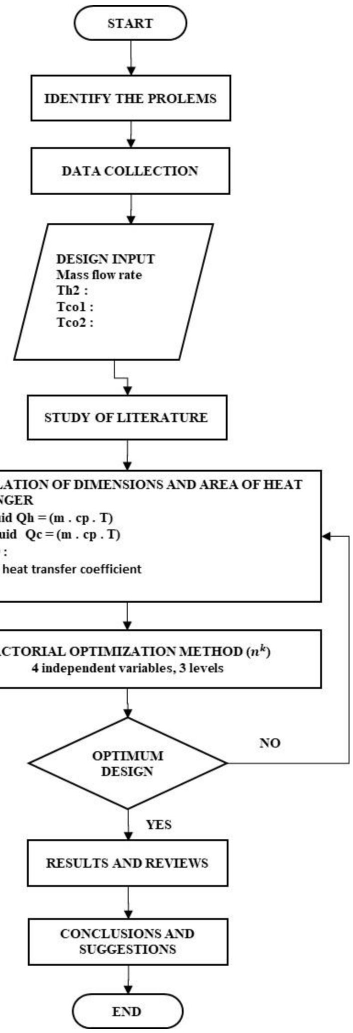

Figure 3. Flowchart of Heat Exchanger Design

The optimization of the design of this heat exchanger was carried out by the full factorial method using four independent variables, namely diameter, length, distance between pipes and pipe angles with three experimental levels in order to obtain 81 count data. The tube material used is SUS304 BWG18 [4-29]. The independent variables to perform design optimization are as follows:

Table 2. Independent Variables and Experiment Level

Code	Independent Variable	Symbol	Level I	Level II	Level III
A	Pipe Outside Diameter (m)	D	0.1270	0.01905	0.0254
B	Long Pipe (m)	L	1.2	1.6	2.0
C	Pitch Tube Ratio	PTR	1.25	1.5	2.0

D	Tube Layout	T	30°	45°	60°

Flowchart Thermal analysis of the heat exchanger using the CFD program is shown in Figure 4.

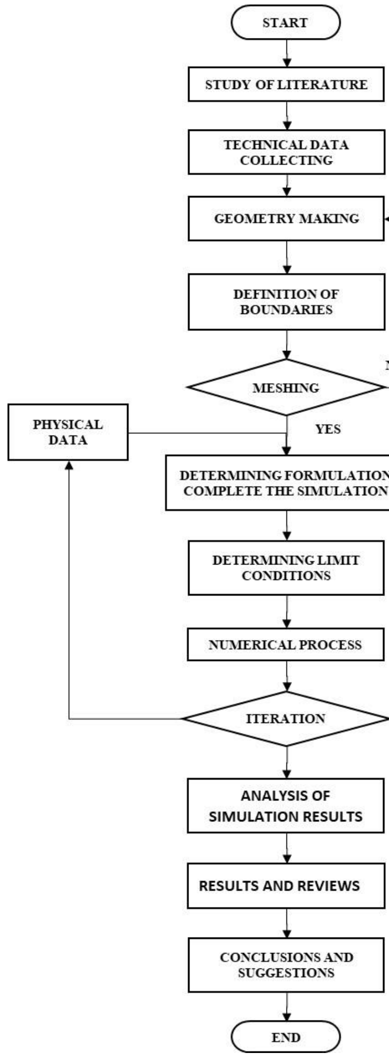

Figure 4. Flowchart of Thermal Analysis of a Heat Exchanger using CFD

Basic Calculation

Energy balance.

The energy equation that occurs between hot fluid and cold fluid is as follows [1,2].

$dq = - m_h c_h dT_h = m_c \, c_c dT_c$

LMTD (Logarithmic Mean Temperature Difference) is a value related to the temperature difference between the hot side and the cold side of the heat exchanger. The LMTD equation is as follows [1,2,3,4].

$$\text{LMTD } (\Delta T_m) = \frac{\Delta T1-\Delta T2}{\ln\frac{\Delta T1}{\Delta T2}} = \frac{\Delta T2-\Delta T1}{\ln\frac{\Delta T2}{\Delta T1}}$$

Overall Heat Transfer Coefficient

Overall heat transfer by a combination of conduction and convection is often expressed in terms of the overall heat transfer coefficient U, determined by the following equation [1,2,3,9].

$$Q = U\ A\ \Delta T_{overall}$$

The overall heat transfer coefficient on the outside or the inside is written with the following equation [1,2,4].

$$Ui = U_o = \frac{1}{\frac{1}{h_o} + \frac{A_o \ln(r_o/r_1)}{2\pi k L} + \frac{A_o}{A_i}\frac{1}{h_i}}$$

Tube side Dimension Calculation

The ratio of the distance between the pipes (tube pitch ratio) [9-242].

$$PR = Pt/do$$

The cross-sectional area of the tube [9-242].

$$Ac = \frac{\pi d_i^2}{4}$$

Pipe surface area (sectional area of the tube) [8,9].

$$A_o = \pi\ d_o N_t\ L$$

The number of pipes (Nt) is calculated based on the value of the coefficients k1 and n1 in table 3 which is Sinot's constant [6,7].

$$Nt = k\left[\frac{Ds}{do}\right]^{n_1}$$

Table 3. Coefficient Values of k_1 and n_1 (MasoudAsadi)

No. of *tube* Phase	Triangular *tube* pitch St=1,25 do		Square *tube* pitch St=1,25 do	
	k1	n1	k1	n1
1	0,3190	2,142	0,215	2,207
2	0,2490	2,207	0,156	2,291
4	0,1750	2,285	0,158	2,263
6	0,0743	2,499	0,0402	2,617
8	0,0365	2,675	0,0331	2,643

Shell side Dimension Calculation

Shell equivalent diameter [4-10]

$D_b = d_o\left[\frac{N_t}{k1}\right]^{1/n_1}$

Shell diameter

$D_s = 0{,}637\left[\frac{Cl}{CT_p}\right]^{0,5}\left[\frac{A\,[PR]^2\,do}{L}\right]^{0,5}$

With Cl [5]:

90 and 45° Cl value 1

30 and 60° Cl value 0.87

With the value of CTp [5]:

One-tube pass : 0.93

Two-tube pass : 0.90

Three-tube pass : 0.85

Shell cross-sectional area [4,5]

$As = \frac{D_b\,C\,B}{P_t}$

Another calculation to get the number of tubes.

$N_t = 0{,}785\left[\frac{CT_p}{Cl}\right]\frac{D_s^2}{[PR]^2[do]^2}$

Shell equivalent diameter [9]

$De = \frac{4\,x\left|P_t^2 - \frac{\pi\,d_o^2}{4}\right|}{\pi\,d_o}$

Tube-side Fluid Properties Calculation

Flow time calculation

Calculation of Reynolds number [5]

$m = \rho\nu\ Ac\left[\frac{N_t}{n}\right]$

Nusselt number.

The Nuselts number equation is highly dependent on the Reynolds number. Referring to the Reynolds number, the number is divided into 3 [1,4].

$Re = \frac{\rho.\nu.d}{\mu}$

Reynolds Number < 2300

$Nu_d = 1.86\ .\ [Re_d\ Pr]^{1/3}\left[\frac{di}{L}\right]^{1/3}\left[\frac{\mu t}{\mu s}\right]^{0.14}$

Reynolds Number 2300 < Re < 10000

Nud = $\frac{[f/8][Re_t - 1000]Pr_t}{1+12.7\ [f/8]^{1/2}[Pr_t{}^{2/3}-1]}\left[1 - \frac{d_i}{L}\right]$

Reynolds Number > 10000

Nud = $\frac{[f/8]Re.Pr}{1.07+12.7\ [f/8]^{1/2}[Pr^{2/3}-1]}\left[\frac{\mu_t}{\mu_s}\right]^n$

Convection heat transfer coefficient [9]

ht $= \frac{Nu_t\ x\ k_t}{dt}$

Shell-Side Fluid Properties Calculation

Flow time calculation

$m_s = \rho_s\ .\ v_s\ .\ A_s$

Calculation of Reynolds number [5]

Res = $\left[\frac{m_s}{A_s}\right]\left[\frac{De}{\mu_s}\right]$

Nusselt number.

The Nuselts number equation is highly dependent on the Reynolds number [4,8].

Nus = $0.36\ Re_s{}^{0.55} Pr_s{}^{1/3}\left[\frac{\mu_t}{\mu_s}\right]^{0.14}$

Convection heat transfer coefficient [9]

ho = $\frac{Nu_s\ x\ k_s}{de}$

Performance Heat Exchanger (HE)

Overall heat transfer coefficient.

$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_1}\frac{d_o}{d_1} + \frac{r_o \ln\left[\frac{r_o}{r_1}\right]}{k}$

Maximum heat transfer possible.

$Q_{max} = (mc)_{min}(T_{h,inlet} - T_{c,inlet})$

Heat exchanger effectiveness

$$\varepsilon = \frac{T_{c,out} - T_{c,in}}{T_{h,in} - T_{c,in}}$$

Calculation of unit transfer rate (NTU) [8-43]

$NTU = UAs / C_{min}$

Global Coefficient of Heat Transfer in Heat Exchangers, U

For the purposes of design calculations, the value of the global heat transfer coefficient, U is initially chosen as suggested from Figure 5 in researchgate.net and Engineers.com, from both the mean U value for energy transfer from gas to water or vice versa is 140 W. /m^{2o}K.

Table 4. Global Heat Transfer Coefficient

Fluids	U W/m^2.K
Water to water	1300-2500
Ammonia to water	1000-2500
Gas to water	10-250
water to compressed air	50-170
Water to lubricating oil	110-340
Light organics to water	370-750
Medium organics to water	240-650
Heavy organics to water	25-400
Steam to water	2200-3500
Steam to ammonia	1000-3400
Water to condensing ammonia	850-1500
Water to Freon-12	280-1000
Steam to gas	25-240
Steam to light organics	490-1000
Steam to medium organics	250-500

III. Results and Discussion

By optimizing 4 independent variables with 3 full factorial experimental levels, 81 combinations were obtained. The combination matrix and the calculation results refer to the equations described in the previous chapter, which can be seen in table 5.

Table 5. Matrix of Optimization Results

No	Do (m)	L (m)	PR	(o),	Ctp'	Cl	Ao	Ds	Nt	Ud	Uc	NTU	ε
1	0.01270	1.2	1.25	30	0.93	0.87	1.897	0.1247	39.6	354	183	2.0	0.264
2	0.01905	1.2	1.25	30	0.93	0.87	2.675	0.1527	37.2	238	130	1.9	0.264
3	0.02540	1.2	1.25	30	0.93	0.87	3.455	0.1763	36.1	180	100	1.9	0.264
4	0.01270	1.6	1.25	30	0.93	0.87	2.530	0.1080	39.6	331	137	2.5	0.264
5	0.01905	1.6	1.25	30	0.93	0.87	3.566	0.1322	37.2	223	97	2.4	0.264
6	0.02540	1.6	1.25	30	0.93	0.87	4.606	0.1527	36.1	168	75	2.3	0.264
7	0.01270	2.0	1.25	30	0.93	0.87	3.162	0.0966	39.6	314	110	3.0	0.264
8	0.01905	2.0	1.25	30	0.93	0.87	4.458	0.1183	37.2	211	78	2.8	0.264
9	0.02540	2.0	1.25	30	0.93	0.87	5.758	0.1366	36.1	159	60	2.8	0.264
10	0.01270	1.2	1.50	30	0.93	0.87	1.318	0.1496	27.5	285	263	1.1	0.264

No	Do (m)	L (m)	PR	(o),	Ctp'	Cl	Ao	Ds	Nt	Ud	Uc	NTU	ε
24	0.02540	1.6	2.00	30	0.93	0.87	1.799	0.2443	14.1	102	193	0.6	0.264
25	0.01270	2.0	2.00	30	0.93	0.87	1.235	0.1545	15.5	196	281	0.7	0.264
26	0.01905	2.0	2.00	30	0.93	0.87	1.741	0.1892	14.5	131	199	0.7	0.264
27	0.02540	2.0	2.00	30	0.93	0.87	2.249	0.2185	14.1	99	154	0.7	0.264
28	0.01270	1.2	1.25	45	0.93	1.00	1.872	0.1398	39.1	331	185	1.9	0.264
29	0.01905	1.2	1.25	45	0.93	1.00	2.657	0.1712	37.0	223	130	1.8	0.264
30	0.02540	1.2	1.25	45	0.93	1.00	3.443	0.1977	36.0	168	101	1.7	0.264
31	0.01270	1.6	1.25	45	0.93	1.00	2.497	0.1211	39.1	311	139	2.3	0.264
32	0.01905	1.6	1.25	45	0.93	1.00	3.542	0.1483	37.0	210	98	2.2	0.264
33	0.02540	1.6	1.25	45	0.93	1.00	4.591	0.1712	36.0	158	76	2.2	0.264
52	0.01270	2.0	2.00	45	0.93	1.00	1.219	0.1733	15.3	180	284	0.7	0.264
53	0.01905	2.0	2.00	45	0.93	1.00	1.730	0.2122	14.4	121	200	0.6	0.264
54	0.02540	2.0	2.00	45	0.93	1.00	2.242	0.2450	14.0	91	155	0.6	0.264
55	0.01270	1.2	1.25	60	0.93	0.87	1.897	0.1247	39.6	354	183	2.0	0.264
76	0.01270	1.6	2.00	60	0.93	0.87	0.988	0.1727	15.5	202	351	0.6	0.264
77	0.01905	1.6	2.00	60	0.93	0.87	1.393	0.2116	14.5	136	249	0.6	0.264
78	0.02540	1.6	2.00	60	0.93	0.87	1.799	0.2443	14.1	102	193	0.6	0.264
79	0.01270	2.0	2.00	60	0.93	0.87	1.235	0.1545	15.5	196	281	0.7	0.264
80	0.01905	2.0	2.00	60	0.93	0.87	1.741	0.1892	14.5	131	199	0.7	0.264
81	0.02540	2.0	2.00	60	0.93	0.87	2.249	0.2185	14.1	99	154	0.7	0.264

From the manual calculation, the optimum value for iteration no.1 and 55 was obtained with the overall heat transfer coefficient value of 354 W/m^{2o}K. The shell and tube heat exchanger construction based on the manual calculation in iteration number 28 is presented in full in table 6.

Table 6. Design of Heat Exchanger Construction

Item	Explanation	Value	Unit
do	Pipe Outside Diameter	12,70	mm
di	Pipe Inner Diameter	10,21	mm
L	Pipe Lenght	1200	mm
C	Pipe clearance	3,18	mm
B	Buffle spacing	50,8	mm
Pt	Tube Pitch	15,875	mm
Cl	Constant Value	0.87	
CTp	Constant Value	0,93	

k	Thermal Conductivitas of Pipe	16,2	W/m °K
ΔTm	Log Mean Temperature average	109,9	°K
Ao	Cross-Sectional area	1,89	m^2
Db	bundle Diameter	99,1	mm
Nb	Number of Bundle	39	
Ds	shell Diameter	124,7	mm
De	Equivalent Diameter	9,18	mm
U	Overall heat transfer coeficient	354	$W/m^{2o}K$
NTU	Net transfer unit	2,0	
ε	Effectiveness of Heat exchanger	26,64	%

Analysis of Visual Validation Results using CFD simulation

In this simulation, data will be obtained in the form of temperature, velocity and pressure distribution visually. The difference in values between areas is seen because there is color degradation and the value can be obtained by comparing it with the standard contour on the left of the image. Figure 6 shows the temperature distribution in the heat exchanger.

Cold fluid enters from the left ($T_{c,i}$) and exits from the right ($T_{c,o}$) and hot fluid enters from the right ($T_{h,i}$) and exits from the left ($T_{h,o}$). From the temperature distribution, it can be seen that the temperature in the cold fluid domain is getting higher and higher from inlet to outlet, while the temperature in the hot fluid domain is getting lower from inlet to outlet as shown in Figure 5.

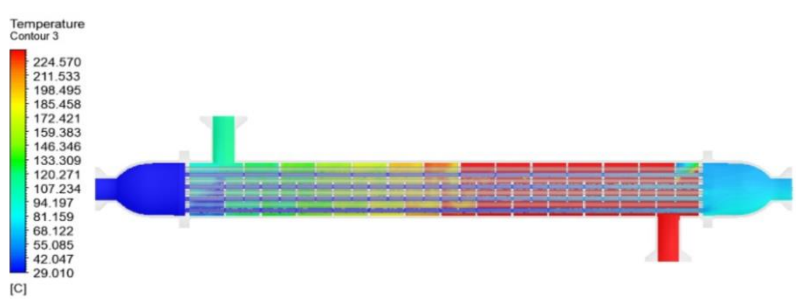

Figure 5. Temperature Distribution in Heat Exchanger

This shows that heat transfer occurs from hot fluid to cold fluid without direct contact, which occurs on the walls of the tubes either by conduction or convection. Comparison of temperature distribution between manual calculations and CFD can be seen in Table 7.

Table 7. Comparison of the Distribution of Manual Calculations and CFD

No	Area	Manual calculation		CFD		Different	
		Tin	Tout	Tin	Tout	Tin	Tout
1	Water	29	80.5	29	76	0	4.5
2	Exhaust Gas	224	110	224	114	0	4.

The output temperature is in the range of 76°C and if we compare it with manual calculations the target is 80.5 °C. This difference is due to the results of visual CFD analysis using a color scale so that it is not an exact number. As for manual analysis, calculations use exact numbers so that there are slight differences in results.

The fluid velocity distribution can be seen in Figure 6. From the velocity distribution, it can be seen that the velocity is relatively high at the buffle turns. This is quite advantageous because the high velocity indicates a high convection heat transfer in the area, so the addition of this buffle increases the effectiveness of heat exchange.

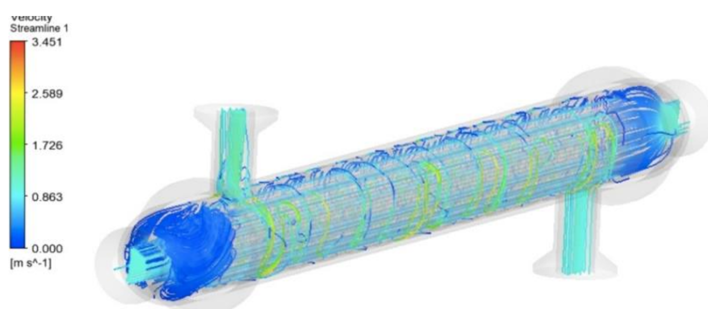

Figure 6. Velocity Distribution on Heat Exchanger

The pressure distribution can be seen in Figure 7. From the Pressure distribution, it can be seen that the pressure gradually decreases from the inlet to the outlet; this is due to the pressure drop either due to friction with the wall or turbulent flow due to the buffle. Significant pressure changes are seen in the water fluid, this is due to the density of water which is much higher than air, and to the decrease in air pressure due to the presence of a lot of buffles.

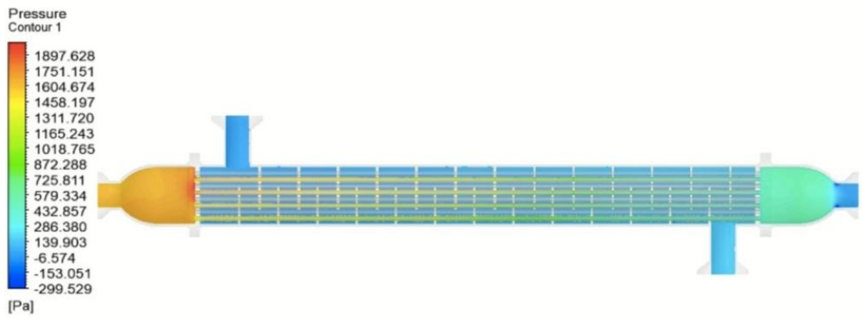

Figure 7. Pressure Distribution in Heat Exchanger

IV. Conclusions

- The performance of the heat exchanger can be seen in the U value and also the NTU value. The value of U which is the largest overall heat transfer coefficient is 354 $W/m^2\ ^oK$ and NTU which is the number of unit transfers 2. The values of Nt and Ds are used as references in selecting the optimization results if there are values that are close to the same. Optimum U and NTU values are also found in optimization number 1 and number 55. At this optimum value, the best design is at conditions at 0.01270 m, pipe length L 1.2 m, pitch tube ratio (PR) 1.25 and pipe lay out angle of 45^oC.
- There is no significant difference between manual calculation and CFD simulation; there is a potential difference due to color degradation readings only. The temperature of the cold fluid input to the heat exchanger is 29^oC, and the hot fluid is 224^oC and after the application of the heat exchanger, the hot fluid temperature is 110^oC and the cold fluid temperature is 80.5^oC. With a flowrate of 0.326 kg/s, the power savings obtained is 37.8 kW, where the energy savings are directly proportional to the time used to operate.

Reference

J. P. Holman, 2010, Department of Mechanical Engineering, Heat Transfer Tenth Edition Southern Methodist University.

Chengel, Yunus A, “Heat Transfer”, McGraw-Hill, New York, 2007

M. Nitsche and R.O. Gbadamosi, 2016, Heat Exchanger Design Guide : Practical Guide for Planning, selecting and designing of shell and tube exchangers, Waltham-USA, Elsevier.

John E. Edwards, Design rating shell and tube heat exchanger, 2008, P & I Design Ltd, Teesside UK.

Kern, Donald Q, 1950, Process Heat Transfer, International Student Edition. McGraw-Hill Kogakusha Ltd, Tokyo, Japan.

D. K. Mohanty. Application of firefly algorithm for design optimization of a shell and tube heat exchanger from economic point of view. International Journal of Thermal Sciences 102 (2016) 228-238.

M. Asadi, Y. Song, B. Sunden, and G. Xie. Economic optimization design of shell-and tube heat exchangers by a cuckoo-searchalgorithm. Applied Thermal Engineering 73 (2014) 1030-1038

JussiSaari, Heat Exchange Dimensioning, Leppeenranta Faculty if Technology, LUT Energy Shell and Tube Heat Exchangers Basic Calculations

Irwin Bizzy, RachmatSetiadi, March 2013, Study of calculation of shell and tube type heat exchanger with heat transfer research inc program. (HTRI), Journal of Mechanical Engineering, Vol. 03, no 01.

Yohanes M. V. Lebo, Gusnawati, JahirwanUtJasron, October 2015, Analysis of the Performance of Shell And Tube Type Heat Exchangers For Cooling Lubricating Oil In Induced Draft Fan Drive Systems, Lontar Journal of Mechanical Engineering

ChandrasaSoekardi, 2015, Analysis of the effect of the effectiveness of heat transfer and thermal resistance on the thermal design of shell and tube heat exchangers, ISSN : 1410-2331 e-ISSN : 2460 – 1217.

JainalArifin, 2017, Full factorial analysis of shell and tube air condenser, UNISKA Mechanical Engineering Journal Vol. 03 No. 01

EkoKiswoyo, Anwar Ilmar Ramadhan, Design and validation of shell and tube type APK designs using computational fluid dynamics, Dinamika Journal of Scientific Engineering, ISSN : 2085-8817.

Sukarman, Yogi SirodzGaos 2018, Optimization of Exhaust Gas Heat Exchanger Design for Degreaser Water Heaters, Scientific Journal of TEKNOBIZ Vol. 8 No.3.

Singh, Sanjay Kumar, and Arvind Kumar. "Experimental study of heat transfer enhancement from dimpled twisted tape in double pipe heat exchanger." *Int. J. Mech. Prod. Eng. Res. Dev* 10 (2020): 469-482.

Jakkula, S. U. B. O. D. H., and G. SRINIVASA Sharma. "Analysis of a cross flow heat exchanger using optimization techniques." *International Journal of Applied Engineering Research and Development (LJAERD)* 4.6 (2007).

Ouardi, E., et al. "A novel approach for thermal designing a single pass counter flow shell and tube heat exchanger." *Int. J. Mech. Prod. Eng. Res. Dev* 10 (2020): 269-280.

Rambabu, V., J. Ramarao, and S. RAVI BABU. "Enhancement of Heat transfer in Shell and Tube heat exchanger by using nano fluid." *International Journal of Mechanical and Production Engineering Research and Development, 7 (5)* (2017): 191-198.

Thakur, G. A. U. R. A. V., and G. U. R. P. R. E. E. T. Singh. "Experimental invistigation of heat transfer characteristics in Al2O3-water based nanofluids operated shell and tube heat exchanger with air bubble injection." *International Journal of Mechanical and Production* 7 (2017): 263-273.

Silaipillayarputhur, Karthik, and Hassan Khurshid. "The design of shell and tube heat exchangers–A review." *International Journal of Mechanical and Production Engineering Research and Development* 9.1 (2019): 87-102.