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ASSESSING AND OPTIMIZING THE PERFORMANCE OF A SHELL AND TUBE HEAT EXCHANGER (E-2502) IN PHOSPHORIC ACID PRODUCTION: A CASE STUDY AT PT. PETROKIMIA GRESIK

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Abstract

PT. Petrokimia Gresik, established with a construction contract on August 10, 1964, stands as Indonesia's most comprehensive fertilizer factory. The company comprises various departments, including the Production Department IIIA, specializing in Phosphoric Acid Production. The objective of assessing the efficiency of a shell and tube cooler-type heat exchanger is to evaluate its performance, determining compliance with design specifications and identifying the need for cleaning and maintenance. The utilized heat exchanger, of the shell and tube type, employs water as its cooling source. According to design calculations conducted between September 13 and September 18, 2023, the expected efficiency of the cooler-type heat exchanger is 91.44%. However, actual data analysis over six days reveals a significant drop in efficiency, registering below 50%. A comparison between design and actual data suggests a decline in efficiency for the E-2502 cooler type. The decrease is attributed to substantial scaling in the E-2502 Heat Exchanger, stemming from the cooled P2O5 Acid solution and resulting in deposition during the heat transfer process. Consequently, it is imperative to initiate a cleaning process for the cooler-type heat exchanger to optimize the heat transfer mechanism.

Keywords: *Heat Exchanger, Cooler, Efficiency.*

1. INTRODUCTION

PT. Petrokimia Gresik stands as Indonesia's most comprehensive fertilizer factory, originally known as the Surabaya Petrokimia Project. Its construction contract, signed on August 10, 1964, took effect on December 8, 1964. This significant project, inaugurated by President HM. Soeharto on July 10, 1972, now marks the anniversary of PT. Petrokimia Gresik. PT Petrokimia Gresik currently occupies an area of more than 450 hectares in Gresik Regency, East Java, the current production capacity exceeds 8.9 million tons per year. This comprises 5 million tons of fertilizer products and 3.9 million tons of non-fertilizer products.PT Petrokimia Gresik is organized into three production units: I A and I B, II A and II B, and III A and III B. The IIIA Production Department, the primary unit producing acid for raw material in Factories I and II, particularly the Phosphoric Acid factory, is of particular focus. The factory encompasses the Phosphoric Acid factory, Sulfuric Acid factory, and ZA II factory. Efficiency assessment of coolers is integral to the IIIA Production Department,

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primarily engaged in acid production. This acid serves as a crucial raw material in Factories I and II, commonly known as the Phosphoric Acid factory. Within the Concentration Unit, tasked with concentrating phosphoric acid solution from 45% to 54% P2O5, cooler efficiency evaluations are conducted. The D-2501 evaporator facilitates water evaporation, circulating it through the E-2501 heater. A portion of the circulating solution is directed to the acid cooler E-2502 tank (TK-2512), producing concentrated Phosphoric Acid.

A heat exchanger facilitates heat transfer between two or more fluids at varying temperatures. The E-2502 shell and tube type, comprising numerous tubes within a cylindrical shell, operates with two fluids – one flowing inside the tube and the other outside. In this study, the Cooler-Chiller type serves to transfer both sensible and latent heat from the fluid, in the form of steam, to the cooling medium, causing a phase change from vapor to liquid. Typically, water or air serves as the cooling medium. The working principle of this unit is indirect contact, signifying heat transfer between hot and cold fluids through a separating wall. Both fluids flow within this system. Alternatively, there is another working principle in heat exchangers known as direct contact, wherein heat transfers between hot and cold fluids directly, without a wall between them.

The heat transfer occurs through the interphase/connection between the two fluids, exemplified by steam flow in direct contact, involving two immiscible liquids, gas-liquid combinations, and solid particles combined with fluids [4]. The E-2502 is a cooler-type heat exchanger designed to cool the acid emerging from Heat Exchanger E-2501 after concentrating phosphoric acid to 52%. This type of heat exchanger, the cooler, is of the shell and tube variety, with cold water circulating through the tubes to cool the product. The E-2502 operates with two units, namely E-2502 A and E-2502 B, both serving the same purpose of cooling the product after the concentration process.

The heat exchanger utilized is of the shell and tube type, using water as a cooling source. With this context, the objective of analyzing the performance of this cooler-type heat exchanger is to ascertain its efficiency. This analysis helps determine whether the equipment requires maintenance or cleaning to prevent any impact on the produced product. Presented below is a block diagram of the Concentration Unit, necessitating a performance analysis of the heat exchanger.

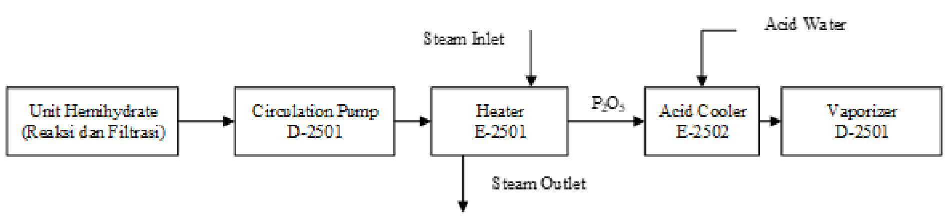

Figure 1. Block Diagram of The Heat Exchanger Equipment Unit E-2502

2. MATERIALS AND METHODS

The efficiency of the E-2502 cooler is determined by analyzing design data gathered at the company and actual data collected from September 13 to September 18, 2023, in the Phosphoric Acid Production Central Control Room.

2.1. Heat Balance Analysis

When analyzing the performance of a Heat Exchanger, key parameters include:

1) Duty (Q)

   Duty refers to the quantity of energy or heat transferred per unit of time. It can be computed for either cold or hot fluids. If the operational duty is less than the duty under design conditions, potential issues such as heat losses, tube fouling, decreased flow rate (for hot or cold fluids), etc., may arise. Duty tends to increase with higher capacity. To calculate the performance of a heat exchanger, you can use the following equation:

$$Q = m \times Cp \times \Delta T \tag{1}$$

2) Log Mean Temperature Difference (LMTD)

   LMTD stands for the logarithmic average temperature difference between the hot and cold streams at the ends of the exchanger. A higher LMTD indicates increased heat transfer. The application of LMTD is derived from analyzing heat exchangers with constant flow rates and consistent fluid thermal properties.

$$LMTD = \frac{\Delta t_h - \Delta t_c}{In\frac{\Delta t_h}{\Delta t_c}} \tag{2}$$

Formula Description:
Q = Amount of heat transfer (Btu/hr)
m = Flowrate (lb/hr)
Cp = Spesific heat fluid (Btu/lb °F)
ΔT = Temperature Difference (°F)
Δth = Difference in hot fluid temperature (°F)
Δtc = Cold fluid temperature difference (°F)

2.2. Fouling Factor Analysis

Rd, or the fouling factor, represents resistance in a heat exchanger designed to mitigate corrosiveness resulting from the interaction between the fluid and the heat exchanger pipe wall. However, over time, Rd accumulates in the form of deposits, which is detrimental to the heat exchanger. A high Rd hinders the rate of heat transfer between the hot and cold fluids. If fouling cannot be prevented, regular cleaning becomes necessary. Various cleaning methods, such as chemical processes for removing carbonate deposits and chlorination, are employed.

$$\mathbf{Rd} = \frac{\mathbf{Uc - Ud}}{\mathbf{Uc - Ud}} \tag{3}$$

If the deposited Rd exceeds the allowed Rd of 0.001 hr.ft^2°F/Btu [6], cleaning is required.

2.3. Analysis of Efficiency

The efficiency of a heat exchanger is determined by the ratio of the actual heat transfer rate within the heat exchanger to the potential heat exchange rate.

$$E = \frac{Qtube}{Qshell} \times 100\% \tag{4}$$

Where:

Q tube = Balance heat in the tube (BTU/hr)

Q shell = Balance heat in the shell (BTU/hr)

2.4. Calculation of Design Data and Actual Conditions E-2502

The design data specifications for the E-2502 were acquired from the IIIA production department archives for conducting design calculations, comparing them with the actual data collected in the Central Control Room from September 13 to September 18, 2023. The table below illustrates the design and actual data for the E-2502 unit:

Table 1. The design data specifications for the Heat Exchanger

	Tube ***P_2O_5 Acid 54 %***	***Shell Side*** ***Acidic Water***
Flowrate (lb/ h)	59762838,96	50909085,04
Density (kg/m^3)	1670	1
Viscosity (lb/ft.h)	3,628	1,693
Conductivity (BTU/hr.ft.°F)	0,215	0,362
Heat Capacity (BTU/lb.°F)	0,54	0,999
Inlet Temperature (°F)	194	149
Outlet Temperature (°F)	105,8	87,8
Number of Passes	5	1
Operating Pressure (Kg/cm^{2}G)	2,3	2
Pressure Drop (Kg/ cm^{2}G)	0,296	
Fouling Resistance (h.m°C/kkal)	0,003	0,0004
LMTD Corrected	32,11	
Bundle	126	
OD tube (in)	2	
ID shell (in)	1,5	
Tube length (in)	236,73	
Tube Pitch (in)	2,27	
Baffle spacing	37,40	

Table 2. Actual data of Heat Exchanger E-2502 Recorded from 13 – 18 September 2023

Date	**Tube P_2O_5 Acid**			**Shell Acidic Water**		
	T_{in} (°F)	***T_{out} (°F)***	***Flowrate (lb/hr)***	***t_{in} (°F)***	***t_{out} (°F)***	***Flowrate (lb/hr)***
13 September	230	176	25291,5	176	141,8	48898,23
14 September	228,2	176	33326,5	167	129,2	48898,23
15 September	226,4	176	30146,3	167	131	48898,23
16 September	230	185	30319,9	167	140	48898,23
17 September	230	194	34404,01	176	154,4	48898,23
18 September	230	194	37009,1	176	161,6	48898,23

3. RESULTS

The results of the design calculations serve as a basis for comparison with the actual data collected at the Central Control Room from September 13 to September 18.

Table 3. The Results of the design calculations Heat Exchanger E-2502

Calculations	*Tube Side (P_2O_5 Acid)*	*Shell Side (Acidic Water)*
Duty (Btu/hr)	2846384494	3112520368
LMTD (°F)	70,0401	
Rd (hr.ft²°F/ Btu)	0,00010838	
Efficiency (%)	91,4495	

Table 3. The Result of Actual Calculations Heat Exchanger E-2502

Date	*Duty*				
	Tube Side (P_2O_5 Acid)	*Shell Side (Acidic Water)*	*LMTD (°F)*	*Rd (hr.ft²°F/ Btu)*	*Efficiency (%)*
13 September	737502,5977	737502,5977	34,7005	0,05905	34,9479
14 September	1101374,384	2286148,727	37,5329	0,04217	48,1759
15 September	966974,0464	2198219,93	36,5969	0,04707	43,9889
16 September	1031484,876	2198219,93	44,736	0,05426	46,9236
17 September	1003221,041	1934433,538	40,13700	0,04989	51,8612
18 September	1079186,51	1582718,349	37,75277882	0,04335	68,1856

The heat exchanger utilized is of the shell-and-tube type with water serving as the cooling source. Based on the design data, the heat received by P2O5 Acid was calculated at 2,846,384,494 BTU/hr, while the coolant received 3,112,520,368 BTU/hr. As a result, heat transfer occurs, experiencing a heat loss of -266,135,874.5 BTU/hr. The efficiency of the cooler-type heat exchanger, obtained from design calculations, is 91.44%, with a fouling factor (Rd) of 0.000108381 Btu/hr.ft². °F. The heat transfer coefficient (Ud) is 972.4326713 Btu/hr. ft². °F. The pressure drop on the shell (acid water) is 1.86 Psi, and the pressure drop on the tube (P_2O_5 Acid) is 4.21 Psi.

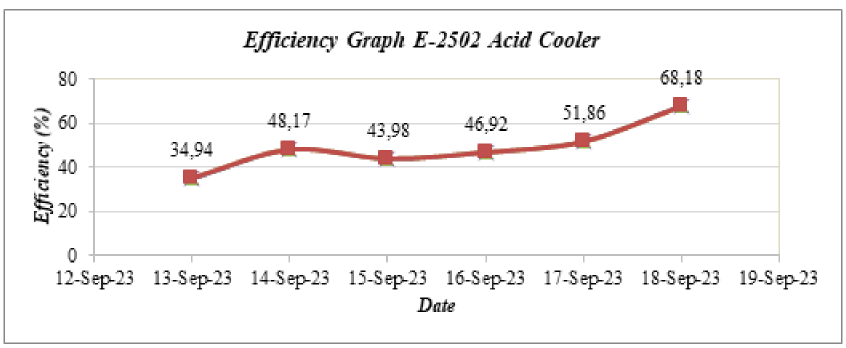

Figure 2. Efficiency Graph of Heat Exchanger E-2502

Referring to Figure 2, the graph illustrating the efficiency of the cooler-type Heat Exchanger indicates daily variations in equipment efficiency. Specifically, the efficiency of E-2502 from September 13 to September 18, 2023, sequentially ranged from 34.94% to 68.18%, accompanied by fouling factor (Rd) values of 0.059 Btu/hr.ft².°F, 0.042 Btu/hr.ft².°F, 0.047 Btu/hr.ft².°F, 0.0542 Btu/hr.ft².°F, 0.049 Btu/hr.ft².°F, and 0.043 Btu/hr.ft².°F, respectively. These data are actual readings obtained from the field conditions experienced by the equipment. Over the six-day period, an average efficiency of 49.01% was computed with a fouling factor (Rd) of 0.04930 Btu/hr.ft².°F. The assessment of this cooler-type heat exchanger's performance involves comparing design data with actual data, serving as a basis for evaluating efficiency. The calculations reveal a decrease in efficiency from design to actual values, with the actual efficiency consistently falling below 50% over the six days. The daily variation in flow rate contributes to this efficiency fluctuation, indicating that higher flow rates result in increased cooler efficiency [13]. Comparing the efficiency values of the E-2502 cooler-type heat exchanger from design to actual data demonstrates a decline. This decline is attributed to the rise in the fouling factor (Rd) from 0.000108381 Btu/hr ft²°F to approximately 0.04930 Btu/hr.ft²°F, surpassing the permissible Rd of 0.001 Btu/hr.ft².°F/Btu. The notable increase in the fouling factor (Rd) in actual calculations significantly influences the efficiency drop, exceeding the allowable limit of 0.001 Btu/hr.ft².°F/Btu.

The Fouling Factor (Rd) indicates the extent of impurity presence, attributed to deposits that introduce additional resistance to heat flow [5]. With prolonged usage, the heat exchanger accumulates fouling on its interior, forming a layer that adds thermal resistance and diminishes the heat transfer rate. This underscores that a lower Fouling Factor (Rd) corresponds to higher efficiency in cooler-type heat exchangers, as it signifies the absence of scaling or dirt buildup from deposition, ensuring optimal heat transfer. Deposition in the heat exchanger may arise when the flowing fluid carries solids. Additionally, fouling factors can be influenced by corrosive chemical processes [1]. In the case of the E-2502 Heat Exchanger, scaling, primarily originating from the cooled P_2O_5 Acid solution, contributes to deposition during the heat transfer process. This, in turn, influences the increase in fouling factor in cooler-type heat exchanger devices. Consequently, it becomes imperative to clean the cooler-type heat exchanger to facilitate an efficient heat transfer process. Mechanical cleaning, specifically the hydro jetting process, involves injecting the heat exchanger with high-pressure water to dislodge deposits adhering to the shell and tube. This cleaning procedure is recommended on a weekly basis.

4. CONCLUSIONS

The IIIA Production Department at PT. Petrokimia Gresik comprises the Sulfuric Acid factory, Phos-phoric Acid factory, and ZA II factory. The cooler-type heat exchanger's efficiency, as per the design, is 91.44%, with a fouling factor (Rd) of 0.000108381 Btu/hr. ft²°F. Actual calculations from September 13 to September 18, 2023, reflect the field conditions experienced by the equipment. Over these six days, an average efficiency of 49.01% was computed, accompanied by a fouling factor (Rd) of 0.04930 Btu/hr. ft²°F. This reveals a decline in efficiency from the design calculation to the actual, with the actual efficiency consistently below 50%. Given this decrease in efficiency, it becomes essential to clean the cooler-type heat exchanger to ensure the optimal functioning of the heat transfer process. Mechanical cleaning, specifically the hydro jetting process, involves injecting the heat exchanger with high-pressure water, facilitating the removal of deposits attached to the shell and tube. This cleaning procedure is recommended on a weekly basis.

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