The process heat exchangers engineering essay

In this chapter, a full unit of heat exchanger will be designed including its chemical and mechanical design. A heat exchanger is a device built for efficient heat transfer between two fluids from one medium to another. The medium may be separated by a solid wall, so that the fluids never mix, or the fluids may never be in direct contact. Two fluids of different temperatures will flow through the heat exchanger. Heat exchangers are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing.

3. 1. 1 Classification of Heat Exchanger

Heat exchangers may be classified according to their flow arrangement. There are two main flow arrangements which are parallel-flow and counter-current-flow. In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. Compared both flow arrangements, the counter current design is most efficient, in that it can transfer the most heat from the heat transfer medium.

3. 1. 2 Types of Heat Exchanger

There are many types of heat exchanger in industry. The types chosen based on the function of the heat exchanger itself. Choosing the right heat exchanger requires knowledge of different type of heat exchanger as well as well as the environment in which the heat exchanger will operate. With sufficient knowledge of heat exchanger types and operating requirements, the best selection can be made in optimizing the process. Below, in Table 3. 1 are list of types and functions of each heat exchanger.

Table 3. 1: Types and Functions of Heat Exchanger in Industry

No.	Types	Functions
1.	Double pipe heat exchanger	The simplest type. Use for heating and cooling.
2.	Shell and tube heat exchanger	Used for all application.
3.	Plate exchanger	Use for heating and cooling.
4.	Plate-fin exchanger	Use for heating and cooling.

5.

Spiral heat exchanger

Use for heating and cooling.

6.

Air cooled

Cooler and condenser.

7.

Direct contact

Cooling and quenching.

8.

Agitated vessels

Use for heating and cooling.

9.

Fired heaters

Use for heating and cooling.

Source: Chemical Engineering Design, R. K. Sinnott.

3. 1. 3 Selections of Heat Exchanger

Typically in the manufacturing industry, several different types of heat exchangers are used for just the one process or system to derive the final product. In order to select an appropriate heat exchanger, one would firstly consider the design limitations for each heat exchanger type. Although cost is often the first criterion evaluated, there are several other important selection criteria which include:

High/ Low pressure limits

Thermal Performance

Temperature ranges

Product Mix (liquid/liquid, particulates or high-solids liquid)

Pressure Drops across the exchanger

Fluid flow capacity

Clean-ability, maintenance and repair

Materials required for construction

Ability and ease of future expansion

3. 2 BASIC PRINCIPLES OF DESIGN

3. 2. 1 Design Criteria for Process Heat Exchangers

There are some criteria that a process heat exchanger must satisfy are easily enough stated if we confine ourselves to a certain process. The criteria include:

The heat exchanger must meet the process requirements. This means that it must effect the desired change in thermal condition of the process stream within the allowable pressure drops. At the same time, it must continue doing this until the next scheduled shut down for maintenance.

The heat exchanger must withstand the service conditions of the environment of the plant which includes the mechanical stresses of installation, startup, shutdown, normal operation, emergencies and maintenance. Besides, the heat exchanger must also resist corrosion by the environment, processes and streams. This is mainly a matter of choosing materials of construction, but mechanical design does have some effect.

The heat exchanger must be maintainable, which usually implies choosing a configuration that permits cleaning and replacement. In order to do this, the limitations is the positioning the exchanger and providing clear space around it. Replacement usually involves tubes and other components that may be especially vulnerable to corrosion, erosion, or vibration.

The cost of the heat exchanger should be consistent with requirements. Meaning of the cost here implement to the cost of installation. Operation cost and cost of lost production due to exchanger malfunction or unavailable should be considered earlier in the design.

The limitations of the heat exchanger. Limitations are on length, diameter, weight and tube specifications due to plant requirements and process flow.

3. 2. 2 Structure of the Heat Exchanger

The basic structure of heat exchanger is the same whether using hand design method or computer design method. The logical structure of the heat exchanger design procedure is shown in Figure 2. 15. From the figure, clearer view and steps of designing a heat exchanger can be obtained.

Figure 3. 1: Basic Logical Structure of Heat Exchanger Design

3. 3 CHEMICAL DESIGN

3. 3. 1 Problem Identification

In designing a heat exchanger in production of 100, 000 metric tonnes/year of Acrylonitrile, there is only one heat exchanger exists. The function of it is to exchange the temperature between the stream from Reactor with the temperature from 125°C to 25°C and the stream comes from Reboiler 5 from 90°C to 120°C.

90. 0 0C

125. 0 0C

450. 0 0C

120. 0 0C

Figure 3. 2: Diagram of shell and tube heat exchanger

3. 3. 2 Determination of physical properties

Table 3. 2: Physical Properties of the tube side fluid (water)

Properties

Inlet

Mean

Outlet

Temperature (0C)

90. 0

105

120

Pressure (kPa)

70. 139

120. 82

198. 52

Specific heat (kJ/kg0C)

4. 204

4. 224

4. 249

Thermal conductivity (W/m0C)

0. 1154

0. 1198

0. 1127

Density (kg/m3)

0. 431

0. 623

0. 721

Viscosity (N sm-2)

3. 145 x 10-4

2. 677 x 10-4

2. 321 x 10-4

Table 3. 3: Physical Properties of shell fluid (process fluid)

Properties

Average Temperature, Tave = 287. 5 0C

Pressure (kPa)

150

Specific heat (kJ/kg0C)

1. 1

Thermal conductivity (W/m0C)

0. 1553

Density (kg/m3)

1. 255

Viscosity (N sm-2)

4. 529 x 10-4

Only the thermal design will be carried out by using Kern's method. Since water is corrosive, so the tube-side is assign.

Logarithmic mean temperature,

Where, T1 = Inlet shell side fluid temperature

T2 = Outlet shell side fluid temperature

t1 = Inlet tube side fluid temperature

t2 = Outlet tube side fluid temperature

Thus, Log mean temperature

= 131. 4477 0C

The true temperature difference is given by,

Where, is the temperature correction factor

From Figure 12. 19, Chemical Engineering Design,

Thus,

0C

From Table 12. 1(Sinnott 2005), we assume value of overall coefficient, U = 500. 0 W/m2. oC.

Heat Load:

Heat transfer area,

Where, Q = heat transferred per unit time (W)

U = overall heat transfer coefficient,(W/m2. oC)

Tm = the mean temperature difference (oC)

Thus,

= 190. 126 m2

3. 3. 3 Tube-side coefficient

Table 3. 4: Dimension of Heat-Exchanger tubes

Material

Carbon Steel

Outer diameter, Dto (mm)

50. 8

Length of tube Lt (m)

5. 0

Inner diameter, Dti (mm)

45. 26

BWG number

12. 0

Source: Transport Processes and Separation Process Principles, C. J. Geankoplis

Heat transfer area of a tube, At = πDoL

= π (50. 8 x 10-3) 5

= 0. 798 m2

Number of tube, Nt = A/At

= 190. 126 / 0. 798

= 238. 25 = 239 tubes

Cross sectional area of a tube = (πDi2) / 4

= [π (45. 26 x 10-3)2]

4

= 1. 6089 x 10-3 m2

By using two passes;

Total tube area, AT = (239 / 2) (1. 6089 x 10-3)

= 0. 1923 m2

Mass velocity, Gs = flowrate / A

= 29. 96 / 0. 1923

= 155. 798 kg/m2. s

Reynolds number, Re = [Gsdi] / μ

= [155. 798 x 0. 04526] / 4. 529 x 10-4

= 1. 557 x 10 4

Prandtl number,

= [3. 1731 x 155. 798] / 0. 1553

= 3183. 275

Nusselt number, NuD = 0. 027 Rea Prb [μ / μw]c

= 0. 027 (1. 557 x 10 4)0. 8 (3183. 275)0. 3 x 1

= 685. 578

Stanton number, St = NuD / [Re(Pr)]

= 685. 578 / [1. 557 x 10 4 x 3183. 275]

= 1. 383 x 10-5

Heat Transfer factor, jh = St Pr0. 67

= 1. 383 x 10-5 (3138. 275)0. 67 x 1

= 3. 045 x 10-3

Tube-side heat transfer coefficient, hi

= 2329. 599 W/ m2. 0C

3. 3. 4 Shell - side coefficient

1. 25 triangular pitch was chosen to calculate the bundle diameter. From table 12. 4 (Sinnott 2005), constants value for 2 tube passes condition is K1 = 0. 249 and n1 = 2. 207

Bundle diameter, Db = Dto (Nt / K1) 1/n1

= 50. 8 (239 / 0. 249)1/2. 207

= 1122. 575 mm

Pull-through floating head type was the best selection. From Figure 12. 10 (Sinnott 2005), bundle diameter clearance is 95 mm.

Shell diameter, Ds = 1122. 575 + 95

= 1217. 575 mm

For selecting baffle spacing, the optimum spacing chosen is 0. 2 times the shell diameters.

Baffle spacing, B = 0. 2 Ds = 0. 2 (1217. 575) = 243. 515mm

Tube pitch pt = 1. 25 Do = 1. 25 (50. 8) = 63. 5mm

Cross-flow area,

= 0. 0593 m2

Mass velocity, Gs = Ws / As

= 47. 7672 / 0. 0593

= 805. 518 kg/m2. s

Equivalent diameter,

= 36. 07 mm

Shell-side heat transfer coefficient, ho

Reynolds number, Re = [Gsdi] / μ

= [805. 518 x 36. 07 x 10-3] / 2. 677 x 10-4

= 1. 0854 x 10 5

Prandtl number,

= [2. 677 x 10-4 (2. 4923 x 103)] / 0. 1553

= 4. 296

Note that 45% baffle cut has been chosen, neglect the viscosity correction term. From Figure 12. 29 (Sinnott, 2005), jh = 2. 8 x 10-3

= 1640. 892 W/m2. 0C

3. 3. 5 Overall Coefficient

Table 3. 5: Dimensions in overall coefficient

Material

Carbon steel

Thermal conductivity of carbon steel

Kw = 45 W/m0C

The fouling factor for cooling water

hid 5000 W/m2. 0C

The fouling factor for aqueous salt solutions

h0 = 3000 W/m2. 0C

Source: Chemical Engineering Design, R. K. Sinnott.

The relationship between overall coefficient and individual coefficients is given by:

UO = 583. 359 W/m2. 0C

Well approximately the initial estimate of 600 W/m2. 0C, so design has adequate area for the duty required.

3. 3. 6 Tube-side Pressure Drop

Reynolds number,

= 14526. 371

From Figure 12. 24 of 'Chemical Engineering'. (Vol. 6) Friction factor, jf = 0. 045

Tube side pressure drop,

Where, m = 0. 25 for laminar flow, Re <2100

m = 0. 14 for turbulent flow, Re> 2100

Np = number of tube side passes

= 23135. 87 N/m2

= 2. 3135 kPa (Acceptable)

3. 3. 7 Shell-side Pressure Drop

Reynolds number, Re = 1. 0854 x 10 5

From the Figure 12. 30 (Sinnott 2005), Friction factor, jf = 0. 024

Shell side pressure drop,

= 64327. 95 N/m2

= 64. 328 kPa (Acceptable)

3. 3. 8 Summary of Calculation

Type of shell and tube is carbon steel with Kw of 45 W/m. 0C. While, specification of inside diameter is 45. 27mm, outside diameter is 50. 8mm and length of 5m.

Table 3. 6: Tube-side specification

Parameter

Results

ΔTlm

131. 4477 oC

R

10. 833

S

0. 833

FT

0. 93

ΔTm

122. 246 oC

Area, A

190. 126 m2

Number of tubes, Nt

239 tubes

Water linear velocity, ut

155. 798 kg/m2. s

Heat transfer coefficient, hi

2329. 599 W/m2. 0C

Pressure drop, ΔPt

2. 3135 kPa

Table 3. 7: Shell-side specification

Parameter

Results

Bundle diameter, Db

1122. 575 mm

Shell diameter, Ds

1217. 575 mm

Baffle spacing, lB

243. 515mm

Shell area, As

0. 0593 m2

Mass velocity, Gs

805. 518 kg/m2. s

Equivalent diameter, de

36. 07 mm

Shell coefficient, ho

1640. 892 W/m2. 0C

Pressure drop, ΔPs

64. 328 kPa

Overall coefficients, U

583. 359 W/m2. 0C

3. 4 MECHANICAL DESIGN OF HEAT EXCHANGER

3. 4. 1 Design Parameter

Table 3. 8: Design Parameter

Parametre

SI Unit

English Unit

Design temperature, TD

460 OC

860 OF

Operating pressure, Po

300 kPa

43. 51 psi

Internal diameter, Di

1. 217 m

47. 913 ft

Hemispherical length

0. 65 m

2. 13 ft

Shell's length

5. 0 m

16. 40

For this heat exchanger, the design pressure is 43. 51 psi and above the atmosphere pressure (15 psi). Based on study, if Po > Patm (Pgage = Pabs - Patm), the calculation for this heat exchanger is under internal pressure and the pressure that will used is,

Po = Pabs - Pgage = 43. 51 psi - 15 psi = 28. 51 psi

Calculation of design pressure for each part of heat exchanger by taking 10% safety factor:

P1 = PO + PH

= 28. 51 + 0. 433 (2. 13) = 29. 431 psi x 1. 1

= 32. 38 psi

Because this heat exchanger design is horizontal, so the value P1 = P2 = P3 = 32. 38 psi

Thickness for each part of vessel:

themispherical , t =

tcylindrical :

Circumferential;

t =

Longitudinal;

t =

For cylindrical, the highest thickness value calculated will be chosen. So, from the calculation above the thickness for cylindrical part is 0. 0446 inch. Now by adding corrosion allowance, CA of 2 mm (0. 07874 in.),

$t_{hemispherical}$ = 0. 0223in + 0. 07874in = 0. 101in

$t_{cylindrical}$ = 0. 0446in + 0. 07874in = 0. 12334in

The material construction for this heat exchanger is carbon steel due to price and work in many applications. The highest value from these two types of wall thicknesses is 0. 12334 inch, so the minimum wall thickness of this heat exchanger is 0. 12334 inch (3. 133mm). The nominal wall thickness for carbon steel at market is 0. 1182 inch (3mm). Because of the nominal wall thickness is lower than the calculated we must take the calculated thickness t = 0. 12334 inch (3. 133 mm) as value of wall thickness.

To calculate the maximum allowable working pressure for each part, $MAWP_{part}$, the thickness must subtract the corrosion allowance:

t = 0. 12334in - 0. 07874in = 0. 0446in

$MAWP_{part}$ (hemispherical):

P =

MAWPpart (cylindrical):

Circumferential;

P =

Longitudinal;

P =

The smallest value of pressure will be chosen. So, the internal pressure for cylindrical part is 32. 383 psi.

By subtracting the hydrostatic pressure, PH for each part,

MAWPpart (hemispherical) = 64. 812 psi - (0. 433)(2. 13) = 63. 889 psi = 440. 5 kPa

MAWPpart (cylindrical) = 32. 383 psi - (0. 433)(16. 01) = 25. 451 psi = 175. 478 kPa

The smallest value of pressure is taken as MAWPpart which is 25. 451psi. This value is the maximum allowable pressure for the whole vessel.