



Training Services

***Fractionator Reboiler,
Condenser, and
Instrumentation Selection***

IPD-2004/RCI-1

***Fractionator
Reboiler Selection***

IPD-2004/RCI-2

Index

- **Boiling**
 - General
 - Reboiler systems
- **Reboiler Types**
 - Thermosiphon
 - Immersed
 - Pumped

IPD-2004/RCI-3

Index *(continued)*

- **Design Considerations**
 - Preferred system
 - Selection of heating medium
 - Temperature/composition calculations
 - Calculation of area
 - Pressure selection
 - Column elevation
 - Mechanical
 - Contingency

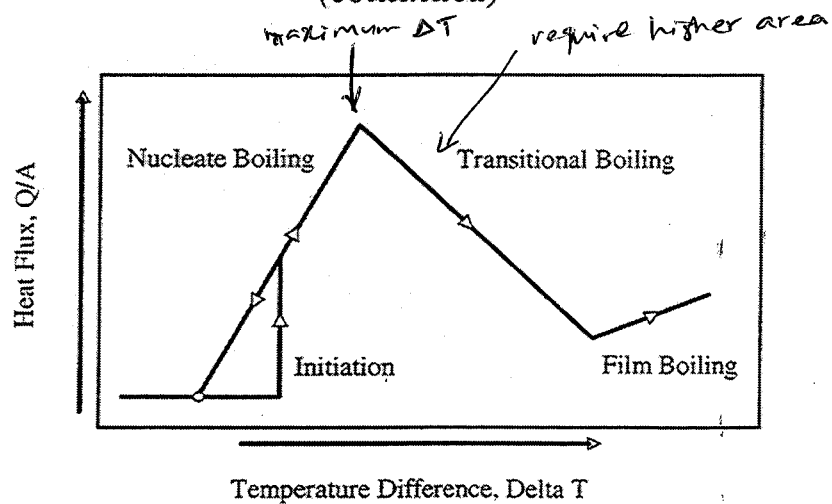
IPD-2004/RCI-4

Boiling - General

- What is boiling?
 - Vapor pressure > static pressure
- How does a reboiler work?
 - Induces boiling by transferring heat into liquid
- What is nucleate boiling?
 - Heat transfer induces the formation of bubbles at surface
 - Bubbles form at specific sites or nuclei

IPD-2004/RCI-5

Boiling - General (continued)

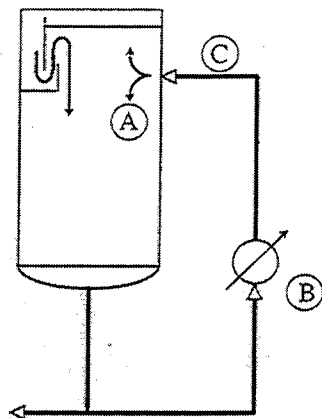


CRI-R00-1
IPD-2004/RCI-6

Reboiler Systems

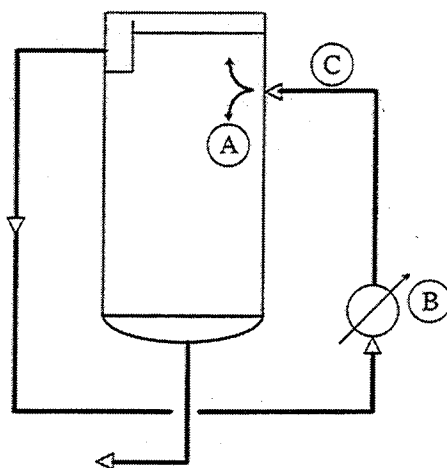
Fractionator Bottoms to Reboiler

1st choice



CRI-R00-6
IPD-2004/RCI-7

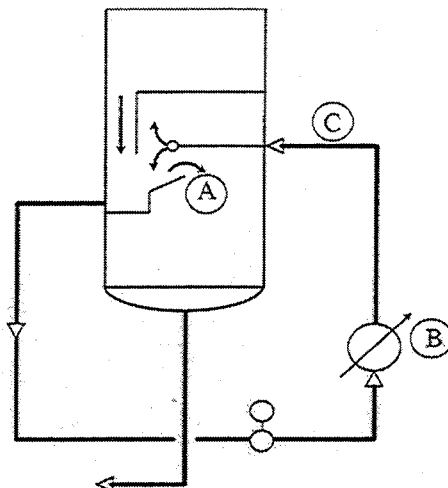
Bottoms Tray Liquid to Reboiler



CRI-R00-7
IPD-2004/RCI-8

Preferential Fractionator Bottoms

2nd choice



CRI-R00-8
IPD-2004/RCI-9

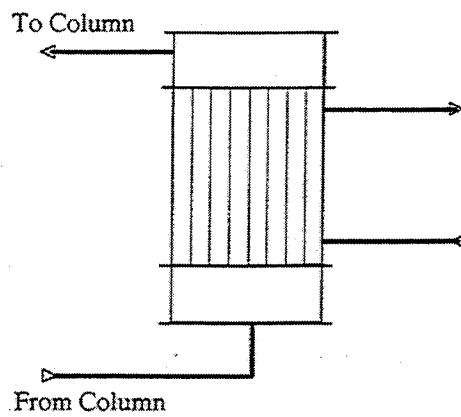
Reboiler Systems

Examples of Three Systems (Heavy Oil Debutanizer)

MATERIAL TO REBOILER	BOTTOMS	BOTTOM TRAY	PREFER MIXED
% Vaporization	33	47	33
Reboiler Temperature, °F			
Inlet	594	479	510
Outlet	668	594	594

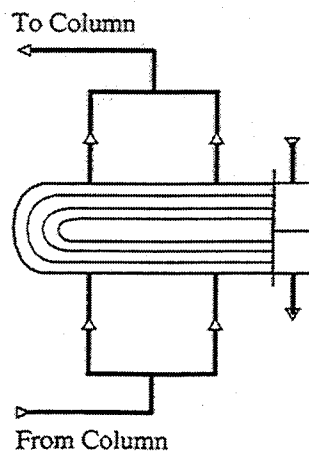
IPD-2004/RCI-10

Vertical



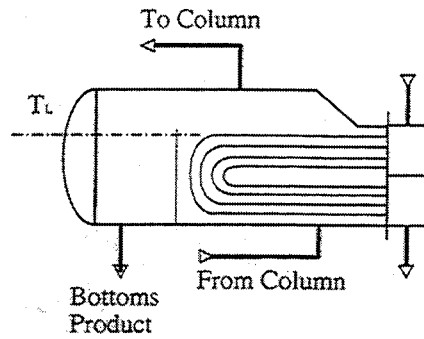
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IPD-2004/RCI-11

Horizontal



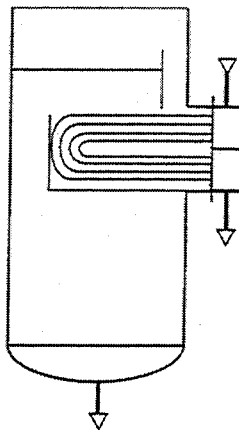
CRI-R01-3
IPD-2004/RCI-12

Kettle (External)



CRI-R00-4
IPD-2004/RCI-13

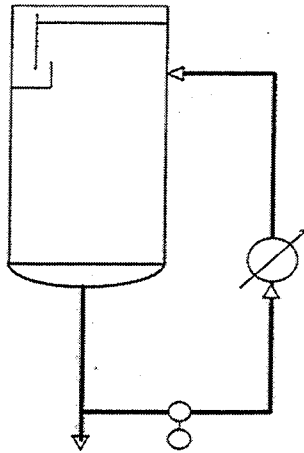
Reboiler Types *Immersed (Natural Circulation) - Stab-In (Internal)*



CRI-R00-5
IPD-2004/RCI-14

Reboiler Types

Pumped (Forced Circulation)



CRI-200-9
IPD-2004/RCI-15

Design Considerations

■ Preferred System

- Most common reboiler system found in refineries is the bottom liquid to reboiler
- Use this system unless there is a strong reason for another system

■ Selection of Heating Medium

- In making decision, consider available temperature levels, allowable pressure drop, fouling tendency, and possibility of thermal decomposition

IPD-2004/RCI-16

Design Considerations ***(continued)***

■ **Outlet Temperature**

- Select desired vaporization rate based on reboiler type
- Two-phase flash calculation at column pressure yields temperature and compositions
- Liquid to reboiler determined by heat balance

IPD-2004/RCI-17

Design Considerations ***(continued)***

■ **Calculation of Area**

- For calculation of the LMTD for natural circulation reboilers, the outlet process temperature shall be used as the inlet temperature
- For bare tubes, the maximum flux rate is limited to a maximum of 15,000 Btu/h/ft²
- Specialty tubing is available that delivers higher flux rates

IPD-2004/RCI-18

Design Considerations ***(continued)***

■ **Pressure Selection**

- Reboiler pressure is set at a minimum of column overhead pressure, plus 0.1 psi per tray, plus any necessary contingency required for a maximum operating pressure level

■ **Hydraulics**

- Safety factor of 1.0 psi shall be added to the calculated pressure drop through thermosyphon reboiler types to calculate the required column height

IPD-2004/RCI-19

Design Considerations ***(continued)***

■ **Column Elevation**

- Reboiler types that have hydraulic requirements to achieve circulation can require considerable column elevation if operation is close to critical conditions

■ **Contingency**

- Normal policy for exchange surface
- Setting LMTD for design
- Fouling factor selection

IPD-2004/RCI-20

Fractionator Condenser Selection

IPD-2004/RCI-21

Index

- **Condensation**
 - General
 - Partial condensation
 - Total condensation
- **Condenser/Receiver Types**
 - Net vent
 - Enclosed
 - Open to flare
 - Gas blanket

IPD-2004/RCI-22

Index ***(continued)***

■ **Condenser/Receiver Hydraulics**

- Net vent
 - Water cooled
- Enclosed
 - Water cooled
 - Air cooled
- Open to flare
 - Air cooled

IPD-2004/RCI-23

Index ***(continued)***

■ **Design Considerations**

- Piping
- Vent condensers
- Subcooling
- Pressure drop
- Contingency

IPD-2004/RCI-24

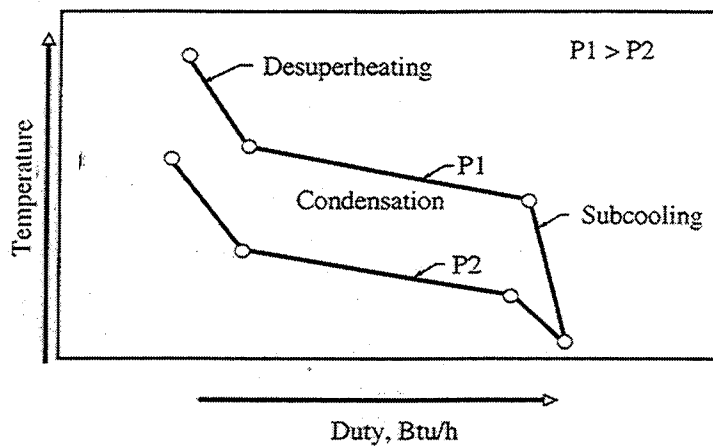
- **Condensation occurs when system pressure > vapor pressure at a specific temperature**

IPD-2004/RCI-25

- **Total condensation refers to systems where there is no vapor product**
- **Partial condensation implies that there is a vapor product**

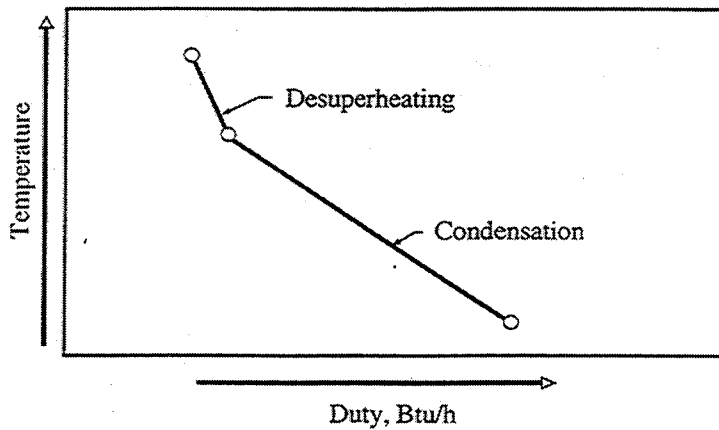
IPD-2004/RCI-26

Condensation Total Condensation



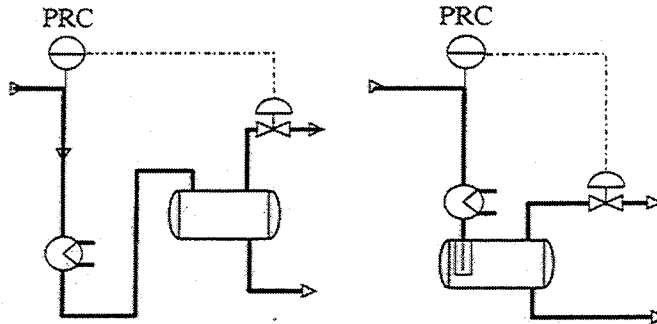
CRI-R00-10
IPD-2004/RCI-27

Condensation Partial Condensation



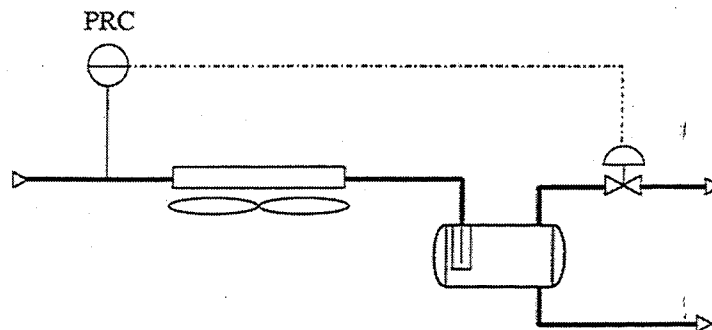
CRI-R00-11
IPD-2004/RCI-28

Condenser/Receiver Types ***Net Vent (Partial Condensation) - Water Cooled***



CRI-R00-12
IPD-2004/RCI-29

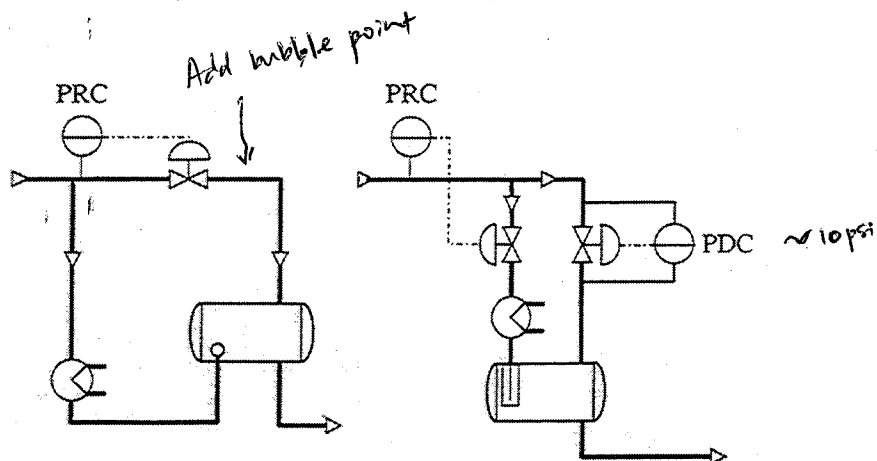
Condenser/Receiver Types ***Net Vent (Partial Condensation) - Air Cooled***



CRI-R00-13
IPD-2004/RCI-30

Condenser/Receiver Types

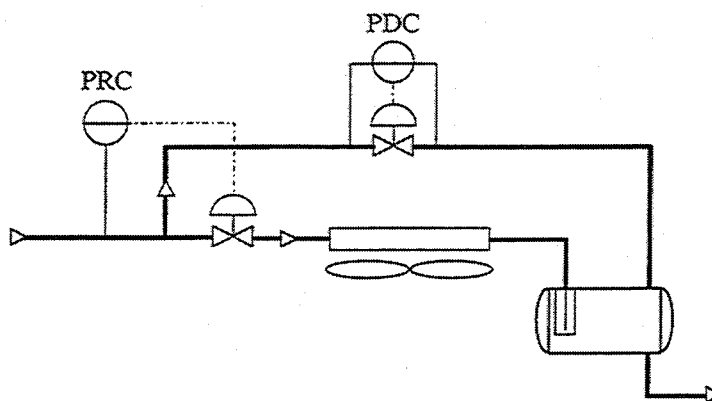
Enclosed (Total Condensation) - Water Cooled



CRJ-R00-14
IPD-2004/RCI-31

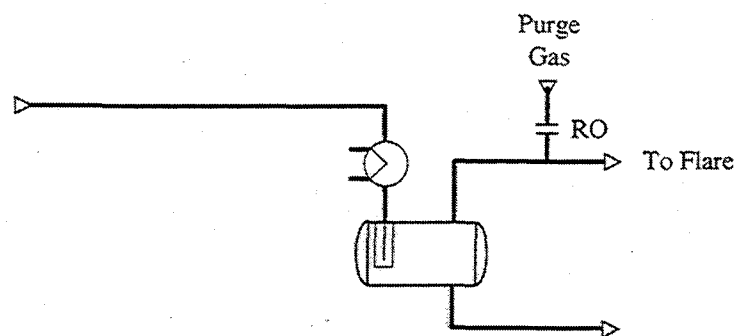
Condenser/Receiver Types

Enclosed (Total Condensation) - Air Cooled



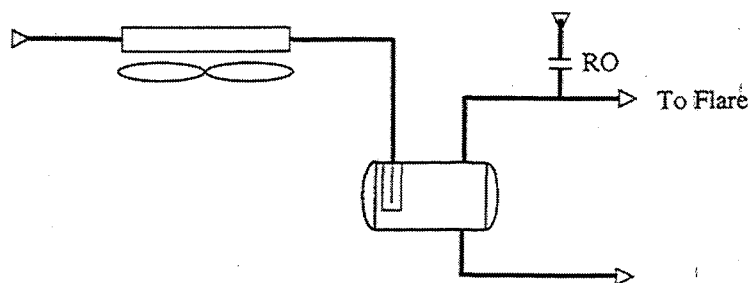
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IPD-2004/RCI-32

Condenser/Receiver Types **Open to Flare (Total Condensation) - Water Cooled**



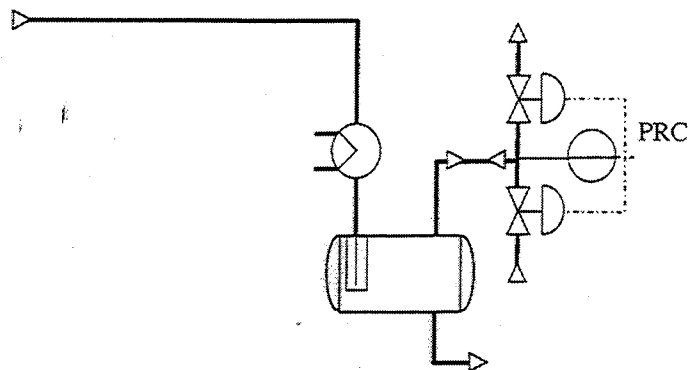
CRI-R00-16
 IPD-2004/RCI-33

Condenser/Receiver Types **Open to Flare (Total Condensation) - Air Cooled**



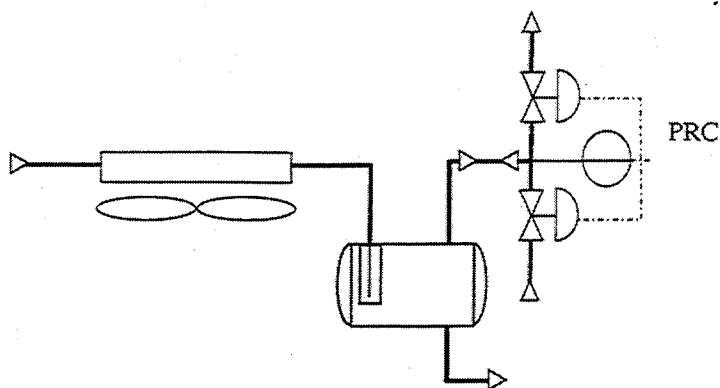
CRI-R00-17
 IPD-2004/RCI-34

Condenser/Receiver Types
Gas Blanket (Total Condensation) - Water Cooled



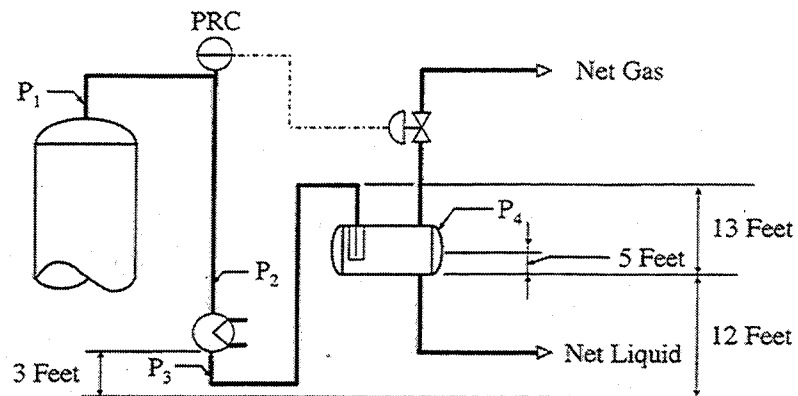
CRI-R00-18
IPD-2004/RCI-35

Condenser/Receiver Types
Gas Blanket (Total Condensation) - Air Cooled



CRI-R00-19
IPD-2004/RCI-36

Condenser/Receiver Hydraulics *Net Vent - Water Cooled*



CRI-R00-20
IPD-2004/RCI-37

Condenser/Receiver Hydraulics *Net Vent - Water Cooled (continued)*

Operation

The PRC controls valve in the net gas and regulates the back pressure on the fractionating column

Hydraulics

$$P_1 = 150 \text{ psig}$$

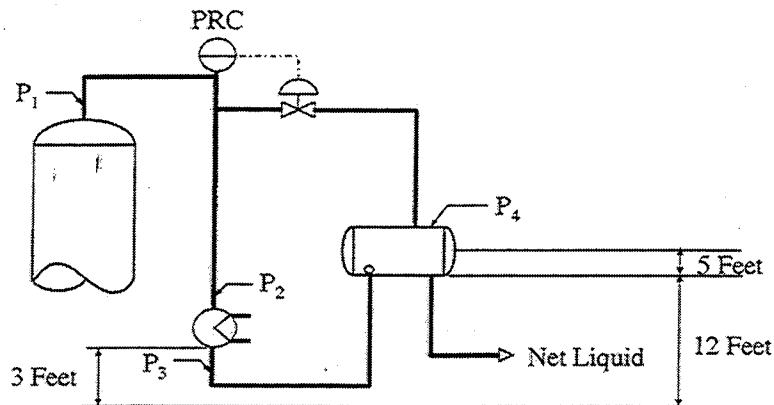
$$P_2 = P_1 - \text{delta P line} + \text{delta P head} \quad 150 - [400 \times (0.5/100)] = 148$$

$$P_3 = P_2 - \text{delta P exchanger} \quad 148 - 3.0 = 145$$

$$P_4 = P_3 - \text{delta P head} - \text{delta P line} \quad 145 - [(14 \times 0.433 \times 0.08) - (100 \times \{0.25/100\})] = 144$$

IPD-2004/RCI-38

Condenser/Receiver Hydraulics *Enclosed - Water Cooled*



CRI-R00-21
IPD-2004/RCI-39

Condenser/Receiver Hydraulics *Enclosed - Water Cooled*

Operation

A change in flow through the hot vapor bypass control valve varies the receiver pressure, which changes the liquid level in the condenser. The surface available for condensation regulates the column pressure.

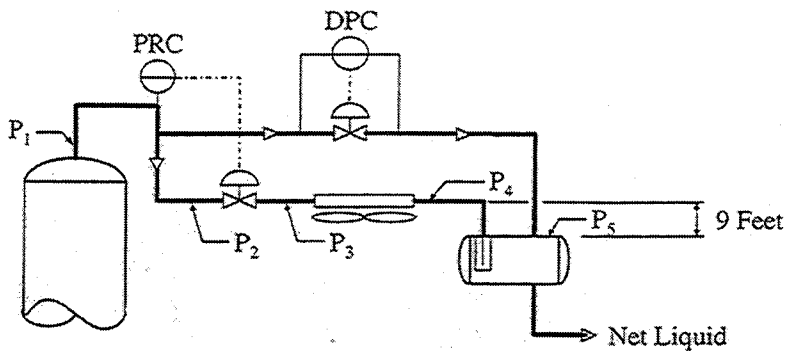
Hydraulics

$$\begin{aligned}
 P_1 &= 15 \text{ psig} \\
 P_2 &= P_1 - \Delta P \text{ line} + \Delta P \text{ head} & 15.0 - [400 \times (0.25/100)] &= 14.0 \\
 P_3 &= P_2 - \Delta P \text{ exchanger} & 14.0 - 3.0 &= 11.0 \\
 P_4 &= P_3 - \Delta P \text{ head} - \Delta P \text{ line} & 11.0 - (14.0 \times 0.433 \times 0.78) & \\
 & & - (100 \times \{0.25/100\}) & \\
 & & = 6.0 &
 \end{aligned}$$

IPD-2004/RCI-40

Condenser/Receiver Hydraulics

Enclosed - Air Cooled



CRI-R00-22
IPD-2004/ACI-41

Condenser/Receiver Hydraulics *Enclosed - Air Cooled (continued)*

Operation

The PRC controls the butterfly valve which regulates overhead vapor flow to the air cooled condenser. This adjustment of flow controls the column pressure. The DPC keeps the butterfly valve in operating range. The DPC regulates the flow of hot vapor to obtain the surface temperature in the receiver to obtain vapor pressure necessary to satisfy the DPC.

1PD-2004/RCI-42

Condenser/Receiver Hydraulics *Enclosed - Air Cooled (continued)*

Hydraulics

$$\begin{aligned}
 P_1 &= 15 \text{ psig} \\
 P_2 &= P_1 - \text{delta P line} & 15.0 - [400 \times (0.25/100)] &= 14.0 \\
 P_3 &= P_2 - \text{delta P valve} & 14.0 - 2.0 &= 12.0 \\
 P_4 &= P_3 - \text{delta P exchanger} & 12.0 - 2.0 &= 10.0
 \end{aligned}$$

If rundown line two phase

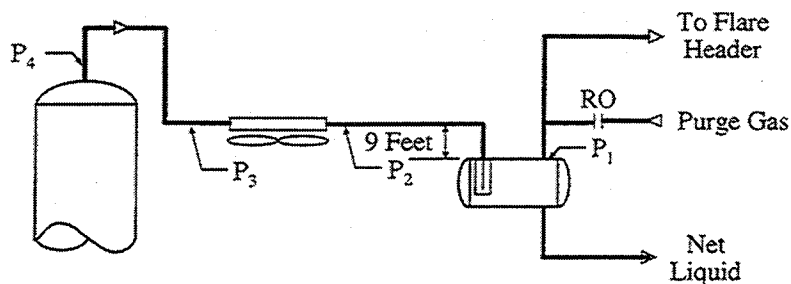
$$\begin{aligned}
 P_5 &= P_4 + \text{delta P head} - \text{delta P line} & [10 + (9 \times 0.433 \times 0.08) \\
 & & - (100 \times \{0.25 \times 100\})] \\
 & & = 9.9
 \end{aligned}$$

If rundown line liquid phase

$$\begin{aligned}
 P_5 &= P_4 + \text{delta P head} - \text{delta P line} & [10 + (9 \times 0.433 \times 0.77) \\
 & & - (100 \times \{0.25 \times 100\})] \\
 & & = 12.0
 \end{aligned}$$

IPD-2004/RCI-43

Condenser/Receiver Hydraulics *Open to Flare - Air Cooled*



CRJ-R00-23
IPD-2004/RCI-44

Condenser/Receiver Hydraulics *Open to Flare - Air Cooled*

Operation

There is an open line from the receiver to the flare header. A purge gas is introduced into the line to flare to maintain a positive flow going to the flare.

Hydraulics

$$P_1 = 1.0 \text{ psig}$$

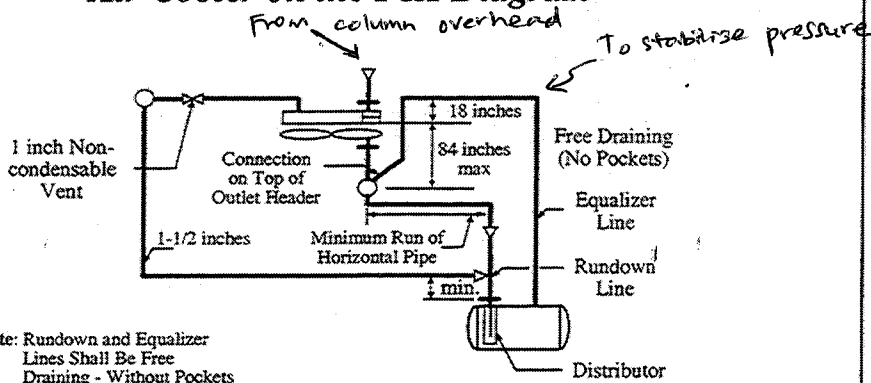
$$P_2 = P_1 + \Delta P \text{ line} - \Delta P \text{ head} \quad 1.0 - (9.0 \times 0.433 \times 0.08) \\ + (100 \times 0.4/100) \\ = 1.1$$

$$P_3 = P_2 + \Delta P \text{ exchanger} \quad 1.1 + 3.0 = 4.3$$

$$P_4 = P_3 + \Delta P \text{ line} \quad 4.3 + [400 \times (0.17/100)] = 5.0$$

IPD-2004/RCI-45

Design Considerations - Piping *Air Cooler on the P&I Diagram*



Equalizer Line - Size 1/4 to 1/3 of Rundown Line Diameter

Rundown Line - Size Large

Distributor - Use Pipe with Vertical Slot

CRJ-R00-24
IPD-2004/RCI-46

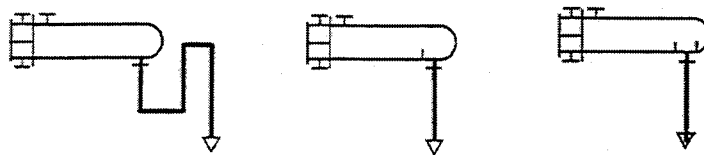
Design Considerations *Vent Condensers*

- Vent Condensers
 - Inerts in feed
 - Uncondensed product

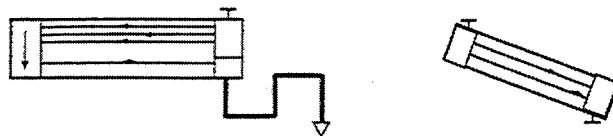
IPD-2004/RCI-47

Design Considerations *Subcooling*

Water - If Elevated Above the Receiver



Air - If Elevated Above the Receiver



CRJ-R00-25
IPD-2004/RCI-48

Design Considerations (continued)

	PRESSURE DROP, psi	
	Minimum	Average
Water Condenser	3.0	4 – 6
Air Condenser	2.0	3 – 5
Overhead Line, psi/100	0.1	0.2 – 0.5
Butterfly @ Cond Inlet	1.0	1.5 – 2.5
Cond Rundown Line, psi/100		
Two phase	0.1	0.25
Liquid phase (free drain)	0.1	0.25
Liquid phase (with seal)	0.5	1.0

IPD-2004/RCI-49

Design Considerations (continued)

- **Contingency**
 - Normal policy for exchange surface
 - Low end temperature approach to cooling medium
 - Straight line condensation
 - Bubble point temperature adjustments
 - Fouling factor selection

IPD-2004/RCI-50

Fractionator Instrument Selection

IPD-2004/RCI-51

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- **Composition Control**
 - General
 - Performance curves
 - Control strategy
 - Direct
 - Indirect
 - Temperature

IPD-2004/RCI-52

Index ***(continued)***

- **Material Balance Control**
 - General
 - Control strategy
 - Overhead
 - Bottoms
- **Pressure Control**
 - Water condensers
 - Air condensers
 - Combination air/water
 - Steam generation

IPD-2004/RCI-53

Index ***(continued)***

- **Heat Input Control**
 - Fired heaters
 - Reboilers
 - Feed heaters
 - Exchanger-type reboilers
 - Steam
 - Hot oil
 - Overhead vapor

IPD-2004/RCI-54

Index ***(continued)***

■ **Miscellaneous**

- **Problems**
 - **Steam versus condensate control**
 - **Purge gas equilibrium**
- **Alternate philosophies**

IPD-2004/RCI-55

Composition Control ***General***

What are the degrees of freedom available to the design engineer for the design of a fractionator?

■ **Basis**

- **Overhead composition**
- **Feed composition**
- **Bottoms composition**

■ **Variables**

- **Reflux**
- **Number of trays**
- **Feed tray location**

IPD-2004/RCI-56

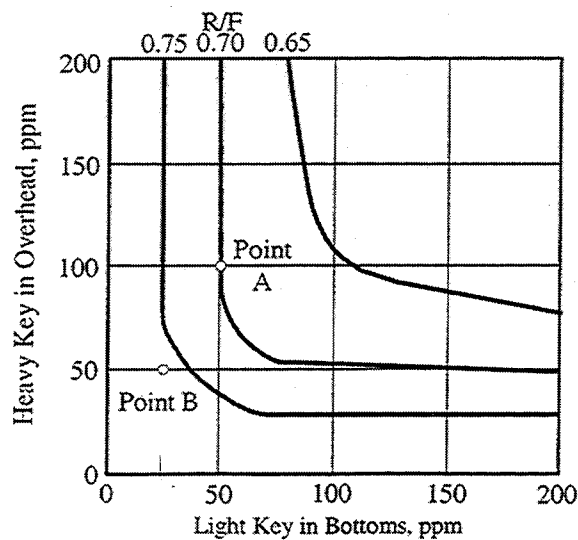
Composition Control General (continued)

What are the degrees of freedom available to the operation engineer for control of a fractionator?

- Basis
 - Feed composition
 - Number of trays
 - Feed tray location
- Variables
 - Reflux (50-115 % design)
 - Overhead composition
 - Bottoms composition

IPD-2004/RCI-57

Composition Control Performance Curves - Reflux Balance Heat



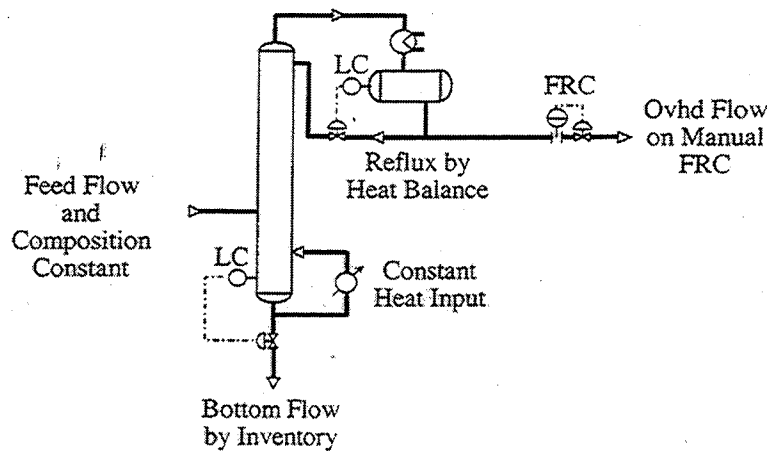
$\alpha \uparrow$, easier separation

$$\alpha = \frac{k_{LK}}{k_{HK}}$$

$$\left(\frac{R}{F}\right)_{\min} = \frac{1}{\alpha - 1}$$

CRJ-R00-26
IPD-2004/RCI-58

Composition Control Performance Curves - Reflux Balance Heat



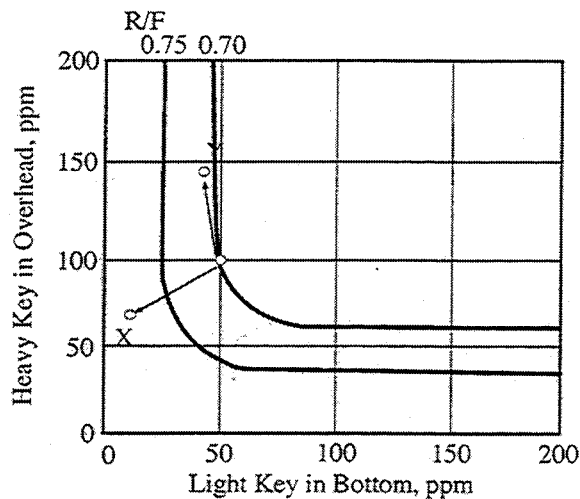
CRI-R00-27
IPD-2004/RCI-59

Composition Control Performance Curves - Reflux Balance Heat

- What is the result if heat input to reboiler increases? → more reflux
- What is the result if the light key decreases in the feed?

IPD-2004/RCI-60

Composition Control Performance Curves



CRJ-R00-28
IPD-2004/RCI-61

Composition Control Performance Curves

- If the light key in feed decreases, the overhead and bottom composition would change such that the composition would follow a line parallel to the performance curve in an upward direction (Point A to Point Y)
- If the heat input is increases, the overhead and bottom composition would change such that the composition of both distillate and bottoms would improve (Point A to Point X)
- Conclusion -- There is a necessity to have instruments sense the product composition and make adjustments to maintain product quality

IPD-2004/RCI-62

	<u>FEED</u>	<u>OVHD</u>	<u>BOTTOMS</u>
LK	1000	998	2
HK	<u>1000</u>	<u>2</u>	<u>998</u>
	2000	1000	1000

$$MF = 0.998$$

Less LK

<u>LK</u>	995	995	0
HK	<u>1005</u>	<u>5</u>	<u>1000</u>
	2000	1000	1000

$$MF = 0.995$$

IPD-2004/RCI-63

Composition Control Control Strategy

- Methods utilized for sensing the composition of hydrocarbon product streams
 - Direct
 - Laboratory analyses
 - “On stream” lab instrumentation
 - Chromatograph
 - Analyzers (boiling point, gravity, octane, water)
- All “on stream” instrumentation will give a response dependent upon the cycle time required to run the analysis

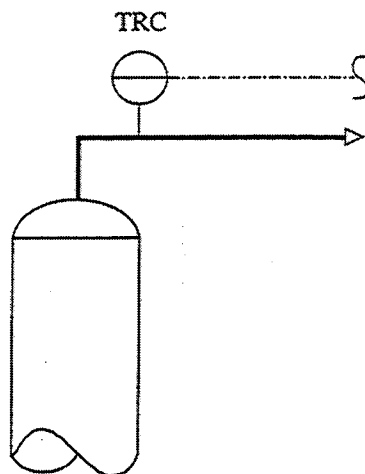
IPD-2004/RCI-64

Composition Control Control Strategy (continued)

- Indirect
 - Temperature
 - Temperature (pressure compensated)
 - Delta temperature difference
- In a binary or a system with pure product overhead, the temperature is a direct indication of composition
- In other cases, Gibbs phase rule would govern and temperature can be only an indication

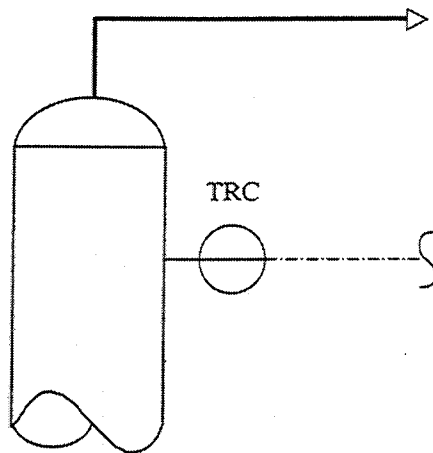
IPD-2004/RCI-66

Composition Control Control Strategy (continued)



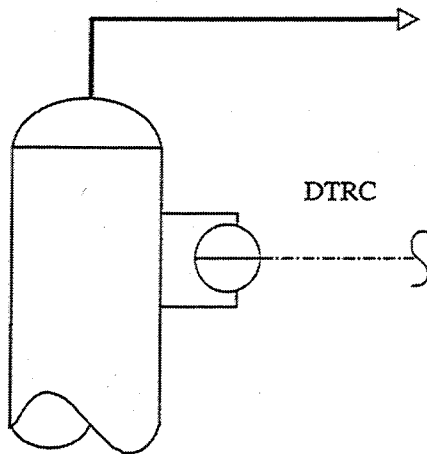
CRI-R00-29
IPD-2004/RCI-66

Composition Control Control Strategy (continued)



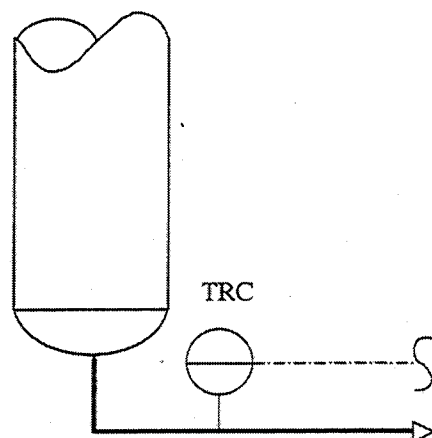
CRI-R00-30
IPD-2004/RCI-67

Composition Control Control Strategy (continued)



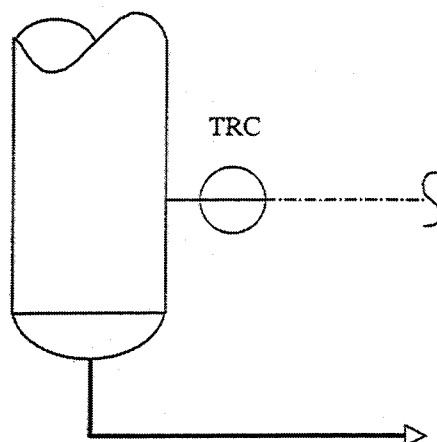
CRI-R00-31
IPD-2004/RCI-68

Composition Control Control Strategy (continued)



CRI-R00-32
IPD-2004/RCI-69

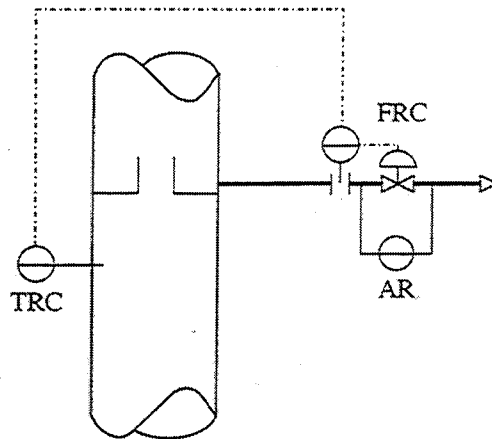
Composition Control Control Strategy (continued)



CRI-R00-33
IPD-2004/RCI-70

Composition Control

Control Strategy - Control for Sidecut Product Quality



CRJ-R00-34
IPD-2004/RCI-71

Composition Control

Control Strategy (continued)

How does one make the tray selection for temperature control?

■ **Guidelines**

- Halfway between top and feed or feed and bottom; normally okay if there is not a more scientific method available
- Use tray-to-tray calculations and find maximum delta T change for a given composition change
- Use tray-to-tray calculations and find effect of a given process change upon tray temperatures

IPD-2004/RCI-72

Material Balance Control

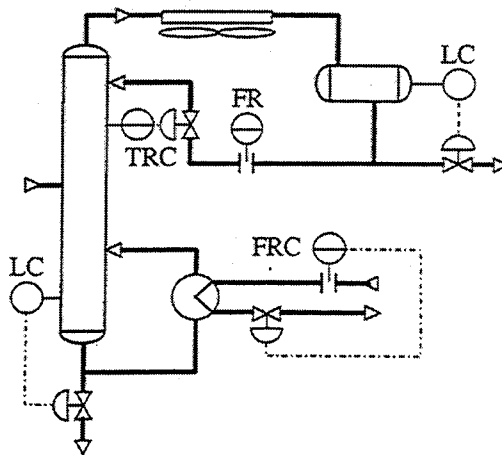
General

- **Concept of material balance control can be divided into two categories**
 - Traditional
 - Modern

IPD-2004/RCI-73

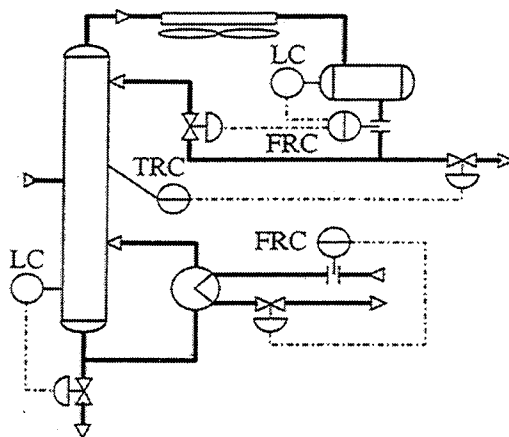
Material Balance Control

Traditional Philosophy



CRI-R00-35
IPD-2004/RCI-74

Material Balance Control Modern Philosophy



CRI-R00-36
IPD-2004/RCI-75

Material Balance Control General (continued)

- From first principles, define key component yield in the distillate stream

F = Feed quantity

D = Distillate quantity

B = Bottom quantity

x = Mol frac of key component in F

y = Mol frac of key component in D

z = Mol frac of key component in B

IPD-2004/RCI-76

Material Balance Control ***General (continued)***

- Overall: $F = D + B$
- For key component: $x_F = y_D + z_B$
- Rearrange: $D/F = (x - z)/(y - z)$
- Conclusion: yield of "on spec" distillates is dependent only upon the composition of the feed and products

IPD-2004/RCI-77

Material Balance Control ***General (continued)***

- For both traditional and modern column,
determine response necessary to reach steady
state after the following upsets
 - A change transpires in the column heat balance
such as the reboiler duty increases
 - A change occurs in the feed composition such that
the light key content increases

IPD-2004/RCI-78

Material Balance Control

General (continued)

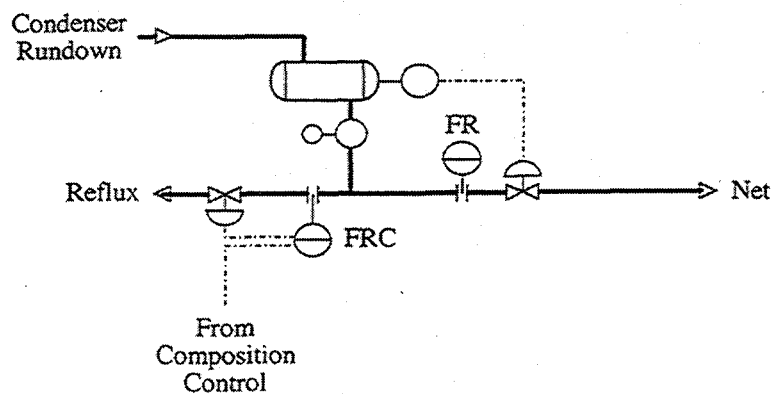
- Using logic to determine the response to these situations should convince a design engineer that the modern philosophy is the best operation

IPO-2004/RCI-79

Material Balance Control

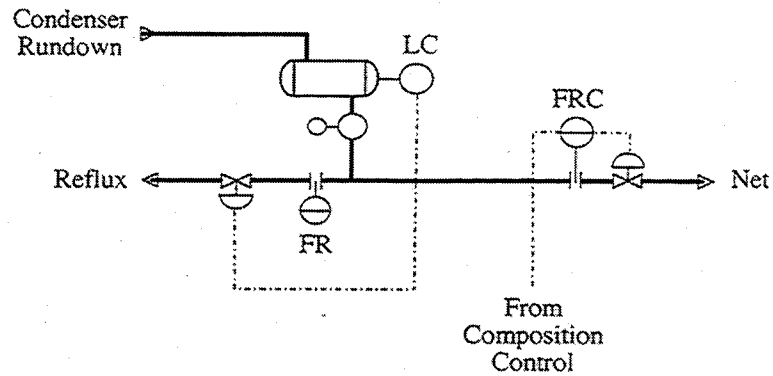
Control Strategy (continued)

Overhead Net Product Yield



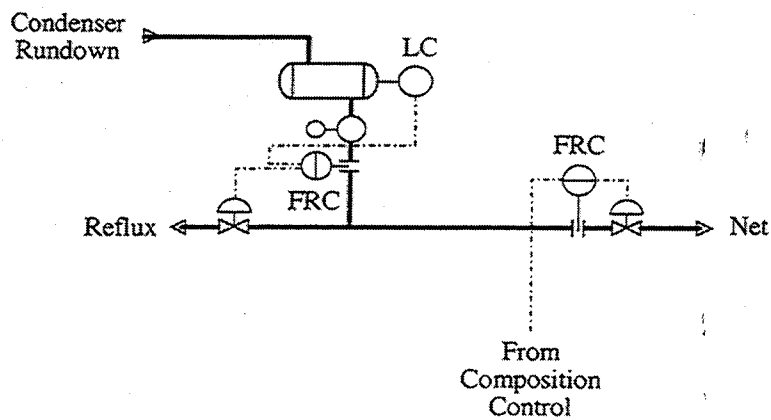
CRI-R00-37
IPO-2004/RCI-80

Material Balance Control *General (continued)* **Overhead Net Product Yield**



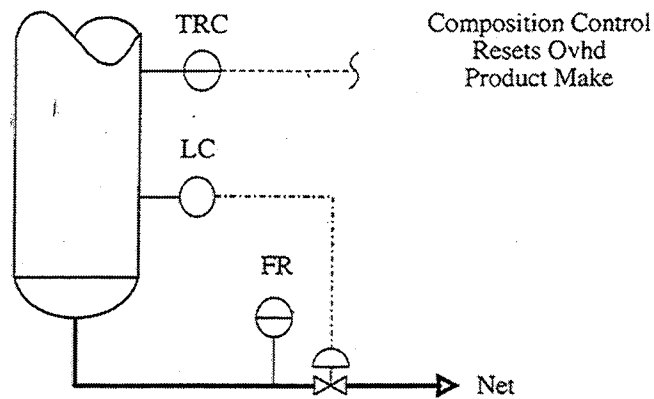
CRI-R00-33
 IPD-2004/RCI-81

Material Balance Control *General (continued)* **Overhead Net Product Yield**



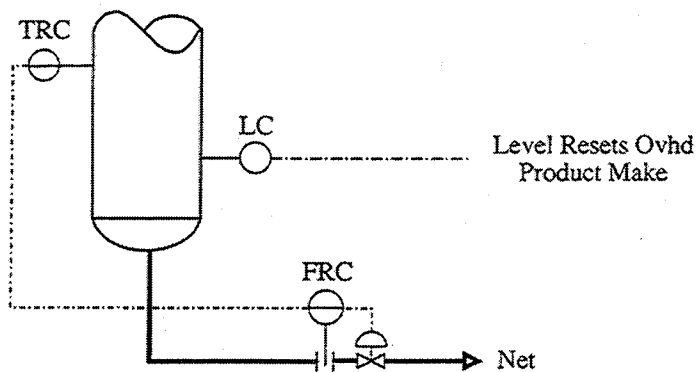
CRI-R00-39
 IPD-2004/RCI-82

Material Balance Control **General (continued)** **Bottoms Net Product Yield**



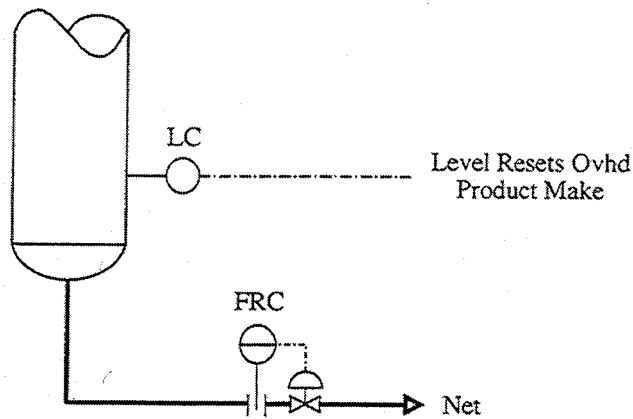
CRI-R00-40
 IPD-2004/RCI-83

Material Balance Control **General (continued)** **Bottoms Net Product Yield**



CRI-R00-41
 IPD-2004/RCI-84

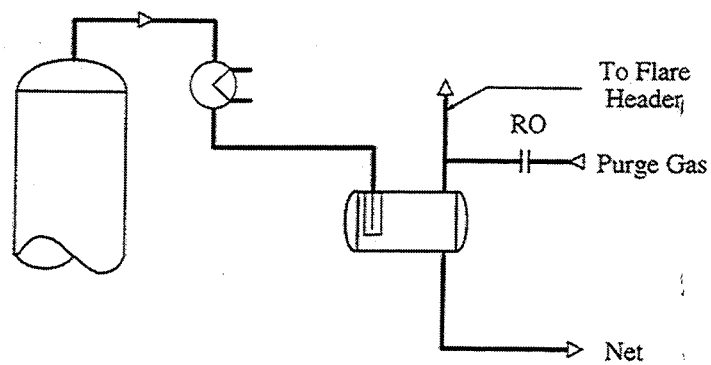
Material Balance Control **General (continued)** **Bottoms Net Product Yield**



CRI-R00-42
 IPD-2004/RCI-85

Pressure Control **Water Condensers**

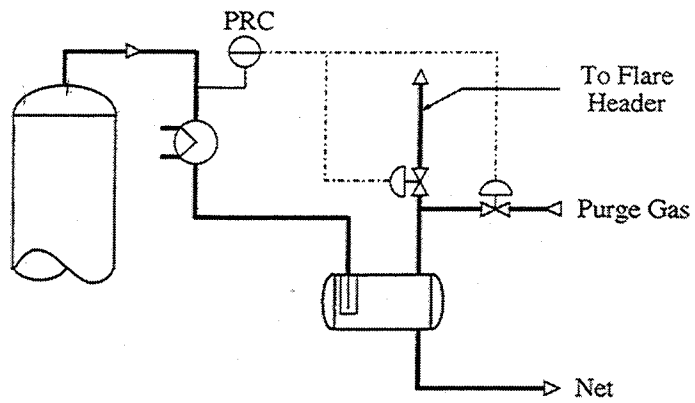
Vent to Flare
 1 - 5 psig



CRI-R00-43
 IPD-2004/RCI-85

Pressure Control ***Water Condensers (continued)***

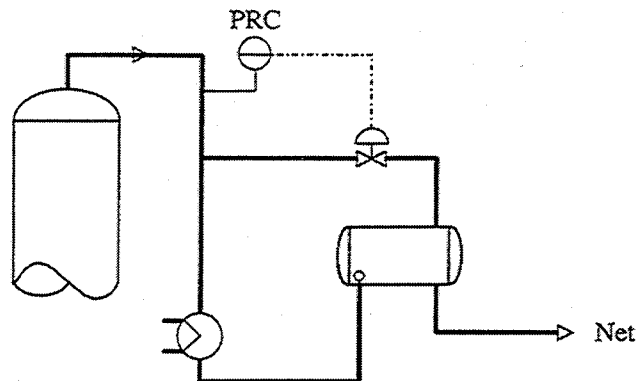
Controlled Vent to Flare
5 - 25 psig



CRJ-R00-44
IPD-2004/RCI-87

Pressure Control ***Water Condensers (continued)***

Enclosed System
Over 10 psig



CRJ-R00-45
IPD-2004/RCI-88

Material Balance Control

Pressure Control (continued)

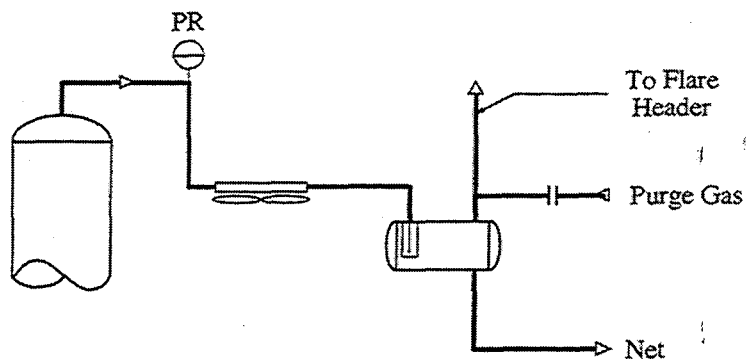
Water Condensers

- **Partial condensation - net overhead partial or total vapor**
 - Condenser can be either below or above receiver
 - Pressure level determined by destination pressure
 - CV delta P set to minimize downstream variations, normally 25 psi

IPD-2004/RCI-89

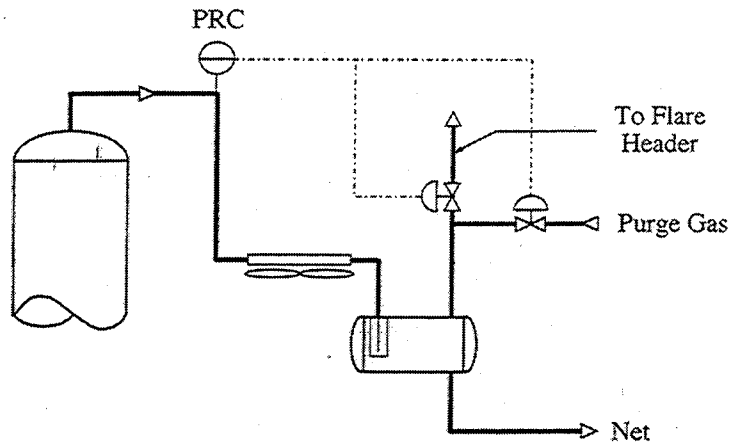
Pressure Control

Air Condensers



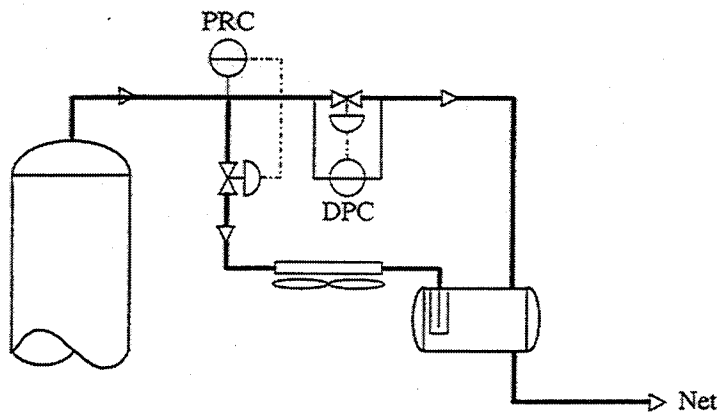
CRJ-R00-46
IPD-2004/RCI-90

Pressure Control Air Condensers (continued)



CRI-R00-47
IPD-2004/RCI-91

Pressure Control Air Condensers (continued)



CRI-R00-48
IPD-2004/RCI-92

Pressure Control

Air Condensers (continued)

For all air cooled systems, condenser

- Must be elevated
- Must have no traps in piping
- Rundown piping free draining
- Size rundown piping loose

IPD-2004/RCI-53

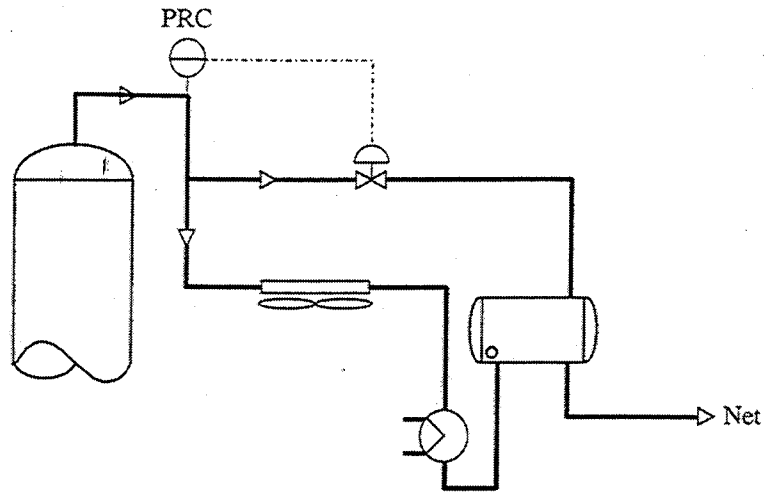
Pressure Control

Air Condensers (continued)

- Partial condensation - net overhead partial or total vapor
 - Condenser always above receiver
 - Pressure level determined by destination pressure
 - CV delta P set to minimize downstream variations, normally 25 psi

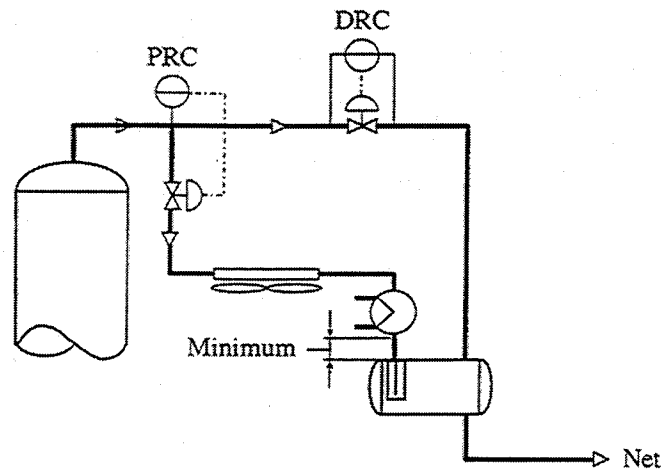
IPD-2004/RCI-54

Pressure Control Combination Air/Water



CRJ-R00-49
IPD-2004/RCI-95

Pressure Control Combination Air/Water (continued)



CRJ-R00-50
IPD-2004/RCI-96

Pressure Control

Air Condensers (continued)

- **Total condensation - floating or controlled vent**
 - Trim condenser should be minimum distance from receiver
 - Condenser
 - Must have no traps in piping
 - Rundown piping free draining
 - Size rundown piping loose

IPD-2004/RCI-97

Pressure Control

Air Condensers (continued)

- **Partial Condensation**
 - Condenser can be either below or above receiver
 - Pressure level determined by destination pressure
 - CV delta P set to minimize downstream variations, normally 25 psi

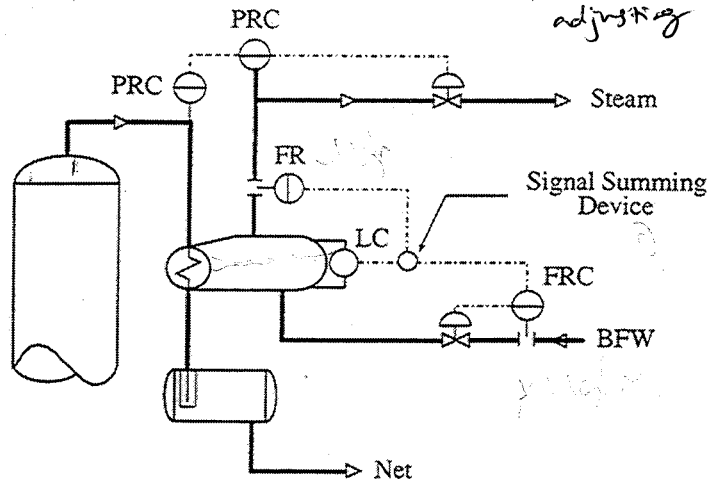
IPD-2004/RCI-98

Pressure Control Steam Generation

$$Q = UA\Delta T$$

only variable is ΔT

ΔT can be control by
adjusting steam pressure

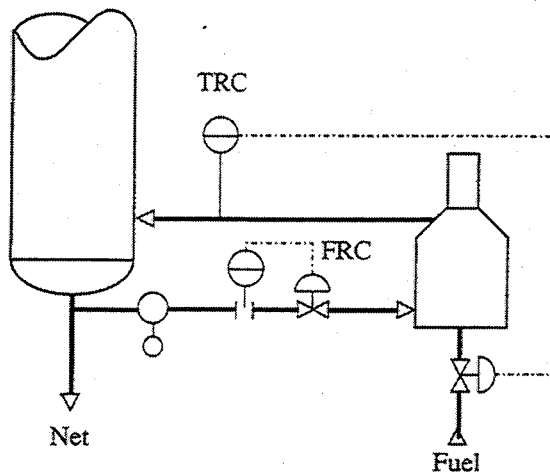


CRI-R00-51
IPD-2004/RCI-99

Heat Input Control Fired Heaters

$$Q = mC_p\Delta T$$

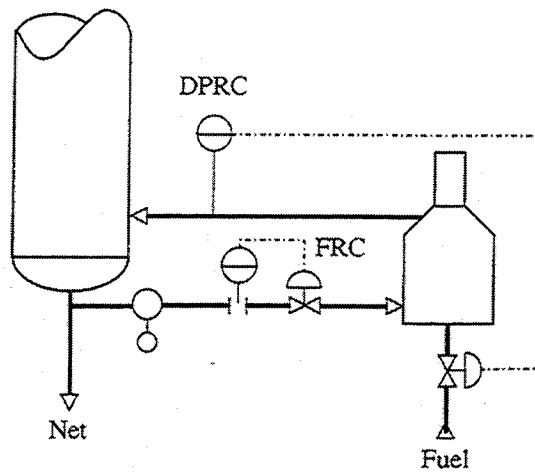
$$= \lambda w + mC_p\Delta T \text{ (vaporization)}$$



T $\nearrow 25^\circ F$
% Vaporization
 $> 25^\circ F$
the system
won't work

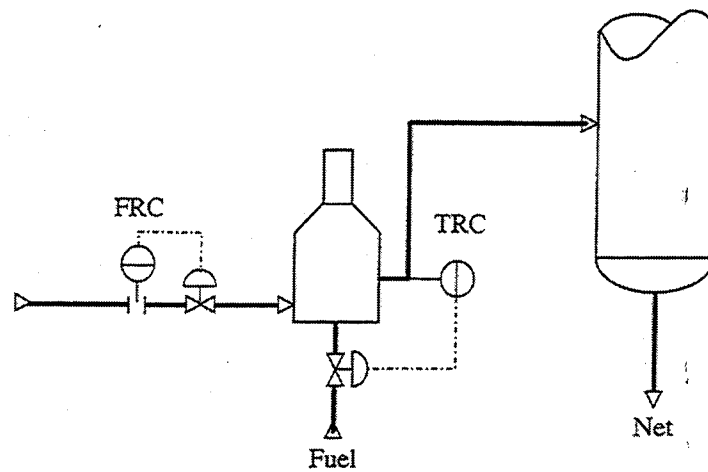
CRI-R00-52
IPD-2004/RCI-100

Heat Input Control Fired Heaters (continued)



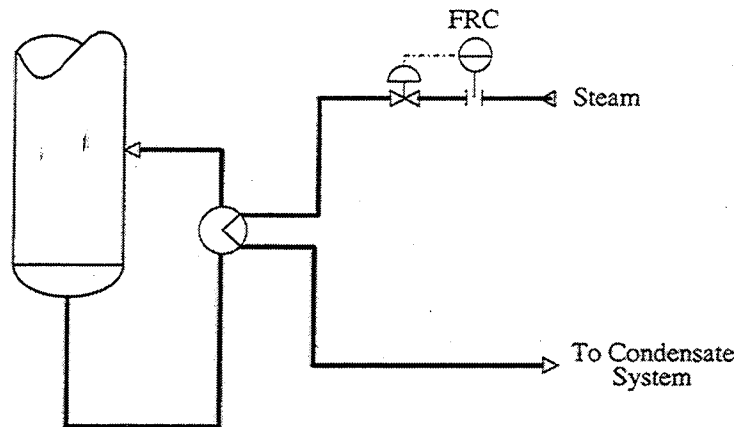
CRI-R00-53
IPD-2004/RCI-101

Heat Input Control Fired Heaters (continued)



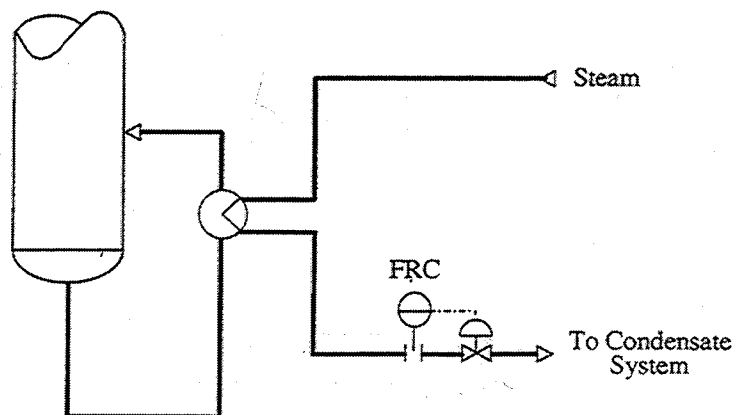
CRI-R00-54
IPD-2004/RCI-102

Heat Input Control Exchanger-Type Reboilers



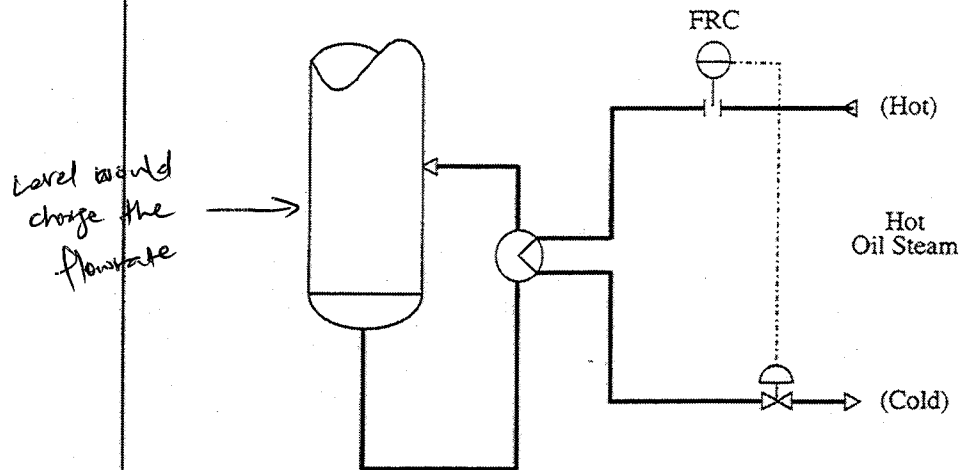
CRI-R00-55
IPD-2004/RCI-103

Heat Input Control Exchanger-Type Reboilers (continued)

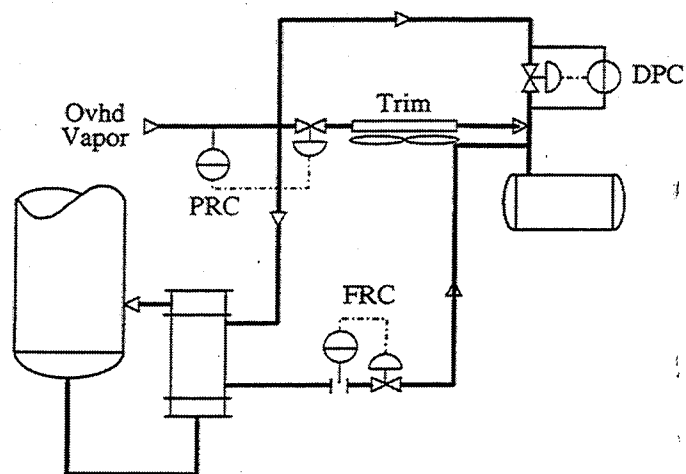


CRI-R00-56
IPD-2004/RCI-104

Heat Input Control Exchanger-Type Reboilers (continued)



Heat Input Control Exchanger-Type Reboilers (continued)



PROBLEM

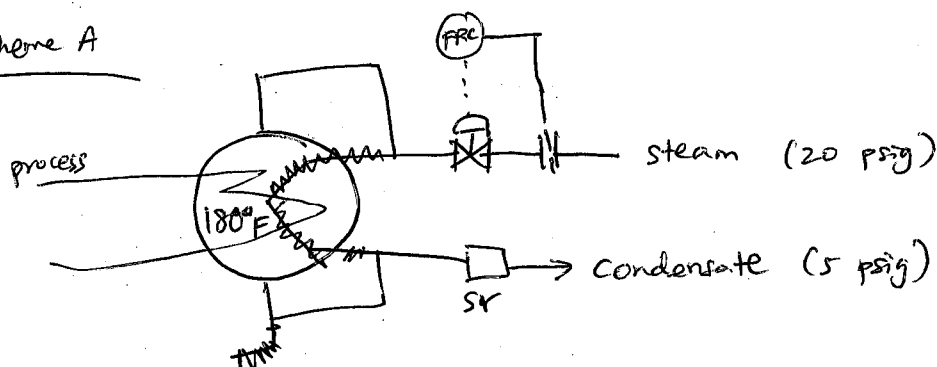
Steam vs. Condensate Control

There is a steam heated exchanger in our process unit that must be operated at both design (100% in the future) and startup (50% when new) of the design duty. We are asked to select whether steam or condensate control provides the best control. Steam is available at 20 psig and condensate must be delivered at 5 psig. The process side is a boiling pure compound at a temperature of 180°F. The heat transfer coefficient for the design case is 84 Btu/hr/ft² and 115 for the 50% operation.

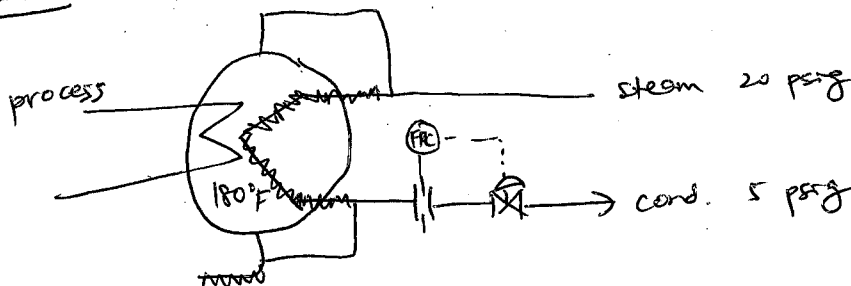
If steam control is used, calculate the steam side pressure that will result for the 50% operation.

For the condensate control case, calculate the volume of the exchanger that is covered by condensate.

Scheme A



Scheme B



ANSWER

BASIS	DESIGN	STARTUP
Thruput, %	100	50
Duty, mmBtu/h	12.8	6.4
Fouling	0.005	0.001
Scheme A – Control Steam		
Temperature, °F		
Steam header	259	259
Exchanger, shell out	228	
Process, in/out	180	180
MTD, °F	48	
Pressure, psia		
Steam header	34.7	34.7
Exchanger shell	20.0	
Exchanger coefficient	84	115
Scheme B – Control Cond		
Temperature, °F		
Steam header	259	259
Exchanger shell	259	259
Pressure, psia		
Steam header	34.7	34.7
Exchanger shell	34.7	34.7
Condensate system	20.0	20.0
Condensate level	0	

Steam vs. Condensate Control

The design basis can be summarized as follows:

BASIS	DESIGN	50%
Thruput, %	100	50
Duty, mmBtu/h	12.8	6.4
U, mmBtu/h/ft ²	84	115

Control Steam Case

Steam Header Temperature, °F Pressure, psia	259 35	259 35
Exchanger Shell Temperature, °F Pressure, psia	228 20	B C
Process side temperature, °F	180	180
MTD, °F	48	A

A. 50% Case MTD

Normal flow MTD

$$\begin{array}{rcl} 228 & \rightarrow & 228 \text{ °F} \\ \underline{180} & \leftarrow & \underline{180} \text{ °F} \\ 48 & & 48 \end{array}$$

$$\text{Area} = \frac{12.6 \text{ mm Btu/h}}{(84)(48)} = 3175 \text{ sq. ft.}$$

$$MTD_{50\%} = \frac{6.4 \text{ mm Btu/h}}{(115)(3175)} = 17.8^\circ \text{F} \quad \text{Say } 18^\circ \text{F}$$

B.

$$\begin{array}{rcl} 198 & \rightarrow & 198 \text{ °F} \\ \underline{180} & \leftarrow & \underline{180} \text{ °F} \\ 18 & & 18 \end{array}$$

- C. Pressure for saturated steam at 198°F is 11 psia from steam table. Therefore, condensate will not flow into the 20 psia header. In fact, condensate will build up in the exchanger until sufficient tubes are covered and the MTD goes back up until the shell side temperature is above the saturation temperature of steam at 20 psia. Collected condensate then rapidly leaves the reboiler, causing sudden increase in heat transfer as tubes are uncovered.

Condensate Control Case

	Design	50%
Steam Header Temperature, °F Pressure, psia	259 35	259 35
Exchanger Shell Temperature, °F Pressure, psia	259 35	259 35
Condensate Level	0	D

- D. Area required for heat transfer can be calculated by ratio:

$$\frac{Q_{50\%}}{Q_{100\%}} = \frac{U_{50} A_{50} MTD_{50}}{U_{100} A_{100} MTD_{100}}$$

$$\frac{A_{50}}{A_{100}} = \left(\frac{Q_{50}}{Q_{100}} \right) \left(\frac{MTD_{100}}{MTD_{50}} \right) \left(\frac{U_{100}}{U_{50}} \right)$$

$$\left(\frac{6.4 \text{ mm Btu/h}}{12.8 \text{ mm Btu/h}} \right) \left(\frac{84}{115} \right) = 0.365$$

This means that the condensate level has increased in the shell until only 36.5% of the total area is exposed to steam. The area covered by the condensate is 63.5% of the total tube bundle area.