Report of Cooperative Education

The Improvement of Pellet Cooling Water Cooler in Plate Heat Exchanger at Pelletizing Unit

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รายงานสหกิจศึกษาฉบับสมบูรณ์

การปรับปรุงเครื่องลดอุณหภูมิของน้ำตัดเม็ด
ในเครื่องแลกเปลี่ยนความร้อนแบบแผ่นที่หน่วยตัดเม็ด
The Improvement of Pellet Cooling Water Cooler
in Plate Heat Exchanger at Pelletizing Unit

นางสาวทอฝัน หาญอมร

รายงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรบัณฑิต

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Cooperative Title: The Improvement of Pellet Cooling Water Cooler in Plate Heat Exchanger at Pelletizing Unit

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ABSTRACT

This cooperative education project demonstrates to investigate and improve performance of plate heat exchanger in pelletizing unit which is used to reduce temperature of pellet cooling water by cooling water. From investigation, cooling water flow rate was overshooted when operated in fouled condition by cooling pump. The performance of plate heat exchanger with 44, 60, and 74 plate along the operating time were decreased due to operating time because of fouling that was occurred from HDPE fine pellet in pellet cooling water. According to the performance and operating cost that was used to operate in cleaned and fouled condition of each plate, plate heat exchanger with 60 plate has the best performance in this operating condition with the smallest in operating cost equal 988,179 baht per year.

Keywords : Heat Exchanger, Plate Heat Exchanger, Fouling, HDPE, HDPE Production Process

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The cooperators of the cooperative education project hope that this cooperative education program will be useful for educational personnel and general interested parties.

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CHAPTER I

INTRODUCTION

High density polyethylene (HDPE) process, in the pelletizing unit, some HDPE polymer could not be formed into pellet, the non-pellets of HDPE will be remained in the pellet cooling water system resulting in a fouling formation in other related devices and shortening the operating time of those devices.

1.1 Background

High density polyethylene (HDPE) process consists of 5 main units including of catalyst preparation, polymerization, drying and separation, pelletizing, and solvent recovery. In pelletizing unit, polymer powder and stabilizers are charged into homogenizer to mixed and discharged into pelletizer. Molten polymer is moved towards the die plate by gear pump and extruded through the die-hole into the cutter box which pellet cooling water (PCW) is circulated. When PCW is passed through cutter box, PCW will be sent to strainer to separate HDPE pellet from PCW and sent to PCW drum to separate fine particles which composition is stabilizer and HDPE. After that, PCW is moved to plate heat exchanger to reduce temperature with cooling water (CW) and back to cutter box.

Fine particles in the PCW is discharged out of the system by the overflow outlet in PCW drum but fine particles are remained. When PCW was passed through plate heat exchanger to reduce temperature with cooling water, longer operating time, fouling is formed. Due to effects of fouling, operating time of plate heat exchanger is decreased to 1 month before being cleaned with chemical which has cost of cleaning. The performance of plate heat exchanger is needed to investigate.

1.2 Objectives

To investigate and improve performance of plate heat exchanger.

1.3 Scopes of Work

1.3.1 Investigate and improve performance of plate heat exchanger in pelletizing unit.

1.3.2 Investigate from operating data.

1.4 Steps of Work

1.4.1 Unknown variable calculation.

1.4.2 Performance of plate heat exchanger investigation.

1.4.3 Operating cost of each plate calculation.

1.5 Expected Outputs

1.5.1 Operating time of plate heat exchanger is increased.

1.5.2 Performance of plate heat exchanger is investigated.

CHAPTER II

LITERATURE REVIEW

2.1 High Density Polyethylene Process

High density polyethylene (HDPE) is thermoplastic polymer. It is classified from other type of polyethylene by in range of density 0.941 to 0.965 g/cm^3. HDPE has a low degree of branching and stronger intermolecular forces and tensile strength. HDPE can be produced by addition polymerization of ethene with co-monomer such as propylene, butene-1 and with supported metal oxide catalyst including of chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts in a solvent such as hexane or heptane under 50-75 °C and slight pressure. HDPE is used in products and packaging such as milk jugs, detergent bottles, margarine tubs, garbage containers and water pipes. There are 2 methods that most widely used for HDPE process which are slurry or suspension and gas phase polymerization.

2.1.1 Slurry or Suspension Polymerization Process

Slurry process is the most widely used and oldest polymerization method of HDPE production. Slurry processes use either continuous stirred-tank reactors (CSTRs) or loop reactor. Ethylene, co-monomer, catalyst and solvent are fed to reactors for polymerization. After that, slurry is entered to the evaporation unit to remove solvent, unreacted monomers and low polymer. Solvent is separated from low polymer and sent back to reactors. Polymer undergoes to palletization and packaging. The reactor temperature is below melting point of polymer. The use of comonomer in each species such as propylene, 1-butene, or 1-hexene are for the adjustment of the polymer properties. Increasing the comonomer content decreases the crystallinity of the polymer product and decreases the polymer density and melting point. The advantages of a slurry process include mild operating conditions, high monomer conversion, easy for heat removal. Disadvantages include long residence times (1-2.5 h per reactor), and limited production rates of polymers that have relatively low densities that lower than 0.940 g/cm^3 because of resin swelling. (Neeraj P. et al. 2002: 5602)

The Ziegler-Natta catalyst system include a primary catalyst and a co-catalyst. The primary catalyst is a transition-metal salt, with a metal from groups IV to VIII from the periodic table. The co-catalyst is a base-metal halide or alkyl, with a metal from groups I to III. Ziegler-Natta catalysts produce polymers with broad molecular weight distributions because of the chemical properties of the catalyst. (Neeraj P. et al. 2002: 5602)

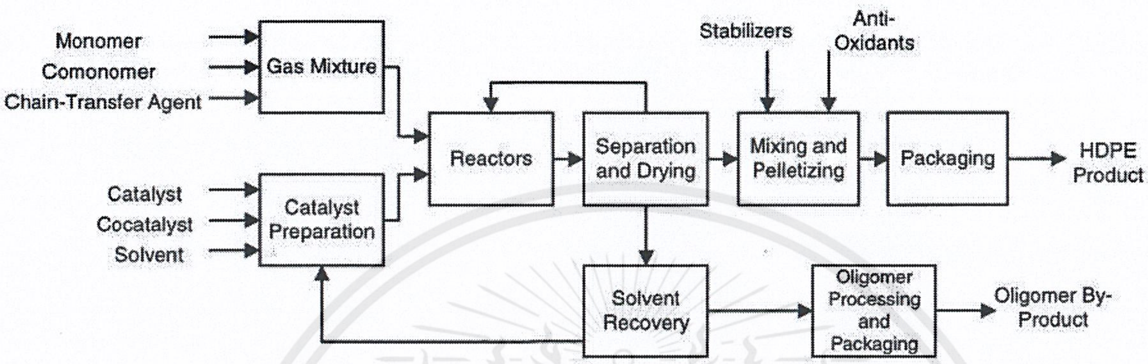

Figure 2.1 HDPE slurry process flow chart. (Neeraj P. et al. 2002: 5602)

2.1.2 Gas Phase Polymerization Process

The unique characteristic of gas phase polymerization is the system does not have any liquid in the polymerization zone. Polymerization occur at the interface between the solid catalyst and the polymer matrix, which is swollen with monomers during polymerization. So, gas phase polymerization is called dry polymerization. (Tuyu Xie et al. 1994:451)

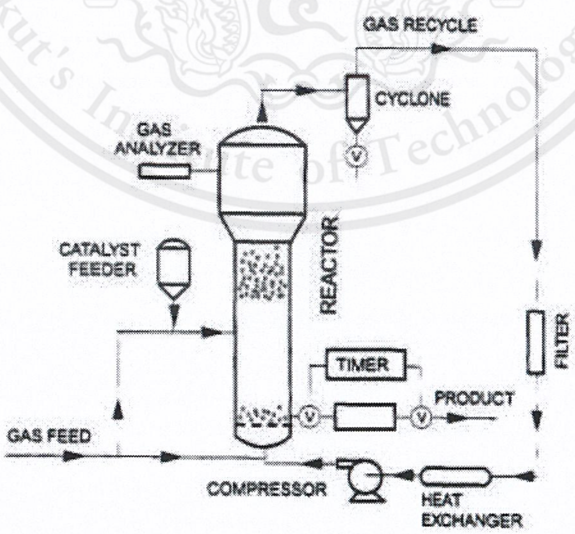

Figure 2.2 - Union Carbide gas phase ethylene polymerization process-UNIPOL (Miller, 1977; Levine and Karol, 1977; Karol and Wu, 1978; Wagner et al., 1981; Jorgensen et al., 1982).

2.2 Plate heat exchanger

2.2.1 Gasketed Plate Heat Exchangers

A gasketed plate heat exchanger consists of a stack of thin plates clamped together in a frame. The edges of plates are sealed by gasket. The thickness of plates is normally between 0.5 and 3 mm, and the gap between plates is 1.5 to 5 mm. Surface area of plate between from 0.03 to 1.5 m^2. The maximum flow rate of fluid is limited to around 2500 m^3/h. The basic layout and flow arrangement for a gasketed plate heat exchanger is shown in Figure 2.3. Corner ports in the plates direct the flow from plate to plate. The plates are embossed with a pattern of ridges, which increase the rigidity of the plate and improve the heat transfer performance. Plates are available in a wide range of metals and alloys, including stainless steel, aluminum, and titanium. A variety of gasket materials is also used; see Table 2.1. (Towler and Sinnott. 2012: 918)

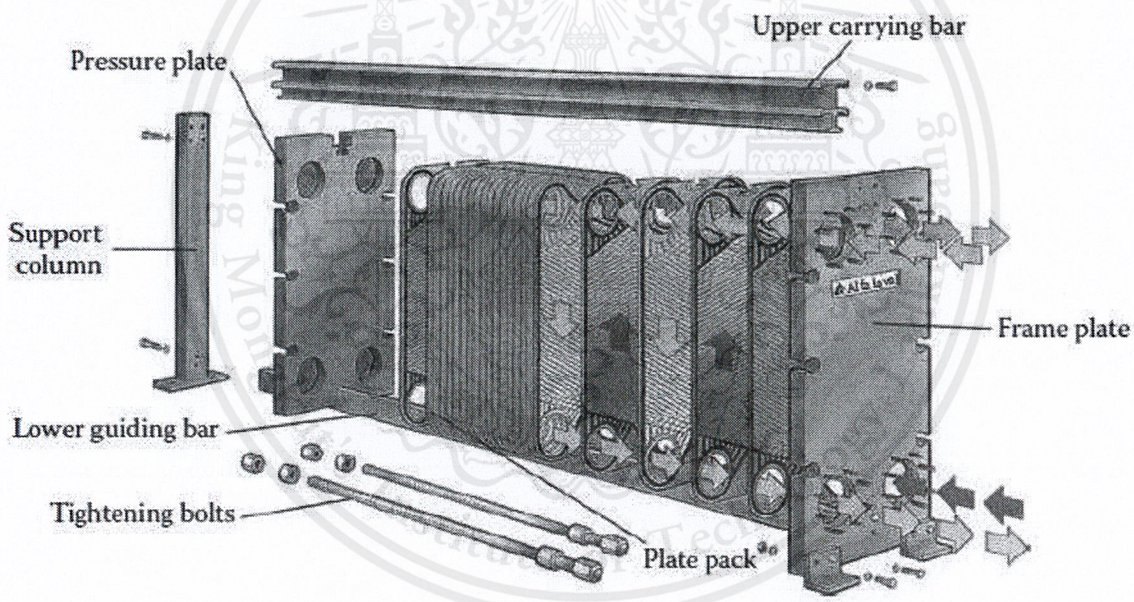

Figure 2.3 - Gasketed plate heat exchanger. (Kakaç, S. et al. 2012:452)

Advantages

1. Plates are interested when the cost of material are high.
2. Plate heat exchangers are easy to maintain.
3. Low approach temperature can be used, as low as 1 °C while 5 to 10°C for shell and tube exchangers.
4. Plate heat exchangers can be adjusted heat transfer area by added extra plate.
5. Plate heat exchangers can be used to exchange heat of viscous fluid.
6. The temperature correction factor (F_t) of plate heat exchangers is normally high, which is higher when the flow is true counter-current flow.
7. Fouling factor in plate heat exchanger has less effect; see table 2.2. (Towler and Sinnott. 2012: 919)

Disadvantages

1. Plate heat exchangers are not suitable for pressures greater than 30 bar.
2. The selection of gasket material is critical; see Table 2.1.
3. The maximum operating temperature is depending on the gasket material. (Towler and Sinnott. 2012: 919)

Table 2.1 - Gasket Materials for Plated Heat Exchangers (Towler and Sinnott. 2012: 920)

Material	Approximate Temperature Limit, °C	Fluids
Styrene-butane rubber	85	Aqueous systems
Acrylonitrile-butane rubber	140	Aqueous system, fats, aliphatic hydrocarbons
Ethylene-propylene rubber	150	Wide range of chemicals
Fluorocarbon rubber	175	Oils
Compressed asbestos	250	General resistance to organic chemicals

Table 2.2 - Fouling Factors (Coefficients), Typical Values for Plate Heat Exchangers (Towler and Sinnott. 2012: 920)

Fluid	Coefficient (W/m^2°C)	Factor (m^2°C /W)
Process water	30,000	0.00003
Towns' water (soft)	15,000	0.00007
Towns' water (hard)	6000	0.00017
Cooling water (treated)	8000	0.00012
Sea water	6000	0.00017
Lubricating oil	6000	0.00017
Light organics	10,000	0.0001
Process fluids	5000–20,000	0.0002–0.00005

2.2.2 Welded Plate Heat Exchanger

Welded plate heat exchangers use plates similar in gasketed plate exchangers, but the plate edges are sealed by welding. This increases the pressure and temperature up to 80 bar and temperatures of 500°C. Leakage of gasketed plate heat exchanger is improved by welded edges but welded plat heat exchanger still compact size but the welded plate heat exchangers cannot be demolished for cleaning. According to the problem, Welded plate heat exchanger is used in the specified application which the exchanger cannot be affected by the effects of fouling. The plates are produced from a variety of materials. A combination between gasketed and welded plate construction is also used. (Towler and Sinnott. 2012: 927)

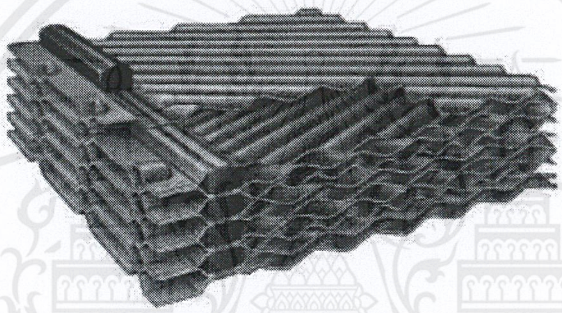

Figure 2.4 - Section of a welded plate heat exchanger.
(Courtesy of Alfa Laval Thermal, Inc., Richmond, VA.)

2.2.3 Plate-Fin Heat Exchanger

Plate-fin exchangers consist essentially of plates separated by corrugated sheets, which form the fins. They are made up in a block and are often referred to as matrix exchangers; see Figure 12.65. They are usually constructed of aluminum and joined and sealed by brazing. The main application of plate-fin exchangers has been in the cryogenics industries, such as air separation plants, where large heat transfer surface areas are needed. They are now finding wider applications in the chemical process industry, where large-surface-area, compact exchangers are required. Their compact size and low weight have led to some use in offshore applications. The brazed aluminum construction is limited to pressures up to around 60 bar and temperatures up to 1508C. The units cannot be mechanically cleaned, so their use is restricted to clean process and service steams. The construction and design of plate-fin exchangers and their applications are discussed by Saunders (1988) and Burley (1991), and their use in cryogenic service by Lowe (1987).

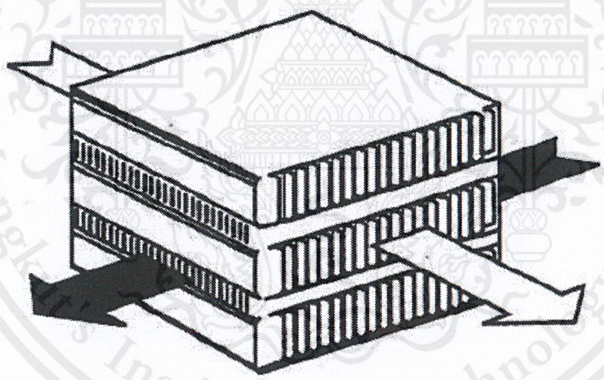

Figure 2.5 – Plate Fin Heat Exchanger (Towler and Sinnott. 2012: 927)

2.2.4 Spiral Heat Exchangers

A spiral heat exchanger consist of plates are formed into a spiral. The fluids are discharged into the channels between the plates. Width of plate between 150 to 1800 mm. Plates are formed into a pair of concentric spiral channels. The ends of channels are closed by gasketed end plates bolted to an outer case. Inlet and outlet nozzles are fitted to the case and connect to the channels; see Figure 2.6. The gap between the sheets varies between 4 and 20 mm, depending on the size of the exchanger and the application. They can be fabricated in any material that can be cold-worked and welded.

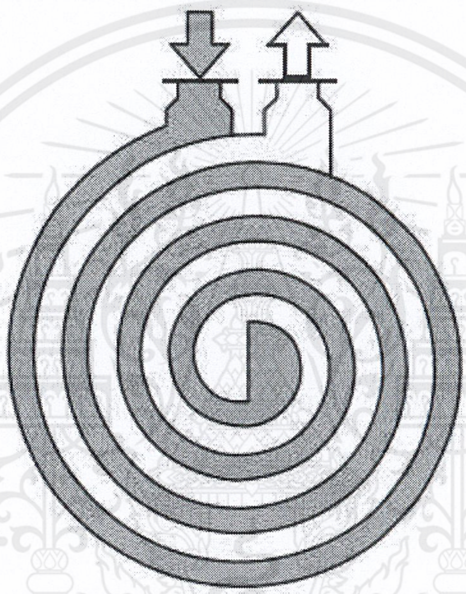

Figure 2.6 - Spiral heat exchanger. (Towler and Sinnott. 2012: 928)

2.3 Basic Design Procedure and Theory

In order to design basic heat exchanger, Heat transfer rate and temperature difference are considered to find heat transfer area of heat exchanger. The equation is shown in equation 2.1 (Towler and Sinnott. 2012: 1048)

$$Q = UA\Delta T_m \tag{2.1}$$

Where Q = heat transferred per unit time, W;

U = the overall heat transfer coefficient, $W/m^2°C$;

A = heat transfer area, m^2;

ΔT_m = the mean temperature difference, the temperature driving force, °C.

Rate of heat transfer can be determined by equation 2.2

$$Q = \dot{m}C_p\Delta T \tag{2.2}$$

Where $\dot{m}$ = mass flow rate, kg/s;

C_p = specific heat capacity, J/kg°C;

ΔT = temperature difference, °C

With the assumption that

1.) No phase changes
2.) Specific heat capacity is constant

In case of changing the fluid phase, rate of heat transfer can be determined by equation 2.3 with the assumption is no changes in fluid temperature. (Kakaç, S. et al. 2012: 300)

$$Q = \dot{m}h_{fg} \tag{2.3}$$

Where $\dot{m}$ = mass flow rate, kg/s;

h_{fg} = latent heat, kJ/kg.

The overall heat transfer coefficient represents the overall resistance to heat transfer, which is the sum of several individual resistances. The relationship between the overall coefficient and the individual coefficients is given by equation 2.2 (Towler and Sinnott. 2012: 1048-1049)

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2k_w} + \left(\frac{d_o}{d_i} \times \frac{1}{h_{id}}\right) + \left(\frac{d_o}{d_i} \times \frac{1}{h_i}\right) \tag{2.4}$$

Where U_o = the overall coefficient based on the outside area of the tube, W/m^{2}°C;

h_o = outside fluid film coefficient, W/m^{2}°C;

h_i = inside fluid film coefficient, W/m^{2}°C;

h_{od} = outside dirt coefficient (fouling factor), W/m^{2}°C;

h_{id} = inside dirt coefficient, W/m^{2}°C;

k_w = thermal conductivity of the tube wall material, W/m^{2}°C;

d_i = tube inside diameter, m;

d_o = tube outside diameter, m.

In order to design heat exchanger, the overall heat transfer coefficient is an unknown value. So, value of overall heat transfer coefficient must be assumed from table 2.1 to estimate heat exchanger area. After that, the heat exchanger is designed to have the desired heat exchanger area. Then calculate the overall heat transfer coefficient obtained from the design and compare with the assumed value. If the value which obtained from the design is less than the assumed value, the new overall heat transfer coefficient will be assumed from the designed value. Then, calculate he desired heat transfer area and redesign it until the designed overall heat transfer coefficient is greater than or equal to the assumed value. (Towler and Sinnott. 2012: 1050-1053)

Table 2.3 The overall heat transfer coefficient for basic heat exchanger (Towler and Sinnott. 2012: 1050-1052)

Shell and tube heat exchangers		
Hot fluid	**Cold fluid**	**U (W/m^2°C)**
Heat exchanger		
Water	Water	800 – 1,500
Organic solvents	Organic solvents	100 – 300
Light oils	Light oils	100 – 400
Heavy oils	Heavy oils	50 – 300
Gases	Gases	10 – 50
Cooler		
Organic solvents	Water	250 – 750
Light oils	Water	350 – 900
Heavy oils	Water	60 – 300
Gases	Water	20 – 300
Gasketed plate exchangers		
Hot fluid	**Cold fluid**	**U (W/m^2°C)**
Light organic	Light organic	2,500 – 5,000
Light organic	Viscous organic	250 – 500
Viscous organic	Viscous organic	100 – 200
Light organic	Process water	2,500 – 3,500
Viscous organic	Process water	250 – 500
Light organic	Cooling water	2,000 – 4,500
Viscous organic	Cooling water	250 – 450

2.4 Plate Heat Exchanger Design

It is not possible to give exact design methods for plate heat exchangers. They are proprietary designs and will normally be specified in consultation with the manufacturers. Information on the performance of the various patterns of plates used is not generally available. Emerson (1967) gives performance data for some proprietary designs, and Kumar (1984) and Bond (1981) have published design data for APV chevron-patterned plates.

The approximate method given here can be used to size an exchanger for comparison with a shell and tube exchanger, and to check performance of an existing exchanger for new duties. More detailed design methods are given by Hewitt et al. (1994) and Cooper and Usher (1983).

The design procedure is similar to shell and tube exchangers design:

1. Calculate duty, the rate of heat transfer required.

2. If the specification is incomplete, determine the unknown fluid temperature or fluid flow rate from a heat balance.

3. Calculate the log mean temperature difference, ΔT_{lm}.

4. Determine the log mean temperature correction factor, Ft; see the method given in this section.

5. Calculate the corrected mean temperature difference, $\Delta T_m = F_t \Delta T_{lm}$

6. Estimate the overall heat transfer coefficient; see Table 2.3.

7. Calculate the surface area required; see equation 2.1.

8. Determine the number of plates required = total surface area/area of one plate.

9. Decide the flow arrangement and number of passes.

10. Calculate the film heat transfer coefficients for each stream; see the method given in this section.

11. Calculate the overall coefficient, allowing for fouling factors.

12. Compare the calculated with the assumed overall coefficient. If it is satisfactory, say -0% to +10% error, proceed. If it is unsatisfactory, return to step 8 and increase or decrease the number of plates.

13. Check the pressure drop for each stream; see the method given in this section. (Towler and Sinnott. 2012: 921)

2.4.1 Flow Arrangement

The stream flows can be arranged in series or parallel, or a combination of series and parallel; see Figure 2.7. Each stream can be subdivided into a number of passes, analogous to the passes used in shell and tube exchangers. (Towler and Sinnott. 2012: 921)

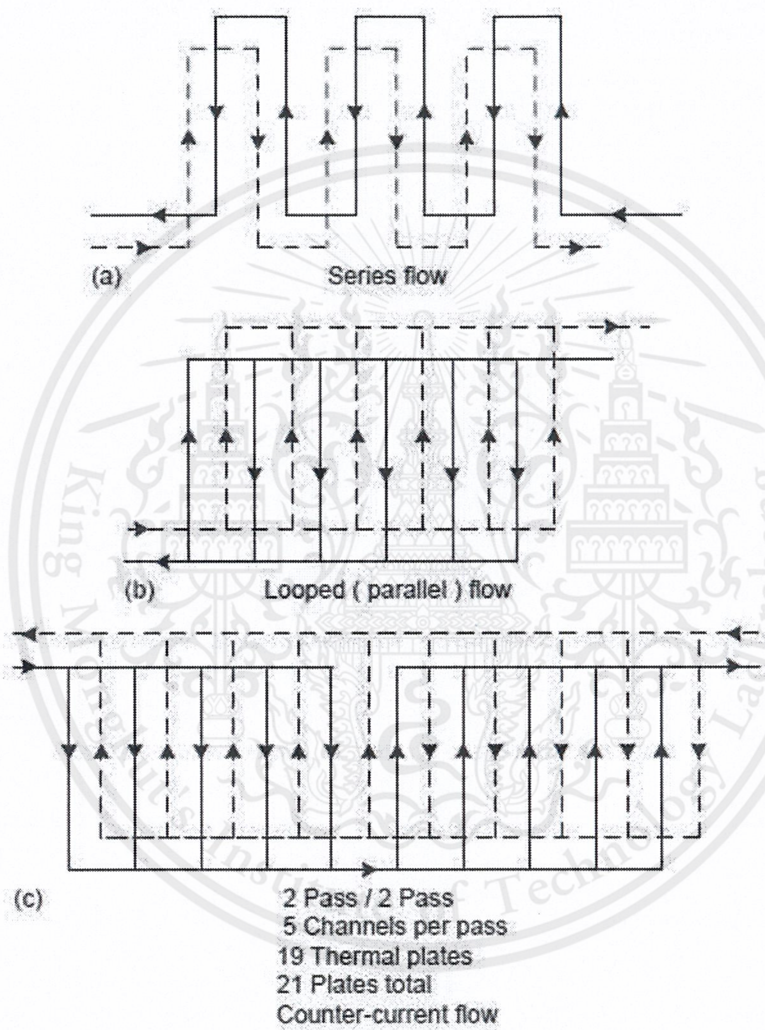

Figure 2.7 – Flow arrangement in plate heat exchanger (Towler and Sinnott. 2012: 922)

2.4.2 Mean Temperature Difference (Temperature Driving Force)

Before equation 2.1 can be used to determine the heat transfer area required for a given duty, an estimate of the mean temperature difference, ΔT_m must be made. This will normally be calculated from the terminal temperature differences: the difference in the fluid temperatures at the inlet and outlet of the exchanger. The well-known ''logarithmic mean'' temperature difference is only applicable to sensible heat transfer in true co-current or counter-current flow (linear temperature-enthalpy curves). For counter-current flow, the logarithmic mean temperature difference is given by

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} \tag{2.5}$$

Where ΔT_{lm} = log mean temperature difference;

T_1 = inlet hot fluid temperature, °C;

T_2 = outlet hot fluid temperature, °C;

t_1 = inlet cold fluid temperature, °C;

t_2 = outlet cold fluid temperature, °C.

The equation is the same for co-current flow, but the terminal temperature differences will be $(T_1 - t_1)$ and $(T_2 - t_2)$. Strictly, equation 2.5 will apply only when there is no change in the specific heats, the overall heat transfer coefficient is constant, and there are no heat losses. In design, these conditions can be assumed to be satisfied, providing the temperature change in each fluid stream is not large.

The mean temperature difference can be calculated from the logarithmic mean temperature by applying a correction factor to allow for the departure from true counter-current flow:

$$\Delta T_m = F_t \Delta T_{lm} \tag{2.6}$$

Where ΔT_m = the mean temperature difference for use in the design equation 2.1;

Ft = the temperature correction factor:

For plate heat exchangers, it is convenient to express the log mean temperature difference correction factor, F_t, as a function of the number of transfer units, NTU, and the flow arrangement (number of passes); see Figure 2.8. The correction will normally be higher for a plate heat exchanger than for a shell and tube exchanger operating with the same temperatures. For rough sizing purposes, the factor can be taken as 0.95 for series flow. The number of transfer units is given by

$$NTU = (t_o - t_i) / \Delta T_{lm} \tag{2.7}$$

Where t_i = stream inlet temperature, °C;

t_0 = stream outlet temperature, °C;

ΔT_{lm} = log mean temperature difference, °C.

Typically, the NTU will range from 0.5 to 4.0, and for most applications will be in between 2.0 to 3.0.

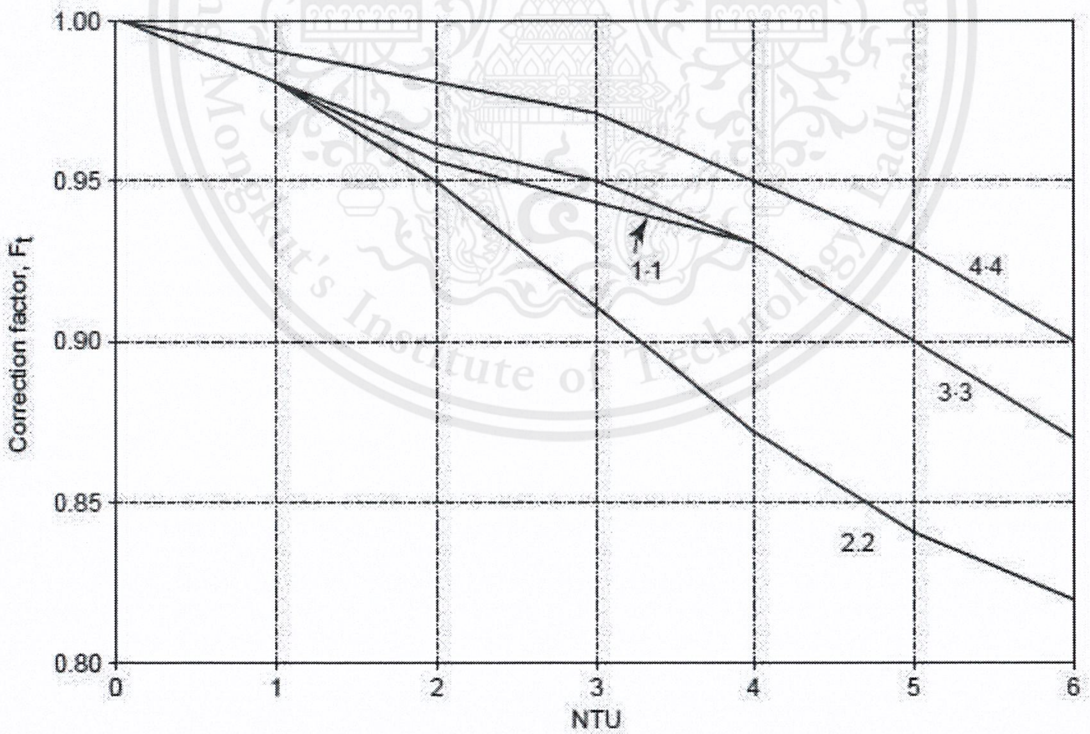

Figure 2.8 - Log mean temperature correction factor for plate heat exchangers [adapted from Raju and Chand (1980)].

2.5 Fouling in Heat Exchanger

After a long period of operation, the heat transfer surfaces in heat exchanger will be coated with various deposits present in the flow systems, or the surfaces may become corroded as a result of the interaction between the fluids and the material that is used for construction of the heat exchanger, resulting in increased thermal resistance and often an increase in the pressure drop and pumping power as well. Both effects complement each other in degrading the performance of the heat exchanger. The heat exchanger may deteriorate to the extent that it must be withdrawn from service for replacement or cleaning. Fouling may significantly influence the overall design of a heat exchanger and may determine the amount of material employed for construction as well as performance between cleaning schedules. Consequently, fouling causes an enormous economic loss as it directly impacts the initial cost, operating cost, and heat exchanger performance. (Kakaç, S. et al. 2012: 237-238)

This coating represents an additional resistance to the heat flow, and thus results in decreased performance. The overall effect is usually represented by a *fouling factor,* or fouling resistance, R_f, which must be included along with the other thermal resistances making up the overall heat transfer coefficient. (J.P,Holman. 2010: 527)

$$R_f = \frac{1}{U_d} - \frac{1}{U_c} \tag{2.8}$$

Where R_f = Fouling factor, m^2K/kW;

U_d = Dirt overall heat transfer coefficient, kW/m^2K;

U_c = Cleaned overall heat transfer coefficient, kW/m^2K

$$\dot{m}_{cold} = \frac{\dot{m}_{hot} C_{p,hot} \Delta T_{hot}}{C_{p,cold} \Delta T_{cold}} \tag{3.1}$$

Cooling water flow rate can be calculated by using equation 3.1 when heat transfer in hot and cold side are equal.

3.2 Plate Heat Exchanger Performance Investigation

3.2.1 Logarithmic Mean Temperature Difference Calculation

Logarithmic mean temperature difference of counter-current flow can be calculated from equation 2.5

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} \tag{2.5}$$

Where ΔT_{lm} = log mean temperature difference;

T_1 = inlet hot fluid temperature, °C;

T_2 = outlet hot fluid temperature, °C;

t_1 = inlet cold fluid temperature, °C;

t_2 = outlet cold fluid temperature, °C.

3.2.2 Temperature Correction Factor Calculation

Log mean temperature difference correction factor, F_t, can be expressed as a function of the number of transfer units, NTU follow equation 2.7, and the flow arrangement (number of passes) as shown in Figure 2.8.

$$NTU = (t_0 - t_i) / \Delta T_{lm} \tag{2.7}$$

Where t_i = stream inlet temperature, °C;

t_0 = stream outlet temperature, °C;

ΔT_{lm} = log mean temperature difference, °C.

3.2.3 Mean Temperature Difference Calculation

The mean temperature difference can be calculated from the logarithmic mean temperature by applying a correction factor follow equation 2.6

$$\Delta T_m = F_t \Delta T_{lm} \tag{2.6}$$

Where ΔT_m = the mean temperature difference;

F_t = the temperature correction factor:

3.2.4 Overall Heat Transfer Coefficient Calculation

Overall Heat Transfer Coefficient can be calculated from equation 2.1

$$Q = UA\Delta T_m \tag{2.1}$$

3.3 Operating Cost Calculation

Operating cost in this work is cost of power of cooling pump when operate in cleaned and fouled condition

3.3.1 Power of Cooling Pump Calculation

Cooling pump does not discharge cooling water directly to plate heat exchanger. So, the equation from cooling pump performance curve is required.

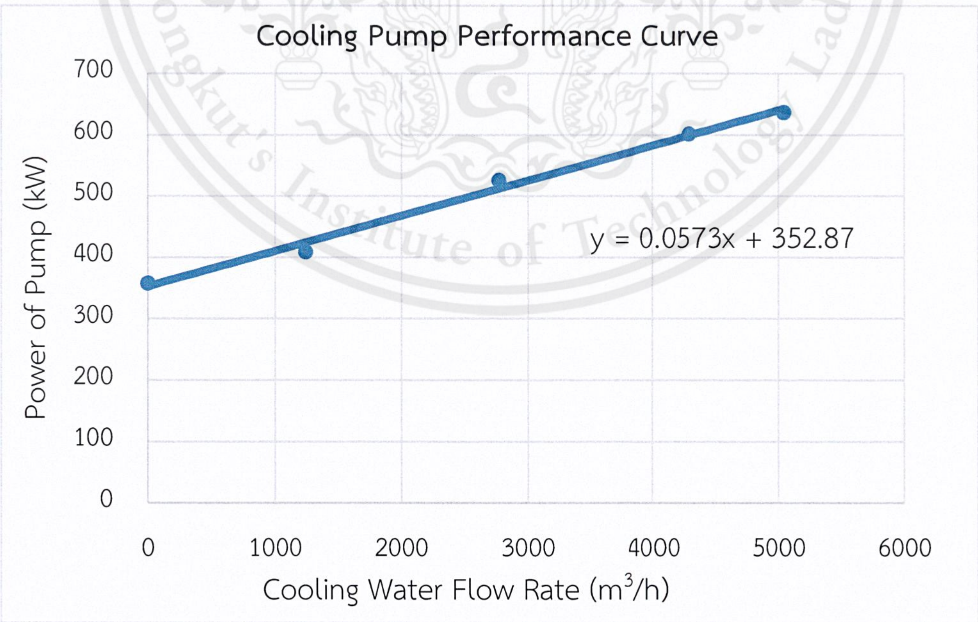

Figure 3.2 – Cooling pump performance curve

Power of cooling pump in each condition can be calculated from equation 3.1 by adding cooling flow rate in the equation to get power of pump in each condition.

$$y = 0.0573x + 352.87 \tag{3.1}$$

Where y = power of cooling pump (kW);

x = cooling water flow rate (m^3/h).

3.3.2 Operating Cost Calculation

Operating cost can be calculated from equation 3.2

$$\text{Cost (THB)} = \text{Power (kW)} \times \text{Operating Time (h)} \times 2.87\ (\text{THB/kW}\cdot\text{h}) \tag{3.2}$$

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Results of Basic Calculation of Heat Exchanger

Basic calculation of heat exchanger started from collected operating data including of operating time of plate heat exchanger, inlet and outlet temperature, volumetric flow rate of pellet cooling water and cooling water but cooling water flow rate was not recorded. So, cooling water flow rate calculation is required. Then, cooling water flow rate in plate heat exchanger with 44, 60, and 74 plate are obtained as shown in figure 4.1.

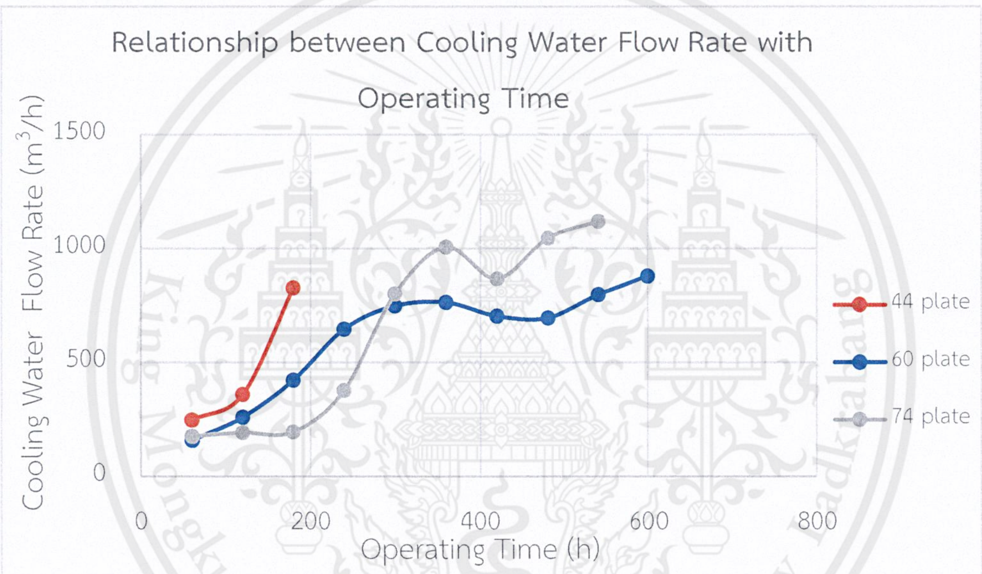

Figure 4.1 – Relationship between cooling water flow rate with operating time of plate heat exchanger with 44, 60, and 74 plate.

In the beginning, cooling water flow rate of plate heat exchanger with 44 plate was highest due to smallest in heat transfer area. But the operating time was too short because outlet temperature of pellet cooling water in plate heat exchanger with 44 plate increased rapidly resulting to stop using plate heat exchanger with 44 plate. After that, cooling water flow rate was increased to maintained pellet cooling water temperature when fouling was occurred. In long term of operating, cooling water flow rate in plate heat exchanger with 60 and 74 plate were overshoot because cooling pump discharged excess cooling water to plate heat exchanger in fouled condition but in plate heat exchanger with 74 plate is higher than 60 plate due to effect of pressure drop in 74 plate that more than in 60 plate.

4.2 Performance of Plate Heat Exchanger

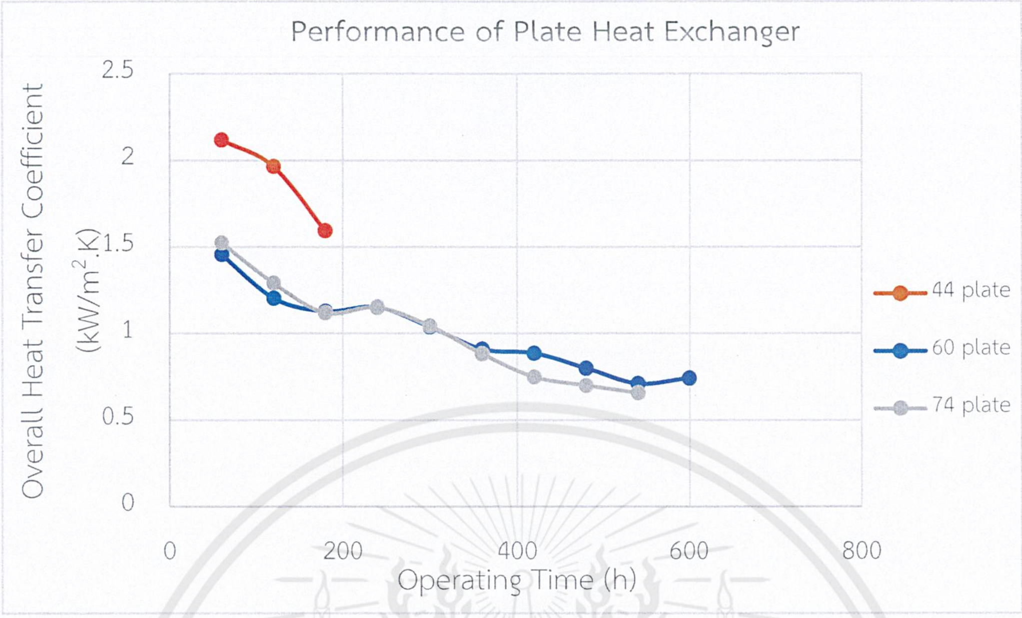

Figure 4.2 – Relationship between overall heat transfer coefficient with operating time of plate heat exchanger with 44, 60, and 74 plate

The performance of plate heat exchanger is described by overall heat transfer coefficient of each number of plates that are plotted with operating time as shown in figure 4.2. The performance of each number of plates was decreased due to increasing in operating time because of effects of fouling. The overall heat transfer coefficient of plate heat exchanger with 44 plate was highest because plate heat exchanger with 44 plate has the smallest exchanger area and highest in cooling water flow rate. In plate heat exchanger with 74 and 60 plate, overall heat transfer coefficient is almost the same because plate heat exchanger with 60 plate are suitable to operate even if the number of plates increase, there is no change in performance.

4.3 Results of Operating Cost Calculation

To obtain operating cost of cooling pump, power of cooling pump is required from cooling pump performance curve. Data of plate heat exchanger with 44 plate could not be used because fouled condition could not be reached. So, only plate heat exchanger with 60 and 74 plates are compared.

4.3.1 Power of Cooling Pump

Table 4.1 – Power of cooling pump

Plate	Cooling Water Flow Rate (m^3/h)		Power of Cooling Pump (kW)		
	Cleaned	Fouled	Cleaned	Fouled	Difference
60	159.47	910.59	362.00	405.04	43.03
74	139.25	1,162.1	360.84	419.46	58.60

Power difference of cooling pump in plate heat exchanger with 60 and 74 plate are obtained as shown in table 4.1. Power difference in plate heat exchanger with 60 plate is less than in plate heat exchanger with 74 plate because of effects of fouling in channel. During fouled condition, pressure drop in process side was increased by increasing in fouling affected to decreasing in heat transfer. So, cooling water flow rate must be increased to maintained temperature of pellet cooling water in process side. According to the results in plate heat exchanger with 60 and 74 plate, cooling water flow rate in plate heat exchanger with 74 plate more than in 60 plate resulting to higher in power difference than in 60 plate.

4.3.2 Operating Cost

Table 4.2 – Operating cost of cooling pump

Plate	Operating Cost Difference	
	(Baht/h)	(Baht/y)*
60	123.52	988,179
74	168.20	1,345,669

*8,000 hours in service

The difference in operating cost when plate heat exchanger was operated at cleaned and fouled condition are shown in table 4.2. Plate heat exchanger with 60 plate has smaller in difference in operating cost due to smaller power of cooling pump difference as shown in table 4.1 which can save operating cost than operated by plate heat exchanger with 74 plate.

CHAPTER V

CONCLUSION

5.1 Conclusion

The performance of plate heat exchanger in pelletizing unit that is used to reduce temperature of pellet cooling water by cooling water is investigated. From the results of investigation, cooling water flow rate in fouled condition of plate heat exchanger with 60 and 74 plate was overshoot because of effects of fouling. Amount of fouling is higher, excess cooling water was discharged to plate heat exchanger. The performance of plate heat exchanger with 44, 60, and 74 plate along the operating time was decreased because of fouling was formed in process side. According to the performance and operating cost that was used to operate in cleaned and fouled condition of each plate, plate heat exchanger with 60 plate has the best performance in this operating condition with the smallest in operating cost difference equal to 988,179 baht per year.

5.2 Suggestions

1. For accurate results of this work, more operating data of other plate are required.
2. Plate detail such as plate angle or pitch are required for more accurate results.
3. Operating cost should be calculated from all operating cost include cleaning cost or other related cost.

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APPENDIXS

Examples of Calculation

Operating variables of plate heat exchanger with 44 plate at operating time 60 hours are used to calculated in example of calculation.

1. Basic Calculation of Heat Exchanger

1.1 Heat Transfer Rate Calculation

Heat transfer rate of hot steam equal to cold steam. So, heat transfer rate can be determined from hot side.

$$Q_{hot} = \dot{m}_{hot} C_{p,hot} \Delta T_{hot}$$
$$= (144.49\ kg/s)(4192.9\ J/kg^{o}C)(81.78 - 71.56\ ^{o}C)$$
$$= 4905.89 kW$$

1.2 Unknown Variable Calculation

$$Q_{cold} = Q_{hot}$$
$$\dot{m}_{cold} C_{p,cold} \Delta T_{cold} = \dot{m}_{hot} C_{p,hot} \Delta T_{cold}$$
$$\dot{m}_{cold} = \frac{\dot{m}_{hot} C_{p,hot} \Delta T_{hot}}{C_{p,cold} \Delta T_{cold}}$$
$$\dot{m}_{cold} = \frac{(144.49\ kg/s)(4192.9 J/kg^{o}C)(81.78 - 71.56\ ^{o}C)}{(4178 J / kg^{o}C)(48.22 - 31.02^{o}C)}$$
$$\dot{m}_{cold} = 68.23 kg / s$$

2. Plate Heat Exchanger Performance Investigation

2.1 Logarithmic Mean Temperature Difference Calculation

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}}$$
$$\Delta T_{lm} = \frac{(81.78 - 48.22) - (71.56 - 31.02)}{\ln \frac{(81.78 - 48.22)}{(71.56 - 31.02)}}$$
$$\Delta T_{lm} = 38.94$$

Operating Condition

- **Operating condition of plate heat exchanger with 44 plate**

Operating time (h)	Cooling Water		Pellet Cooling Water		
	Inlet Temperature (°C)	Outlet Temperature (°C)	Inlet Temperature (°C)	Outlet Temperature (°C)	Flow Rate (m^3/h)
0					
60	31.02	48.22	81.78	71.56	423.23
120	30.46	42.55	82.00	71.56	422.58
180	31.05	36.17	86.83	76.67	425.53

- **Operating condition of plate heat exchanger with 60 plate**

Operating time (h)	Cooling Water		Pellet Cooling Water		
	Inlet Temperature (°C)	Outlet Temperature (°C)	Inlet Temperature (°C)	Outlet Temperature (°C)	Flow Rate (m^3/h)
0					
60	29.50	54.33	83.67	74.67	445.02
120	29.82	44.44	83.78	75.00	440.83
180	29.97	39.00	83.87	75.00	437.99
240	30.42	36.70	85.10	75.60	435.73
300	29.97	35.20	87.10	77.88	433.08
360	29.73	34.40	88.20	79.80	433.85
420	27.56	32.70	88.50	80.00	435.04
480	27.93	32.70	89.20	81.40	435.12
540	28.89	32.67	90.56	83.44	433.80
600	28.64	32.30	91.80	84.15	431.10

- **Operating condition of plate heat exchanger with 74 plate**

Operating time (h)	Cooling Water		Pellet Cooling Water		
	Inlet Temperature (°C)	Outlet Temperature (°C)	Inlet Temperature (°C)	Outlet Temperature (°C)	Flow Rate (m^3/h)
0					
60	30.67	55.17	80.00	70.17	446.11
120	30.56	50.83	78.67	69.83	448.21
180	30.51	48.55	78.00	70.00	445.18
240	30.73	41.56	79.33	70.00	445.91
300	30.64	35.80	80.60	71.20	448.16
360	30.92	35.00	87.67	78.33	449.18
420	30.97	35.22	90.22	81.78	446.88
480	31.64	35.00	91.30	83.20	444.10
540	31.39	34.40	91.80	84.00	441.76

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  (5th August 2019 – 22nd November 2019)