# BASIC ENGINEERING PACKAGE FOR DEPROPYLENIZER UNIT


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M.Tech (Process Design Engineering)

**College of Engineering**

**University of Petroleum and Energy Studies,**

**Dehradun, Uttarakhand, India**



MAY - 2011

# BASIC ENGINEERING PACKAGE FOR

# DEPROPYLENIZER UNIT

**A Thesis submitted to College of Engineering Studies for the partial fulfillment of Degree of Master of Technology**

(Process Design Engineering)

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Vasudev [signature] 13/5/2011
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## CERTIFICATE

This is to certify that the work contained in this thesis titled "Basic Engineering Package for Depropylenizer Unit" has been carried out by Mr. Md Zunaid Ali under my supervision and has not been submitted elsewhere for a degree.

sddalvi

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Date: 14/04/2011

# ACKNOWLEDGEMENT

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My special thanks to **Mr. Alok Saxena** for his support and suggestion throughout the project.

I would also like to thank the faculty member of the Chemical Engineering department, U.P.E.S, and all my friends for helping me in any possible way to complete this project.

## ABSTRACT

This project aims to develop **Basic Engineering Package** of **Depropylenizer unit** which separates mixed $C_3/C_4$ feed into Polymer Grade Propylene as overhead, $C_4$ Recycle as side draw and $C_4$+ Purge as bottom product.

The unit is designed to produce **165 KTA** of Polymer Grade Propylene in 8,000 operating hours a year when processing the design feed stocks during the normal operation while composition of the Feed and Products is supplied by the client.

Process Flow Diagram (PFD) for the Unit is developed and Control Philosophy for the process is decided.

To obtain Polymer grade Propylene with the specified specification from the given feed streams, the process is designed and simulated using software PRO-II. Optimization of the Unit is done to meet the optimum operating and installation costs.

Based on Material Balance generated by PRO-II, Data Sheet for all the Process Equipments and Line Sizing has been done.

Piping & Instrumentation Diagram (P&ID) of the unit is also prepared.

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# NOMENCLATURE

G = Vapour flow rate

$U_f$ = Flooding velocity

$F_{HA}$ = Fractional Hole Area

$H_R$ = Height of Rectifying section

$H_T$ = Total Height of column

A = Cross Sectional Area

Re = Reynolds Number

KTA = Kilo Ton per Annum

Kg = Kilogram

Kcal = Kilocalories

L = Length

V = Volume

C.S = Carbon Steel

MTD= Mean Temperature Difference

f = Percentage Flooding

$P_g$ = Vapour density

$A_h$ = Hole Area

$H_S$ = Height of Stripping section

$Q_L$ = Volumetric Flow Rate

V = Velocity of liquid

$\Delta P$ = Pressure Drop

LLL = Low Liquid Level

$^0C$ = Degree Centigrade

CW = Cooling Water

D = Diameter

fhv = Fraction of vessel head

HLL = High Liquid Level

MPS = Medium Pressure Steam

# 1. INTRODUCTION

Process Design Engineers are concerned with Development of new process and modification of existing process. They develop a lab based process to production scale with minimum production cost.

A process design engineer has to design a plant or a part of it. He may have to design a complete complex plant or unit operation or a unit process or a system. The task of a process engineer is to convert the research and development effort into industrial reality. The important aspect is that it must work and operate reliably and smoothly. The unit is to be designed for a commercial purpose and hence, it has to be economical and cost effective. A good process design engineer has to have a good knowledge and understanding of process, technology and behaviour of process under given operating condition & changing operating condition must be known for process design. So, Process design can be called as an art which comes through years of experience.

The Role of Process Design Engineer starts right from the Project Concept. The Project concept is like the preface of project giving idea that is there to be done in project. It is like a proposal based on client or Bidder requirement. It is mainly prepared for the confirmation of service and the order from the customer with relevant details for design. The project concept is based on the information provided by customers as Raw material specification, Finished Product Specs, Expected Capacity, Environmental data, Site location, Level of Automation and many more.

The aim of the project is to develop Basic Engineering Package of Depropylenizer unit which separates mixed $C_3/C_4$ feed into Polymer Grade Propylene, $C_4$ Recycle and $C_4$+ Purge.

During the course of the preparation of the package, I utilized my Basic Process Engineering knowledge and usage of the software tools learnt during my Post Graduation and also got hands on feel of the work related to Process Design Engineering.

The unit is designed to produce 165 KTA of Polymer Grade Propylene in 8,000 operating hours a year when processing the design feed stocks during the normal operation. Composition of the Feed and Products was supplied by the client.

## 2. GENERAL DESCRIPTION OF THE DEPROPYLENIZER UNIT

**FUNCTION:**

The Depropylenizer Unit is designed to separate feed into Polymer Grade Propylene, $C_4$ recycle and $C_4$+ purge. The processing scheme shall be as shown in Process flow diagram.

**CAPACITY:**

The unit is designed to produce **165 KTA** of Polymer Grade Propylene in 8,000 operating hours a year when processing the design feed stocks during the normal operation.

**FEED STOCKS:**

The unit is designed to process the following feedstock during normal operation to produce required amount of Propylene. Complete composition of the feed stock is given in ANNEXURE-1

**PRODUCTS:**

a) Polymer Grade Propylene (high purity)

b) $C_4$ Recycle

c) $C_4$+ purge

Composition of product streams can be referred from ANNEXURE-2

**TURNDOWN:**

Plant shall be designed to operate at 50% of normal capacity.

**UTILITIES:**

a) Cooling water

b) Steam

c) Power

Condition and characteristics of utilities used can be referred from ANNEXURE-3

**BATTERY LIMIT CONDITION:**

Battery limit conditions for feedstock and products can be referred from ANNEXURE-4

## 3. PROCESS FLOW DIAGRAM

A process flow diagram for the process has been attached as ANNEXURE-5

### 3.1 PROCESS DESCRIPTION

The purpose of Depropylenizer unit is to separate feed into three products:

a) Polymer Grade Propylene (Overhead)

b) $C_4$ Recycle (Side draw)

c) $C_4$+ (Bottoms product)

Mixed $C_3/C_4$ feed from Deethylenizer is sent to the Depropylenizer tower. The tower operates at a pressure which permits total condensation of Depropylenizer overhead against cooling water. Part of the Distillate is used as Reflux and the net Polymer grade Propylene product is pumped to the OSBL storage. Reboiler heat to the Depropylenizer is supplied by MP steam. $C_4$ Recycle is taken as side draw from the Depropylenizer tower and cooled against cooling water (cooler outlet temperature of $C_4$ recycle is $40^oc$) and sent to the fresh recycle $C_4$ surge drum. The Bottoms from Depropylenizer containing $C_4$+ and heavier material is cooled against cooling water and pumped to the Ethylene plant outside the battery limit.

### 3.2 EQUIPMENT LIST

A list of Equipments with Name and their Notation used in the PFD has been attached as ANNEXURE-6

### 3.3CONTROL PHILOSOPHY

A process flow diagram with control philosophy for the process has been attached as ANNEXURE-7

Column overhead pressure is controlled by coolant flow rate and column temperature is controlled by cascading the temperature controller with steam flow controller.

To control liquid level in the bottom of the column, a level controller is cascaded with bottom product flow controller. Reflux to the column is controlled by a fixed flow controller.

Side draw product flow is controlled by a fixed flow controller which is cascaded with the level controller located on the side draw product removal tray.

To control the liquid level in the reflux drum, a level controller is cascaded with the flow controller of the propylene product.

## 4. PRESSURE PROFILE

Since this unit is expansion of an existing plant, the actual plant layout is known. Plant layout is necessary in order to know elevation of equipments, length of the pipes on which the frictional loses depends. In order to do preliminary pressure calculations, reasonable frictional loses, pressure drop per tray, pressure drop across Cooler, Control valve pressure drop are assumed which will not bring much error in the final calculations.

a) Tower bottom tangent line from grade: 8m
b) Reflux drum tangent line from grade: 3m
c) Pressure drop across Cooler: 0.14 $kg/cm^2$
d) Control valve pressure drop: 0.7 $kg/cm^2$
e) Losses in each line segment: 0.07 $kg/cm^2$
f) Pressure drop per tray: 0.01 $kg/cm^2$

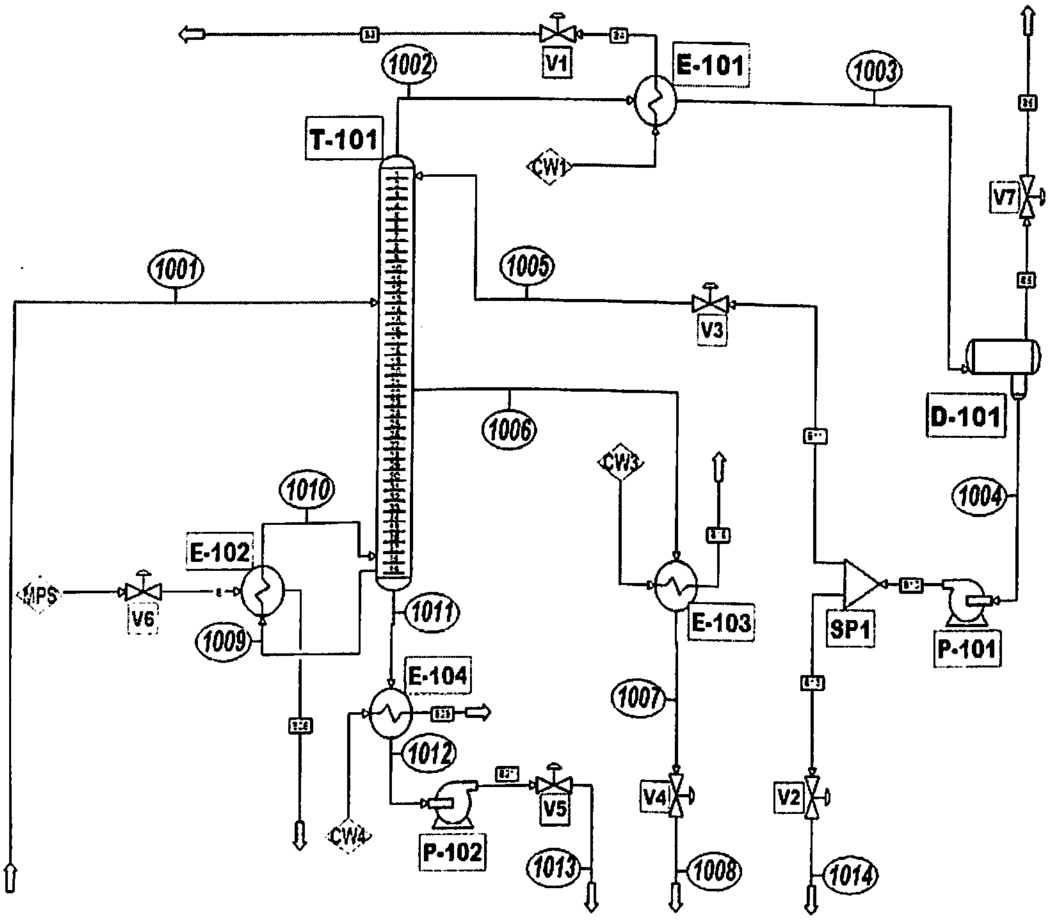
| Name | Pressure ($kg/cm^2$) | Pressure Drop ($kg/cm^2$) | | | Static Head ($kg/cm^2$) | Height (m) |
|---|---|---|---|---|---|---|
| | | Line loss | Equipment | CV | | |
| T-101 top tray | 18.56 | | | | | |
| E-101 inlet | 18.49 | 0.07 | | | | |
| E-101 outlet | 18.35 | | 0.14 | | | 26 |
| Reflux drum | 18.56 | 0.282 | | 0.7 | -1.193 | 3 |
| P-101-suction | 18.63 | 0.07 | | | -0.1434 | |
| P-101-discharge | 36.63 | | | | | |
| C4 Recycle Tray | 18.85 | | | | | 11 |
| E-103 inlet | 19.281 | 0.17 | | | -0.601 | |
| Bottom tray | 18.92 | | | | | 8 |

## 5. SIMULATION OF DEPROPYLENIZER UNIT

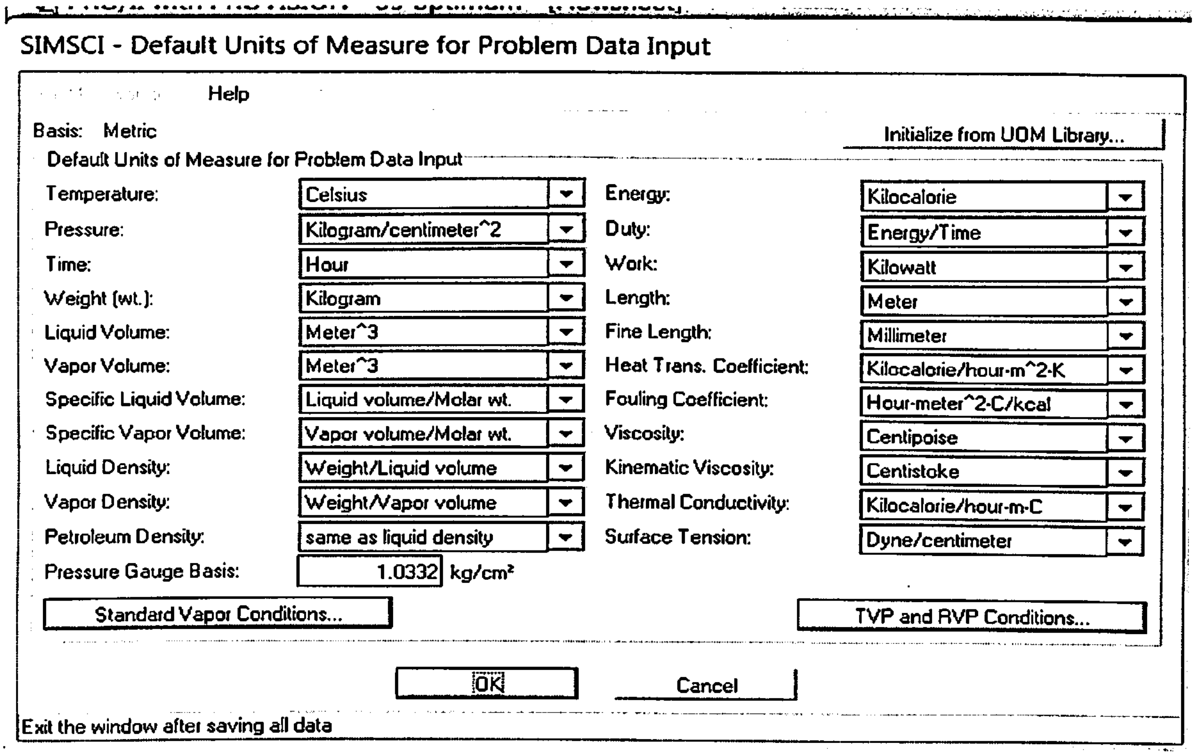
In order to obtain Polymer grade Propylene with the specified specification (ANNEXURE-2) from the given feed streams, the process was designed and simulated using software PRO-II. The propylene flow rate in the Distillate and composition in the Bottom are almost kept constant at 20,625 kg/hr and 500 wt ppm respectively. It was also ensured that the composition (mole %) of cis-2-Butene and trans-2-Butene in the $C_4$ Recycle product stream matches with the Estimated Product specifications.

## 5.1 SIMULATION STEPS IN PRO-II

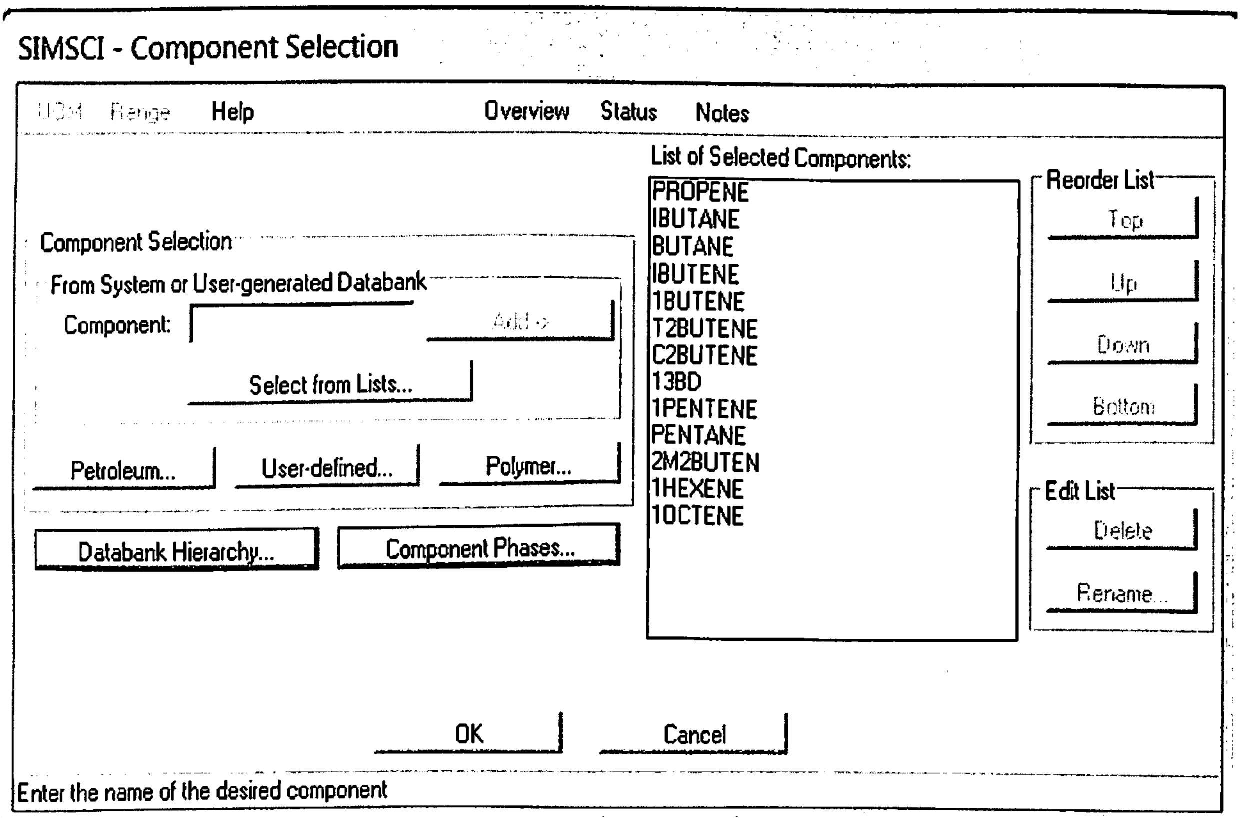
1. **Build flow sheet**



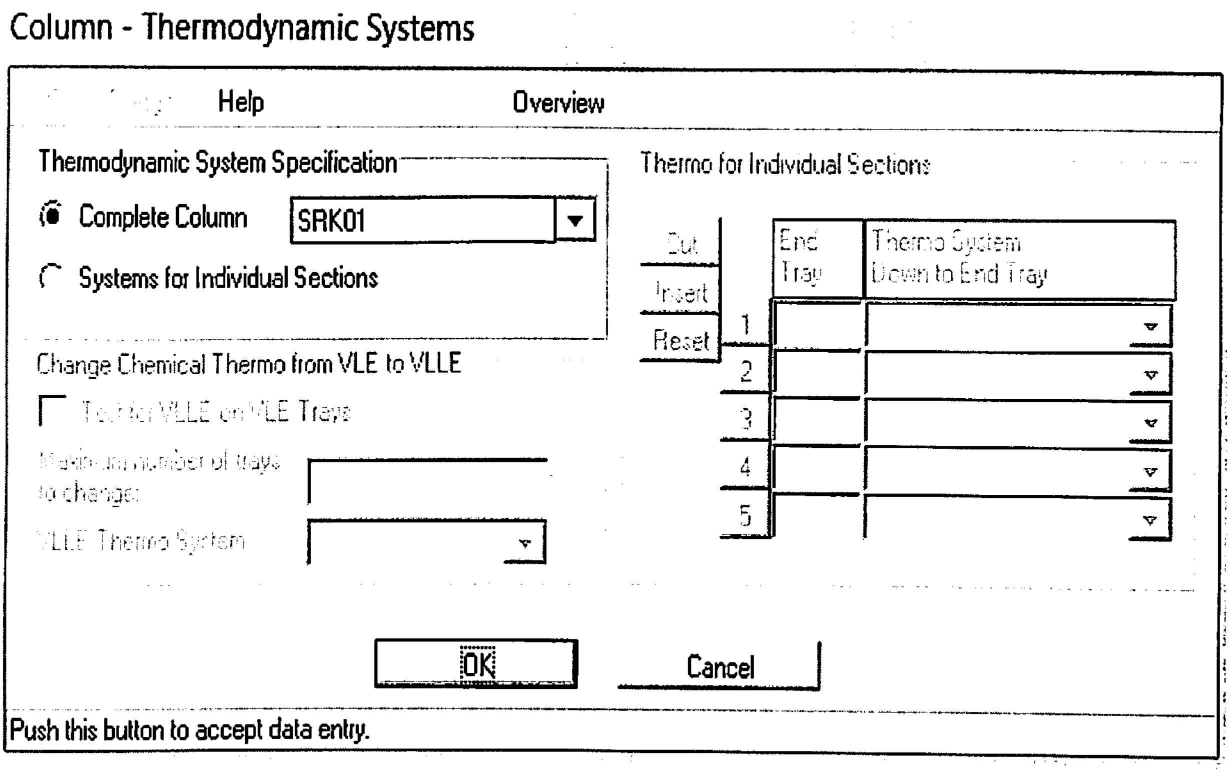
## 2. Check units of measure



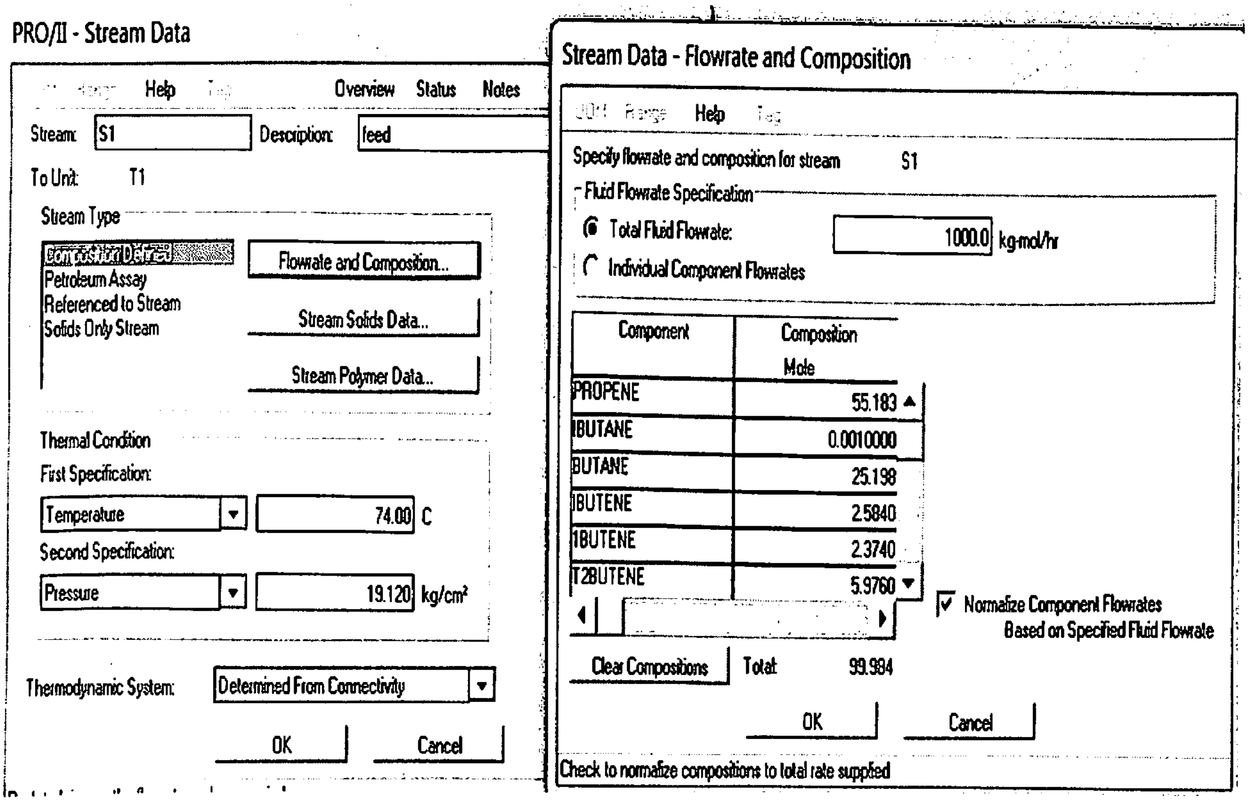

## 3. Define components



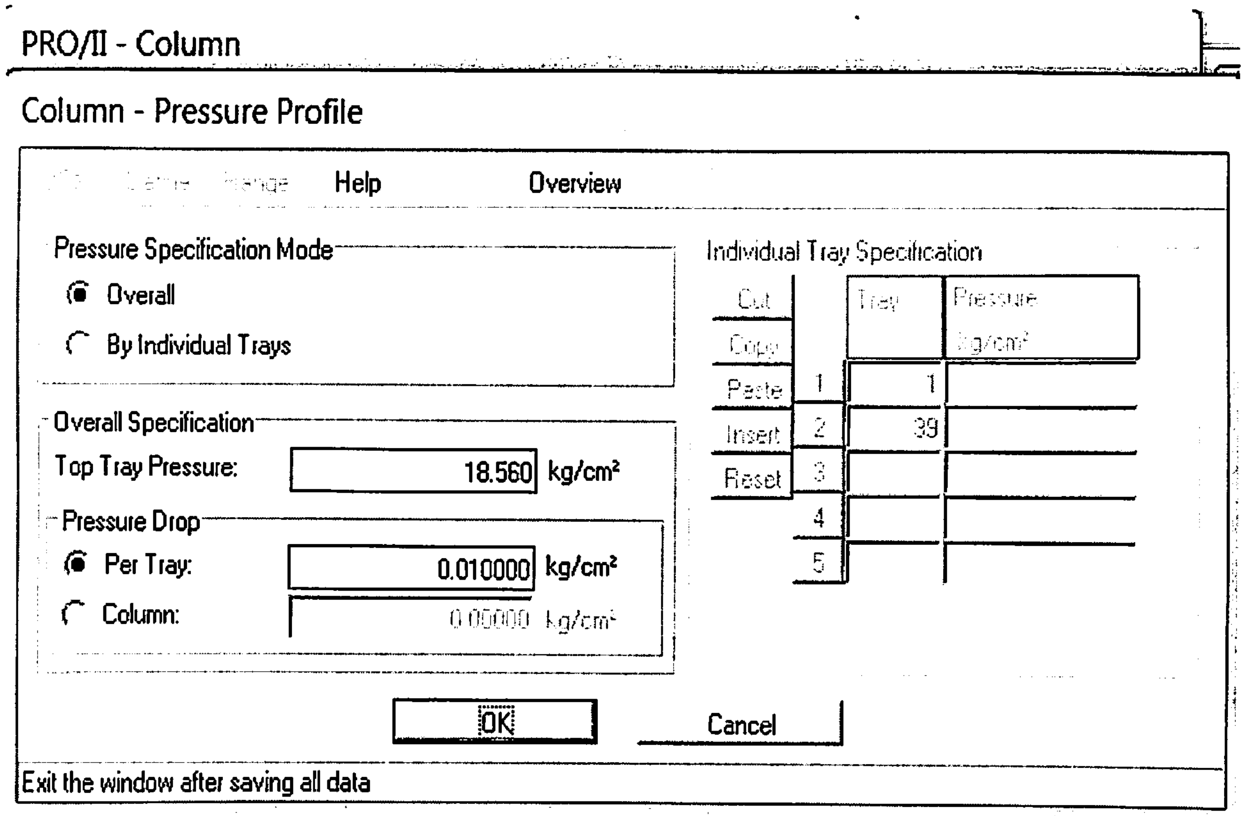
## 4. Select Thermodynamic Package

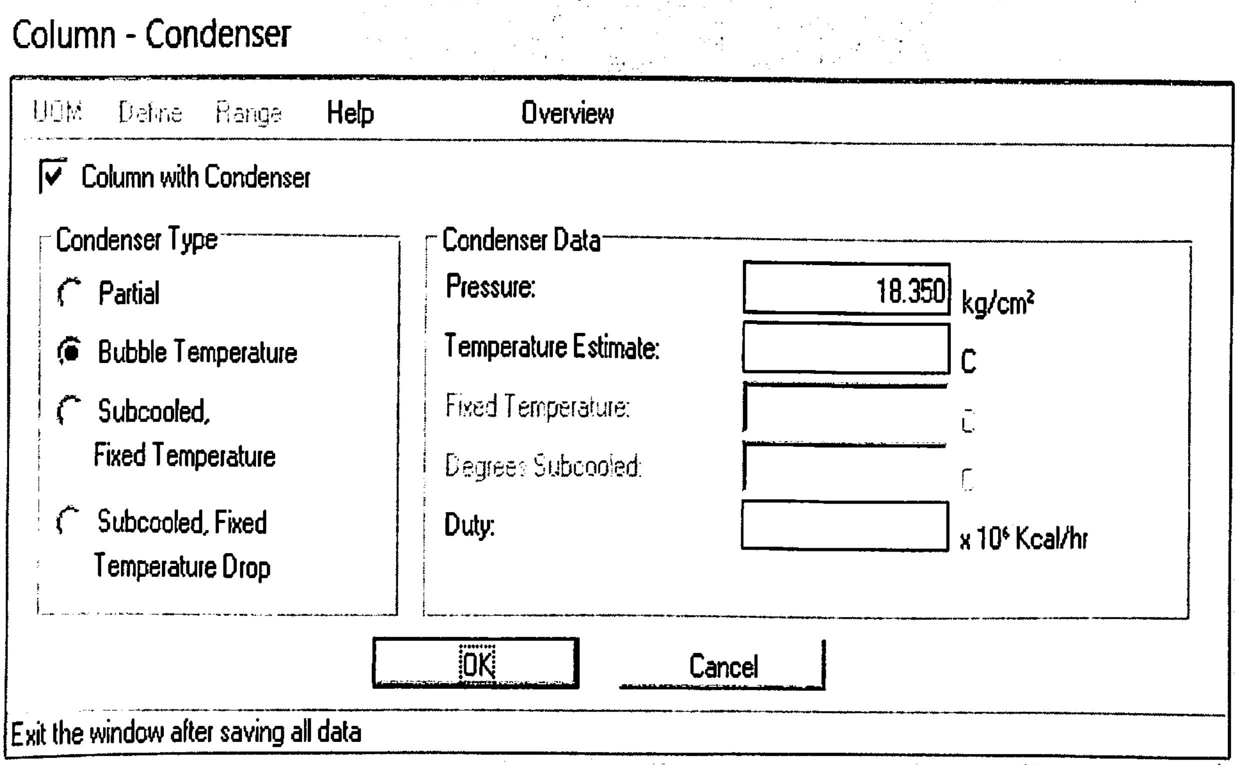



## 5. Supply stream data

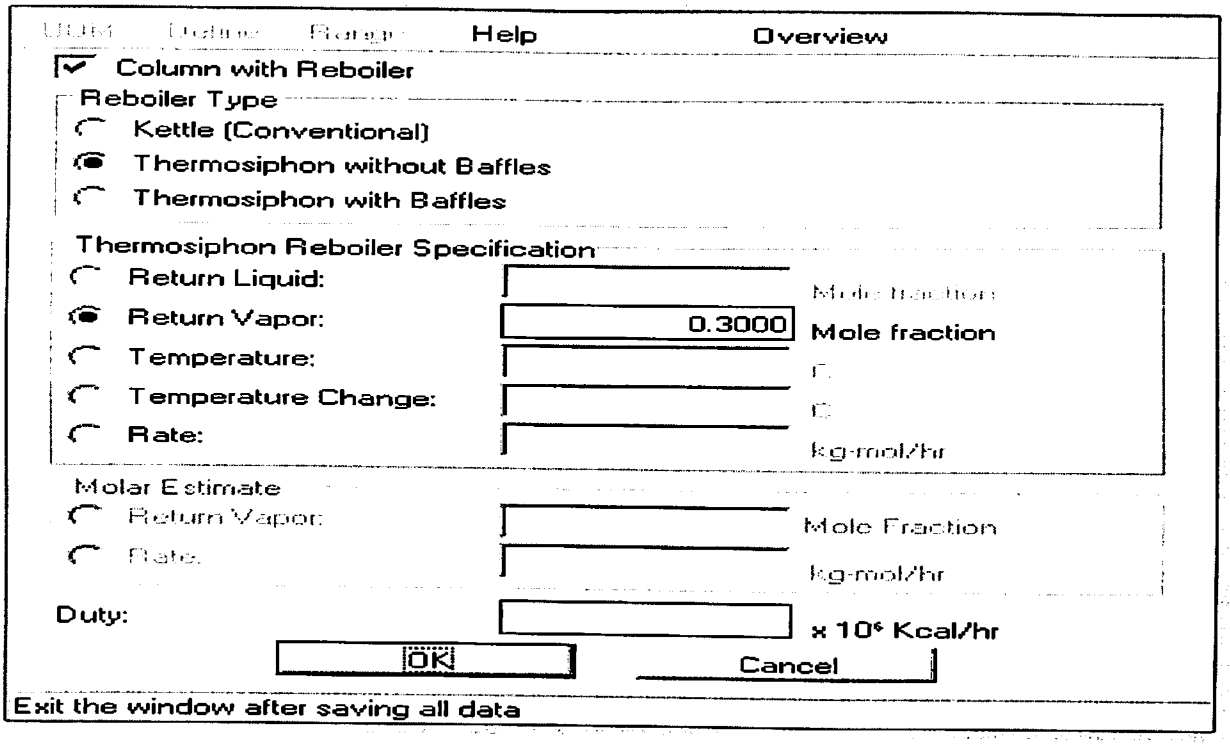


**6. Provide process condition**

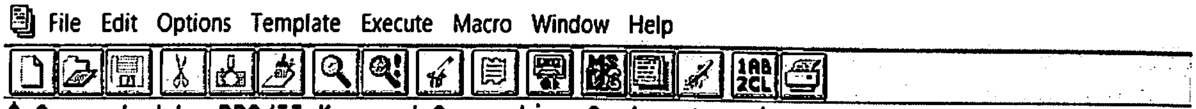


## Column - Reboiler




## 7. Run and view results

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$ Generated on: Fri Oct 15 11:28:27 2010
TITLE
  DIMENSION METRIC, STDTEMP=0, STDPRES=1.03323
  SEQUENCE SIMSCI
  CALCULATION RVPBASIS=APIN, TVP=37.778
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  LIBID 1,PROPENE/2,IBUTANE/3,BUTANE/4,IBUTENE/5,1BUTENE/6,T2BUTENE/ &
        7,C2BUTENE/8,13BD/9,1PENTENE/10,PENTANE/11,2M2BUTEN/ &
        12,1HEXENE/13,1OCTENE
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  METHOD SYSTEM=SRK, SET=SRK01, DEFAULT
STREAM DATA
  PROPERTY STREAM=S1, TEMPERATURE=74, PRESSURE=19.12, PHASE=M, &
         RATE(M)=1000, COMPOSITION(M)=1,55.183/2,0.001/3,25.198/ &
        4,2.584/5,2.374/6,5.976/7,3.516/8,0.001/9,2.468/10,0.971/ &
        11,0.504/12,1.061/13,0.147
  NAME S1,feed/S2,top/S3,bottom/S4,side draw
UNIT OPERATIONS
  COLUMN UID=T1
      PARAMETER TRAY=39,IO=120
```

## 5.2 SIMULATION DATA

The data is being collected by varying the following things of the tower to ensure that the composition (mole %) of cis-2-Butene and trans-2-Butene in the $C_4$ Recycle product stream matches with the Estimated Product specifications.

a) No. of stages
b) Position of feed stream to the column
c) Position of $C_4$ Recycle product stream

From the simulation data collected, the **Most Optimum Data** for a **Particular Number of Stage** is being chosen and the useful data is being listed below:

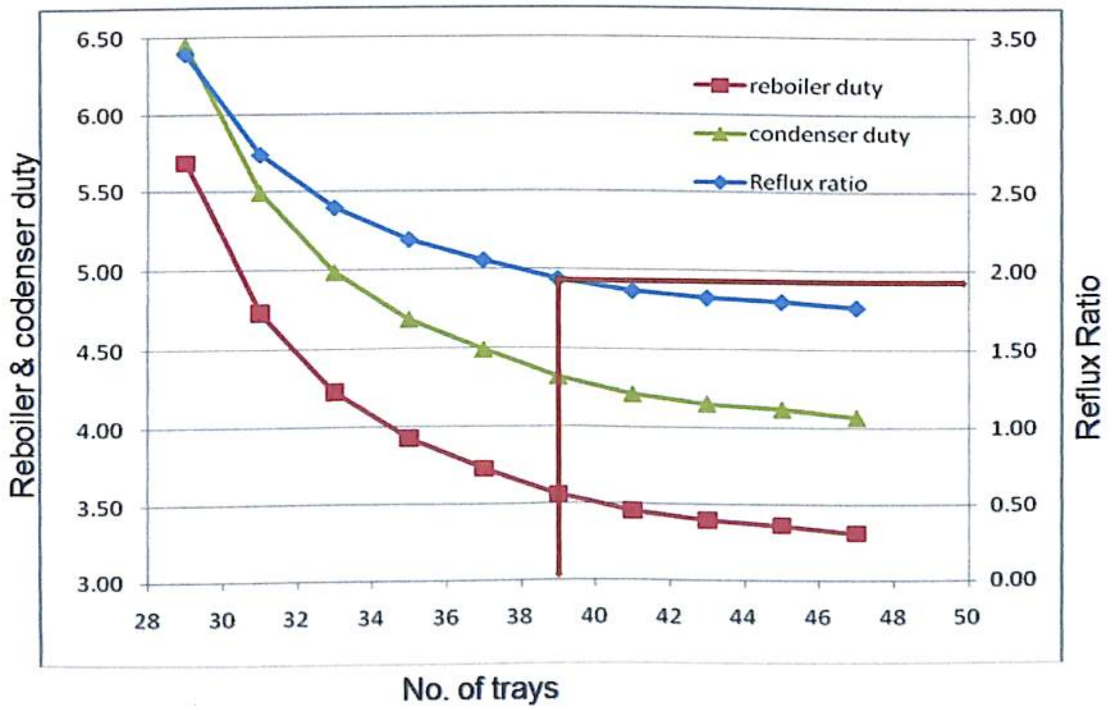
| No. of Stages | Feed at Tray No. | $C_4$ Recycle Stream Tray no. | Condenser Duty $*10^6$ kcal | Reboiler Duty $*10^6$ kcal | Reflux Ratio | C2B Mol% | T2B Mol% |
|---|---|---|---|---|---|---|---|
| 29 | 18 | 21 | -6.4484 | 5.6884 | 3.3909 | 7.083 | 12.13 |
| 31 | 19 | 23 | -5.4922 | 4.7317 | 2.7392 | 7.081 | 12.12 |
| 33 | 20 | 25 | -4.9868 | 4.2265 | 2.3951 | 7.074 | 12.12 |
| 35 | 21 | 27 | -4.6844 | 3.9249 | 2.1893 | 7.070 | 12.10 |
| 37 | 22 | 29 | -4.4875 | 3.7289 | 2.0552 | 7.065 | 12.09 |
| 39 | 24 | 31 | -4.3147 | 3.5570 | 1.9376 | 7.061 | 12.09 |
| 41 | 26 | 33 | -4.2105 | 3.4537 | 1.8666 | 7.056 | 12.08 |
| 43 | 28 | 35 | -4.1495 | 3.3939 | 1.8260 | 7.053 | 12.08 |
| 45 | 30 | 37 | -4.1176 | 3.3633 | 1.8033 | 7.047 | 12.08 |

## 6. OPTIMIZATION OF DEPROPYLENIZER UNIT

The data in the above table is approximate which is used to judge the best column among the above cases. As mentioned earlier, the operating and installation costs are the due to Condenser duties, Reboiler duties, Reflux ratio and Number of trays. A plot of Condenser duty, Reboiler duty and Reflux ratio v/s Number of stages is given below was used to decide the Optimum Number of Theoretical stages from the above tabulated cases. In order to meet operating and installation costs, the case with ***39 Number of Theoretical Stages*** is being selected.

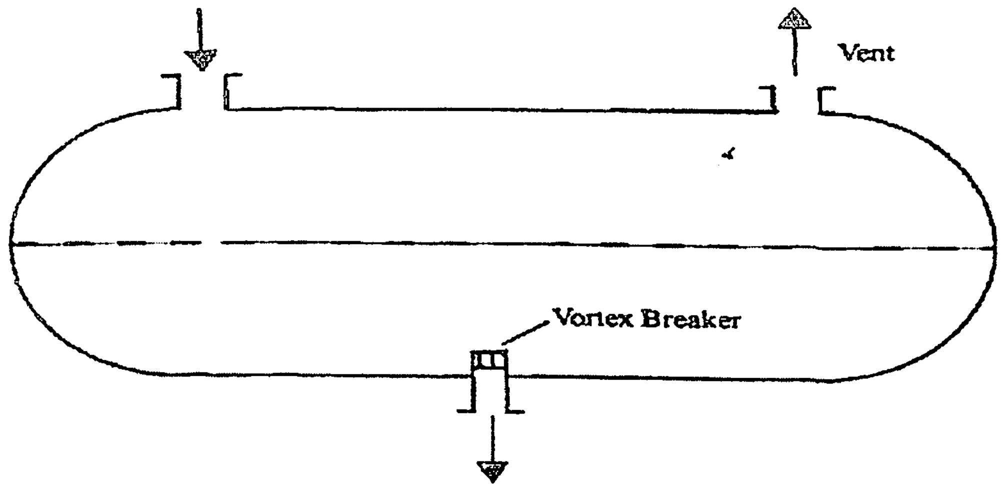
### 6.1 OPTIMIZATION GRAPH

A plot of Condenser duty, Reboiler duty and Reflux ratio v/s Number of stages is given below was used to decide the Optimum Number of Theoretical stages from the above tabulated cases. In order to meet the optimum operating and installation costs, the case with ***39 Number of Theoretical Stages*** is being selected.



## 7. REFLUX DRUM DESIGN

An accumulator is placed after the condenser to provide reflux to the fractionators and prevents column fluctuations in flow rate from affecting downstream equipment.




Accumulators are not separators. In this application the accumulator is called a reflux drum. A reflux drum is shown in the above figure. Liquid from a condenser accumulates in the drum before being split into reflux and product streams. At the top of the drum is a vent to exhaust noncondensable gases that may enter the distillation column. The liquid flows out of the drum into a pump. To prevent gases from entering the pump, the drum is designed with vortex breaker at the exit line.

The total volume of an accumulator is calculated using a residence time, also called surge time, which is obtained from experience, according to the type and degree of the process control required. Commonly it is recommended that to take residence time of 5 to 10 minutes. Once a residence time is selected, accumulator is sized for half-full operation to accommodate either increase or decrease in liquid level.

## 7.1 DESIGN BASIS FOR ACCUMULATOR SIZING

**Holdup time**

7 minutes of holdup on Reflux flow quantity or 10 minutes on liquid product, whichever is greater.

**Heads**

| | |
|---|---|
| Pressure <= 10 $kg/cm^2$ g | Use Torispherical Head |
| Pressure >= 10 $kg/cm^2$ g | Use Ellipsoidal Head |

**Length to diameter ratio**

| | |
|---|---|
| For Design Pressures up To 7 $Kg/cm^2g$ | L/D = 3 |
| For Design Pressures from 7 $Kg/cm^2g$ - 21$kg/cm^2g$ | L/D = 4 |

**Design pressure**

Maximum design pressure for any pressure vessel shall be Maximum normal operating pressure plus 2.0 $kg/cm^2$

The minimum design pressure for any pressure vessel shall be 3.5 $kg/cm^2g$.

**Design temperature**

In general the design temperature of pressure vessels is dependent upon the operating temperature range as follows:

No maximum design temperature will be set less than 65°C.

| Operating Temp Range, (°C) | Design Temp, (°C) |
|---|---|
| T < 50 | Minimum anticipated operating temperature margin to be determined by metallurgical limits |
| 50 < T < 400 | Maximum anticipated operating temperature + 15°C (round up to nearest 5°C.) |

| | |
|---|---|
| T > 400* | Maximum anticipated operating temperature 10% minimum margin |

**Round off**

The calculated diameter and length of the vessel is rounded off to match the standard size available in the market to control the cost.

Diameter Round off in increment of 6 inch

Length Round off in increment of 3 inch

**Limitations**

The maximum vessel diameter is limited to about 4.11 meters because of shipping limitation by rail and truck and minimum vessel diameter is limited to about 0.762 meters for economic purpose.

## 7.2 PROCEDURE FOR SIZING ACCUMULATORS

1) Select Residence time or Holdup time
2) Calculate accumulator volume using formula

$$V = 2 * (\text{Vol. flow rate}) * (\text{Residence time})$$

3) Also we know

$$V = \{(3.14 * D^2 * L) / 4\} + \{2\, fhv * D^3\}$$

Where fhv = fraction of vessel head

fhv = 0.1309 for Ellipsoidal head

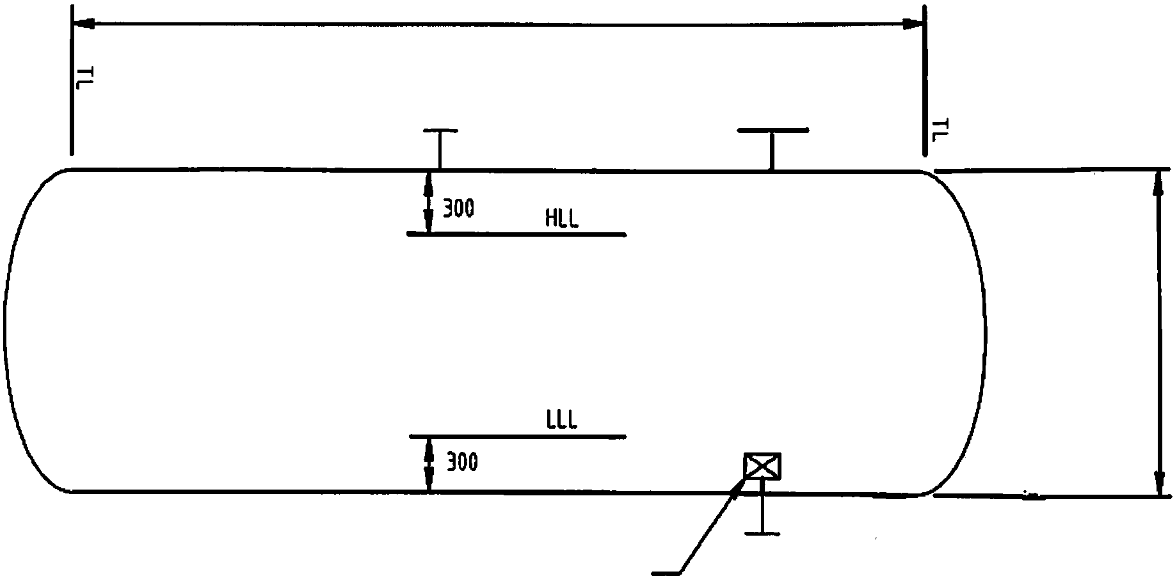
fhv = 0.778 for Torispherical head

4) Select Vessel Head and L/D ratio based on the operating pressure
5) Calculate Vessels Diameter and round off "D" in 6 inch increment
6) Calculate length and round off "L" in increment of 3 inch

## 7.3 DATA SHEET FOR REFLUX DRUM

ITEM NUMBER: **D-101**

ITEM NAME: **Depropylenizer Reflux Drum**




| | |
|---|---|
| **VESSEL NO.** | **D-101** |
| **VESSEL NAME** | **DEPROPYLENIZER REFLUX DRUM** |
| Diameter | 2134 MM (84") |
| Horizontal Length(T/T) | 8534 MM(336") |
| Operating Temperature | 43$^{0}$C |
| Operating Pressure | 1.74 MPAG |
| Liquid Density | 474 KG/M3 |
| Design Temperature | 65$^{0}$C |
| Design Pressure | 1.91 MPAG |
| Head | ELLIPSOIDAL |
| Shell Material | C.S |
| Corrosion Allowance Shell | 3 MM |

# 8. COLUMN DESIGN

The sizing of columns is critical. Almost all of the mass transfer operations occur in columns. As a thumb rule, the diameter of the column directly relates to the flow rate to be handled and the height to the degree of separation to be achieved.

## 8.1 DESIGN BASIS FOR COLUMN SIZING

**Tray Type**

Depropylenizer will be provided with all Valve Trays.

**Tray Efficiency**

Tray efficiencies and hydraulic criteria to be used for these towers are summarized below:

| | Tower | % Tray Efficiency | |
|---|---|---|---|
| 1 | Depropylenizer | Above Feed | 55% |
| | | Below Feed | 65% |

**Tray Spacing**

| | |
|---|---|
| Above Feed | 500 mm |
| Below Feed | 600 mm |

**Tower and their Behaviours**

| Tower | Behaviour |
|---|---|
| Depropylenizer | Non Foaming |
| Debutanizer | Non Foaming |
| Demethanizer | Moderate Foaming |
| Caustic Tower | Severe Foaming |

**Design pressure**

Maximum design pressure for any pressure vessel shall be Maximum normal operating pressure plus 2.0 $kg/cm^2$

The minimum design pressure for any pressure vessel shall be 3.5 $kg/cm^2g$.

**Design temperature**

In general the design temperature of pressure vessels is dependent upon the operating temperature range as follows:

No maximum design temperature will be set less than 65°C.

| Operating Temp Range, (°C) | Design Temp, (°C) |
|---|---|
| T < 50 | Minimum anticipated operating temperature margin to be determined by metallurgical limits |
| 50 < T < 400 | Maximum anticipated operating temperature + 15°C (round up to nearest 5°C.) |
| T > 400* | Maximum anticipated operating temperature 10% minimum margin |

**Manholes**

Vessels with trays shall be provided with the following number of manholes:

| Number of Trays | Number of Manholes |
|---|---|
| 1 to 25 | 2 |
| 26 to 41 | 3 |
| 42 to 61 | 4 |
| 62 to 80 | 5 |
| 81 to 100 | 6 |

| | |
|---|---|
| 101 to 120 | 7 |
| 121 to 150 | 8 |
| 151 to 175 | 9 |
| 176 to 200 | 10 |

Manholes shall be provided above the top tray, and below the bottom tray. Where manholes are provided between trays, the minimum tray spacing should be as follows:

| Manhole Size | Min. Tray Spacing |
|---|---|
| 20 inch | 36 in (900 mm) |
| 24 inch | 40 in (1000 mm) |

For towers, unless there are special considerations, manhole sizes shall be as follows:

| Tower Diameter, ID, mm | Size, Inches |
|---|---|
| $< 900$ | 18 |
| $900 < D < 3000$ | 20 |
| $> 3000$ | 24 |

**Miscellaneous**

Trays shall be numbered from the top down, that is, tray No. 1 shall be the top most tray.

## 8.2 PROCEDURE TO CALCULATE COLUMN DIAMETER

1. Calculate Column diameter by using Formula

$$D_T = \left( \sqrt{\frac{4G}{f \times u_f \times \pi \left(1 - {A_D}/{A_T}\right) \times \rho_G}} \right)$$

Where

| | |
|---|---|
| G | Vapour flow rate |
| F | Percentage Flooding |
| $U_f$ | Flooding velocity |
| $P_g$ | Vapour density |
| $D_T$ | Tower Diameter |
| $A_D$ | Downcomer area |
| $A_T$ | Total cross sectional area |

2. As a thumb rule take percentage flooding from 70% to 90%

3. Flooding velocity is calculated using formula

$$u_f = C_{SB} \times (\frac{\sigma}{20})^{0.2} \times F_F \times F_{HA} \times \sqrt{\frac{\rho_L - \rho_G}{\rho_G}}$$

| | | |
|---|---|---|
| $F_F$ | 1 | Foaming |
| | 0.6 | Nonfoaming |

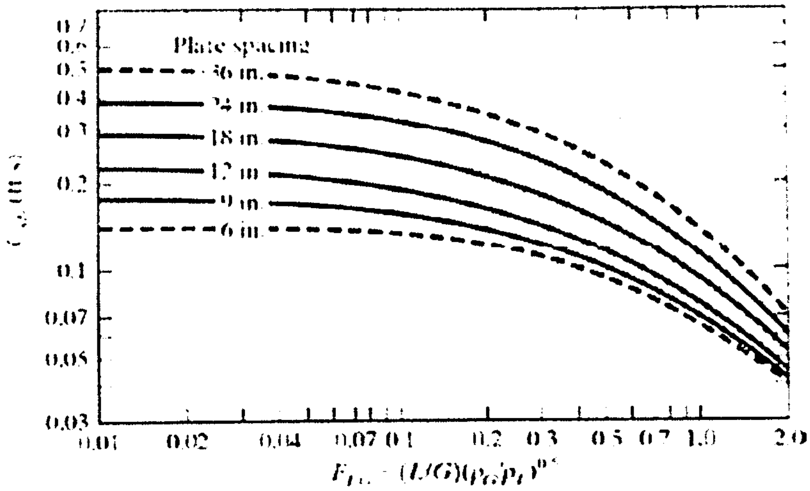
4. Fractional Hole Area ( $F_{HA}$) is function of ratio of Hole Area ( $A_h$ )and Tray Active Area( $A_a$ )and calculated using correlation

$$F_{HA} = \begin{cases} 1 & \frac{A_h}{A_a} \geq 0.1 \\ 5\left(\frac{A_h}{A_a}\right) + 0.5, & 0.06 \leq \frac{A_h}{A_a} \leq 0.1 \end{cases}$$

As thumb rule

| Type of Service | $A_h/A_a$ (%) |
|---|---|
| Pressure | 6 - 10 |
| Atmospheric | 8 - 12 |
| Vacuum | 10 - 16 |

5. CSB is function of Plate spacing and ratio of gas liquid flow, calculated using correlation




## 8.3 PROCEDURE TO CALCULATE COLUMN HEIGHT

1. Calculate Height of Rectifying section using formula

$H_R$ = [(No. Of trays)*(Tray spacing)] + [Disengagement height] +[Manhole spacing]

As a Thumb rule take Disengagement height = 4 ft

As a Thumb rule take Tray spacing = 500 mm

2. Calculate Height of Stripping section using formula

$H_S$ = [(No. Of trays)*(Tray spacing)] + [Sump height] + [Manhole spacing]

As a Thumb rule take Sump height = 10 ft

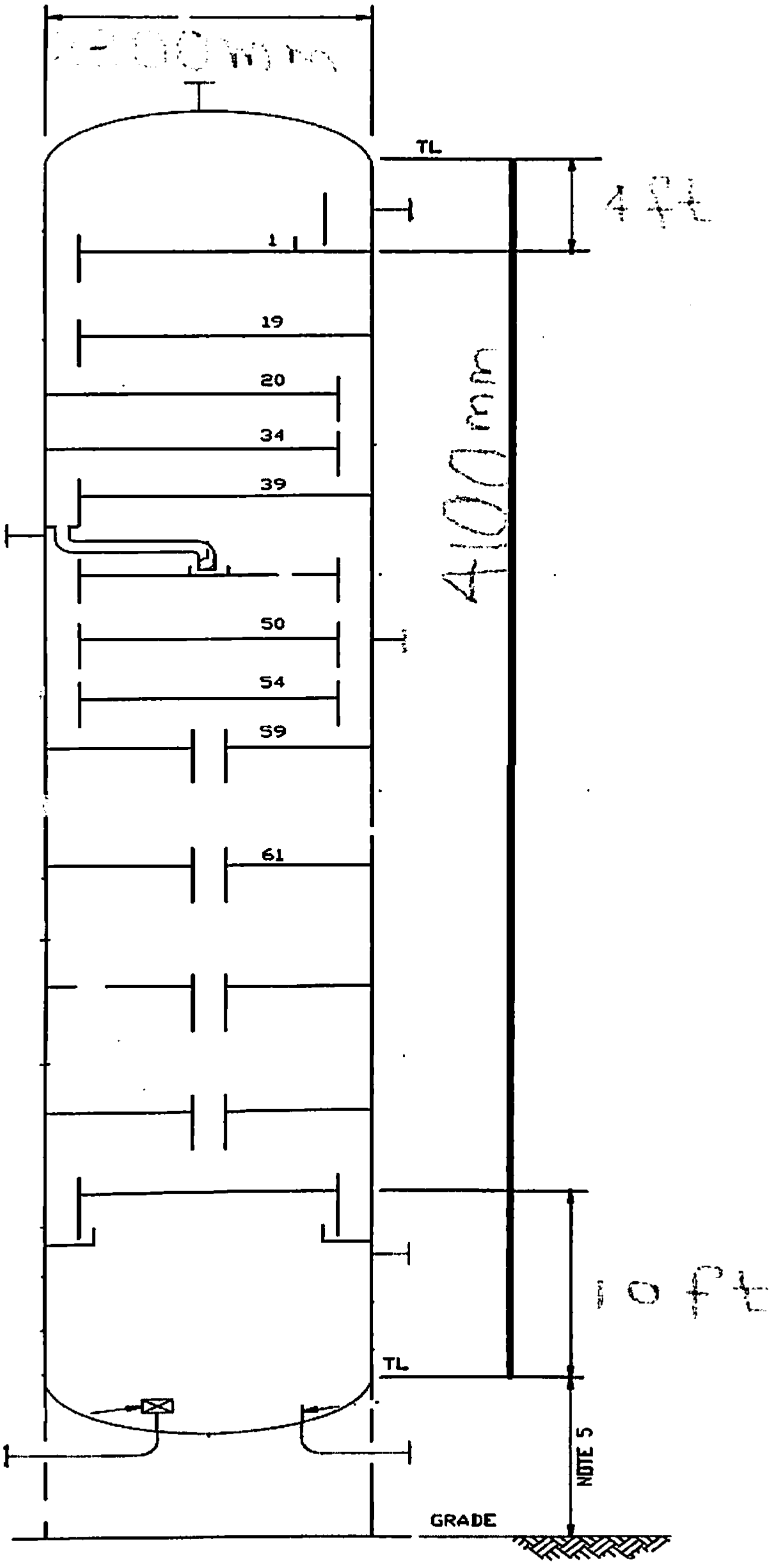
As a Thumb rule take Tray spacing = 600 mm

3. Total Height of column is given by

$H_T = H_R + H_S$

ITEM NUMBER: **T-101**

ITEM NAME: **Depropylenizer Tower**



## 8.4 DATA SHEET FOR DEPROPYLENIZER TOWER

ITEM NUMBER: **T-101**

ITEM NAME: **Depropylenizer Tower**

| **VESSEL NO.** | **T-101** |
|---|---|
| **VESSEL NAME** | **DEPROPYLENIZER TOWER** |
| Inside Diameter (Rectifying Section) | 2300 MM |
| Inside Diameter (Stripping Section) | 2300 MM |
| Vertical Height (T/T) | 4100 MM |
| No. Of Trays above Feed Tray | 40 |
| No. Of Trays below Feed Tray | 24 |
| Feed Tray Location | 41$^{th}$ |
| Operating Temperature ( TOP ) | 43.7 $^0$C |
| Operating Temperature ( BOTT ) | 143.3 $^0$C |
| Operating Pressure ( TOP ) | 1.74 MPAG |
| Operating Pressure ( BOTT ) | 1.80 MPAG |
| Liquid Density ( TOP ) | 474 KG/M$^3$ |
| Liquid Density ( BOTT ) | 467 KG/M$^3$ |
| Design Temperature | 160$^0$C |
| Design Pressure | 1.91 MPAG |
| Shell Material | C.S |
| Corrosion Allowance Shell | 3 MM |

# 9. DESIGN OF CONDENSER E 101

## 9.1 DESIGN BASIS

**Design pressure**

Maximum design pressure for any pressure vessel shall be Maximum normal operating pressure plus 2.0 $kg/cm^2$

The minimum design pressure for any pressure vessel shall be 3.5 $kg/cm^2g$.

**Design temperature**

In general the design temperature of pressure vessels is dependent upon the operating temperature range as follows:

No maximum design temperature will be set less than 65°C.

| Operating Temp Range, (°C) | Design Temp, (°C) |
|---|---|
| $T < 50$ | Minimum anticipated operating temperature margin to be determined by metallurgical limits |
| $50 < T < 400$ | Maximum anticipated operating temperature + 15°C (round up to nearest 5°C.) |
| $T > 400$* | Maximum anticipated operating temperature 10% minimum margin |

**Fouling Factors**

Fouling factors shall be specified as follows:

| Utility Services | $m^2$-°C-h/kcal |
|---|---|
| Steam (all levels) | 0.0001 |
| Cooling Water | 0.0004 |

| Process Streams | $m^2$-°C-h/kcal |
|---|---|
| Depropylenizer Overhead | 0.0001 |
| Depropylenizer bottoms | 0.0004 |

**Corrosion Allowance**

| Utility Services | Corrosion Allowance |
|---|---|
| Steam (all levels except SHP) | 3 mm |
| Steam Condensate | 1.5 mm |
| Cooling Water | 3 mm |

## 9.2 INPUTS TO HTRI

(•) Rating ( ) Simulation ( ) Design

**Exchanger Configuration**

Exchanger service: Generic Shell and Tube

**Process Conditions**

| | Hot Shell | | Cold Tube | | |
|---|---|---|---|---|---|
| Flow rate | | 17.0689 | | | kg/s |
| Inlet/outlet Y | 1 | 0 | 0 | 0 | Weight fraction vapor |
| Inlet/outlet T | 43.75 | 43 | 33 | 38 | C |
| Inlet P/allow dP | 1820.11 | 19.613 | | 68.647 | kPa / kPa |
| Fouling resistance | 0.000086 | | 0.000086 | | m2-K/W |

**Shell Geometry**

| | |
|---|---|
| TEMA type | A E L |
| ID | 1600 mm |
| Orientation | Horizontal |
| Hot fluid | Shellside |

**Baffle Geometry**

| | |
|---|---|
| Type | Single segmental |
| Orientation | Parallel |
| Cut | 20 % ID |
| Spacing | 500 mm |

**Tube Geometry**

| | | | |
|---|---|---|---|
| Type | Plain | Wall thickness | 2.108 mm |
| Length | 6.096 m | Layout angle | 30 degrees |
| Tube OD | 31.75 mm | Tubepasses | 4 |
| Pitch | 39.6875 mm | Tubecount | |

## 9.3 OUTPUT SUMMARY

| Process Conditions | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | Propylene | | Water | |
| Flow rate | (kg/s) | 17.0690 | | 259.572 | |
| Inlet/Outlet Y | (Wt. frac vap.) | 1.000 | 0.000 | 0.000 | 0.000 |
| Inlet/Outlet T | (Deg C) | 43.75 | 43.00 | 33.00 | 38.00 |
| Inlet P/Avg | (kPa) | 1820.14 | 1816.71 | 0.000 | 0.000 |
| dP/Allow. | (kPa) | 6.856 | 19.614 | 32.641 | 68.648 |
| Fouling | (m2-K/W) | 0.000086 | | 0.000086 | |

**Exchanger Performance**

| | | | | | |
|---|---|---|---|---|---|
| Shell h | (W/m2-K) | 1656.22 | Actual U | (W/m2-K) | 972.71 |
| Tube h | (W/m2-K) | 5727.33 | Required U | (W/m2-K) | 925.02 |
| Hot regime | (--) | Gravity | Duty | (MegaWatts) | 5.1016 |
| Cold regime | (--) | Sens. Liquid | Area | (m2) | 755.539 |
| EMTD | (Deg C) | 7.3 | Overdesign | (%) | 5.16 |

| Shell Geometry | | | Baffle Geometry | | |
|---|---|---|---|---|---|
| TEMA type | (--) | AEL | Baffle type | (--) | Single-Seg. |
| Shell ID | (mm) | 1600.00 | Baffle cut | (Pct Dia.) | 20.00 |
| Series | (--) | 1 | Baffle orientation | (--) | Parallel |
| Parallel | (--) | 1 | Central spacing | (mm) | 500.000 |
| Orientation | (deg) | 0.00 | Crosspasses | (--) | 11 |

| Tube Geometry | | | Nozzles | | |
|---|---|---|---|---|---|
| Tube type | (--) | Plain | Shell inlet | (mm) | 258.877 |
| Tube OD | (mm) | 31.750 | Shell outlet | (mm) | 205.004 |
| Length | (m) | 6.096 | Inlet height | (mm) | 83.144 |
| Pitch ratio | (--) | 1.2500 | Outlet height | (mm) | 29.369 |
| Layout | (deg) | 30 | Tube inlet | (mm) | 387.351 |
| Tubecount | (--) | 1286 | Tube outlet | (mm) | 387.351 |
| Tube Pass | (--) | 4 | | | |

| Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|
| Shell | 58.73 | Shellside | 0.85 | A | 0.151 |
| Tube | 19.59 | Tubeside | 1.37 | B | 0.522 |
| Fouling | 18.01 | Crossflow | 1.33 | C | 0.062 |
| Metal | 3.673 | Window | 1.43 | E | 0.205 |
| | | | | F | 0.060 |

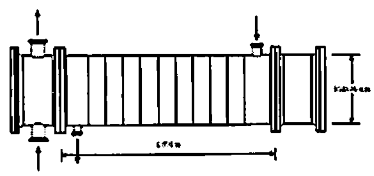
## 9.4 TEMA SHEET

| | | | | |
|---|---|---|---|---|
| Plant Location | | Date | 08-03-2011 | Rev |
| Service of Unit | | Item No. | | |
| Size | 1600.00 x 6095.93 mm | Type AEL Horz. | Connected In | 1 Parallel 1 Series |
| Surf/Unit (Gross/Eff) | 781.94 / 755.54 m2 | Shell/Unit 1 | Surf/Shell (Gross/Eff) | 781.94 / 755.54 m2 |

| PERFORMANCE OF ONE UNIT | | | | | |
|---|---|---|---|---|---|
| Fluid Allocation | | Shell Side | | Tube Side | |
| Fluid Name | | Propylene | | Water | |
| Fluid Quantity, Total | kg/hr | 61448.3 | | 934459 | |
| Vapor (In/Out) | | 61448.3 | | | |
| Liquid | | | 61448.3 | 934459 | 934459 |
| Steam | | | | | |
| Water | | | | | |
| Noncondensables | | | | | |
| Temperature (In/Out) | C | 43.75 | 43.00 | 33.00 | 38.00 |
| Specific Gravity | | | 0.4247 | 0.9952 | 0.9934 |
| Viscosity | mN-s/m2 | 0.0103 | 0.0516 | 0.7491 | 0.6783 |
| Molecular Weight, Vapor | | | | | |
| Molecular Weight, Noncondensables | | | | | |
| Specific Heat | kJ/kg-C | 2.0615 | 3.2747 | 3.9151 | 3.9504 |
| Thermal Conductivity | W/m-C | 0.0193 | 0.0773 | 0.6206 | 0.6281 |
| Latent Heat | kJ/kg | 297.425 | 297.429 | | |
| Inlet Pressure | kPa | 1820.14 | | | |
| Velocity | m/s | 0.85 | | 1.37 | |
| Pressure Drop, Allow/Calc | kPa | 19.614 | 6.856 | 68.648 | 32.641 |
| Fouling Resistance (min) | m2-K/W | 0.000086 | | 0.000086 | |
| Heat Exchanged W | 5101550 | MTD (Corrected) | 7.3 C | | |
| Transfer Rate, Service | 925.02 W/m2-K | Clean | 1186.40 W/m2-K | Actual | 972.71 W/m2-K |

| CONSTRUCTION OF ONE SHELL | | | |
|---|---|---|---|
| | | Shell Side | Tube Side |
| Design/Test Pressure | kPaG | 1930.03 / | 1000.02 / |
| Design Temperature | C | 140.00 | 65.00 |
| No Passes per Shell | | 1 | 4 |
| Corrosion Allowance | mm | | |
| Connections Size & Rating | In mm | 1 @ 258.877 | 1 @ 387.351 |
| | Out mm | 1 @ 205.004 | 1 @ 387.351 |
| | Intermediate | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | | | |
|---|---|---|---|---|---|
| Tube No. 1286 | OD 31.750 mm | Thk(Avg) 2.108 mm | Length 6.096 m | Pitch 39.687 mm | Layout 30 |
| Tube Type | Plain | | Material CARBON STEEL | | |
| Shell | ID 1600.00 mm | OD mm | Shell Cover | | |
| Channel or Bonnet | | | Channel Cover | | |
| Tubesheet-Stationary | | | Tubesheet-Floating | | |
| Floating Head Cover | | | Impingement Plate | Circular plate | |
| Baffles-Cross | Type SINGLE-SEG. | %Cut (Diam) 20.0 | Spacing(c/c) 500.000 | Inlet 735.718 mm | |
| Baffles-Long | | Seal Type | | | |
| Supports-Tube | | U-Bend | Type | | |
| Bypass Seal Arrangement | | Tube-Tubesheet Joint | | | |
| Expansion Joint | | Type | | | |
| Rho-V2-Inlet Nozzle | 2730.67 kg/m-s2 | Bundle Entrance 512.56 | Bundle Exit 159.22 kg/m-s2 | | |
| Gaskets-Shell Side | | Tube Side | | | |
| -Floating Head | | | | | |
| Code Requirements | | | TEMA Class | | |
| Weight/Shell 28645.6 | | Filled with Water 43586.2 | Bundle 15018.5 kg | | |
| Remarks: | | | | | |
| | | | | | Reprinted with Permission (v5) |

## 9.5 RATING DATA SHEET

| | | |
|---|---|---|
| Type AEL | Orientation Horizontal | Connected In 1 Parallel 1 Series |
| Surf/Unit (Gross/Eff) 781.94 / 755.54 m2 | Shell/Unit 1 | Surf/Shell (Gross/Eff) 781.94 / 755.54 m2 |

**PERFORMANCE OF ONE UNIT**

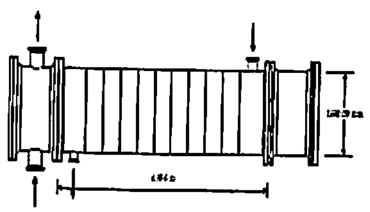
| Fluid Allocation | | Shell Side | | Tube Side | |
|---|---|---|---|---|---|
| Fluid Name | | Propylene | | Water | |
| Fluid Quantity, Total | kg/s | 17.0690 | | 259.572 | |
| Vapor (In/Out) | wt% | 100.0 | 0.0 | 0.0 | 0.0 |
| Liquid | wt% | 0.0 | 100.0 | 100.0 | 100.0 |
| Temperature (In/Out) | C | 43.75 | 43.00 | 33.00 | 38.00 |
| Density | kg/m3 | 38.511 | 424.46 | 994.72 | 992.98 |
| Viscosity | mN-s/m2 | 0.0103 | 0.0516 | 0.7491 | 0.6783 |
| Specific Heat | kJ/kg-C | 2.0615 | 3.2747 | 3.9151 | 3.9504 |
| Thermal Conductivity | W/m-C | 0.0193 | 0.0773 | 0.6206 | 0.6281 |
| Critical Pressure | kPa | | | | |
| Inlet Pressure | kPa | 1820.14 | | | |
| Velocity | m/s | | 0.85 | | 1.37 |
| Pressure Drop, Allow/Calc | kPa | 19.614 | 6.856 | 68.648 | 32.641 |
| Average Film Coefficient | W/m2-K | 1656.22 | | 5727.33 | |
| Fouling Resistance (min) | m2-K/W | 0.000086 | | 0.000086 | |

| | | |
|---|---|---|
| Heat Exchanged 5.1016 MegaWatts | MTD (Corrected) 7.3 C | Overdesign 5.16 % |
| Transfer Rate, Service 925.02 W/m2-K | Calculated 972.71 W/m2-K | Clean 1186.40 W/m2-K |

**CONSTRUCTION OF ONE SHELL**

| | | | Shell Side | Tube Side |
|---|---|---|---|---|
| Design Pressure | | kPaG | 1930.03 | 1000.02 |
| Design Temperature | | C | 140.00 | 65.00 |
| No Passes per Shell | | | 1 | 4 |
| Flow Direction | | | Downward | Upward |
| Connections Size & Rating | In | mm | 1 @ 258.877 | 1 @ 387.351 |
| | Out | mm | 1 @ 205.004 | 1 @ 387.351 |
| | Liq. Out | mm | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | | |
|---|---|---|---|---|
| Tube No. 1286 OD 31.750 mm | Thk(Avg) 2.108 mm | Length 6.096 m | Pitch 39.687 mm | Layout 30 |
| Tube Type Plain | Material CARBON STEEL | | Pairs seal strips 0 | |
| Shell ID 1600.00 mm | Kettle ID mm | | Passlane Seal Rod No. 10 | |
| Cross Baffle Type PARALLEL SINGLE-SEG. | %Cut (Diam) 20.0 | | Impingement Plate Circular plate | |
| Spacing(c/c) 500.000 mm | Inlet 735.718 mm | | No. of Crosspasses 11 | |
| Rho-V2-Inlet Nozzle 2730.67 kg/m-s2 | Shell Entrance 1888.01 | | Shell Exit 1152.35 kg/m-s2 | |
| | Bundle Entrance 512.56 | | Bundle Exit 159.22 kg/m-s2 | |
| Weight/Shell 28645.6 | Filled with Water 43586.2 | | Bundle 15018.5 kg | |

| Notes: | Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|---|
| | Shell | 58.73 | Shellside | 0.85 | A | 0.151 |
| | Tube | 19.59 | Tubeside | 1.37 | B | 0.522 |
| | Fouling | 18.01 | Crossflow | 1.33 | C | 0.062 |
| | Metal | 3.67 | Window | 1.43 | E | 0.205 |
| | | | | | F | 0.060 |

## 9.6 VIBRATION ANALYSIS

| | | | | |
|---|---|---|---|---|
| Shellside condition | | Cond. Vapor | (Level 2.2) | |
| Axial stress loading | (Mpa) | 0.000 | Added mass factor | 1.761 |
| Beta | | 4.000 | | |
| **Position In The Bundle** | | **Inlet** | **Center** | **Outlet** |
| Length for natural frequency | (m) | 1.236 | 1.000 | 1.154 |
| Length/TEMA maximum span | (--) | 0.553 | 0.447 | 0.516 |
| Number of spans | (--) | 6 | 6 | 6 |
| Tube natural frequency | (Hz) | 75.9 | 74.9 | 68.0 + |
| Shell acoustic frequency | (Hz) | 64.0 + | | |
| **Flow Velocities** | | **Inlet** | **Center** | **Outlet** |
| Window parallel velocity | (m/s) | 2.51 | 1.21 | 0.23 |
| Bundle crossflow velocity | (m/s) | 1.17 | 0.83 | 0.12 |
| Bundle/shell velocity | (m/s) | 1.27 | 0.90 | 0.13 |
| **Fluidelastic Instability Check** | | **Inlet** | **Center** | **Outlet** |
| Log decrement | HTRI | 0.030 | 0.070 | 0.044 |
| Critical velocity | (m/s) | 11.22 | 18.37 | 5.22 |
| Baffle tip cross velocity ratio | (--) | 0.120 | 0.052 | 0.027 |
| Average crossflow velocity ratio | (--) | 0.104 | 0.045 | 0.023 |
| **Acoustic Vibration Check** | | **Inlet** | **Center** | **Outlet** |
| Vortex shedding ratio | (--) | 0.230 | | |
| Chen number | (--) | 79899 | | |
| Turbulent buffeting ratio | (--) | 0.171 | | |
| **Tube Vibration Check** | | **Inlet** | **Center** | **Outlet** |
| Vortex shedding ratio | (--) | 0.099 | 0.070 | 0.010 |
| Turbulent buffeting ratio | (--) | 0.161 | 0.114 | 0.016 |
| Parallel flow amplitude | (mm) | 0.000 | 0.000 | 0.000 |
| Crossflow amplitude | (mm) | 0.006 | 0.003 | 0.001 |
| Turbulent buffeting amplitude | (mm) | 0.001 | 0.001 | 0.000 |
| Tube gap | (mm) | 7.938 | 7.938 | 7.938 |
| Crossflow RHO-V-SQ | (kg/m-s2) | 52.50 | 54.82 | 6.02 |
| **Bundle Entrance/Exit (analysis at first tube row)** | | | **Entrance** | **Exit** |
| Fluidelastic instability ratio | (--) | | 0.400 | 0.144 |
| Vortex shedding ratio | (--) | | 0.310 | 0.052 |
| Crossflow amplitude | (mm) | | 0.06251 | 0.01340 |
| Crossflow velocity | (m/s) | | 3.65 | 0.61 |
| Turbulent buffeting amplitude | (mm) | | 0.015 | 0.001 |
| Tubesheet to inlet/outlet support | (mm) | | None | None |
| **Shell Entrance/Exit Parameters** | | | **Entrance** | **Exit** |
| Impingement plate | | | Yes | |
| Flow area | (m2) | | 0.063 | 0.024 |
| Velocity | (m/s) | | 7.00 | 1.65 |
| RHO-V-SQ | (kg/m-s2) | | 1888.01 | 1152.35 |

| | | | |
|---|---|---|---|
| Shell type | AEL | Baffle type | Single-Seg. |
| Tube type | Plain | Baffle layout | Parallel |
| Pitch ratio | 1.2500 | Tube diameter, (mm) | 31.750 |
| Layout angle | 30 | Tube material | Carbon steel |
| | | Supports/baffle space | |

## 9.7 FINAL RESULTS

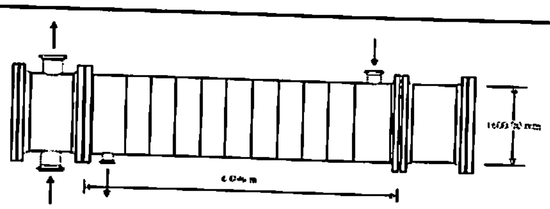
| Process Data | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | Propylene | | Water | |
| Fluid condition | | | Cond. Vapor | | Sens. Liquid |
| Total flow rate | (kg/s) | | 17.0690 | | 259.572 |
| Weight fraction vapor, In/Out | (--) | 1.000 | 0.000 | 0.000 | 0.000 |
| Temperature, In/Out | (Deg C) | 43.75 | 43.00 | 33.00 | 38.00 |
| Temperature, Average/Skin | (Deg C) | 43.4 | 38.79 | 35.5 | 37.21 |
| Wall temperature, Min/Max | (Deg C) | 36.29 | 39.67 | 35.96 | 39.48 |
| Pressure, In/Average | (kPa) | 1820.14 | 1816.71 | 0.000 | 0.000 |
| Pressure drop, Total/Allowed | (kPa) | 6.856 | 19.613 | 32.641 | 68.647 |
| Velocity, Mid/Max allow | (m/s) | 0.85 | | 1.37 | |
| Mole fraction inert | (--) | | 0.000 | | |
| Average film coef. | (W/m2-K) | | 1656.22 | | 5727.33 |
| Heat transfer safety factor | (--) | | 1.000 | | 1.000 |
| Fouling resistance | (m2-K/W) | | 0.000086 | | 0.000086 |

**Overall Performance Data**

| | | | | |
|---|---|---|---|---|
| Overall coef., Reqd/Clean/Actual | (W/m2-K) | 925.02 / | 1186.40 / | 972.71 |
| Heat duty, Calculated/Specified | (MegaWatts) | 5.1016 / | | |
| Effective overall temperature difference | (Deg C) | 7.3 | | |
| EMTD = (MTD) * (DELTA) * (F/G/H) | (Deg C) | 7.30 * | 1.0000 * | 1.0000 |

**Exchanger Fluid Volumes**

| | | |
|---|---|---|
| Approximate shellside | (L) | 5721.4 |
| Approximate tubeside | (L) | 9229.0 |



**Shell Construction Information**

| | | | | | |
|---|---|---|---|---|---|
| TEMA shell type | AEL | | Shell ID | (mm) | 1600.00 |
| Shells Series | 1 Parallel | 1 | Total area | (m2) | 781.939 |
| Passes Shell | 1 Tube | 4 | Eff. area | (m2/shell) | 755.539 |
| Shell orientation angle (deg) | 0.00 | | | | |
| Impingement present | Circular plate | | Impingement diameter/nozzle | | 1.1 |
| Pairs seal strips | 0 | | Passlane seal rods (mm) | 31.750 | No. 10 |
| Shell expansion joint | No | | Rear head support plate | | No |

Weight estimation Wet/Dry/Bundle 43586 / 28646 / 15018 (kg/shell)

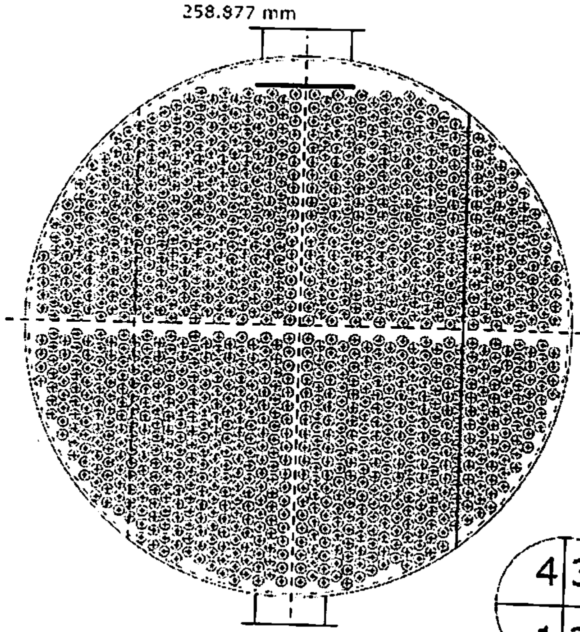
**Baffle Information**

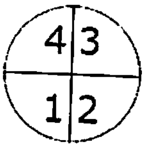
| | | | | | |
|---|---|---|---|---|---|
| Type | | Parallel Single-Seg. | Baffle cut (% dia) | 20.00 | |
| Crosspasses/shellpass | | 11 | No. | (Pct Area) | (mm) to C.L |
| Central spacing | (mm) | 500.000 | 1 | 15.10 | 480.000 |
| Inlet spacing | (mm) | 735.718 | 2 | 0.00 | 0.000 |
| Outlet spacing | (mm) | 654.407 | | | |
| Baffle thickness | (mm) | 15.875 | | | |

**Tube Information**

| | | | | | |
|---|---|---|---|---|---|
| Tube type | | Plain | Tubecount per shell | | 1286 |
| Overall length | (m) | 6.096 | Pct tubes removed (both) | | 2.26 |
| Effective length | (m) | 5.890 | Outside diameter | (mm) | 31.750 |
| Total tubesheet | (mm) | 205.813 | Wall thickness | (mm) | 2.108 |
| Area ratio | (out/in) | 1.1531 | Pitch (mm) 39.6875 | Ratio | 1.2500 |
| Tube metal | | Carbon steel | Tube pattern (deg) | | 30 |

## 9.8 TUBE LAYOUT AND DRAWING



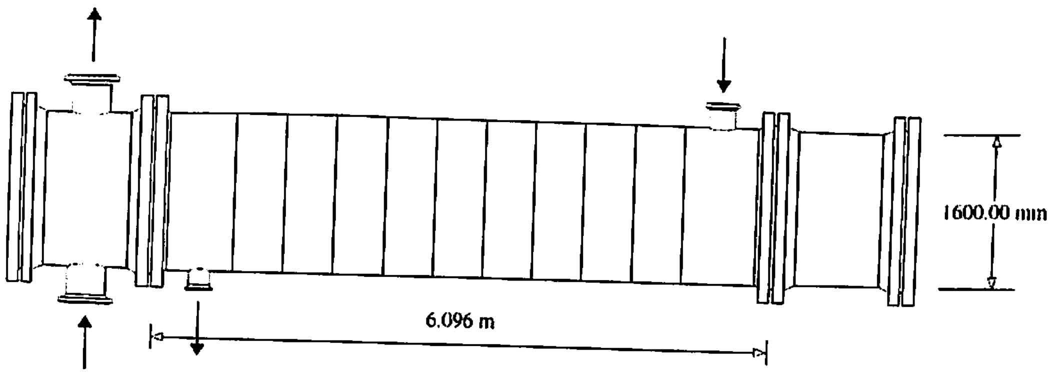

| | | |
|---|---|---|
| Item number | | |
| TEMA type | AEL | |
| Shell diameter | 1600.00 | mm |
| Outer tube limit | 1580.61 | mm |
| Height under inlet nozzle | 83.144 | mm |
| Height under outlet nozzle | 29.369 | mm |
| Tube diameter | 31.750 | mm |
| Tube pitch | 39.687 | mm |
| Tube layout angle | 30 | |
| Number of tubes (specified) | 1286 | |
| Number of tubes (calculated) | 1286 | |
| Number of tie rods | 12 | |
| Number of seal strip pairs | 0 | |
| Number of passlane seal rods | 10 | |
| Number of passes | 4 | |
| Parallel passlane width | 22.225 | mm |
| Perpendicular passlane width | 22.225 | mm |
| Baffle cut % diameter | 20 | |

TUBEPASS DETAILS

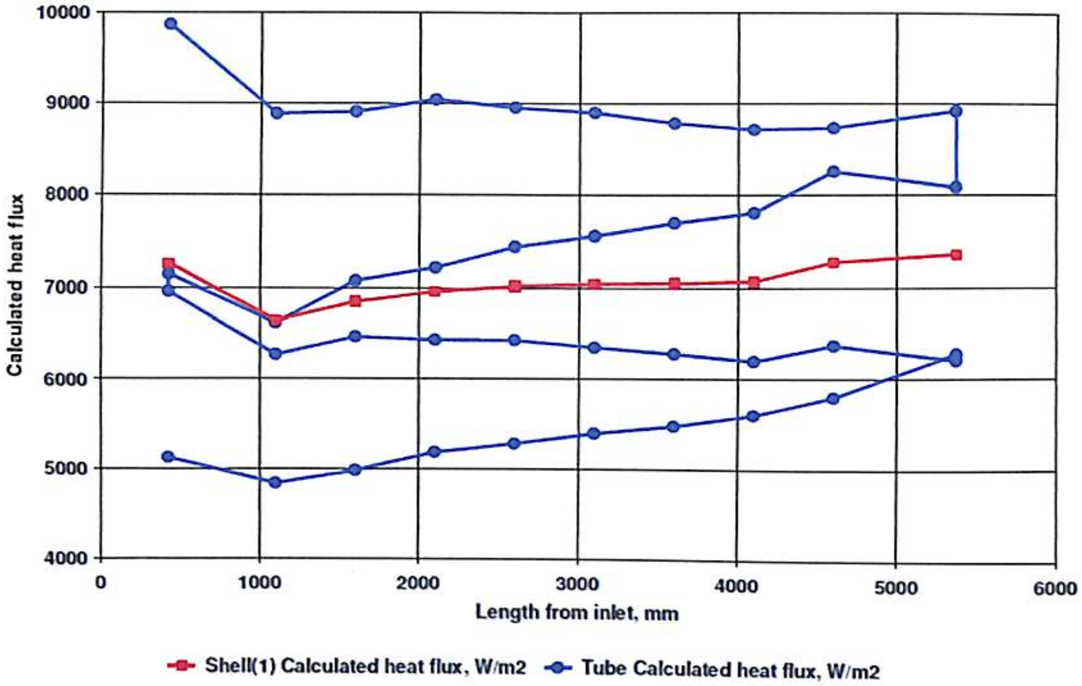
| Pass | Rows | Tubes | Plugged |
|---|---|---|---|
| 1 | 37 | 323 | 0 |
| 2 | 37 | 323 | 0 |
| 3 | 35 | 326 | 0 |
| 4 | 35 | 326 | 0 |

SYMBOL LEGEND

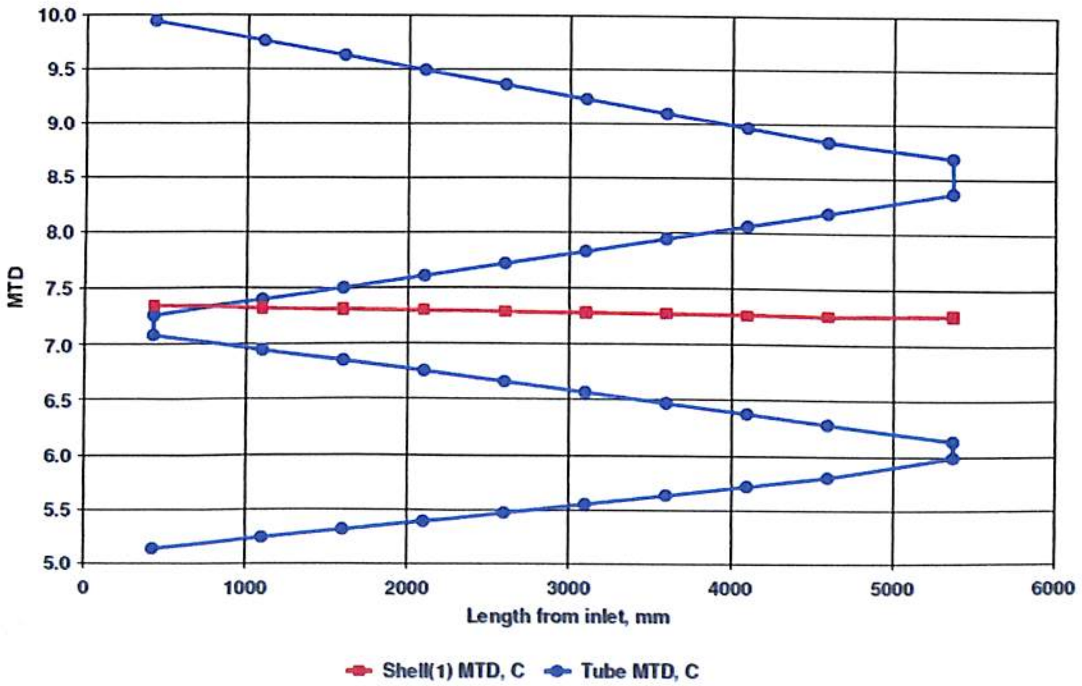
- Tube
- Plugged tube
- Tie rod
- Impingement rod
- Dummy tube
- Seal rod
- Seal strip/Skid bar



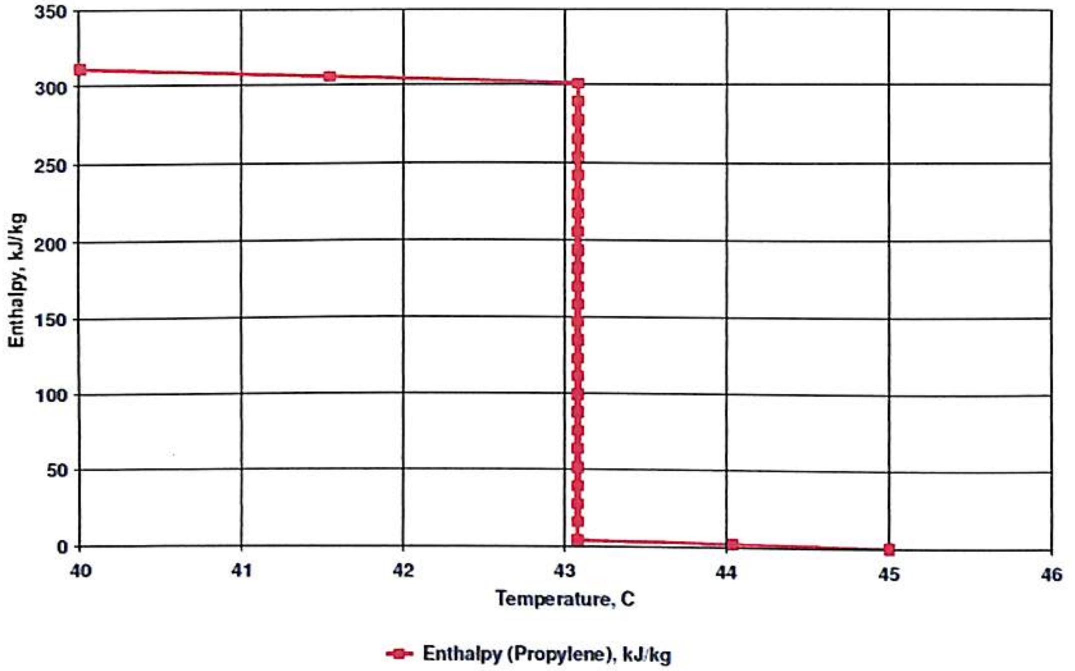
## 9.9 VARIATION OF HEAT FLUX ACROSS LENGTH



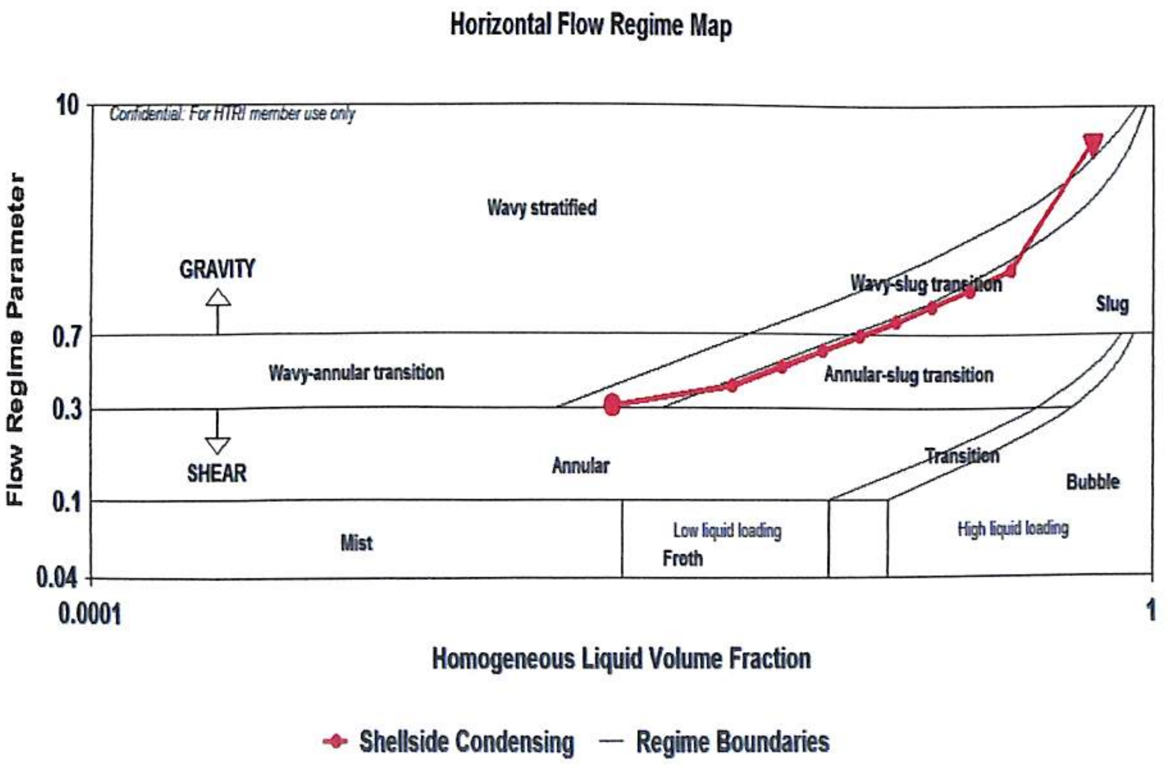

## 9.10 VARIATION OF MTD ACROSS LENGTH



## 9.11 ENTHALPY GRAPH




## 9.12 FLOW REGIME



# 10. DESIGN OF COOLER E-103

## 10.1 DESIGN BASIS

**Design pressure**

Maximum design pressure for any pressure vessel shall be Maximum normal operating pressure plus 2.0 $kg/cm^2$

The minimum design pressure for any pressure vessel shall be 3.5 $kg/cm^2g$.

**Design temperature**

In general the design temperature of pressure vessels is dependent upon the operating temperature range as follows:

No maximum design temperature will be set less than 65°C.

| Operating Temp Range, (°C) | Design Temp, (°C) |
|---|---|
| T < 50 | Minimum anticipated operating temperature margin to be determined by metallurgical limits |
| 50 < T < 400 | Maximum anticipated operating temperature + 15°C (round up to nearest 5°C.) |
| T > 400* | Maximum anticipated operating temperature 10% minimum margin |

**Fouling Factors**

Fouling factors shall be specified as follows:

| Utility Services | $m^2$-°C-h/kcal |
|---|---|
| Steam (all levels) | 0.0001 |
| Cooling Water | 0.0004 |

| Process Streams | $m^2$-°C-h/kcal |
|---|---|
| Depropylenizer Overhead | 0.0001 |
| Depropylenizer bottoms | 0.0004 |

**Corrosion Allowance**

| Utility Services | Corrosion Allowance |
|---|---|
| Steam (all levels except SHP) | 3 mm |
| Steam Condensate | 1.5 mm |
| Cooling Water | 3 mm |

## 10.2 INPUTS TO HTRI

Rating | Simulation | **Design**

Exchanger Configuration

Exchanger service: Generic Shell and Tube

Process Conditions

| | Hot Shell | | Cold Tube | | |
|---|---|---|---|---|---|
| Flow rate | 27078.5 | | | | kg/hr |
| Inlet/outlet Y | 0 | 0 | 0 | 0 | Weight fraction vapor |
| Inlet/outlet T | 100 | 40 | 33 | 40 | C |
| Inlet P/allow dP | | 0.7 | | 0.7 | kPa / kgf/cm2 |
| Fouling resistance | 0.000344 | | 0.000086 | | m2-K/W |

Shell Geometry

| | | |
|---|---|---|
| TEMA type | A E S | |
| ID | | mm |
| Orientation | Horizontal | |
| Hot fluid | Shellside | |

Baffle Geometry

| | | |
|---|---|---|
| Type | Single segmental | |
| Orientation | Parallel | |
| Cut | 30 | % ID |
| Spacing | | mm |

Tube Geometry

| | | | | | |
|---|---|---|---|---|---|
| Type | Plain | | Wall thickness | 2.108 | mm |
| Length | 1.829 | m | Layout angle | 30 | degrees |
| Tube OD | 19.05 | mm | Tubepasses | 2 | |
| Pitch | 25 | mm | Tubecount | | |

## 10.3 OUTPUT SUMMARY

| Process Conditions | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | propylene | | water | |
| Flow rate | (kg/s) | | 7.5218 | | 46.6670 |
| Inlet/Outlet Y | (Wt. frac vap.) | 0.000 | 0.000 | 0.000 | 0.000 |
| Inlet/Outlet T | (Deg C) | 99.40 * | 40.00 | 33.00 | 40.00 |
| Inlet P/Avg | (kPa) | 0.000 | 0.000 | 0.000 | 0.000 |
| dP/Allow. | (kPa) | 1.277 | 68.648 | 14.492 | 68.648 |
| Fouling | (m2-K/W) | | 0.000344 | | 0.000086 |

**Exchanger Performance**

| | | | | | |
|---|---|---|---|---|---|
| Shell h | (W/m2-K) | 787.53 | Actual U | (W/m2-K) | 490.39 |
| Tube h | (W/m2-K) | 5121.30 | Required U | (W/m2-K) | 465.83 |
| Hot regime | (--) | Sens. Liquid | Duty | (MegaWatts) | 1.2863 |
| Cold regime | (--) | Sens. Liquid | Area | (m2) | 139.596 |
| EMTD | (Deg C) | 19.8 | Overdesign | (%) | 5.27 |

| Shell Geometry | | | Baffle Geometry | | |
|---|---|---|---|---|---|
| TEMA type | (--) | AES | Baffle type | (--) | Single-Seg. |
| Shell ID | (mm) | 715.000 | Baffle cut | (Pct Dia.) | 35.00 |
| Series | (--) | 1 | Baffle orientation | (--) | Parallel |
| Parallel | (--) | 1 | Central spacing | (mm) | 400.000 |
| Orientation | (deg) | 0.00 | Crosspasses | (--) | 7 |

| Tube Geometry | | | Nozzles | | |
|---|---|---|---|---|---|
| Tube type | (--) | Plain | Shell inlet | (mm) | 154.051 |
| Tube OD | (mm) | 15.875 | Shell outlet | (mm) | 154.051 |
| Length | (m) | 3.048 | Inlet height | (mm) | 24.522 |
| Pitch ratio | (--) | 1.2500 | Outlet height | (mm) | 24.522 |
| Layout | (deg) | 30 | Tube inlet | (mm) | 154.051 |
| Tubecount | (--) | 950 | Tube outlet | (mm) | 154.051 |
| Tube Pass | (--) | 2 | | | |

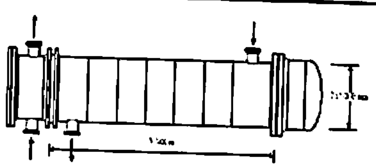
| Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|
| Shell | 62.29 | Shellside | 0.16 | A | 0.127 |
| Tube | 13.03 | Tubeside | 0.93 | B | 0.512 |
| Fouling | 22.60 | Crossflow | 0.21 | C | 0.121 |
| Metal | 2.081 | Window | 0.21 | E | 0.113 |
| | | | | F | 0.127 |

## 10.4 TEMA SHEET

| | | | | | |
|---|---|---|---|---|---|
| Plant Location | | | Date | 22-01-2011 | Rev |
| Service of Unit | | | Item No. | | |
| Size | 715.000 x 3047.96 mm | Type AES Horz. | Connected In | 1 Parallel | 1 Series |
| Surf/Unit (Gross/Eff) | 144.41 / 139.60 m2 | Shell/Unit 1 | Surf/Shell (Gross/Eff) | 144.41 / 139.60 m2 | |

| PERFORMANCE OF ONE UNIT | | | | | |
|---|---|---|---|---|---|
| Fluid Allocation | | Shell Side | | Tube Side | |
| Fluid Name | | propylene | | water | |
| Fluid Quantity, Total | kg/hr | 27078.7 | | 168001 | |
| Vapor (In/Out) | | | | | |
| Liquid | | 27078.7 | 27078.7 | 168001 | 168001 |
| Steam | | | | | |
| Water | | | | | |
| Noncondensables | | | | | |
| Temperature (In/Out) | C | 99.40 | 40.00 | 33.00 | 40.00 |
| Specific Gravity | | 0.4119 | 0.5207 | 0.9952 | 0.9927 |
| Viscosity | mN-s/m2 | 0.0504 | 0.0875 | 0.7491 | 0.6532 |
| Molecular Weight, Vapor | | | | | |
| Molecular Weight, Noncondensables | | | | | |
| Specific Heat | kJ/kg-C | 3.3797 | 2.5634 | 3.9151 | 3.9649 |
| Thermal Conductivity | W/m-C | 0.0709 | 0.0973 | 0.6205 | 0.6309 |
| Latent Heat | kJ/kg | | | | |
| Inlet Pressure | kPa | | | | |
| Velocity | m/s | 0.16 | | 0.93 | |
| Pressure Drop, Allow/Calc | kPa | 68.648 | 1.277 | 68.648 | 14.492 |
| Fouling Resistance (min) | m2-K/W | 0.000344 | | 0.000086 | |
| Heat Exchanged W | 1286295 | MTD (Corrected) | 19.8 C | | |
| Transfer Rate, Service | 465.83 W/m2-K | Clean | 633.67 W/m2-K | Actual | 490.39 W/m2-K |

| CONSTRUCTION OF ONE SHELL | | | | | |
|---|---|---|---|---|---|
| | | | Shell Side | Tube Side | Sketch (Bundle/Nozzle Orientation) |
| Design/Test Pressure | | kPaG | 1930.03 / | 1000.02 / | |
| Design Temperature | | C | 130.00 | 65.00 | |
| No Passes per Shell | | | 1 | 2 | |
| Corrosion Allowance | | mm | | | |
| Connections Size & Rating | In | mm | 1 @ 154.051 | 1 @ 154.051 | |
| | Out | mm | 1 @ 154.051 | 1 @ 154.051 | |
| | Intermediate | | @ | @ | |



| | | | | | |
|---|---|---|---|---|---|
| Tube No. 950 | OD 15.875 mm | Thk(Avg) 2.108 mm | Length 3.048 m | Pitch 19.844 mm | Layout 30 |
| Tube Type | Plain | | Material CARBON STEEL | | |
| Shell | ID 715.000 mm | OD mm | Shell Cover | | |
| Channel or Bonnet | | | Channel Cover | | |
| Tubesheet-Stationary | | | Tubesheet-Floating | | |
| Floating Head Cover | | | Impingement Plate | None | |
| Baffles-Cross | Type SINGLE-SEG. | %Cut (Diam) 35.0 | Spacing(c/c) 400.000 | Inlet 532.625 mm | |
| Baffles-Long | | Seal Type | | | |
| Supports-Tube | | U-Bend | Type | | |
| Bypass Seal Arrangement | | Tube-Tubesheet Joint | | | |
| Expansion Joint | | Type | | | |
| Rho-V2-Inlet Nozzle | 395.58 kg/m-s2 | Bundle Entrance 82.42 | Bundle Exit | 107.90 | kg/m-s2 |
| Gaskets-Shell Side | | Tube Side | | | |
| -Floating Head | | | | | |
| Code Requirements | | | TEMA Class | | |
| Weight/Shell 4492.08 | | Filled with Water 5861.96 | Bundle 2311.32 | kg | |
| Remarks: | | | | | |

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## 10.5 RATING DATA SHEET

| | | | |
|---|---|---|---|
| Type AES | Orientation Horizontal | Connected In 1 Parallel 1 Series | |
| Surf/Unit (Gross/Eff) 144.41 / 139.60 m2 | Shell/Unit 1 | Surf/Shell (Gross/Eff) 144.41 / 139.60 m2 | |

**PERFORMANCE OF ONE UNIT**

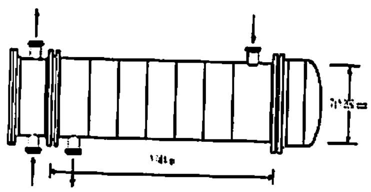
| Fluid Allocation | | Shell Side | | Tube Side | |
|---|---|---|---|---|---|
| Fluid Name | | propylene | | water | |
| Fluid Quantity, Total | kg/s | 7.5218 | | 46.6670 | |
| Vapor (In/Out) | wt% | 0.0 | 0.0 | 0.0 | 0.0 |
| Liquid | wt% | 100.0 | 100.0 | 100.0 | 100.0 |
| Temperature (In/Out) | C | 99.40 | 40.00 | 33.00 | 40.00 |
| Density | kg/m3 | 411.68 | 520.48 | 994.70 | 992.22 |
| Viscosity | mN-s/m2 | 0.0504 | 0.0875 | 0.7491 | 0.6532 |
| Specific Heat | kJ/kg-C | 3.3797 | 2.5634 | 3.9151 | 3.9649 |
| Thermal Conductivity | W/m-C | 0.0709 | 0.0973 | 0.6205 | 0.6309 |
| Critical Pressure | kPa | | | | |
| Inlet Pressure | kPa | | | | |
| Velocity | m/s | | 0.16 | | 0.93 |
| Pressure Drop, Allow/Calc | kPa | 68.648 | 1.277 | 68.648 | 14.492 |
| Average Film Coefficient | W/m2-K | 787.53 | | 5121.30 | |
| Fouling Resistance (min) | m2-K/W | 0.000344 | | 0.000086 | |

| | | | |
|---|---|---|---|
| Heat Exchanged | 1.2863 MegaWatts | MTD (Corrected) 19.8 C | Overdesign 5.27 % |
| Transfer Rate, Service | 465.83 W/m2-K | Calculated 490.39 W/m2-K | Clean 633.67 W/m2-K |

**CONSTRUCTION OF ONE SHELL**

| | | Shell Side | Tube Side |
|---|---|---|---|
| Design Pressure | kPaG | 1930.03 | 1000.02 |
| Design Temperature | C | 130.00 | 65.00 |
| No Passes per Shell | | 1 | 2 |
| Flow Direction | | Downward | Upward |
| Connections Size & Rating | In mm | 1 @ 154.051 | 1 @ 154.051 |
| | Out mm | 1 @ 154.051 | 1 @ 154.051 |
| | Liq. Out mm | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | |
|---|---|---|---|
| Tube No. 950 OD 15.875 mm | Thk(Avg) 2.108 mm | Length 3.048 m | Pitch 19.844 mm Layout 30 |
| Tube Type Plain | Material CARBON STEEL | Pairs seal strips 2 | |
| Shell ID 715.000 mm | Kettle ID mm | Passlane Seal Rod No. 6 | |
| Cross Baffle Type PARALLEL SINGLE-SEG. | %Cut (Diam) 35.0 | Impingement Plate None | |
| Spacing(c/c) 400.000 mm | Inlet 532.625 mm | No. of Crosspasses 7 | |
| Rho-V2-Inlet Nozzle 395.58 kg/m-s2 | Shell Entrance 586.32 | Shell Exit 463.77 kg/m-s2 | |
| | Bundle Entrance 82.42 | Bundle Exit 107.90 kg/m-s2 | |
| Weight/Shell 4492.08 | Filled with Water 5861.96 | Bundle 2311.32 kg | |

| Notes: | Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|---|
| | Shell | 62.29 | Shellside | 0.16 | A | 0.127 |
| | Tube | 13.03 | Tubeside | 0.93 | B | 0.512 |
| | Fouling | 22.60 | Crossflow | 0.21 | C | 0.121 |
| | Metal | 2.08 | Window | 0.21 | E | 0.113 |
| | | | | | F | 0.127 |

## 10.6 VIBRATION ANALYSIS

| | | | | |
|---|---|---|---|---|
| Shellside condition | | Sens. Liquid | (Level 2.2) | |
| Axial stress loading | (Mpa) | 0.000 | Added mass factor | 1.761 |
| Beta | | 4.000 | | |

| Position In The Bundle | | Inlet | Center | Outlet |
|---|---|---|---|---|
| Length for natural frequency | (m) | 0.933 | 0.800 | 0.814 |
| Length/TEMA maximum span | (--) | 0.693 | 0.594 | 0.604 |
| Number of spans | (--) | 4 | 4 | 4 |
| Tube natural frequency | (Hz) | 61.1 | 60.1 | 59.9 + |
| Shell acoustic frequency | (Hz) | | | |
| **Flow Velocities** | | **Inlet** | **Center** | **Outlet** |
| Window parallel velocity | (m/s) | 0.23 | 0.19 | 0.18 |
| Bundle crossflow velocity | (m/s) | 0.15 | 0.16 | 0.15 |
| Bundle/shell velocity | (m/s) | 0.10 | 0.11 | 0.10 |
| **Fluidelastic Instability Check** | | **Inlet** | **Center** | **Outlet** |
| Log decrement | HTRI | 0.038 | 0.038 | 0.038 |
| Critical velocity | (m/s) | 2.26 | 2.82 | 2.69 |
| Baffle tip cross velocity ratio | (--) | 0.066 | 0.057 | 0.056 |
| Average crossflow velocity ratio | (--) | 0.066 | 0.057 | 0.056 |
| **Acoustic Vibration Check** | | **Inlet** | **Center** | **Outlet** |
| Vortex shedding ratio | (--) | | | |
| Chen number | (--) | | | |
| Turbulent buffeting ratio | (--) | | | |
| **Tube Vibration Check** | | **Inlet** | **Center** | **Outlet** |
| Vortex shedding ratio | (--) | 0.028 | 0.031 | 0.029 |
| Turbulent buffeting ratio | (--) | 0.046 | 0.050 | 0.046 |
| Parallel flow amplitude | (mm) | 0.000 | 0.000 | 0.000 |
| Crossflow amplitude | (mm) | 0.002 | 0.001 | 0.001 |
| Turbulent buffeting amplitude | (mm) | 0.000 | 0.001 | 0.001 |
| Tube gap | (mm) | 3.969 | 3.969 | 3.969 |
| Crossflow RHO-V-SQ | (kg/m-s2) | 8.77 | 12.69 | 11.50 |

| Bundle Entrance/Exit (analysis at first tube row) | | Entrance | Exit |
|---|---|---|---|
| Fluidelastic instability ratio | (--) | 0.244 | 0.208 |
| Vortex shedding ratio | (--) | 0.086 | 0.088 |
| Crossflow amplitude | (mm) | 0.01478 | 0.01121 |
| Crossflow velocity | (m/s) | 0.45 | 0.46 |
| Turbulent buffeting amplitude | (mm) | 0.007 | 0.009 |
| Tubesheet to inlet/outlet support | (mm) | None | None |
| **Shell Entrance/Exit Parameters** | | **Entrance** | **Exit** |
| Impingement plate | | No | |
| Flow area | (m2) | 0.015 | 0.015 |
| Velocity | (m/s) | 1.19 | 0.94 |
| RHO-V-SQ | (kg/m-s2) | 586.32 | 463.77 |

| | | | |
|---|---|---|---|
| Shell type | AES | Baffle type | Single-Seg. |
| Tube type | Plain | Baffle layout | Parallel |
| Pitch ratio | 1.2500 | Tube diameter, (mm) | 15.875 |
| Layout angle | 30 | Tube material | Carbon steel |
| | | Supports/baffle space | |

## 10.7 FINAL RESULTS

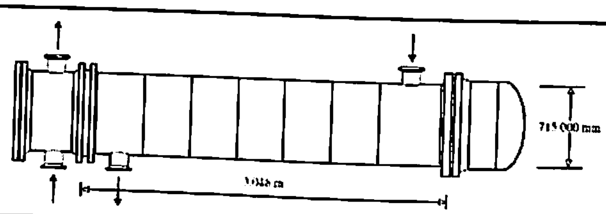
| Process Data | Unit | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | propylene | | water | |
| Fluid condition | | | Sens. Liquid | | Sens. Liquid |
| Total flow rate | (kg/s) | | 7.5218 | | 46.6670 |
| Weight fraction vapor, In/Out | (--) | 0.000 | 0.000 | 0.000 | 0.000 |
| Temperature, In/Out | (Deg C) | 99.40 * | 40.00 | 33.00 | 40.00 |
| Temperature, Average/Skin | (Deg C) | 69.7 | 44.79 | 36.5 | 39.49 |
| Wall temperature, Min/Max | (Deg C) | 34.43 | 49.15 | 34.30 | 47.99 |
| Pressure, In/Average | (kPa) | 0.000 | 0.000 | 0.000 | 0.000 |
| Pressure drop, Total/Allowed | (kPa) | 1.277 | 68.647 | 14.492 | 68.647 |
| Velocity, Mid/Max allow | (m/s) | 0.16 | | 0.93 | |
| Mole fraction inert | (--) | | | | |
| Average film coef. | (W/m2-K) | | 787.53 | | 5121.30 |
| Heat transfer safety factor | (--) | | 1.000 | | 1.000 |
| Fouling resistance | (m2-K/W) | | 0.000344 | | 0.000086 |

**Overall Performance Data**

| | | | | |
|---|---|---|---|---|
| Overall coef., Reqd/Clean/Actual | (W/m2-K) | 465.83 / | 633.67 / | 490.39 |
| Heat duty, Calculated/Specified | (MegaWatts) | 1.2863 / | | |
| Effective overall temperature difference | (Deg C) | 19.8 | | |
| EMTD = (MTD) * (DELTA) * (F/G/H) | (Deg C) | 21.40 * | 0.9245 * | 1.0000 |

**Exchanger Fluid Volumes**

| | | |
|---|---|---|
| Approximate shellside | (L) | 632.9 |
| Approximate tubeside | (L) | 737.9 |



**Shell Construction Information**

| | | | |
|---|---|---|---|
| TEMA shell type | AES | | |
| Shells Series | 1 | Parallel | 1 |
| Passes Shell | 1 | Tube | 2 |
| Shell orientation angle (deg) | 0.00 | | |
| Impingement present | No | | |
| Pairs seal strips | 2 | | |
| Shell expansion joint | No | | |

| | | |
|---|---|---|
| Shell ID | (mm) | 715.000 |
| Total area | (m2) | 144.409 |
| Eff. area | (m2/shell) | 139.596 |
| Passlane seal rods (mm) | 15.875 | No. 6 |
| Rear head support plate | | No |

Weight estimation Wet/Dry/Bundle 5862.0 / 4492.1 / 2311.3 (kg/shell)

**Baffle Information**

| | | |
|---|---|---|
| Type | Parallel | Single-Seg. |
| Crosspasses/shellpass | | 7 |
| Central spacing | (mm) | 400.000 |
| Inlet spacing | (mm) | 532.625 |
| Outlet spacing | (mm) | 413.745 |
| Baffle thickness | (mm) | 6.350 |

Baffle cut (% dia) 35.00

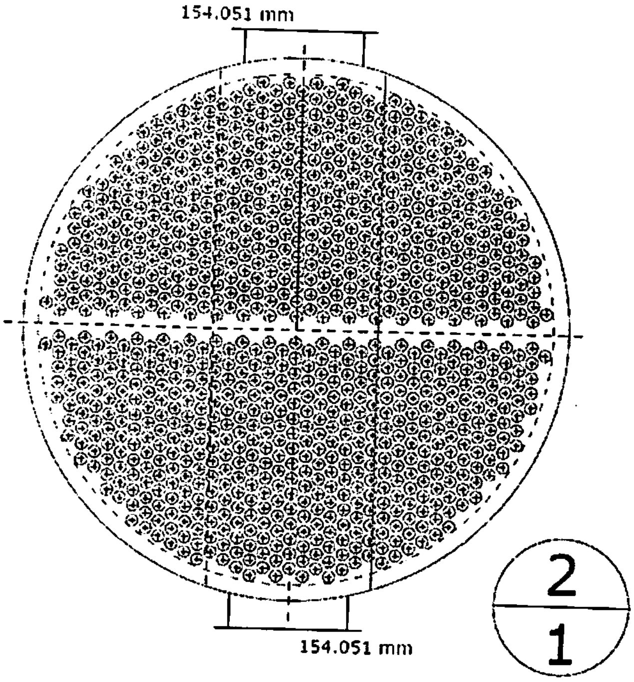
| No. | (Pct Area) | (mm) to C.L |
|---|---|---|
| 1 | 32.57 | 107.250 |
| 2 | 0.00 | 0.000 |

**Tube Information**

| | | |
|---|---|---|
| Tube type | | Plain |
| Overall length | (m) | 3.048 |
| Effective length | (m) | 2.946 |
| Total tubesheet | (mm) | 101.600 |
| Area ratio | (out/in) | 1.3616 |
| Tube metal | | Carbon steel |

| | | |
|---|---|---|
| Tubecount per shell | | 950 |
| Pct tubes removed (both) | | 0.11 |
| Outside diameter | (mm) | 15.875 |
| Wall thickness | (mm) | 2.108 |
| Pitch (mm) 19.8437 | Ratio | 1.2500 |
| Tube pattern (deg) | | 30 |

## 10.8 TUBE LAYOUT AND DRAWING



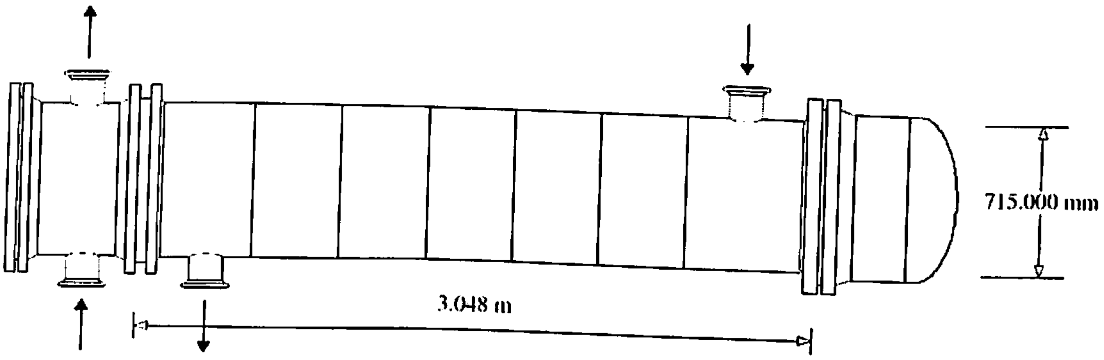

| | | |
|---|---|---|
| Item number | | |
| TEMA type | AES | |
| Shell diameter | 715.000 | mm |
| Outer tube limit | 674.084 | mm |
| Height under inlet nozzle | 24.522 | mm |
| Height under outlet nozzle | 24.522 | mm |
| Tube diameter | 15.875 | mm |
| Tube pitch | 19.844 | mm |
| Tube layout angle | 30 | |
| Number of tubes (specified) | 950 | |
| Number of tubes (calculated) | 950 | |
| Number of tie rods | 6 | |
| Number of seal strip pairs | 2 | |
| Number of passlane seal rods | 6 | |
| Number of passes | 2 | |
| Parallel passlane width | 19.050 | mm |
| Baffle cut % diameter | 35 | |

TUBEPASS DETAILS

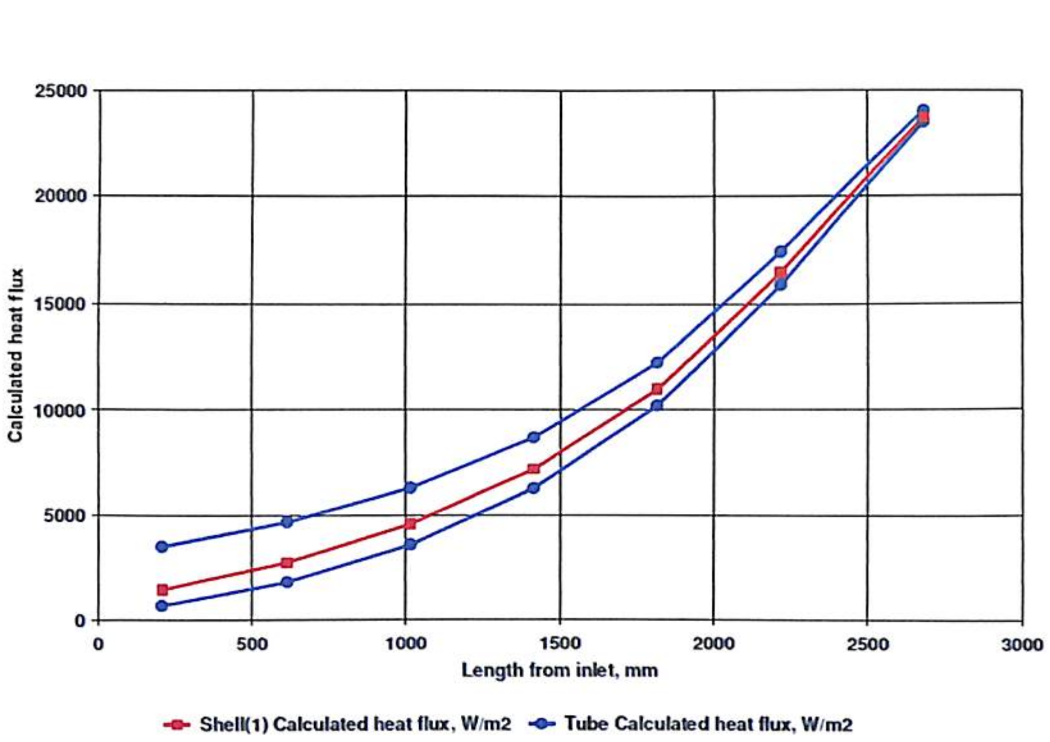
| Pass | Rows | Tubes | Plugged |
|---|---|---|---|
| 1 | 32 | 478 | 0 |
| 2 | 32 | 478 | 0 |

SYMBOL LEGEND

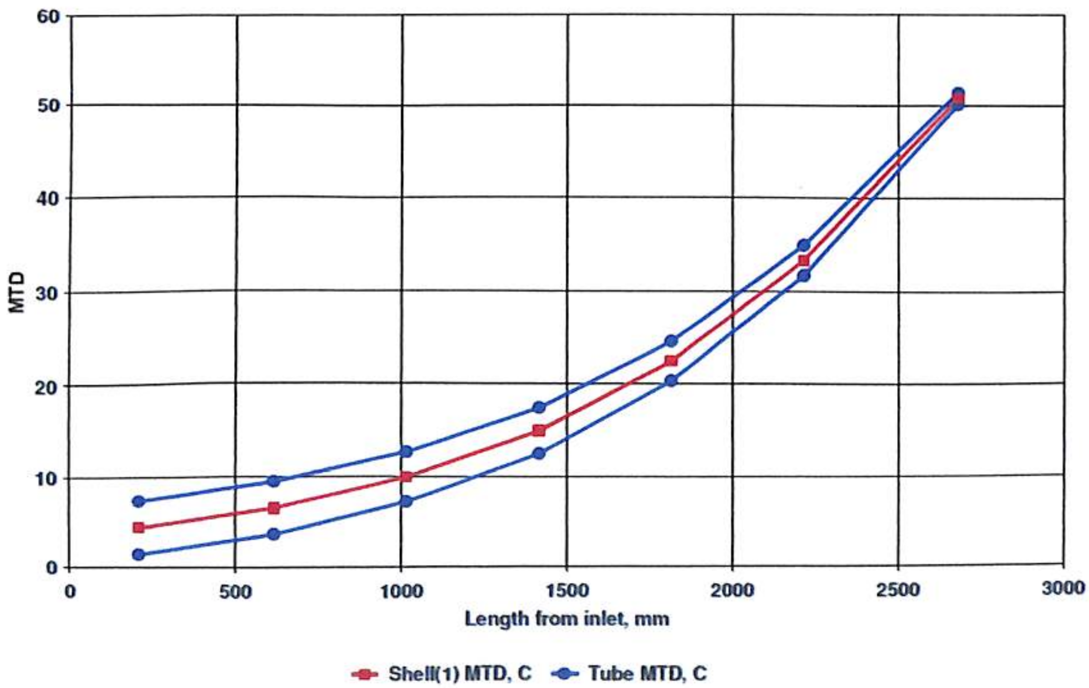
| | |
|---|---|
| ○ | Tube |
| ⊖ | Plugged tube |
| o | Tie rod |
| ● | Impingement rod |
| ⊘ | Dummy tube |
| ● | Seal rod |
| ▭ | Seal strip/Skid bar |



## 10.9 VARIATION OF HEAT FLUX ACROSS LENGTH




## 10.10 VARIATION OF MTD ACROSS LENGTH



# 11. DESIGN OF COOLER E-104

## 11.1 DESIGN BASIS

**Design pressure**

Maximum design pressure for any pressure vessel shall be Maximum normal operating pressure plus 2.0 $kg/cm^2$

The minimum design pressure for any pressure vessel shall be 3.5 $kg/cm^2g$.

**Design temperature**

In general the design temperature of pressure vessels is dependent upon the operating temperature range as follows:

No maximum design temperature will be set less than 65°C.

| Operating Temp Range, (°C) | Design Temp, (°C) |
| --- | --- |
| $T < 50$ | Minimum anticipated operating temperature margin to be determined by metallurgical limits |
| $50 < T < 400$ | Maximum anticipated operating temperature + 15°C (round up to nearest 5°C.) |
| $T > 400$* | Maximum anticipated operating temperature 10% minimum margin |

**Fouling Factors**

Fouling factors shall be specified as follows:

| Utility Services | $m^2$-°C-h/kcal |
| --- | --- |
| Steam (all levels) | 0.0001 |
| Cooling Water | 0.0004 |

| Process Streams | $m^2$-°C-h/kcal |
|---|---|
| Depropylenizer Overhead | 0.0001 |
| Depropylenizer bottoms | 0.0004 |

**Corrosion Allowance**

| Utility Services | Corrosion Allowance |
|---|---|
| Steam (all levels except SHP) | 3 mm |
| Steam Condensate | 1.5 mm |
| Cooling Water | 3 mm |

## 11.2 INPUTS TO HTRI

○ Rating ○ Simulation ◉ Design

**Exchanger Configuration**

Exchanger service: Generic Shell and Tube

**Process Conditions**

| | Hot Shell | | Cold Tube | | |
|---|---|---|---|---|---|
| Flow rate | 2124 | | | | kg/hr |
| Inlet/outlet Y | 0 | 0 | 0 | 0 | Weight fraction vapor |
| Inlet/outlet T | 143 | 40 | 33 | 40 | C |
| Inlet P/allow dP | | 0.7 | | 0.7 | kPa / kgf/cm2 |
| Fouling resistance | 0.00034 | | 0.000086 | | m2-K/W |

**Shell Geometry**

| | | |
|---|---|---|
| TEMA type | A / E / S | |
| ID | | mm |
| Orientation | Horizontal | |
| Hot fluid | Shellside | |

**Baffle Geometry**

| | | |
|---|---|---|
| Type | Single segmental | |
| Orientation | Parallel | |
| Cut | 30 | % ID |
| Spacing | | mm |

**Tube Geometry**

| | | | | | |
|---|---|---|---|---|---|
| Type | Plain | | Wall thickness | 2.108 | mm |
| Length | 1.829 | m | Layout angle | 30 | degrees |
| Tube OD | 12.7 | mm | Tubepasses | 2 | |
| Pitch | 15.875 | mm | Tubecount | | |

## 11.3 OUTPUT SUMMARY

| Process Conditions | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | C4+ Product | | Water | |
| Flow rate | (kg/s) | | 0.5900 | | 5.9239 |
| Inlet/Outlet Y | (Wt. frac vap.) | 0.000 | 0.000 | 0.000 | 0.000 |
| Inlet/Outlet T | (Deg C) | 141.53 * | 40.00 | 33.00 | 40.00 |
| Inlet P/Avg | (kPa) | 0.000 | 0.000 | 0.000 | 0.000 |
| dP/Allow. | (kPa) | 1.312 | 19.614 | 1.358 | 19.614 |
| Fouling | (m2-K/W) | | 0.000340 | | 0.000086 |

**Exchanger Performance**

| | | | | | |
|---|---|---|---|---|---|
| Shell h | (W/m2-K) | 426.14 | Actual U | (W/m2-K) | 263.98 |
| Tube h | (W/m2-K) | 1447.46 | Required U | (W/m2-K) | 247.54 |
| Hot regime | (--) | Sens. Liquid | Duty | (MegaWatts) | 0.1633 |
| Cold regime | (--) | Sens. Liquid | Area | (m2) | 19.102 |
| EMTD | (Deg C) | 34.5 | Overdesign | (%) | 6.64 |

| Shell Geometry | | | Baffle Geometry | | |
|---|---|---|---|---|---|
| TEMA type | (--) | AES | Baffle type | (--) | Single-Seg. |
| Shell ID | (mm) | 360.000 | Baffle cut | (Pct Dia.) | 28.00 |
| Series | (--) | 1 | Baffle orientation | (--) | Parallel |
| Parallel | (--) | 1 | Central spacing | (mm) | 160.000 |
| Orientation | (deg) | 0.00 | Crosspasses | (--) | 9 |

| Tube Geometry | | | Nozzles | | |
|---|---|---|---|---|---|
| Tube type | (--) | Plain | Shell inlet | (mm) | 52.553 |
| Tube OD | (mm) | 15.875 | Shell outlet | (mm) | 26.645 |
| Length | (m) | 1.829 | Inlet height | (mm) | 18.273 |
| Pitch ratio | (--) | 1.2500 | Outlet height | (mm) | 18.273 |
| Layout | (deg) | 30 | Tube inlet | (mm) | 77.927 |
| Tubecount | (--) | 218 | Tube outlet | (mm) | 77.927 |
| Tube Pass | (--) | 1 | | | |

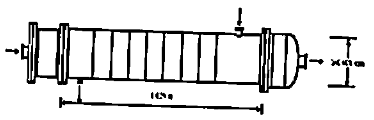
| Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|
| Shell | 61.90 | Shellside | 5.041e-2 | A | 0.245 |
| Tube | 24.87 | Tubeside | 0.26 | B | 0.426 |
| Fouling | 12.08 | Crossflow | 7.255e-2 | C | 0.175 |
| Metal | 1.156 | Window | 7.235e-2 | E | 0.154 |
| | | | | F | 0.000 |

## 11.4 TEMA SHEET

| | | | | |
|---|---|---|---|---|
| Plant Location | | | | |
| Service of Unit | | Date 24-01-2011 | Rev | |
| Size 360.000 x 1828.98 mm | Type AES Horz. | Item No. | | |
| Surf/Unit (Gross/Eff) 19.89 / 19.10 m2 | Shell/Unit 1 | Connected In | 1 Parallel | 1 Series |
| | | Surf/Shell (Gross/Eff) 19.89 / 19.10 m2 | | |
| PERFORMANCE OF ONE UNIT | | | | |
| Fluid Allocation | Shell Side | | Tube Side | |
| Fluid Name | C4+ Product | | Water | |
| Fluid Quantity, Total kg/hr | 2124.01 | | 21326.2 | |
| Vapor (In/Out) | | | | |
| Liquid | 2124.01 | 2124.01 | 21326.2 | 21326.2 |
| Steam | | | | |
| Water | | | | |
| Noncondensables | | | | |
| Temperature (In/Out) C | 141.53 | 40.00 | 33.00 | 40.00 |
| Specific Gravity | 0.4092 | 0.5606 | 0.9952 | 0.9927 |
| Viscosity mN-s/m2 | 0.0495 | 0.1112 | 0.7491 | 0.6532 |
| Molecular Weight, Vapor | | | | |
| Molecular Weight, Noncondensables | | | | |
| Specific Heat kJ/kg-C | 3.3290 | 2.3601 | 3.9151 | 3.9649 |
| Thermal Conductivity W/m-C | 0.0615 | 0.1079 | 0.6206 | 0.6309 |
| Latent Heat kJ/kg | | | | |
| Inlet Pressure kPa | | | | |
| Velocity m/s | 5.041e-2 | | 0.26 | |
| Pressure Drop, Allow/Calc kPa | 19.614 | 1.312 | 19.614 | 1.358 |
| Fouling Resistance (min) m2-K/W | 0.000340 | | 0.000086 | |
| Heat Exchanged W 163283 | | MTD (Corrected) 34.5 C | | |
| Transfer Rate, Service 247.54 W/m2-K | Clean 300.20 W/m2-K | | Actual 263.98 W/m2-K | |

| CONSTRUCTION OF ONE SHELL | Shell Side | Tube Side |
|---|---|---|
| Design/Test Pressure kPaG | 1863.29 / | 1000.02 / |
| Design Temperature C | 160.00 | 65.00 |
| No Passes per Shell | 1 | 1 |
| Corrosion Allowance mm | | |
| Connections Size & Rating — In mm | 1 @ 52.553 | 1 @ 77.927 |
| Out mm | 1 @ 26.645 | 1 @ 77.927 |
| Intermediate | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | |
|---|---|---|---|
| Tube No. 218 OD 15.875 mm | Thk(Avg) 2.108 mm | Length 1.829 m | Pitch 19.844 mm Layout 30 |
| Tube Type Plain | | Material CARBON STEEL | |
| Shell ID 360.000 mm | OD mm | Shell Cover | |
| Channel or Bonnet | | Channel Cover | |
| Tubesheet-Stationary | | Tubesheet-Floating | |
| Floating Head Cover | | Impingement Plate | None |
| Baffles-Cross Type SINGLE-SEG. | %Cut (Diam) 28.0 | Spacing(c/c) 160.000 | Inlet 405.772 mm |
| Baffles-Long | Seal Type | | |
| Supports-Tube | U-Bend | Type | |
| Bypass Seal Arrangement | Tube-Tubesheet Joint | | |
| Expansion Joint | Type | | |
| Rho-V2-Inlet Nozzle 180.91 kg/m-s2 | Bundle Entrance 2.36 | Bundle Exit 6.35 | kg/m-s2 |
| Gaskets-Shell Side | Tube Side | | |
| -Floating Head | | | |
| Code Requirements | | TEMA Class | |
| Weight/Shell 983.28 | Filled with Water 1201.46 | Bundle 329.78 | kg |
| Remarks: | | | |
| | | | |
| | | | |
| | | | |

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## 11.5 RATING DATA SHEET

| | | |
|---|---|---|
| Type AES | Orientation Horizontal | Connected In 1 Parallel 1 Series |
| Surf/Unit (Gross/Eff) 19.89 / 19.10 m2 | Shell/Unit 1 | Surf/Shell (Gross/Eff) 19.89 / 19.10 m2 |

**PERFORMANCE OF ONE UNIT**

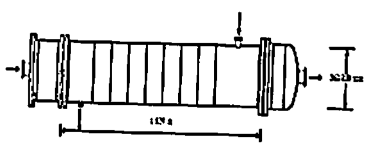
| Fluid Allocation | | Shell Side | | Tube Side | |
|---|---|---|---|---|---|
| Fluid Name | | C4+ Product | | Water | |
| Fluid Quantity, Total | kg/s | 0.5900 | | 5.9239 | |
| Vapor (In/Out) | wt% | 0.0 | 0.0 | 0.0 | 0.0 |
| Liquid | wt% | 100.0 | 100.0 | 100.0 | 100.0 |
| Temperature (In/Out) | C | 141.53 | 40.00 | 33.00 | 40.00 |
| Density | kg/m3 | 408.97 | 560.40 | 994.72 | 992.23 |
| Viscosity | mN-s/m2 | 0.0495 | 0.1112 | 0.7491 | 0.6532 |
| Specific Heat | kJ/kg-C | 3.3290 | 2.3601 | 3.9151 | 3.9649 |
| Thermal Conductivity | W/m-C | 0.0615 | 0.1079 | 0.6206 | 0.6309 |
| Critical Pressure | kPa | | | | |
| Inlet Pressure | kPa | | | | |
| Velocity | m/s | | 5.041e-2 | | 0.26 |
| Pressure Drop, Allow/Calc | kPa | 19.614 | 1.312 | 19.614 | 1.358 |
| Average Film Coefficient | W/m2-K | 426.14 | | 1447.46 | |
| Fouling Resistance (min) | m2-K/W | 0.000340 | | 0.000086 | |

| | | |
|---|---|---|
| Heat Exchanged 0.1633 MegaWatts | MTD (Corrected) 34.5 C | Overdesign 6.64 % |
| Transfer Rate, Service 247.54 W/m2-K | Calculated 263.98 W/m2-K | Clean 300.20 W/m2-K |

**CONSTRUCTION OF ONE SHELL**

| | | Shell Side | Tube Side |
|---|---|---|---|
| Design Pressure | kPaG | 1863.29 | 1000.02 |
| Design Temperature | C | 160.00 | 65.00 |
| No Passes per Shell | | 1 | 1 |
| Flow Direction | | Downward | |
| Connections Size & Rating | In mm | 1 @ 52.553 | 1 @ 77.927 |
| | Out mm | 1 @ 26.645 | 1 @ 77.927 |
| | Liq. Out mm | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | | |
|---|---|---|---|---|
| Tube No. 218 OD 15.875 mm | Thk(Avg) 2.108 mm | Length 1.829 m | Pitch 19.844 mm | Layout 30 |
| Tube Type Plain | Material CARBON STEEL | | Pairs seal strips 2 | |
| Shell ID 360.000 mm | Kettle ID mm | | Passlane Seal Rod No. 0 | |
| Cross Baffle Type PARALLEL SINGLE-SEG. | %Cut (Diam) 28.0 | | Impingement Plate None | |
| Spacing(c/c) 160.000 mm | Inlet 405.772 mm | | No. of Crosspasses 9 | |
| Rho-V2-Inlet Nozzle 180.91 kg/m-s2 | Shell Entrance 71.33 | | Shell Exit 231.82 kg/m-s2 | |
| | Bundle Entrance 2.36 | | Bundle Exit 6.35 kg/m-s2 | |
| Weight/Shell 983.28 | Filled with Water 1201.46 | | Bundle 329.78 kg | |

| Notes: | Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|---|
| | Shell | 61.90 | Shellside | 5.041e-2 | A | 0.245 |
| | Tube | 24.87 | Tubeside | 0.26 | B | 0.426 |
| | Fouling | 12.08 | Crossflow | 7.255e-2 | C | 0.175 |
| | Metal | 1.16 | Window | 7.235e-2 | E | 0.154 |
| | | | | | F | 0.000 |

## 11.6 VIBRATION ANALYSIS

| | | | | |
|---|---|---|---|---|
| Shellside condition | | Sens. Liquid | (Level 2.2) | |
| Axial stress loading | (Mpa) | 0.000 | Added mass factor | 1.761 |
| Beta | | 4.000 | | |
| **Position In The Bundle** | | **Inlet** | **Center** | **Outlet** |
| Length for natural frequency | (m) | 0.566 | 0.320 | 0.391 |
| Length/TEMA maximum span | (--) | 0.420 | 0.238 | 0.291 |
| Number of spans | (--) | 5 | 5 | 5 |
| Tube natural frequency | (Hz) | 188.4 + | 351.1 | 349.5 |
| Shell acoustic frequency | (Hz) | | | |
| **Flow Velocities** | | **Inlet** | **Center** | **Outlet** |
| Window parallel velocity | (m/s) | 7.182e-2 | 5.491e-2 | 5.242e-2 |
| Bundle crossflow velocity | (m/s) | 2.611e-2 | 5.063e-2 | 3.344e-2 |
| Bundle/shell velocity | (m/s) | 1.832e-2 | 3.552e-2 | 2.346e-2 |
| **Fluidelastic Instability Check** | | **Inlet** | **Center** | **Outlet** |
| Log decrement | HTRI | 0.038 | 0.038 | 0.038 |
| Critical velocity | (m/s) | 7.12 | 19.90 | 13.06 |
| Baffle tip cross velocity ratio | (--) | 0.004 | 0.003 | 0.003 |
| Average crossflow velocity ratio | (--) | 0.004 | 0.003 | 0.003 |
| **Acoustic Vibration Check** | | **Inlet** | **Center** | **Outlet** |
| Vortex shedding ratio | (--) | | | |
| Chen number | (--) | | | |
| Turbulent buffeting ratio | (--) | | | |
| **Tube Vibration Check** | | **Inlet** | **Center** | **Outlet** |
| Vortex shedding ratio | (--) | 0.002 | 0.003 | 0.002 |
| Turbulent buffeting ratio | (--) | 0.003 | 0.005 | 0.003 |
| Parallel flow amplitude | (mm) | 0.000 | 0.000 | 0.000 |
| Crossflow amplitude | (mm) | 0.000 | 0.000 | 0.000 |
| Turbulent buffeting amplitude | (mm) | 0.000 | 0.000 | 0.000 |
| Tube gap | (mm) | 3.969 | 3.969 | 3.969 |
| Crossflow RHO-V-SQ | (kg/m-s2) | 0.28 | 1.37 | 0.63 |
| **Bundle Entrance/Exit (analysis at first tube row)** | | | **Entrance** | **Exit** |
| Fluidelastic instability ratio | (--) | | 0.013 | 0.010 |
| Vortex shedding ratio | (--) | | 0.005 | 0.007 |
| Crossflow amplitude | (mm) | | 0.00006 | 0.00004 |
| Crossflow velocity | (m/s) | | 7.602e-2 | 0.11 |
| Turbulent buffeting amplitude | (mm) | | 0.000 | 0.000 |
| Tubesheet to inlet/outlet support | (mm) | | None | None |
| **Shell Entrance/Exit Parameters** | | | **Entrance** | **Exit** |
| Impingement plate | | | No | |
| Flow area | (m2) | | 3.454e-3 | 1.637e-3 |
| Velocity | (m/s) | | 0.42 | 0.64 |
| RHO-V-SQ | (kg/m-s2) | | 71.33 | 231.82 |

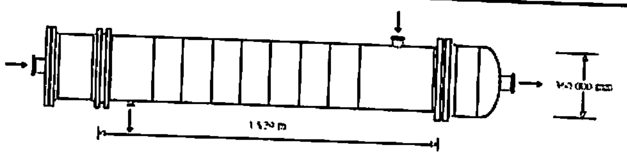
| | | | |
|---|---|---|---|
| Shell type | AES | Baffle type | Single-Seg. |
| Tube type | Plain | Baffle layout | Parallel |
| Pitch ratio | 1.2500 | Tube diameter, (mm) | 15.875 |
| Layout angle | 30 | Tube material | Carbon steel |
| | | Supports/baffle space | |

## 11.7 FINAL RESULTS

| Process Data | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | C4+ Product | | Water | |
| Fluid condition | | Sens. Liquid | | Sens. Liquid | |
| Total flow rate | (kg/s) | 0.5900 | | 5.9239 | |
| Weight fraction vapor, In/Out | (--) | 0.000 | 0.000 | 0.000 | 0.000 |
| Temperature, In/Out | (Deg C) | 141.53 | 40.00 | 33.00 | 40.00 |
| Temperature, Average/Skin | (Deg C) | 90.8 | 49.34 | 36.5 | 44.49 |
| Wall temperature, Min/Max | (Deg C) | 34.90 | 62.73 | 34.83 | 61.75 |
| Pressure, In/Average | (kPa) | 0.000 | 0.000 | 0.000 | 0.000 |
| Pressure drop, Total/Allowed | (kPa) | 1.312 | 19.613 | 1.358 | 19.613 |
| Velocity, Mid/Max allow | (m/s) | 5.041e-2 | | 0.26 | |
| Mole fraction inert | (--) | | | | |
| Average film coef. | (W/m2-K) | 426.14 | | 1447.46 | |
| Heat transfer safety factor | (--) | 1.000 | | 1.000 | |
| Fouling resistance | (m2-K/W) | 0.000340 | | 0.000086 | |

**Overall Performance Data**

| | | | | |
|---|---|---|---|---|
| Overall coef., Reqd/Clean/Actual | (W/m2-K) | 247.54 / | 300.20 / | 263.98 |
| Heat duty, Calculated/Specified | (MegaWatts) | 0.1633 / | | |
| Effective overall temperature difference | (Deg C) | 34.5 | | |
| EMTD = (MTD) * (DELTA) * (F/G/H) | (Deg C) | 37.65 * | 0.9171 * | 1.0000 |



**Exchanger Fluid Volumes**

| | | |
|---|---|---|
| Approximate shellside | (L) | 102.3 |
| Approximate tubeside | (L) | 116.0 |

**Shell Construction Information**

| | | | |
|---|---|---|---|
| TEMA shell type | AES | | |
| Shells Series | 1 | Parallel | 1 |
| Passes Shell | 1 | Tube | 1 |
| Shell orientation angle (deg) | 0.00 | | |
| Impingement present | No | | |
| Pairs seal strips | 2 | | |
| Shell expansion joint | No | | |

| | | |
|---|---|---|
| Shell ID | (mm) | 360.000 |
| Total area | (m2) | 19.885 |
| Eff. area | (m2/shell) | 19.102 |

Passlane seal rods (mm) 0.000 No. 0

Rear head support plate No

Weight estimation Wet/Dry/Bundle 1201.5 / 983.28 / 329.78 (kg/shell)

**Baffle Information**

| | | |
|---|---|---|
| Type | Parallel | Single-Seg. |
| Crosspasses/shellpass | | 9 |
| Central spacing | (mm) | 160.000 |
| Inlet spacing | (mm) | 405.772 |
| Outlet spacing | (mm) | 231.209 |
| Baffle thickness | (mm) | 3.175 |

Baffle cut (% dia) 28.00

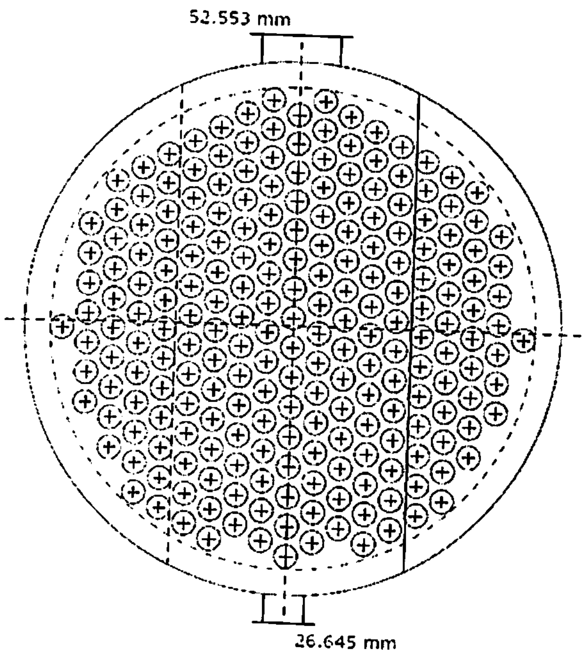
| No. | (Pct Area) | (mm) to C.L |
|---|---|---|
| 1 | 25.88 | 79.200 |
| 2 | 0.00 | 0.000 |

**Tube Information**

| | | |
|---|---|---|
| Tube type | | Plain |
| Overall length | (m) | 1.829 |
| Effective length | (m) | 1.757 |
| Total tubesheet | (mm) | 72.000 |
| Area ratio | (out/in) | 1.3616 |
| Tube metal | | Carbon steel |

| | | |
|---|---|---|
| Tubecount per shell | | 218 |
| Pct tubes removed (both) | | |
| Outside diameter | (mm) | 15.875 |
| Wall thickness | (mm) | 2.108 |
| Pitch (mm) | 19.8438 Ratio | 1.2500 |
| Tube pattern (deg) | | 30 |

## 11.8 TUBE LAYOUT AND DRAWING



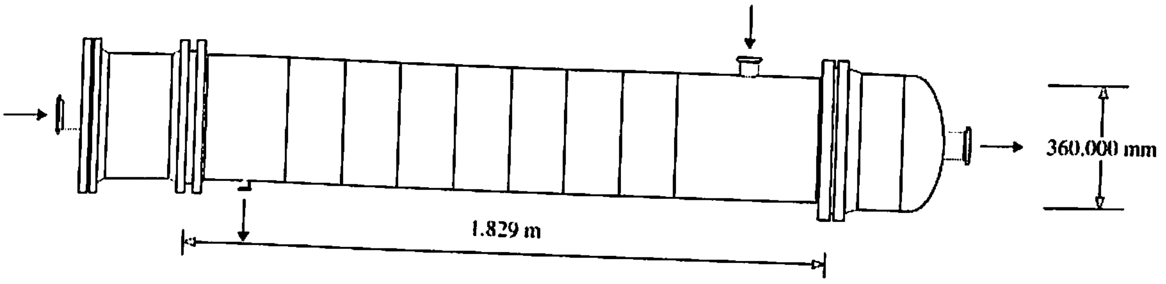

| | | |
|---|---|---|
| Item number | | |
| TEMA type | AES | |
| Shell diameter | 360.000 | mm |
| Outer tube limit | 325.369 | mm |
| Height under inlet nozzle | 18.273 | mm |
| Height under outlet nozzle | 18.273 | mm |
| Tube diameter | 15.875 | mm |
| Tube pitch | 19.844 | mm |
| Tube layout angle | 30 | |
| Number of tubes (specified) | 218 | |
| Number of tubes (calculated) | 218 | |
| Number of tie rods | 4 | |
| Number of seal strip pairs | 2 | |
| Number of passes | 1 | |
| Baffle cut % diameter | 28 | |

TUBEPASS DETAILS

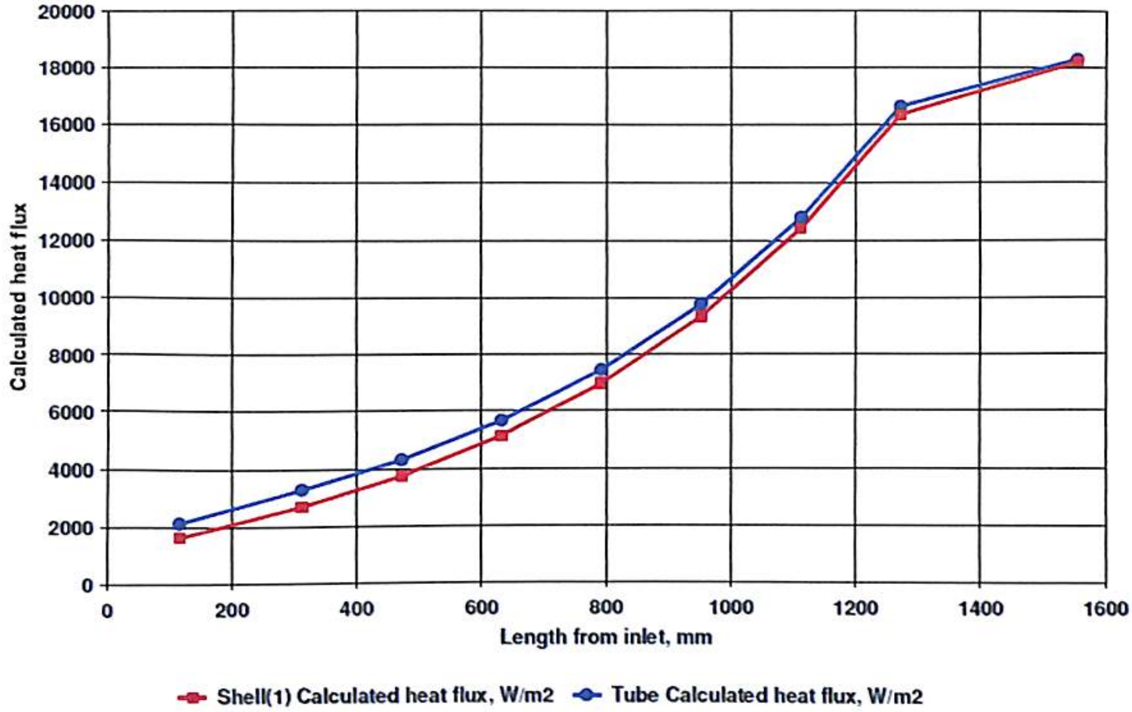
| Pass | Rows | Tubes | Plugged |
|---|---|---|---|
| 1 | 32 | 222 | 0 |

SYMBOL LEGEND

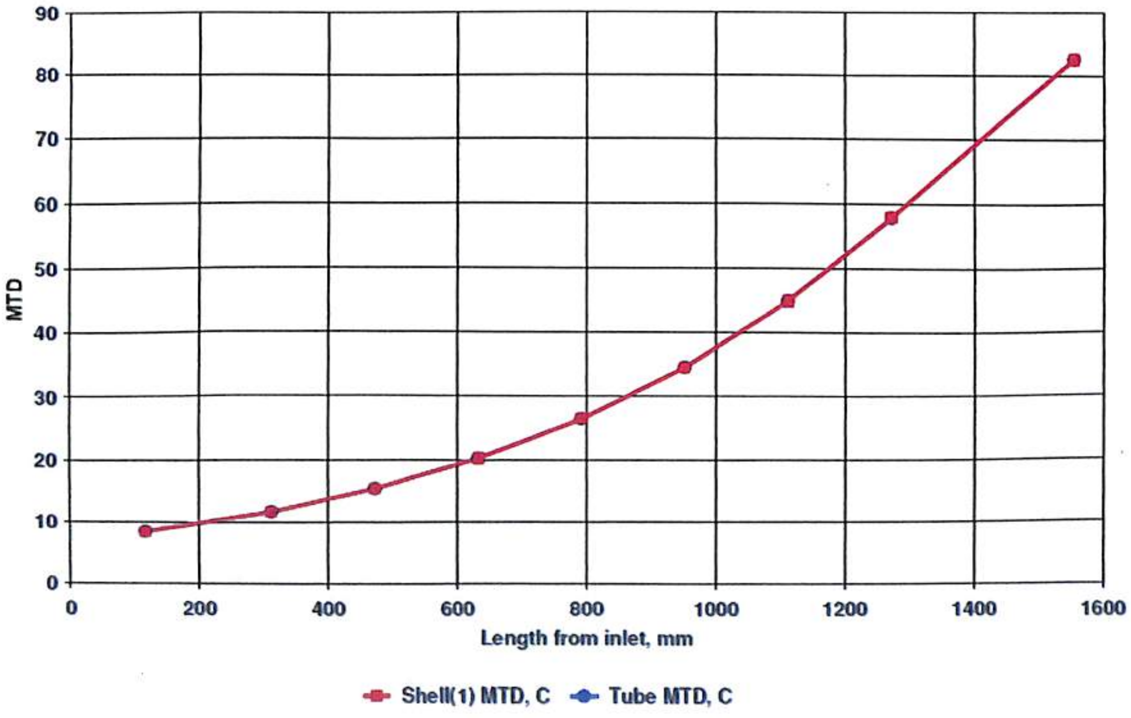
- Tube
- Plugged tube
- Tie rod
- Impingement rod
- Dummy tube
- Seal rod
- Seal strip/Skid bar



## 11.9 VARIATION OF HEAT FLUX ACROSS LENGTH




## 11.10 VARIATION OF MTD ACROSS LENGTH



# 12. DESIGN OF REBOILER E 102

## 12.1 DESIGN BASIS

**Design pressure**

Maximum design pressure for any pressure vessel shall be Maximum normal operating pressure plus 2.0 kg/cm$^2$

The minimum design pressure for any pressure vessel shall be 3.5 kg/cm$^2$g.

**Design temperature**

In general the design temperature of pressure vessels is dependent upon the operating temperature range as follows:

No maximum design temperature will be set less than 65°C.

| Operating Temp Range, (°C) | Design Temp, (°C) |
|---|---|
| T < 50 | Minimum anticipated operating temperature margin to be determined by metallurgical limits |
| 50 < T < 400 | Maximum anticipated operating temperature + 15°C (round up to nearest 5°C.) |
| T > 400* | Maximum anticipated operating temperature 10% minimum margin |

**Fouling Factors**

Fouling factors shall be specified as follows:

| Utility Services | m$^2$-°C-h/kcal |
|---|---|
| Steam (all levels) | 0.0001 |
| Cooling Water | 0.0004 |

| Process Streams | $m^2$-°C-h/kcal |
|---|---|
| Depropylenizer Overhead | 0.0001 |
| Depropylenizer bottoms | 0.0004 |

**Corrosion Allowance**

| Utility Services | Corrosion Allowance |
|---|---|
| Steam (all levels except SHP) | 3 mm |
| Steam Condensate | 1.5 mm |
| Cooling Water | 3 mm |

## 12.2 INPUTS TO HTRI

**Case Mode**

( ) Rating ( ) Simulation (•) Design

**Exchanger Configuration**

Exchanger service: Generic Shell and Tube

**Process Conditions**

| | Hot Shell | | Cold Tube | | |
|---|---|---|---|---|---|
| Flow rate | | | 50.8328 | | kg/s |
| Inlet/outlet Y | 1 | 0 | 0 | 0.3 | Weight fraction vapor |
| Inlet/outlet T | | | 143.3 | | C |
| Inlet P/allow dP | 1471 | 176.52 | 1855.418 | | kPa / kPa |
| Fouling resistance | 0.000086 | | 0.000344 | | m2-K/W |

**Shell Geometry**

| | | |
|---|---|---|
| TEMA type | B E L | |
| ID | | mm |
| Orientation | Vertical | |
| Hot fluid | Shellside | |

**Baffle Geometry**

| | | |
|---|---|---|
| Type | Single segmental | |
| Orientation | Parallel | |
| Cut | | % ID |
| Spacing | | mm |

**Tube Geometry**

| | | | | | |
|---|---|---|---|---|---|
| Type | Plain | | Wall thickness | 2.108 | mm |
| Length | 6.096 | m | Layout angle | 60 | degrees |
| Tube OD | 31.75 | mm | Tubepasses | 1 | |

## 12.3 OUTPUT SUMMARY

| Process Conditions | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | steam | | C4+ | |
| Flow rate | (kg/s) | | 2.1818 | | 50.8331 |
| Inlet/Outlet Y | (Wt. frac vap.) | 1.000 | 0.000 | 0.000 | 0.300 |
| Inlet/Outlet T | (Deg C) | 197.35 | 197.35 | 143.30 | 149.29 |
| Inlet P/Avg | (kPa) | 1471.02 | 1462.37 | 1855.45 | 1843.92 |
| dP/Allow. | (kPa) | 17.303 | 176.523 | 23.061 | 0.000 |
| Fouling | (m2-K/W) | | 0.000086 | | 0.000344 |

**Exchanger Performance**

| | | | | | |
|---|---|---|---|---|---|
| Shell h | (W/m2-K) | 9633.17 | Actual U | (W/m2-K) | 1138.83 |
| Tube h | (W/m2-K) | 4621.56 | Required U | (W/m2-K) | 1058.08 |
| Hot regime | (--) | Gravity | Duty | (MegaWatts) | 4.2516 |
| Cold regime | (--) | Nucl | Area | (m2) | 79.520 |
| EMTD | (Deg C) | 50.5 | Overdesign | (%) | 7.63 |

| Shell Geometry | | | Baffle Geometry | | |
|---|---|---|---|---|---|
| TEMA type | (--) | BEL | Baffle type | (--) | Single-Seg. |
| Shell ID | (mm) | 539.751 | Baffle cut | (Pct Dia.) | 25.92 |
| Series | (--) | 1 | Baffle orientation | (--) | Parallel |
| Parallel | (--) | 1 | Central spacing | (mm) | 197.953 |
| Orientation | (deg) | 90.00 | Crosspasses | (--) | 28 |

| Tube Geometry | | | Nozzles | | |
|---|---|---|---|---|---|
| Tube type | (--) | Plain | Shell inlet | (mm) | 128.194 |
| Tube OD | (mm) | 31.750 | Shell outlet | (mm) | 77.927 |
| Length | (m) | 6.096 | Inlet height | (mm) | 42.136 |
| Pitch ratio | (--) | 1.2500 | Outlet height | (mm) | 40.720 |
| Layout | (deg) | 60 | Tube inlet | (mm) | 457.000 |
| Tubecount | (--) | 133 | Tube outlet | (mm) | 457.000 |
| Tube Pass | (--) | 1 | | | |

| Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|
| Shell | 11.82 | Shellside | 3.93 | A | 0.181 |
| Tube | 28.41 | Tubeside | 3.10 | B | 0.565 |
| Fouling | 54.98 | Crossflow | 5.58 | C | 0.067 |
| Metal | 4.795 | Window | 5.05 | E | 0.188 |
| | | | | F | 0.000 |

## 12.4 TEMA SHEET

| | | | | | |
|---|---|---|---|---|---|
| Plant Location | | | | | |
| Service of Unit | | | Date | 08-03-2011 | Rev |
| Size | 539.751 x 6095.79 mm | Type BEL Vert. | Item No. | | |
| Surf/Unit (Gross/Eff) 80.87 / 79.52 m2 | | Shell/Unit 1 | Connected In | 1 Parallel | 1 Series |
| | | | Surf/Shell (Gross/Eff) 80.87 / 79.52 m2 | | |

**PERFORMANCE OF ONE UNIT**

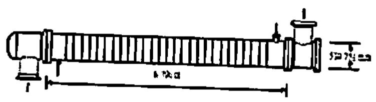
| Fluid Allocation | Unit | Shell Side | | Tube Side | |
|---|---|---|---|---|---|
| Fluid Name | | steam | | C4+ | |
| Fluid Quantity, Total | kg/hr | 7854.37 | | 182999 | |
| Vapor (In/Out) | | 7854.37 | | | 54899.7 |
| Liquid | | | 7854.37 | 182999 | 128099 |
| Steam | | | | | |
| Water | | | | | |
| Noncondensables | | | | | |
| Temperature (In/Out) | C | 197.35 | 197.35 | 143.30 | 149.29 |
| Specific Gravity | | | 0.8681 | 0.4059 | 0.4016 |
| Viscosity | mN-s/m2 | 0.0160 | 0.1362 | 0.0488 | 0.0116 V/L 0.048 |
| Molecular Weight, Vapor | | | | | |
| Molecular Weight, Noncondensables | | | | | |
| Specific Heat | kJ/kg-C | 2.9498 | 4.4825 | 3.3576 | 2.5342 V/L 3.394 |
| Thermal Conductivity | W/m-C | 0.0430 | 0.6650 | 0.0602 | 0.0275 V/L 0.059 |
| Latent Heat | kJ/kg | 1949.94 | 1949.94 | 214.369 | 211.521 |
| Inlet Pressure | kPa | 1471.02 | | 1855.45 | |
| Velocity | m/s | 3.93 | | 3.10 | |
| Pressure Drop, Allow/Calc | kPa | 176.523 | 17.303 | | 23.061 |
| Fouling Resistance (min) | m2-K/W | 0.000086 | | 0.000344 | |

| | | | | | |
|---|---|---|---|---|---|
| Heat Exchanged W | 4251647 | MTD (Corrected) | 50.5 C | | |
| Transfer Rate, Service | 1058.08 W/m2-K | Clean | 2529.01 W/m2-K | Actual | 1138.83 W/m2-K |

**CONSTRUCTION OF ONE SHELL**

| | | | Shell Side | Tube Side |
|---|---|---|---|---|
| Design/Test Pressure | | kPaG | 1369.70 / | 1754.12 / |
| Design Temperature | | C | | |
| No Passes per Shell | | | 1 | 1 |
| Corrosion Allowance | | mm | | |
| Connections Size & Rating | In | mm | 1 @ 128.194 | 1 @ 457.000 |
| | Out | mm | 1 @ 77.927 | 1 @ 457.000 |
| | Intermediate | | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | |
|---|---|---|---|
| Tube No. 133 | OD 31.750 mm | Thk(Avg) 2.108 mm | Length 6.096 m Pitch 39.687 mm Layout 60 |
| Tube Type | Plain | | Material CARBON STEEL |
| Shell | ID 539.751 mm | OD mm | Shell Cover |
| Channel or Bonnet | | | Channel Cover |
| Tubesheet-Stationary | | | Tubesheet-Floating |
| Floating Head Cover | | | Impingement Plate Circular plate |
| Baffles-Cross | Type SINGLE-SEG. | %Cut (Diam) 25.9 | Spacing(c/c) 197.953 Inlet 468.356 mm |
| Baffles-Long | | Seal Type | |
| Supports-Tube | | U-Bend | Type |
| Bypass Seal Arrangement | | Tube-Tubesheet Joint | |
| Expansion Joint | | Type | |
| Rho-V2-Inlet Nozzle | 3834.98 kg/m-s2 | Bundle Entrance 596.24 | Bundle Exit 8.54 kg/m-s2 |
| Gaskets-Shell Side | | Tube Side | |
| -Floating Head | | | |
| Code Requirements | | | TEMA Class |
| Weight/Shell 3756.37 | | Filled with Water 5439.19 | Bundle 1466.94 kg |
| Remarks: | | | |

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## 12.5 RATING DATA SHEET

| | | |
|---|---|---|
| Type BEL | Orientation Vertical | Connected In 1 Parallel 1 Series |
| Surf/Unit (Gross/Eff) 80.87 / 79.52 m2 | Shell/Unit 1 | Surf/Shell (Gross/Eff) 80.87 / 79.52 m2 |

**PERFORMANCE OF ONE UNIT**

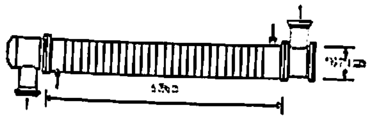
| Fluid Allocation | | Shell Side | | Tube Side | |
|---|---|---|---|---|---|
| Fluid Name | | steam | | C4+ | |
| Fluid Quantity, Total | kg/s | 2.1818 | | 50.8331 | |
| Vapor (In/Out) | wt% | 100.0 | 0.0 | 0.0 | 30.0 |
| Liquid | wt% | 0.0 | 100.0 | 100.0 | 70.0 |
| Temperature (In/Out) | C | 197.35 | 197.35 | 143.30 | 149.29 |
| Density | kg/m3 | 7.4507 | 867.73 | 405.72 | 49.993 V/L 401.38 |
| Viscosity | mN-s/m2 | 0.0160 | 0.1362 | 0.0488 | 0.0116 V/L 0.048 |
| Specific Heat | kJ/kg-C | 2.9498 | 4.4825 | 3.3576 | 2.5342 V/L 3.3941 |
| Thermal Conductivity | W/m-C | 0.0430 | 0.6650 | 0.0602 | 0.0275 V/L 0.0588 |
| Critical Pressure | kPa | | | | |
| Inlet Pressure | kPa | 1471.02 | | 1855.45 | |
| Velocity | m/s | | 3.93 | | 3.10 |
| Pressure Drop, Allow/Calc | kPa | 176.523 | 17.303 | | 23.061 |
| Average Film Coefficient | W/m2-K | 9633.17 | | 4621.56 | |
| Fouling Resistance (min) | m2-K/W | 0.000086 | | 0.000344 | |

| | | |
|---|---|---|
| Heat Exchanged 4.2516 MegaWatts | MTD (Corrected) 50.5 C | Overdesign 7.63 % |
| Transfer Rate, Service 1058.08 W/m2-K | Calculated 1138.83 W/m2-K | Clean 2529.01 W/m2-K |

**CONSTRUCTION OF ONE SHELL**

| | | Shell Side | Tube Side |
|---|---|---|---|
| Design Pressure | kPaG | 1369.70 | 1754.12 |
| Design Temperature | C | | |
| No Passes per Shell | | 1 | 1 |
| Flow Direction | | Downward | Upward |
| Connections Size & Rating | In mm | 1 @ 128.194 | 1 @ 457.000 |
| | Out mm | 1 @ 77.927 | 1 @ 457.000 |
| | Liq. Out mm | @ | @ |

Sketch (Bundle/Nozzle Orientation)



| | | | |
|---|---|---|---|
| Tube No. 133 OD 31.750 mm | Thk(Avg) 2.108 mm | Length 6.096 m | Pitch 39.687 mm Layout 60 |
| Tube Type Plain | Material CARBON STEEL | | Pairs seal strips 2 |
| Shell ID 539.751 mm | Kettle ID mm | | Passlane Seal Rod No. 0 |
| Cross Baffle Type PARALLEL SINGLE-SEG. | %Cut (Diam) 25.9 | | Impingement Plate Circular plate |
| Spacing(c/c) 197.953 mm | Inlet 468.356 mm | | No. of Crosspasses 28 |
| Rho-V2-Inlet Nozzle 3834.98 kg/m-s2 | Shell Entrance 2691.51 | | Shell Exit 49.08 kg/m-s2 |
| | Bundle Entrance 596.24 | | Bundle Exit 8.54 kg/m-s2 |
| Weight/Shell 3756.37 | Filled with Water 5439.19 | | Bundle 1466.94 kg |

Notes:

| Thermal Resistance, % | | Velocities, m/s | | Flow Fractions | |
|---|---|---|---|---|---|
| Shell | 11.82 | Shellside | 3.93 | A | 0.181 |
| Tube | 28.41 | Tubeside | 3.10 | B | 0.565 |
| Fouling | 54.98 | Crossflow | 5.58 | C | 0.067 |
| Metal | 4.79 | Window | 5.05 | E | 0.188 |
| | | | | F | 0.000 |

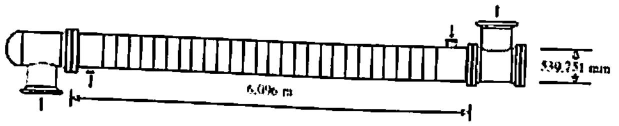
## 12.6 FINAL RESULTS

| Process Data | | Hot Shellside | | Cold Tubeside | |
|---|---|---|---|---|---|
| Fluid name | | steam | | C4+ | |
| Fluid condition | | Cond. Vapor | | Boil. Liquid | |
| Total flow rate | (kg/s) | 2.1818 | | 50.8331 | |
| Weight fraction vapor, In/Out | (--) | 1.000 | 0.000 | 0.000 | 0.300 |
| Temperature, In/Out | (Deg C) | 197.35 | 197.35 | 143.30 | 149.29 |
| Temperature, Average/Skin | (Deg C) | 197.4 | 191.35 | 146.3 | 161.18 |
| Wall temperature, Min/Max | (Deg C) | 185.08 | 189.22 | 182.54 | 186.67 |
| Pressure, In/Average | (kPa) | 1471.02 | 1462.37 | 1855.45 | 1843.92 |
| Pressure drop, Total/Allowed | (kPa) | 17.303 | 176.520 | 23.061 | |
| Velocity, Mid/Max allow | (m/s) | 3.93 | | 3.10 | |
| Mole fraction inert/Boiling range | (Deg C) | 0.000 | | 15.7 | |
| Average film coef. | (W/m2-K) | 9633.17 | | 4621.56 | |
| Heat transfer safety factor | (--) | 1.000 | | 1.000 | |
| Fouling resistance | (m2-K/W) | 0.000086 | | 0.000344 | |

**Overall Performance Data**

| | | | | |
|---|---|---|---|---|
| Overall coef., Reqd/Clean/Actual | (W/m2-K) | 1058.08 / | 2529.01 / | 1138.83 |
| Heat duty, Calculated/Specified | (MegaWatts) | 4.2516 / | | |
| Effective overall temperature difference | (Deg C) | 50.5 | | |
| EMTD = (MTD) * (DELTA) * (F/G/H) | (Deg C) | 50.53 * | 1.0000 * | 1.0000 |
| Liquid static head, Required/Specified | (m) | 6.72 / | 0.00 | |

See Runtime Messages Report for warnings.




**Exchanger Fluid Volumes**

| | | |
|---|---|---|
| Approximate shellside | (L) | 731.1 |
| Approximate tubeside | (L) | 952.9 |

**Shell Construction Information**

| | | | | | |
|---|---|---|---|---|---|
| TEMA shell type | | BEL | | | |
| Shells Series | 1 | Parallel | 1 | | |
| Passes Shell | 1 | Tube | 1 | | |
| Shell orientation angle (deg) | | 90.00 | | | |
| Impingement present | | Circular plate | | | |
| Pairs seal strips | | 2 | | | |
| Shell expansion joint | | No | | | |

| | | |
|---|---|---|
| Shell ID | (mm) | 539.751 |
| Total area | (m2) | 80.867 |
| Eff. area | (m2/shell) | 79.520 |
| Impingement diameter/nozzle | | 1.1 |
| Passlane seal rods (mm) | 0.000 | No. 0 |
| Rear head support plate | | No |

Weight estimation Wet/Dry/Bundle 5439.2 / 3756.4 / 1466.9 (kg/shell)

**Baffle Information**

| | | |
|---|---|---|
| Type | Parallel | Single-Seg. |
| Crosspasses/shellpass | | 28 |
| Central spacing | (mm) | 197.953 |
| Inlet spacing | (mm) | 468.356 |
| Outlet spacing | (mm) | 379.064 |
| Baffle thickness | (mm) | 4.763 |

Baffle cut (% dia) 25.92

| No. | (Pct Area) | (mm) to C.L |
|---|---|---|
| 1 | 22.40 | 129.993 |
| 2 | 0.00 | 0.000 |

**Tube Information**

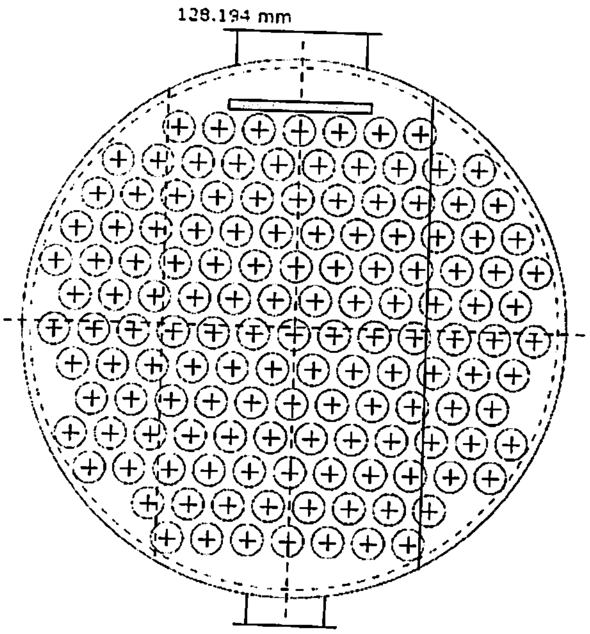
| | | |
|---|---|---|
| Tube type | | Plain |
| Overall length | (m) | 6.096 |
| Effective length | (m) | 5.994 |
| Total tubesheet | (mm) | 101.600 |
| Area ratio | (out/in) | 1.1531 |
| Tube metal | | Carbon steel |

| | | | |
|---|---|---|---|
| Tubecount per shell | | | 133 |
| Pct tubes removed (both) | | | 6.77 |
| Outside diameter | | (mm) | 31.750 |
| Wall thickness | | (mm) | 2.108 |
| Pitch (mm) | 39.6875 | Ratio | 1.2500 |
| Tube pattern (deg) | | | 60 |

## 12.7 REBOILER PIPING DETAILS

| *** Boiling Side Piping Data *** | | Inlet | Outlet |
|---|---|---|---|
| Total piping pressure drop | (kPa) | 0.270 | 3.424 |
| Static pressure loss | (kPa) | | 1.989 |
| Exit pipe choke ratio | (--) | | 0.03895 |
| Inlet valve pressure drop | (kPa) | 0.000 | |
| **Main Pipe** | | | |
| - Diameter | (mm) | 457.000 | 457.000 |
| - Number of lines | (--) | 1 | 1 |
| - Length | (m) | 5.000 | 5.000 |
| - Height above shell | (m) | | 0.000 |
| - Fitting allowance | (m) | 31.076 | 15.538 |
| - Contraction loss from tower | (kPa) | 0.178 | |
| - Expansion loss into tower | (kPa) | | 0.613 |
| - Frictional loss in pipe | (kPa) | 0.013 | 0.040 |
| - Frictional loss in fittings | (kPa) | 0.079 | 0.782 |
| **Header Pipe** | | | |
| - Diameter | (mm) | 0.000 | 0.000 |
| - Length | (m) | 0.000 | 0.000 |
| - Fitting allowance | (m) | 0.000 | 0.000 |
| - Height above shell | (m) | | 0.000 |
| - Contraction/expansion loss | (kPa) | 0.000 | 0.000 |
| - Frictional loss in pipe | (kPa) | 0.000 | 0.000 |
| - Frictional loss in fittings | (kPa) | 0.000 | 0.000 |
| **Nozzle Pipe** | | | |
| - Diameter | (mm) | 457.000 | 457.000 |
| - Number at each position | (--) | 1 | 1 |
| - Pipe length | (m) | 0.000 | 0.000 |
| - Vapor RHO-V2 | (kg/m-s2) | | 172.89 |
| - Exit vertical header height | (m) | | 1.142 |
| - Contraction/expansion loss | (kPa) | 0.000 | 0.000 |
| - Frictional loss in pipe | (kPa) | 0.000 | 0.000 |
| **Exit Vertical Pipe Flow Regime (Estimated)** | | | |
| - J.R. Fair flow map | | | |
| - A.E. Dukler flow map | | | |
| **Thermosiphon Process Conditions** | | Column / Inlet / Outlet / Column | |
| - Temperature | (C) | 143.30 / 143.30 / 149.29 / 149.29 | |
| - Weight fraction vapor | (--) | 0.0000 / 0.000 / 0.300 / 0.3000 | |
| - Pressure | (kPa) | 1828.96 / 1855.45 / 1832.39 / 1828.96 | |

## 12.8 TUBE LAYOUT AND DRAWING



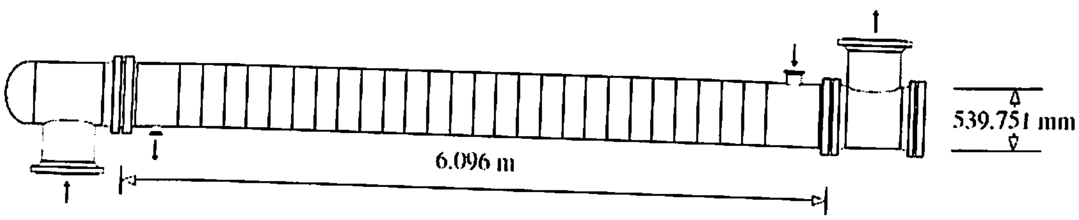

| | | |
|---|---|---|
| Item number | | |
| TEMA type | BEL | |
| Shell diameter | 539.751 | mm |
| Outer tube limit | 523.720 | mm |
| Height under inlet nozzle | 42.136 | mm |
| Height under outlet nozzle | 40.720 | mm |
| Tube diameter | 31.750 | mm |
| Tube pitch | 39.687 | mm |
| Tube layout angle | 60 | |
| Number of tubes (specified) | 133 | |
| Number of tubes (calculated) | 133 | |
| Number of tie rods | 6 | |
| Number of seal strip pairs | 2 | |
| Number of passes | 1 | |
| Baffle cut % diameter | 25.9161 | |

TUBEPASS DETAILS

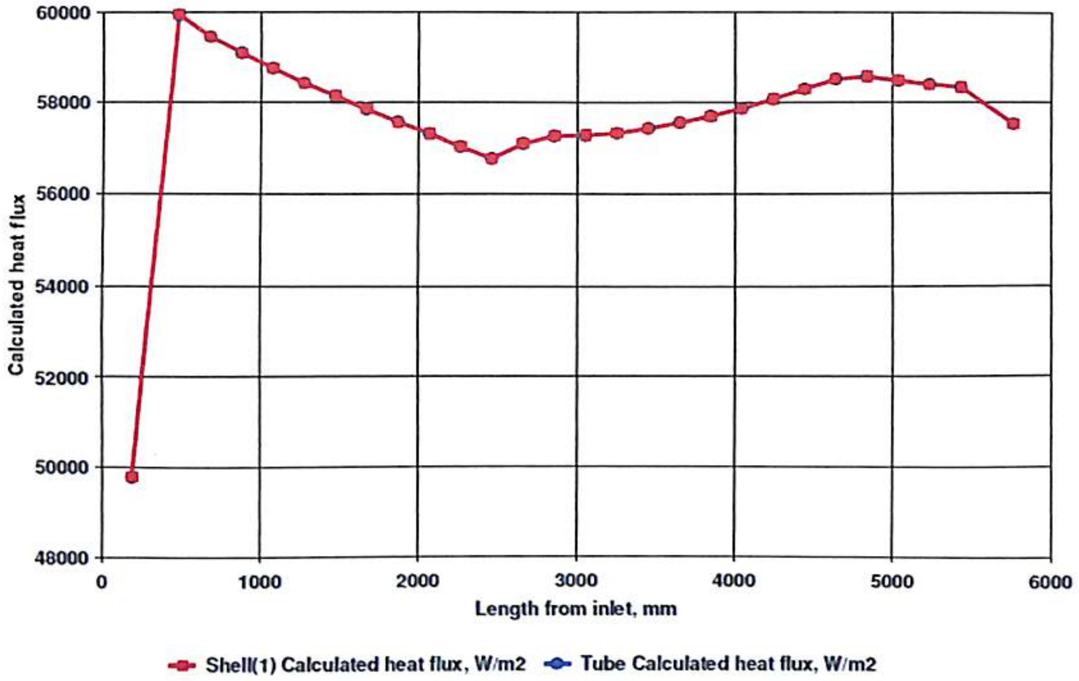
| Pass | Rows | Tubes | Plugged |
|---|---|---|---|
| 1 | 13 | 139 | 0 |

SYMBOL LEGEND

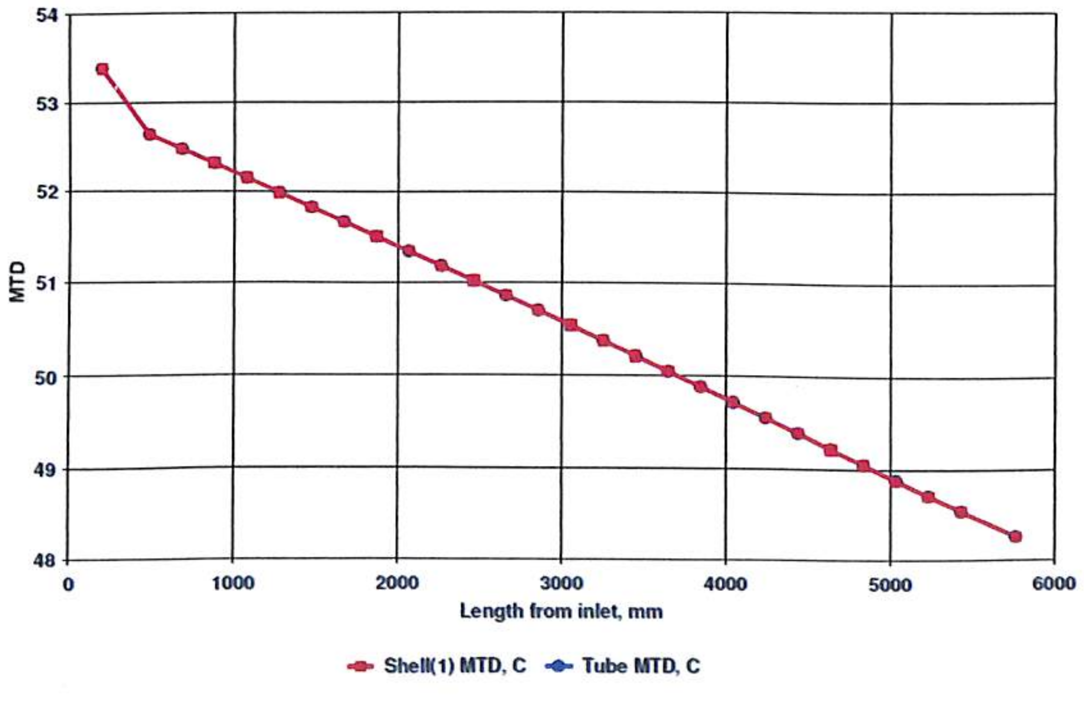
- Tube
- Plugged tube
- Tie rod
- Impingement rod
- Dummy tube
- Seal rod
- Seal strip/Skid bar



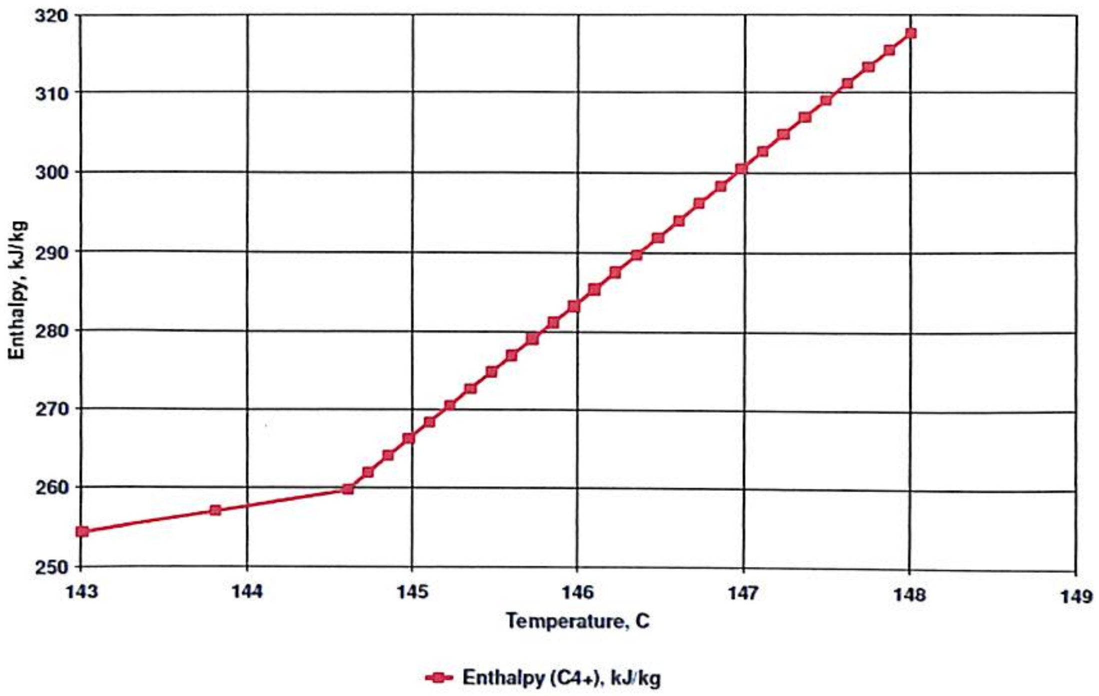
## 12.9 VARIATION OF HEAT FLUX ACROSS LENGTH



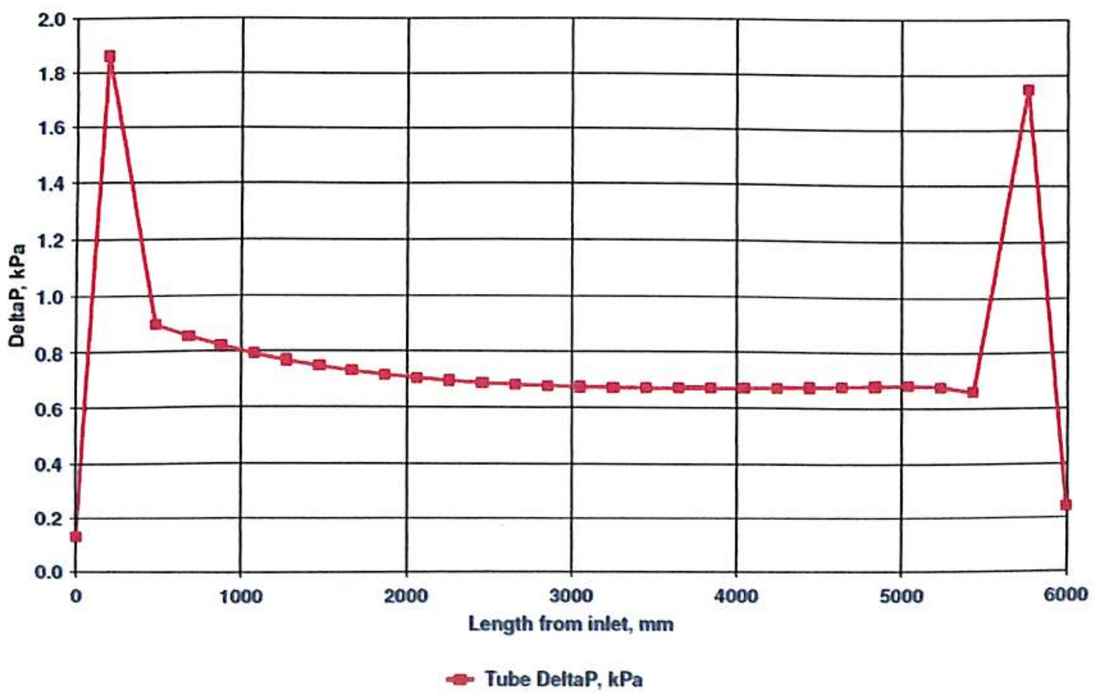

## 12.10 VARIATION OF MTD ACROSS LENGTH



## 12.11 ENTHALPY CURVE




## 12.12 PRESSURE VARIATION ACROSS TUBE LENGTH



# 13. LINE SIZING

## 13.1 PROCEDURE TO SIZE A LIQUID PHASE LINE

**1. Assume Diameter**

A standard diameter of line is assumed (D)

**2. Calculate Velocity**

Volumetric Flow Rate ($Q_L$) = $M_L/\rho_L$

Cross Sectional Area (A) = $\pi D^2/4$

Velocity of liquid (V) = $Q_L/A$

**3. Calculate Reynolds Number**

Reynolds Number (Re) = $D*V*\rho/\mu$

**4.Calculate Friction Factor**

**If Re<=2000**

Moody Friction Factor = 64/Re

**If Re>2000**

Moody Friction Factor = 4*f

**5. Calculate Pressure Drop**

$$\Delta P = 6370 * \frac{Q_L^2 f d}{D^5}$$

where

| | |
|---|---|
| d | Specific gravity of liquid |
| D | Diameter in cm |
| f | Moody friction factor |
| $Q_L$ | Volumetric Flow Rate in $m^3/hr$ |

**6. Check Condition**

If ΔP and V are not within the given conditions of maximum value, then go to step 1, else stop.

## 13.2 SOME RECOMMENDED VALUE FOR A LIQUID LINE SIZING

| Type of Service | Velocity (m/sec) | Max. Pressure Drop ($kg/cm^2/km$) |
|---|---|---|
| General Recommendation | 1.5 - 4.5 | 8.8 |
| Laminar Flow | 1.2 - 1.5 | |
| Turbulent Flow | | |
| Liquid Density (kg/m3) | | |
| 1600 | 1.5 - 2.5 | |
| 800 | 1.8 - 3.0 | |
| 320 | 3.0 - 4.5 | |
| Pump Suction | | |
| Boiling liquid | 0.6 - 1.8 | 1.1 |
| Non-boiling liquid | 1.2 - 2.5 | 2.2 |
| Pump Discharge ($m^3/hr$) | | |
| 0 - 55 | 1.8 - 2.5 | 13.2 |
| 55- 160 | 2.5 - 3.0 | 8.8 |
| More than 160 | 3.0 - 4.5 | 4.4 |
| Bottom Outlet | 1.2 - 1.8 | 1.32 |
| Reboiler Trapout | 0.3 - 1.2 | 0.33 |
| Liquid from condensor | 0.9 - 2.5 | 1.1 |
| Liquid to chillers | 1.2 - 1.8 | |
| Refrigerant Lines | 0.6 - 1.2 | 0.88 |
| Gravity run lines | 0.9 - 2.5 | 0.88 |
| Liquid feed to towers | 1.2 - 1.8 | |
| Boiler feed | 2.5 - 4.5 | |
| Refinery Water Lines | 0.6 - 1.5 | 5.5 |
| Cooling Water | 1.5 - 4.5 | 4.4 |
| Liquid with suspended solids | 0.9 (Min) | |
| Pipe carrying Phenolic Water | 0.9 | |
| Pipe carrying conc. $H_2SO_4$ | 1.2 | |
| Pipe carrying Salt Water | 1.8 | |
| Pipe carrying Caustic Solution | 1.2 | |
| Pipe carrying $CO_2$ rich amine liquid | 3.0 | |

## 13.3 PROCEDURE TO SIZE A VAPOUR PHASE LINE

**1. Assume Diameter**

A standard diameter of line is assumed (D)

**2. Calculate Velocity**

| | | |
|---|---|---|
| Volumetric Flow Rate ($Q_V$) | = | $M_V/\rho_V$ |
| Cross Sectional Area (A) | = | $\pi D^2/4$ |
| Velocity of liquid (V) | = | $Q_V/A$ |

**3. Calculate Reynolds Number**

| | | |
|---|---|---|
| Reynolds Number (Re) | = | $D*V*\rho/\mu$ |

**4.Calculate Friction Factor**

**If Re<=2000**

| | | |
|---|---|---|
| Moody Friction Factor | = | 64/Re |

**If Re>2000**

| | | |
|---|---|---|
| Moody Friction Factor | = | 4*f |

**5. Calculate Pressure Drop**

$$\Delta P = 6370 * \frac{M^2 f}{D^5 d}$$

where

| | |
|---|---|
| d | Density of vapour |
| D | Diameter in cm |
| f | Moody friction factor |
| $Q_L$ | Volumetric Flow Rate in $m^3/hr$ |

**6. Check Condition**

If ΔP and V are not within the given conditions of maximum value, then go to step 1, else stop.

## 13.4 SOME RECOMMENDED VALUE FOR A VAPOUR LINE SIZING

| Type of Service | Velocity (m/sec) | Max. Pressure Drop (kg/cm$^2$/km) |
|---|---|---|
| General Recommendation | | |
| Pressure level (kg/cm$^2$ g) | | |
| Above 35 | $V = \frac{13.0\ to\ 24.0}{\rho^{1/3}}$ | 4.5 |
| 14 - 35 | | 3.3 |
| 10 - 14 | | 1.32 |
| 3.5 - 10 | | 0.66 |
| 0 - 3.5 | | 0.33 |
| Sub-atmospheric (vacuum) | where ρ = density (kg/m$^3$) | 0.22 |
| Gas lines within battery limits | | 1.1 |
| Compressor Piping Suction | | 0.25 - 0.6 |
| Compressor Piping Discharge | | 1.0 - 2.2 |
| Refrigerant Suction lines | 4.5 - 10.7 | |
| Refrigerant Discharge lines | 10.7 - 18.0 | |
| Tower Overhead | | |
| 3.5 - 15 kg/cm$^2$ g | 12.0 - 15.0 | 1.5 |
| 0 - 3.5 kg/cm$^2$ g | 18.0 - 30.0 | 0.33 |
| 0 - 0.7 kg/cm$^2$ a | 40.0 - 60.0 | 0.11 - 0.22 |

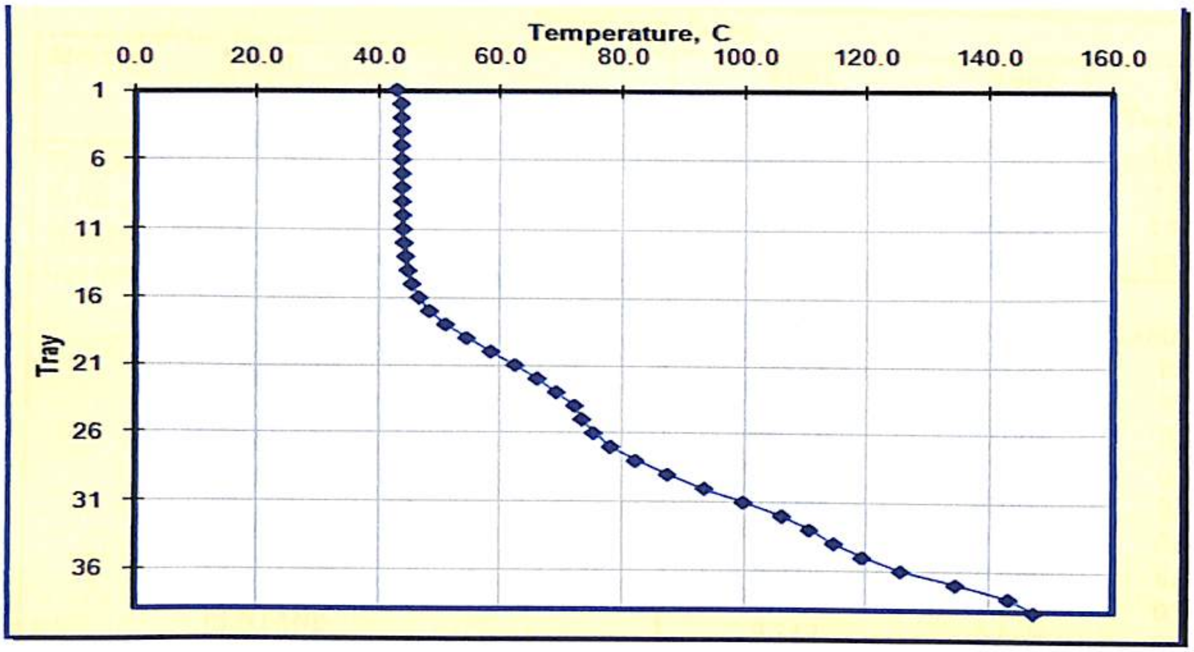
## 13.5 LINE LIST

| LINE NO. | LINE SIZE (Inches) |
|---|---|
| 1001 | 8 |
| 1002 | 12 |
| 1003 | 8 |
| 1004 | 8 |
| 1005 | 5 |
| 1006 | 5 |
| 1007 | 5 |
| 1008 | 5 |
| 1009 | 18 |
| 1010 | 18 |
| 1011 | 2 |
| 1012 | 2 |
| 1013 | 2 |
| 1014 | 4 |

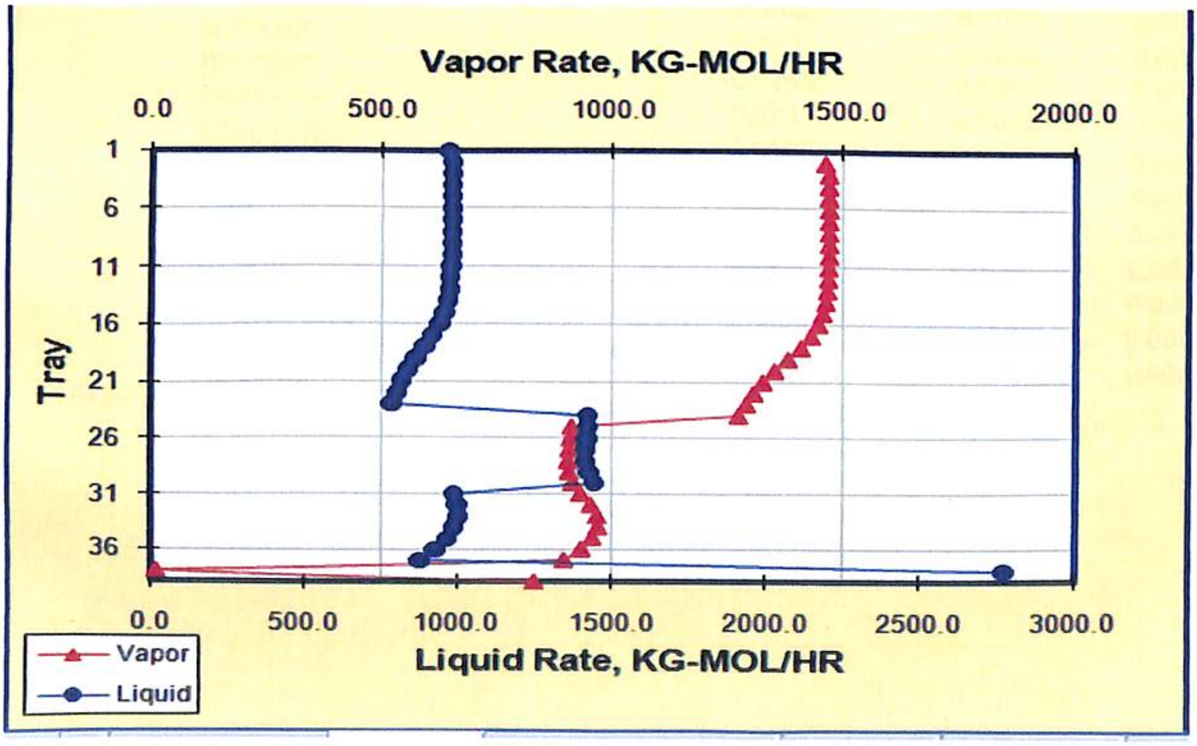
## 14. COLUMN T-101 SUMMARY

| Column T-101 Summary | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Net Flow Rates | | | | |
| Tray | Temp. C | Pressure KG/CM2 | Liquid | Vapor | Feed | Product | Duties M*KCAL/HR |
| | | | KG-MOL/HR | | | | |
| 1 | 43.0 | 18.56 | 970.1 | | | 490.1 | -4.3916 |
| 2 | 43.7 | 18.56 | 977.9 | 1460.2 | | | |
| 3 | 43.8 | 18.57 | 978.1 | 1468.0 | | | |
| 4 | 43.8 | 18.58 | 978.2 | 1468.2 | | | |
| 5 | 43.8 | 18.59 | 978.4 | 1468.4 | | | |
| 6 | 43.8 | 18.60 | 978.5 | 1468.5 | | | |
| 7 | 43.9 | 18.61 | 978.6 | 1468.6 | | | |
| 8 | 43.9 | 18.62 | 978.5 | 1468.7 | | | |
| 9 | 44.0 | 18.63 | 978.3 | 1468.7 | | | |
| 10 | 44.0 | 18.64 | 977.8 | 1468.5 | | | |
| 11 | 44.1 | 18.65 | 976.8 | 1468.0 | | | |
| 12 | 44.3 | 18.66 | 974.9 | 1467.0 | | | |
| 13 | 44.5 | 18.67 | 971.4 | 1465.0 | | | |
| 14 | 44.9 | 18.68 | 965.4 | 1461.6 | | | |
| 15 | 45.6 | 18.69 | 955.4 | 1455.5 | | | |
| 16 | 46.8 | 18.70 | 939.7 | 1445.5 | | | |
| 17 | 48.5 | 18.71 | 917.5 | 1429.8 | | | |
| 18 | 51.1 | 18.72 | 890.1 | 1407.7 | | | |
| 19 | 54.6 | 18.73 | 861.1 | 1380.2 | | | |
| 20 | 58.5 | 18.74 | 835.4 | 1351.3 | | | |
| 21 | 62.5 | 18.75 | 815.2 | 1325.5 | | | |
| 22 | 66.1 | 18.76 | 799.4 | 1305.3 | | | |
| 23 | 69.3 | 18.77 | 782.8 | 1289.5 | | | |
| 24 | 72.3 | 18.78 | 1422.0 | 1273.0 | 1000.0 | | |
| 25 | 73.5 | 18.79 | 1419.8 | 912.2 | | | |
| 26 | 75.4 | 18.80 | 1417.1 | 909.9 | | | |
| 27 | 78.2 | 18.81 | 1415.1 | 907.2 | | | |
| 28 | 82.3 | 18.82 | 1416.6 | 905.3 | | | |
| 29 | 87.5 | 18.83 | 1424.9 | 906.8 | | | |
| 30 | 93.6 | 18.84 | 1441.7 | 915.0 | | | |
| 31 | 100.0 | 18.85 | 984.8 | 931.8 | | 479.5 | |
| 32 | 106.3 | 18.86 | 998.4 | 954.4 | | | |
| 33 | 110.8 | 18.87 | 999.8 | 968.0 | | | |
| 34 | 114.8 | 18.88 | 988.2 | 969.4 | | | |
| 35 | 119.4 | 18.89 | 963.6 | 957.8 | | | |
| 36 | 125.7 | 18.90 | 926.3 | 933.2 | | | |
| 37 | 134.6 | 18.91 | 875.4 | 895.8 | | | |
| 38 | 143.3 | 18.92 | 2772.7 | 13.2 | | 30.4 | |
| 39 | 147.4 | 18.93 | | 831.8 | | | 3.4758 |

## 14.1 TEMPERATURE VARIATION CURVE




## 14.2 LIQUID AND VAPOUR FLOW RATE



# 15. DETAILED MATERIAL BALANCES

## 15.1 Component Rates

| Component Rates | | | | |
|---|---|---|---|---|
| ***Stream*** | ***Name / Description / Phase*** | **1001 FEED Mixed** | **1002 T-101 ovhd Vapor** | **1003 To D101 Liquid** |
| Temperature | C | 74.000 | 43.742 | 42.984 |
| Pressure | KG/CM2 | 18.780 | 18.560 | 18.350 |
| Molecular Weight | | 49.827 | 42.081 | 42.081 |
| Component Molar Rates | KG-MOL/HR | | | |
| PROPENE | | 551.919 | 1460.209 | 1460.209 |
| IBUTANE | | 0.010 | 0.000 | 0.000 |
| BUTANE | | 252.021 | 0.002 | 0.002 |
| IBUTENE | | 25.844 | 0.008 | 0.008 |
| 1BUTENE | | 23.744 | 0.003 | 0.003 |
| T2BUTENE | | 59.770 | 0.000 | 0.000 |
| C2BUTENE | | 35.166 | 0.000 | 0.000 |
| 13BD | | 0.010 | 0.000 | 0.000 |
| 1PENTENE | | 24.684 | 0.000 | 0.000 |
| PENTANE | | 9.712 | 0.000 | 0.000 |
| 2M2BUTEN | | 5.041 | 0.000 | 0.000 |
| 1HEXENE | | 10.612 | 0.000 | 0.000 |
| 1OCTENE | | 1.470 | | |
| Total | KG-MOL/HR | 1000.000 | 1460.222 | 1460.222 |
| Component Mole Fractions | | | | |
| PROPENE | | 0.5519 | 1.0000 | 1.0000 |
| IBUTANE | | 0.0000 | 0.0000 | 0.0000 |
| BUTANE | | 0.2520 | 0.0000 | 0.0000 |
| IBUTENE | | 0.0258 | 0.0000 | 0.0000 |
| 1BUTENE | | 0.0237 | 0.0000 | 0.0000 |
| T2BUTENE | | 0.0598 | 0.0000 | 0.0000 |
| C2BUTENE | | 0.0352 | 0.0000 | 0.0000 |
| 13BD | | 0.0000 | 0.0000 | 0.0000 |
| 1PENTENE | | 0.0247 | 0.0000 | 0.0000 |
| PENTANE | | 0.0097 | 0.0000 | 0.0000 |
| 2M2BUTEN | | 0.0050 | 0.0000 | 0.0000 |
| 1HEXENE | | 0.0106 | 0.0000 | 0.0000 |
| 1OCTENE | | 0.0015 | | |

| Component Rates | | | | |
|---|---|---|---|---|
| ***Stream*** | ***Name*** ***Description*** ***Phase*** | **1004** **TO P-101** **Liquid** | **1005** **REFLUX** **Mixed** | **1006** **SIDE DRAW** **Liquid** |
| Temperature | C | 43.000 | 43.741 | 99.979 |
| Pressure | KG/CM2 | 18.561 | 18.560 | 18.850 |
| Molecular Weight | | 42.081 | 42.081 | 56.478 |
| Component Molar Rates | KG-MOL/HR | | | |
| PROPENE | | 1460.209 | 970.089 | 61.768 |
| IBUTANE | | 0.000 | 0.000 | 0.010 |
| BUTANE | | 0.002 | 0.002 | 244.898 |
| IBUTENE | | 0.008 | 0.005 | 25.443 |
| 1BUTENE | | 0.003 | 0.002 | 23.326 |
| T2BUTENE | | 0.000 | 0.000 | 57.899 |
| C2BUTENE | | 0.000 | 0.000 | 33.852 |
| 13BD | | 0.000 | 0.000 | 0.010 |
| 1PENTENE | | 0.000 | 0.000 | 17.621 |
| PENTANE | | 0.000 | 0.000 | 6.528 |
| 2M2BUTEN | | 0.000 | 0.000 | 3.095 |
| 1HEXENE | | 0.000 | 0.000 | 4.488 |
| 1OCTENE | | | | 0.515 |
| Total | KG-MOL/HR | 1460.222 | 970.097 | 479.452 |
| Component Mole Fractions | | | | |
| PROPENE | | 1.0000 | 1.0000 | 0.1288 |
| IBUTANE | | 0.0000 | 0.0000 | 0.0000 |
| BUTANE | | 0.0000 | 0.0000 | 0.5108 |
| IBUTENE | | 0.0000 | 0.0000 | 0.0531 |
| 1BUTENE | | 0.0000 | 0.0000 | 0.0487 |
| T2BUTENE | | 0.0000 | 0.0000 | 0.1208 |
| C2BUTENE | | 0.0000 | 0.0000 | 0.0706 |
| 13BD | | 0.0000 | 0.0000 | 0.0000 |
| 1PENTENE | | 0.0000 | 0.0000 | 0.0368 |
| PENTANE | | 0.0000 | 0.0000 | 0.0136 |
| 2M2BUTEN | | 0.0000 | 0.0000 | 0.0065 |
| 1HEXENE | | 0.0000 | 0.0000 | 0.0094 |
| 1OCTENE | | | | 0.0011 |

| Component Rates | | | | |
|---|---|---|---|---|
| *Stream* | *Name* *Description* *Phase* | **1007** **FromE-103** **Liquid** | **1008** **C4 RECYCLE** **Liquid** | **1011** **BOTTOMS** **Liquid** |
| Temperature | C | 40.000 | 40.009 | 143.290 |
| Pressure | KG/CM2 | 19.141 | 18.441 | 18.920 |
| Molecular Weight | | 56.478 | 56.478 | 69.812 |
| Component Molar Rates | KG-MOL/HR | | | |
| PROPENE | | 61.768 | 61.768 | 0.025 |
| IBUTANE | | 0.010 | 0.010 | 0.000 |
| BUTANE | | 244.898 | 244.898 | 7.122 |
| IBUTENE | | 25.443 | 25.443 | 0.399 |
| 1BUTENE | | 23.326 | 23.326 | 0.417 |
| T2BUTENE | | 57.899 | 57.899 | 1.871 |
| C2BUTENE | | 33.852 | 33.852 | 1.314 |
| 13BD | | 0.010 | 0.010 | 0.000 |
| 1PENTENE | | 17.621 | 17.621 | 7.063 |
| PENTANE | | 6.528 | 6.528 | 3.183 |
| 2M2BUTEN | | 3.095 | 3.095 | 1.946 |
| 1HEXENE | | 4.488 | 4.488 | 6.124 |
| 1OCTENE | | 0.515 | 0.515 | 0.955 |
| Total | KG-MOL/HR | 479.452 | 479.452 | 30.419 |
| Component Mole Fractions | | | | |
| PROPENE | | 0.1288 | 0.1288 | 0.0008 |
| IBUTANE | | 0.0000 | 0.0000 | 0.0000 |
| BUTANE | | 0.5108 | 0.5108 | 0.2341 |
| IBUTENE | | 0.0531 | 0.0531 | 0.0131 |
| 1BUTENE | | 0.0487 | 0.0487 | 0.0137 |
| T2BUTENE | | 0.1208 | 0.1208 | 0.0615 |
| C2BUTENE | | 0.0706 | 0.0706 | 0.0432 |
| 13BD | | 0.0000 | 0.0000 | 0.0000 |
| 1PENTENE | | 0.0368 | 0.0368 | 0.2322 |
| PENTANE | | 0.0136 | 0.0136 | 0.1046 |
| 2M2BUTEN | | 0.0065 | 0.0065 | 0.0640 |
| 1HEXENE | | 0.0094 | 0.0094 | 0.2013 |
| 1OCTENE | | 0.0011 | 0.0011 | 0.0314 |

| Component Rates | | | | |
|---|---|---|---|---|
| ***Stream*** | ***Name*** | **1012** | **1013** | **1014** |
| | ***Description*** | **FromE-104** | **C4+ product** | **PROPYLENE PRODUCT** |
| | ***Phase*** | **Liquid** | **Liquid** | **Liquid** |
| Temperature | C | 40.000 | 40.267 | 45.442 |
| Pressure | KG/CM2 | 19.142 | 23.302 | 33.650 |
| Molecular Weight | | 69.812 | 69.812 | 42.081 |
| Component Molar Rates | KG-MOL/HR | | | |
| PROPENE | | 0.025 | 0.025 | 490.120 |
| IBUTANE | | 0.000 | 0.000 | 0.000 |
| BUTANE | | 7.122 | 7.122 | 0.001 |
| IBUTENE | | 0.399 | 0.399 | 0.003 |
| 1BUTENE | | 0.417 | 0.417 | 0.001 |
| T2BUTENE | | 1.871 | 1.871 | 0.000 |
| C2BUTENE | | 1.314 | 1.314 | 0.000 |
| 13BD | | 0.000 | 0.000 | 0.000 |
| 1PENTENE | | 7.063 | 7.063 | 0.000 |
| PENTANE | | 3.183 | 3.183 | 0.000 |
| 2M2BUTEN | | 1.946 | 1.946 | 0.000 |
| 1HEXENE | | 6.124 | 6.124 | 0.000 |
| 1OCTENE | | 0.955 | 0.955 | 0.000 |
| Total | KG-MOL/HR | 30.419 | 30.419 | 490.125 |
| Component Mole Fractions | | | | |
| PROPENE | | 0.0008 | 0.0008 | 1.0000 |
| IBUTANE | | 0.0000 | 0.0000 | 0.0000 |
| BUTANE | | 0.2341 | 0.2341 | 0.0000 |
| IBUTENE | | 0.0131 | 0.0131 | 0.0000 |
| 1BUTENE | | 0.0137 | 0.0137 | 0.0000 |
| T2BUTENE | | 0.0615 | 0.0615 | 0.0000 |
| C2BUTENE | | 0.0432 | 0.0432 | 0.0000 |
| 13BD | | 0.0000 | 0.0000 | 0.0000 |
| 1PENTENE | | 0.2322 | 0.2322 | 0.0000 |
| PENTANE | | 0.1046 | 0.1046 | 0.0000 |
| 2M2BUTEN | | 0.0640 | 0.0640 | 0.0000 |
| 1HEXENE | | 0.2013 | 0.2013 | 0.0000 |
| 1OCTENE | | 0.0314 | 0.0314 | 0.0000 |

## 15.2 Total Stream Properties

| *Stream* | *Name / Description / Phase* | | 1001 FEED Mixed | 1002 T-101 ovhd Vapor | 1003 To D101 Liquid |
|---|---|---|---|---|---|
| ***Total Stream Properties*** | | | | | |
| Rate | | KG-MOL/HR | 1000.000 | 1460.222 | 1460.222 |
| | | KG/HR | 49827.309 | 61447.797 | 61447.797 |
| Std. Liquid Rate | | M3/HR | 88.790 | 117.832 | 117.832 |
| Temperature | | C | 74.000 | 43.742 | 42.984 |
| Pressure | | KG/CM2 | 18.780 | 18.560 | 18.350 |
| Molecular Weight | | | 49.827 | 42.081 | 42.081 |
| Enthalpy | | M*KCAL/HR | 3.348 | 6.046 | 1.654 |
| | | KCAL/KG | 67.184 | 98.388 | 26.919 |
| Mole Fraction Liquid | | | 0.6453 | 0.0000 | 1.0000 |
| Reduced Temp. | | | 0.8791 | 0.8683 | 0.8662 |
| | Pres. | | 0.4316 | 0.3939 | 0.3895 |
| Acentric Factor | | | 0.1729 | 0.1435 | 0.1435 |
| Watson K (UOPK) | | | 13.655 | 14.183 | 14.183 |
| Standard Liquid Density | | KG/M3 | 561.180 | 521.486 | 521.486 |
| | Specific Gravity | | 0.5617 | 0.5220 | 0.5220 |
| | API Gravity | | 120.398 | 139.572 | 139.572 |
| ***Vapor Phase Properties*** | | | | | |
| Rate | | KG-MOL/HR | 354.718 | 1460.222 | n/a |
| | | KG/HR | 16660.852 | 61447.797 | n/a |
| | | M3/HR | 419.981 | 1568.601 | n/a |
| Std. Vapor Rate | | M3/HR | 7950.638 | 32729.408 | n/a |
| Specific Gravity (Air=1.0) | | | 1.622 | 1.453 | n/a |
| Molecular Weight | | | 46.969 | 42.081 | n/a |
| Enthalpy | | KCAL/KG | 111.616 | 98.388 | n/a |
| CP | | KCAL/KG-C | 0.512 | 0.489 | n/a |
| Density | | KG/M3 | 39.670 | 39.174 | n/a |
| Thermal Conductivity | | KCAL/HR-M-C | n/a | n/a | n/a |
| Viscosity | | CP | n/a | n/a | n/a |
| ***Liquid Phase Properties*** | | | | | |
| Rate | | KG-MOL/HR | 645.283 | n/a | 1460.222 |
| | | KG/HR | 33166.457 | n/a | 61447.797 |
| | | M3/HR | 69.308 | n/a | 129.670 |
| Std. Liquid Rate | | M3/HR | 58.349 | n/a | 117.832 |
| Specific Gravity (H2O @ 60 F) | | | 0.5690 | n/a | 0.5220 |
| Molecular Weight | | | 51.398 | n/a | 42.081 |
| Enthalpy | | KCAL/KG | 44.864 | n/a | 26.919 |
| CP | | KCAL/KG-C | 0.750 | n/a | 0.775 |
| Density | | KG/M3 | 478.540 | n/a | 473.880 |
| Surface Tension | | DYNE/CM | n/a | n/a | n/a |
| Thermal Conductivity | | KCAL/HR-M-C | n/a | n/a | n/a |
| Viscosity | | CP | n/a | n/a | n/a |

| ***Stream Name Description Phase*** | | 1004 TO P-101 Liquid | 1005 REFLUX Mixed | 1006 SIDE DRAW Liquid |
|---|---|---|---|---|
| ***Total Stream Properties*** | | | | |
| Rate | KG-MOL/HR | 1460.222 | 970.097 | 479.452 |
| | KG/HR | 61447.797 | 40822.801 | 27078.496 |
| Std. Liquid Rate | M3/HR | 117.832 | 78.282 | 45.915 |
| Temperature | C | 43.000 | 43.741 | 99.979 |
| Pressure | KG/CM2 | 18.561 | 18.560 | 18.850 |
| Molecular Weight | | 42.081 | 42.081 | 56.478 |
| Enthalpy | M*KCAL/HR | 1.654 | 1.142 | 1.692 |
| | KCAL/KG | 26.919 | 27.966 | 62.486 |
| Mole Fraction Liquid | | 1.0000 | 0.9934 | 1.0000 |
| Reduced Temp. | | 0.8663 | 0.8683 | 0.8859 |
| Pres. | | 0.3940 | 0.3939 | 0.4676 |
| Acentric Factor | | 0.1435 | 0.1435 | 0.1984 |
| Watson K (UOPK) | | 14.183 | 14.183 | 13.318 |
| Standard Liquid Density | KG/M3 | 521.486 | 521.486 | 589.751 |
| Specific Gravity | | 0.5220 | 0.5220 | 0.5903 |
| API Gravity | | 139.572 | 139.572 | 108.195 |
| ***Vapor Phase Properties*** | | | | |
| Rate | KG-MOL/HR | n/a | 6.437 | n/a |
| | KG/HR | n/a | 270.859 | n/a |
| | M3/HR | n/a | 6.914 | n/a |
| Std. Vapor Rate | M3/HR | n/a | 144.270 | n/a |
| Specific Gravity (Air=1.0) | | n/a | 1.453 | n/a |
| Molecular Weight | | n/a | 42.081 | n/a |
| Enthalpy | KCAL/KG | n/a | 98.387 | n/a |
| CP | KCAL/KG-C | n/a | 0.489 | n/a |
| Density | KG/M3 | n/a | 39.174 | n/a |
| Thermal Conductivity | KCAL/HR-M-C | n/a | n/a | n/a |
| Viscosity | CP | n/a | n/a | n/a |
| ***Liquid Phase Properties*** | | | | |
| Rate | KG-MOL/HR | 1460.222 | 963.661 | 479.452 |
| | KG/HR | 61447.797 | 40551.941 | 27078.496 |
| | M3/HR | 129.658 | 85.844 | 58.111 |
| Std. Liquid Rate | M3/HR | 117.832 | 77.762 | 45.915 |
| Specific Gravity (H2O @ 60 F) | | 0.5220 | 0.5220 | 0.5903 |
| Molecular Weight | | 42.081 | 42.081 | 56.478 |
| Enthalpy | KCAL/KG | 26.919 | 27.495 | 62.486 |
| CP | KCAL/KG-C | 0.774 | 0.780 | 0.809 |
| Density | KG/M3 | 473.924 | 472.392 | 465.982 |
| Surface Tension | DYNE/CM | n/a | n/a | n/a |
| Thermal Conductivity | KCAL/HR-M-C | n/a | n/a | n/a |
| Viscosity | CP | n/a | n/a | n/a |

| *Stream* | *Name* | 1007 | 1008 | 1011 |
|---|---|---|---|---|
| | *Description* | FromE-103 | C4 RECYCLE | BOTTOMS |
| | *Phase* | Liquid | Liquid | Liquid |
| ***Total Stream Properties*** | | | | |
| Rate | KG-MOL/HR | 479.452 | 479.452 | 30.419 |
| | KG/HR | 27078.496 | 27078.496 | 2123.590 |
| Std. Liquid Rate | M3/HR | 45.915 | 45.915 | 3.324 |
| Temperature | C | 40.000 | 40.009 | 143.290 |
| Pressure | KG/CM2 | 19.141 | 18.441 | 18.920 |
| Molecular Weight | | 56.478 | 56.478 | 69.812 |
| Enthalpy | M*KCAL/HR | 0.581 | 0.581 | 0.185 |
| | KCAL/KG | 21.441 | 21.441 | 86.917 |
| Mole Fraction Liquid | | 1.0000 | 1.0000 | 1.0000 |
| Reduced Temp. | | 0.7435 | 0.7435 | 0.8993 |
| Pres. | | 0.4749 | 0.4575 | 0.5241 |
| Acentric Factor | | 0.1984 | 0.1984 | 0.2426 |
| Watson K (UOPK) | | 13.318 | 13.318 | 12.809 |
| Standard Liquid Density | KG/M3 | 589.751 | 589.751 | 638.835 |
| Specific Gravity | | 0.5903 | 0.5903 | 0.6395 |
| API Gravity | | 108.195 | 108.195 | 89.779 |
| ***Vapor Phase Properties*** | | | | |
| Rate | KG-MOL/HR | n/a | n/a | n/a |
| | KG/HR | n/a | n/a | n/a |
| | M3/HR | n/a | n/a | n/a |
| Std. Vapor Rate | M3/HR | n/a | n/a | n/a |
| Specific Gravity (Air=1.0) | | n/a | n/a | n/a |
| Molecular Weight | | n/a | n/a | n/a |
| Enthalpy | KCAL/KG | n/a | n/a | n/a |
| CP | KCAL/KG-C | n/a | n/a | n/a |
| Density | KG/M3 | n/a | n/a | n/a |
| Thermal Conductivity | KCAL/HR-M-C | n/a | n/a | n/a |
| Viscosity | CP | n/a | n/a | n/a |
| ***Liquid Phase Properties*** | | | | |
| Rate | KG-MOL/HR | 479.452 | 479.452 | 30.419 |
| | KG/HR | 27078.496 | 27078.496 | 2123.590 |
| | M3/HR | 48.218 | 48.232 | 4.514 |
| Std. Liquid Rate | M3/HR | 45.915 | 45.915 | 3.324 |
| Specific Gravity (H2O @ 60 F) | | 0.5903 | 0.5903 | 0.6395 |
| Molecular Weight | | 56.478 | 56.478 | 69.812 |
| Enthalpy | KCAL/KG | 21.441 | 21.441 | 86.917 |
| CP | KCAL/KG-C | 0.605 | 0.605 | 0.815 |
| Density | KG/M3 | 561.581 | 561.424 | 470.466 |
| Surface Tension | DYNE/CM | n/a | n/a | n/a |
| Thermal Conductivity | KCAL/HR-M-C | n/a | n/a | n/a |
| Viscosity | CP | n/a | n/a | n/a |

# 16. ANNEXURE-1

**FEED STOCKS:**

Mixed $C_3$-$C_4$ Feed

| Feed | Composition |
|---|---|
| **Hydrocarbon Components,** | **mol %** |
| Propylene | 55.183 |
| i-Butane | 0.001 |
| n-Butane | 25.198 |
| i-Butene | 2.584 |
| 1-Butene | 2.374 |
| trans-2-Butene | 5.976 |
| cis-2-Butene | 3.516 |
| 1,3-Butadiene | 0.001 |
| 1-Pentene | 2.468 |
| n-C5 | 0.971 |
| 2M-2-Butene | 0.504 |
| 1-Hexene | 1.061 |
| 1-Octene | 0.147 |
| **Total, mol%** | 100.00 |
| **Total, kgmol/hr** | 1000 |

# 17. ANNEXURE-2

**PRODUCTS:**

A) Polymer Grade Propylene Product (High Purity)

| Component | Units | Specifications |
|---|---|---|
| Propylene | wt% | 99.9+ min |
| Ethylene | ppm wt | 10 max |
| Ethane | ppm wt | 200 max |
| Total $C_4$'s | ppm wt | 10 max |

B) $C_4$ Product

Estimated composition:

| Components | Mol % |
|---|---|
| Isobutene | 6.41 |
| 1-Butene | 5.79 |
| cis-2-Butene | 7.95 |
| trans-2-Butene | 13.95 |
| Isobutane | 0.01 |
| n-Butane | 58.4 |
| C5 Hydrocarbons | 5.9 |
| C6 Hydrocarbons | 1.1 |
| Water | 0.0 |
| Total | 100 |

# 18. ANNEXURE-3

**UTILITIES:**

A) Steam

Battery limits specification for equipment using steam directly from the site steam headers:

| | Pressure, MPaG | | | | Temperature, °C | | | |
|---|---|---|---|---|---|---|---|---|
| | Min Op. | Norm Op. | Max Op. | Design | Min Op. | Norm Op. | Max Op. | Design |
| HP | 4.00 | 4.20 | 4.40 | 5.00 | 350 | 380 | 410 | 435 |
| MP | 0.8 | 1.5 | 2.6 | 3 | 165 | 195 | 225 | 255 |
| LP | 0.36 | 0.40 | 0.44 | 0.60 | 130 | 134 | 138 | 165 |

B) Cooling Water

Cooling water shall be supplied and returned to the battery limits at the following conditions:

| | Pressure, MPaG | | | | Temperature °C | |
|---|---|---|---|---|---|---|
| | Min Op | Norm Op | Max Op | Design | Operating | Design |
| Supply | 0.48 | 0.50 | 0.58 | 1.00 | 33 | 65 |
| Return | 0.25 | 0.30 | 0.35 | 1.00 | 43 max | 65 |

# 19. ANNEXURE-4

## BATTERY LIMIT CONDITIONS

A. Feed stocks

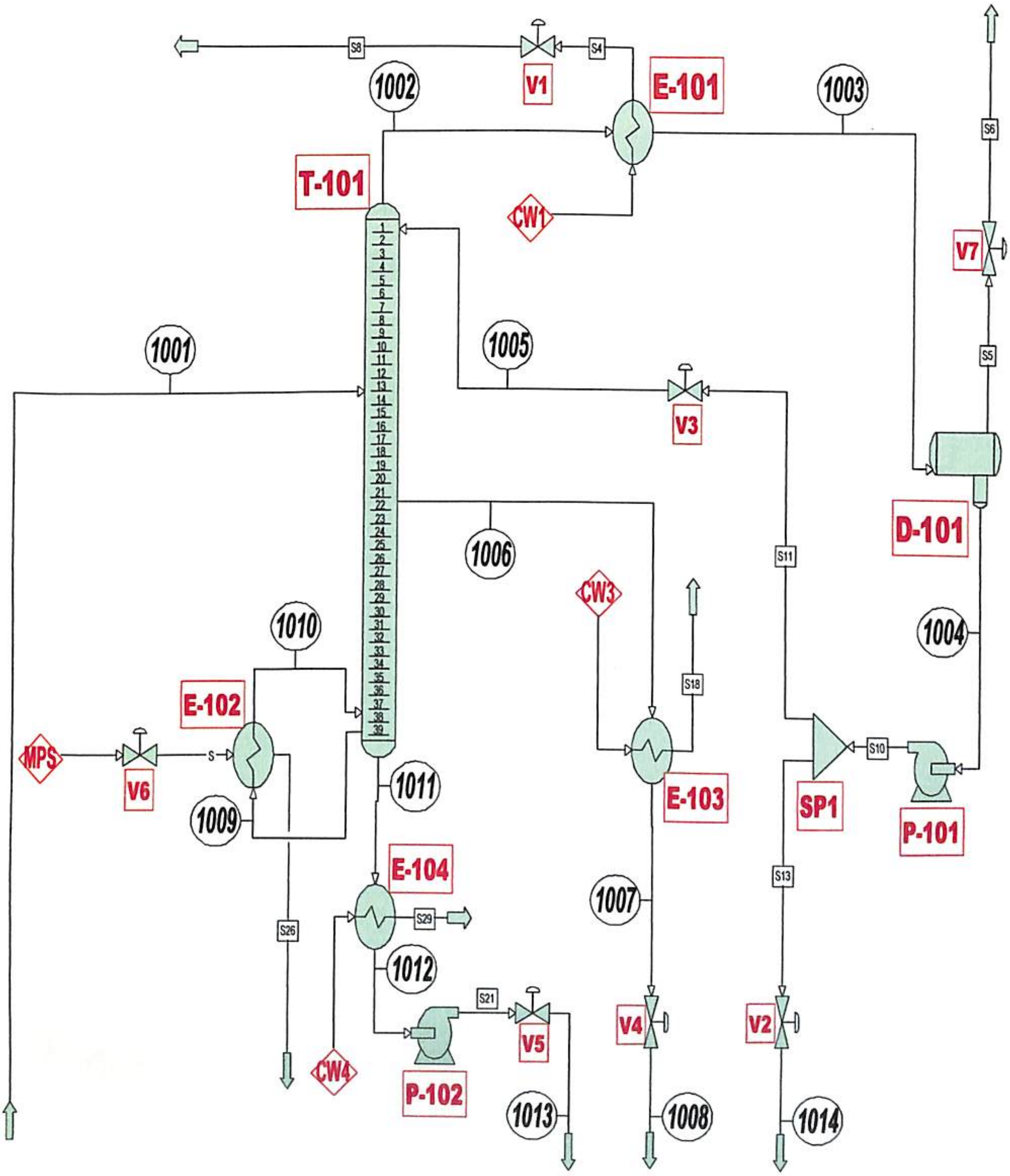
| | | Operating Conditions | |
|---|---|---|---|
| | State | Pressure, MPaG | Temp,°C |
| Depropylenizer feed | Liquid | 1.876 | 74 |

A) Products

| | | Operating Conditions | |
|---|---|---|---|
| | | Pressure, MPaG | Temp, °C |
| Propylene product | Liquid | 3.3 | 47 |
| $C_4$ Side draw | Liquid | 0.3 | 40 |

**20. ANNEXURE-5**

**PROCESS FLOW DIAGRAM**



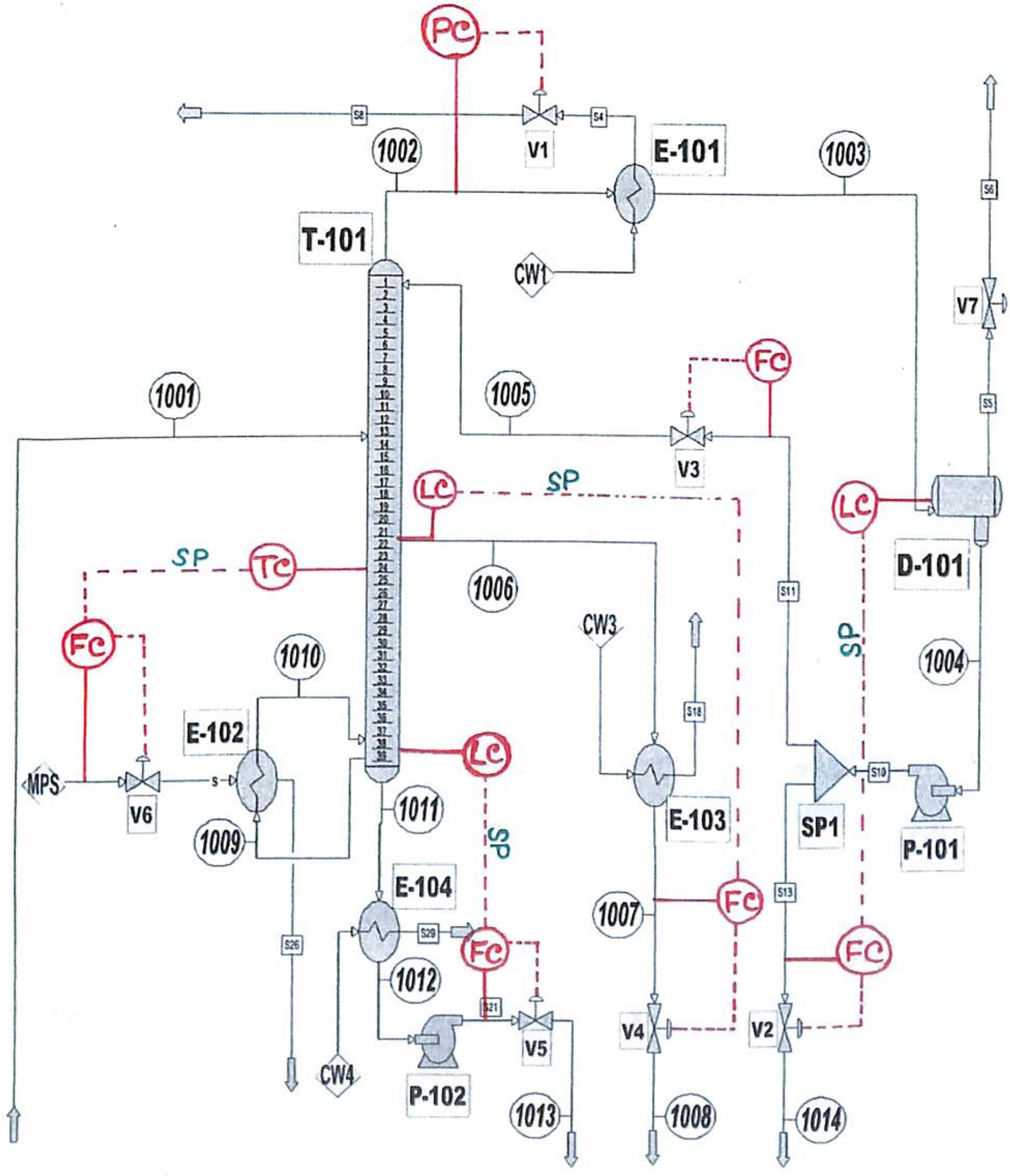
## 21. ANNEXURE-6

**EQUIPMENTS LIST**

| Equipment | Service | No. |
|---|---|---|
| **Drums** | | |
| D-101 | Depropylenizer Reflux Drum | 1 |
| D-102 | Depropylenizer Reboiler Condensate Pot | 1 |
| **Heat Exchangers** | | |
| E-101 | Depropylenizer Condenser | 1 |
| E-102 | Depropylenizer Reboiler | 1 |
| E-103 | C4 Recycle Cooler | 1 |
| E-104 | C4+ Product Cooler | 1 |
| **Pumps** | | |
| P-101A/B | Depropylenizer Reflux/Propylene Product Pump | 2 |
| P-102A/B | C4+ Product Pump | 2 |
| **Towers** | | |
| T-101 | Depropylenizer | 1 |

## 22. ANNEXURE 7

## PROCESS FLOW DIAGRAM WITH CONTROL SCHEME



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