PERFORMANCE ANALYSIS OF HEAT EXCHANGER AT PHOSPHATE ACID CONCENTRATED UNIT PT PETROCHEMICAL GRESIK

Erwan Adi Saputro
Department of Chemical Engineering, Faculty of Engineering
University of Pembangunan Nasional "Veteran" Jawa Timur
Email: erwanadi.tk@upnjatim.ac.id

Widiya Ningrum
Department of Chemical Engineering, Faculty of Engineering
University of Pembangunan Nasional "Veteran" Jawa Timur
Email: 17031010013@student.upnjatim.ac.id

Muhammad Faishal Ma'arif
PT Petrokimia Gresik
Email: mfaishal@petrokimia-gresik.com

AR Yelvia Sunarti
Department of Chemical Engineering, Faculty of Engineering
University of Pembangunan Nasional "Veteran" Jawa Timur
Email: ar.yelvia.tk@upnjatim.ac.id

ABSTRAK

PT Petrokimia Gresik merupakan perusahaan penghasil pupuk terlengkap dan juga memproduksi bahan baku pembuatan pupuk seperti asam fosfat. Pada pembuatan asam fosfat, teknologi proses yang digunakan adalah Nissan C Process. Salah satu tahapan proses tersebut yaitu unit pemekat konsentrasi asam fosfat. Proses pemekatan konsentrasi ini dibagi menjadi 3 bagian, yaitu penguapan, pendinginan, dan penangkapan gas fluorine. Pada proses penguapan, hal yang terpenting adalah alat penukar panas. Seiring dengan berjalannya waktu, maka perlu diadakan evaluasi kinerja terhadap peralatan yang dipakai sehari-hari, termasuk alat penukar panas. Oleh karena itu studi kasus ini bertujuan untuk mengevaluasi kinerja alat penukar panas yang meliputi tekanan alat penukar panas dengan tekanan yang diizinkan, serta menghitung efisiensi alat penukar panas untuk mentukan apakah alat masih layak untuk digunakan atau tidak. Metode yang digunakan yaitu studi literatur, studi lapangan, analisis dan evaluasi kinerja alat penukar panas. Dari analisis dan perhitungan yang telah dilakukan diperoleh penurunan tekanan pada shell sebesar 0,8817 psi, sedangkan penurunan tekanan pada tube sebesar 4,549 psi, dan effisiensi alat mencapai 82,7%. *Pressure drop* (penurunan tekanan) yang diizinkan adalah 10 psi, sehingga dapat disimpulkan bahwa alat penukar panas yang digunakan pada PT Petrokimia Gresik masih layak digunakan.

Kata kunci: asam fosfat, efisiensi, penukar panas, penurunan tekanan.

ABSTRACT

PT Petrokimia Gresik is the most complete fertilizer producing company and also produces fertilizer raw materials such as phosphoric acid. The process technology used in this company is Nissan C Process. One of the steps in this process is the phosphoric acid concentration unit. This unit consists of several steps such as evaporation, cooling, and fluorine scrubber. In the evaporation process, the most important equipment is the heat exchanger. As time goes by, it is necessary to evaluate the performance of this equipment. So, this case study aims to evaluate the performance of the heat exchanger, including the pressure of the heat exchanger the allowable pressure also to

calculate the efficiency of the heat exchanger to determine whether the equipment is still suitable for use or not. Based on the calculation and analysis, obtained the pressure drop on the shell is 0.8817 psi, the pressure drop on the tube is 4.549 psi, and the efficiency of the equipment is 82.7%. So, it can be concluded that the heat exchanger used by PT Petrokimia Gresik is still suitable for use.

Keywords: *phosphoric acid, efficiency, heat exchanger, pressure drop.*

1. INTRODUCTION

PT Petrokimia Gresik is a fertilizer company in Indonesia, which produces various kinds of fertilizers such as urea, ZA, SP-36, NPK Kebomas, and organic fertilizers such as petrogenic. Besides that, it also produces various types of fertilizers, PT Petrokimia Gresik also produces raw materials for the manufacture of fertilizers, one of which is phosphoric acid. The process used in the manufacture of phosphoric acid is the Nissan C Process. The process consists of several stages, namely a grinding unit, a reaction, and hemihydrate filtration unit, a hydration and filtration unit conversion, a fluorine recovery unit, and a phosphoric acid concentration unit. These stages are very important to achieve the most optimal production.

To obtain P_2O_5 of 54%, the important process is the process concentration of phosphoric acid. In this process, there was an increase in P_2O_5 from $\pm$ 40% to concentrated phosphoric acid P_2O_5 of 54%. The stages in the process of concentrating this concentration are divided into 3, Evaporation Unit, Cooling Unit, and capture of fluorine gas (Fluorine Scrubber). In the evaporation process, a dilute phosphoric acid solution is introduced into a vacuum vessel to form concentrated phosphoric acid. Furthermore, the feed in the form of dilute H_3PO_4 from the filter will enter through the heat exchanger. In the heat exchanger, H_3PO_4 is heated using steam. Then the heated H_3PO_4 will enter the vaporizer. The bottom product that will come out of the vaporizer is concentrated H_3PO_4 (54%), while the top product which consists of water, a small amount of H_3PO_4, and fluorine in the gas are sent to a mist separator to get a product in the form of fluorine gas.

A heat exchanger (HE) is a device used to transfer heat from one system to another without mass transfer and also functions as a heater as well as a cooler [1]. Usually, the heating medium used is water which is heated as a hot fluid, and plain water as cooling water. Heat transfer occurs when there is a temperature difference between two substances, whether solid, liquid, or gas. Energy in the form of heat transfers by 3 kinds of mechanisms conduction, convection, and radiation [2]. Heat exchangers are broadly divided according to the direction of the fluid flow. Based on the direction of fluid flow, heat exchangers are divided into 3 types of flow: parallel flow, counterflow, and crossflow. Based on its use, the heat exchanger consists of a cooler, heat exchanger, reboiler, chiller, and condenser [3]. Heat exchangers are designed with the aim that heat transfer between fluids runs efficiently.

PT Petrokimia Gresik uses a shell and tube-type heat exchanger. Shell and tube heat exchangers are usually used more widely in industries where industrial production systems involve chemical processes, especially in the refining industry. The advantages of Shell and Tube Heat Exchangers are: (1) condensation or boiling heat transfer is easily accommodated, (2) pressure drop can be varied according to capacity, (3) thermal stress can be suppressed, (4) material selection can also be varied [4].

Heat exchangers are included in components or machines in general that have a useful life. The longer the heat exchanger is used, the more residue will accumulate and fouling will occur on the inside of the device. This layer of dirt can cause an increase in thermal resistance and cause the rate of heat transfer in the heat exchanger to decrease [5]. So that it will affect the performance of the heat exchanger and the productivity of the phosphoric acid concentration unit decreases. Therefore, it is necessary to analyze the heat exchanger at PT Petrokimia Gresik, especially the unit of concentration of phosphoric acid.

Several previous studies have analyzed the performance of heat exchangers in various places such as in (1) PT Pupuk Sriwijaya Palembang, (2) PLTU Asam-asam, (3) Integrated Steel Mill (ISM) Krakatau, and (4) PT Semen Kupang [6], [7],[8]. In addition, the analysis of the heat exchanger has also been carried out at PT Petrokimia Gresik at the PHONSKA III Unit and Sulfuric Acid Unit [9], [10]. So there has never been an analysis of a heat exchanger in the Phosphoric Acid Concentration Unit.

At PT Petrokimia Gresik, especially the Phosphoric Acid Concentration Unit, also needs to evaluate the performance of the heat exchanger used daily to support production activities. So, based on the description of the problem, it is necessary to conduct this case study which aims to evaluate the performance of the heat exchanger including the pressure of the heat exchanger with the permissible pressure, and calculate the efficiency of the heat exchanger to determine whether the device is still suitable for use or not [11].

2. RESEARCH METHOD

The efficiency and pressure of the heat exchanger are calculated by conducting a case study by looking for equations from the literature study. After that, the field study of the concentration unit of PT Petrokimia Gresik to collect the data that will be needed. After obtaining these observational data, analyze the pressure and efficiency of the heat exchanger. From problem formulation to decision making, it is modeled in the form of a flow chart (Figure 1) which is expected to be able to explain the steps to be taken.
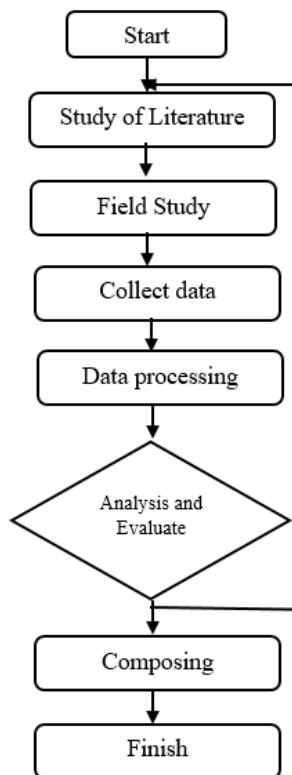

Figure 1 . *Flow chart research*

3. RESULTS AND DISCUSSION

Based on the results of field studies, to determine the feasibility and calculate the efficiency of the heat exchanger, the following data in Table 1 were obtained:

Table 1. Heat exchanger design data

	Shell side	Tube side
Fluid	steam	H_3PO_4
Fluid quantity (Max./Design)	44093	15463223
Temperatur in (ºF)	272.61	190.4
Temperatur out (ºF)	270.25	194.2
Spesific Heat (BTU/lbf)	0.5066	0.5494
Pressure Drop in Allow (psi)	1.45	7.25
Tube Material	Carbon Graphite	
Numer of passes	1	1
Thermal Conductivity (BTU/fthºF)	0.151	0.301
Number of tubes	421	
Outside Diameter Tube (in)	2	
Thickness (in)	0.25	
Length (ft)	20.089	
Pitch of Tube (in)	2.28	
Inside Diameter Shell (in)	68	
Outside DiameterShell (in)	68.625	
Baffle Space	26	
Viscosity H_3PO_4	65	
Latent heat (BTU/lb)	958.7274	

In the data processing, analysis, and evaluation of the heat exchanger design, the results were obtained:

3.1 Heat Balance Analysis

In the heat balance calculation analysis, first analyze the LMTD (Log Mean Difference Temperature), which is used to determine the temperature driving force for heat transfer in flow systems, especially in heat exchangers. The LMTD is the logarithmic average of the temperature difference between the hot and cold streams at the end of the exchanger. The larger the LMTD, the more heat is transferred. The use of LMTD is obtained from the analysis of heat exchangers with constant flow rates and fluid thermal properties. The results of the LMTD calculation analysis on the heat exchanger can use in Equation 1.

$$LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}} \qquad (1)$$

Where:

LMTD = Log Mean Difference Temperature
T_1 = Temperature Hot in (ºF)
T_2 = Temperature Hot out (ºF)
t_1 = Temperature Cold in (ºF)

t_2 = Temperature Cold out (°F)

Based on the analysis of the LMTD calculation on the heat exchanger using the equation, it is obtained as follows.

$$LMTD \ = \ \frac{(T_1-t_2)-(T_2-t_1)}{ln\frac{(T_1-t_2)}{(T_2-t_1)}}$$

$$= \frac{(272.61 - 194.2) - (270.25 - 190.4)}{ln\frac{(272.61 - 194.2)}{(270.25 - 190.4)}}$$

$$= \frac{78.41 - 79.85}{ln\frac{78.41}{79.85}}$$

$$= \frac{-1.44}{-0.018}$$

$$= \ 79.12^oF$$

The heat balance calculation analysis is intended to find the working heat of the tool [12]. In the heat balance, Equation 2 is used as shown [13]:

$$Q = W \times Cp \times (T_1 - T_2) = w \times cp \ (t_2 - t_1) \tag{2}$$

Where:
Q	= Specific heat (Btu/hr)
W	= Hot fluid flow rate (lb/hr)
w	= Cold fluid flow rate (lb/hr)
Cp	= Hot fluid heat capacity (Btu/lb °F)
cp	= Cold fluid heat capacity (Btu/lb °F)
T_1	= Inlet hot fluid temperature (°F)
T_2	= Outlet hot fluid temperature (°F)
t_1	= Inlet cold fluid temperature (°F)
t_2	= Outlet cold fluid temperature (°F)

Based on the results of the calculation of the shell and tube heat balance using this equation, is obtained Q shell as shown below.

$$Q_s \ = \ W_s \ x \ Cp_{steam} \ x \ (T_1 - T_2) \ + \ W_s \ x \ Panas \ Laten$$

$$= \ (44,093 \ x \ 0.151 \ x \ (272.61 - 270.25)) \ + \ 44,093 \ x \ 958.7274$$

$$= \ 15,712.98 \ + \ 42,273,167$$

$$= \ 42288880 \ BTU/hour$$

$$Q_t \ = \ W_t \ x \ Cp_{H3PO4} \ x \ (t_2 - t_1)$$

$$= \ (15,463,223 \ x \ 0.5949 \ x \ (194.2 - 190.4)$$

$$= 34,956,471 \ BTU/hour$$

3.2 Shell Pressure Drop Analysis

Pressure drop is the maximum pressure drop that is allowed in the heat exchanger when a fluid passes through it [14]. The pressure drop will be greater with the increase in the fouling factor in the heat exchanger because it is used for too long. The pressure drop can be calculated using Equation 3:\

$$\Delta P_s = \frac{f \ x \ Gs^2 \ x \ D_s \ x \ N+1}{5,22x1010 \ x \ D_e \ x \ s \ x \ \Phi s} \tag{3}$$

Where:

ΔPs = Total *pressure drop* at *shell* (psi)

f = Friction factor shell (ft2 /in^2) (Fig.26 Kern)

Gs = Mass speed (lb/hr.ft^2)

s = Spec. gravity

N+1 = Number of flow paths through the baffle

Based on the results of the pressure drop shell calculation using this equation, the shell pressure drop is obtained as shown below:

$$V = 14.3981$$

$$s = \frac{1}{V \ x \ 62.5} = 0.00111$$

$$D_s = \frac{ID_{Shell}}{L} = \frac{5.66667 \ ft}{20.089} = 0.28208$$

$$\Delta P_s = \frac{f \ x \ Gs^2 \ x \ D_s \ x \ N+1}{5,22x1010 \ x \ De \ x \ s \ x \ \Phi s}$$

$$= \frac{5,591,508.2}{6,341,700.5}$$

$$= 0.8817 \ psi$$

Based on the results of the shell pressure drop calculation using this equation, a value of 0.8817 psi is obtained. Meanwhile, previous research conducted by Ali Imron (2018) at the Sulfuric Acid Unit obtained a value of 0.510568 psi [9].

3.3 Pressure Drop Tube Analysis

The pressure drop on the tube side heat exchanger has been formulated [6]. Equation 4 for the friction factor of the fluid being heated or cooled in the tube is:

$$\Delta P_t = \frac{f \ x \ Gt^2 \ x \ L \ x \ n}{5,22x1010 \ x \ D \ x \ s \ x \ \Phi t} \tag{4}$$

Where:

ΔP_t = Total *pressure* drop at tube (psi)
f = Friction factor tube (ft2 /in^2) (Fig.26 Kern)
Gs = Mass speed (lb/hr.ft^2)
s = Spec. gravity
n = Number of heat tube

Given that the fluid undergoes bends during its pass, there will be an additional pressure drop loss calculated using the following equation:

$$\Delta P_r = \frac{4xn}{s} x \frac{V^2}{2g} \tag{5}$$

Where:

ΔPr = Return Pressure Drop at tube (psi)
$\frac{V^2}{2g}$ = Velocity head (psi)
s = Spec. gravity

so,

$$\Delta P_T = \Delta P_t + \Delta P_r \tag{6}$$

Based on the results of the calculation of the pressure drop tube using this equation, a value of 4,591 psi is obtained. Meanwhile, previous research was conducted by Ali Imron (2018) at the Sulfuric Acid Unit of PT Petrokimia Gresik obtained a value of 0.2988 psi [9].

3.3 Analysis of Efficiency

The efficiency of the heat exchanger is calculated from the ratio of the actual heat transfer rate in the heat exchanger to the possible heat exchange rate [15].

$$Efficiency = \frac{Q_{tube}}{Q_{shell}} x\ 100\% \tag{7}$$

Where:

Q $_{tube}$ = Balance heat in the *tube* (BTU/hr)
Q $_{shell}$ = Balance heat in the *shell* (BTU/hr)

Based on the results of calculations using this equation, the efficiency of the heat exchanger is 82.7%. Therefore, the heat exchanger is still feasible to use because the efficiency value is above 75%.

In previous studies, the efficiency of the heat exchanger was calculated by comparing the actual heat transfer rate with the maximum heat transfer rate. The results obtained by Jajat Sudrajat who conducted research at the Integrated Steel Mill (ISM) Krakatau were 37.4% in the first period and 33.7% in the final period [8]. While the research results of Irwin Bizzy and Setiadi who conducted research at PT Sriwijaya fertilizer obtained an efficiency of 79% [6].

Different from others, Yohanes Lebo et al researched the performance of heat exchangers at PT Semen Kupang to calculate efficiency by comparing Cmin/Cmax and the results are 28-29% [11].

4. CONCLUSION

Based on the results of the analysis and calculations, the pressure drop on the shell is 0.8817 psi and the pressure drop on the tube is 3.549 psi. While the allowable pressure for the shell is 1.45 psi and the allowable pressure for the tube is 7.25 psi. The efficiency of the heat measuring device is 82.7%. So it can be concluded that the heat exchanger used in PT Petrokimia Gresik Department III A Phosphoric Acid Concentration Unit is still feasible to use.

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