PSV Calculation and Philosophy

Role of Pressure Safety Valve (PSV)

PSVs are installed to make sure that

Accumulated Pressure ≤ Maximum Allowable Accumulated Pressure as dictated by applicable code & standard

- **Pressure Vessels** (ASME Sect VIII, API 520 & 521)
- **Unfired Boilers** (ASME Sect I)
- **Piping** (ASME B16.5 and 31.3)

Design Code & Standard (Pressure Vessel)

- ASME Section VIII
- API 520 Sizing, Selection and Installation of Pressure-Relieving Devices in Refineries

Table 1—Set Pressure and Accumulation Limits for Pressure Relief Valves

	Single-Valve Installations		Multiple-Valve Installations	
Contingency	Maximum Set Pressure (percent)	Maximum Accumulated Pressure (percent)	Maximum Set Pressure (percent)	Maximum Accumulated Pressure (percent)
Nonfire Cases				
First valve	100	110	100	116
Additional valve(s)	—	—	105	116
Fire Case				
First valve	100	121	100	121
Additional valve(s)	—	—	105	121
Supplemental valve	—	—	110	121

Note: All values are percentages of the maximum allowable working pressure.

Source : API 520

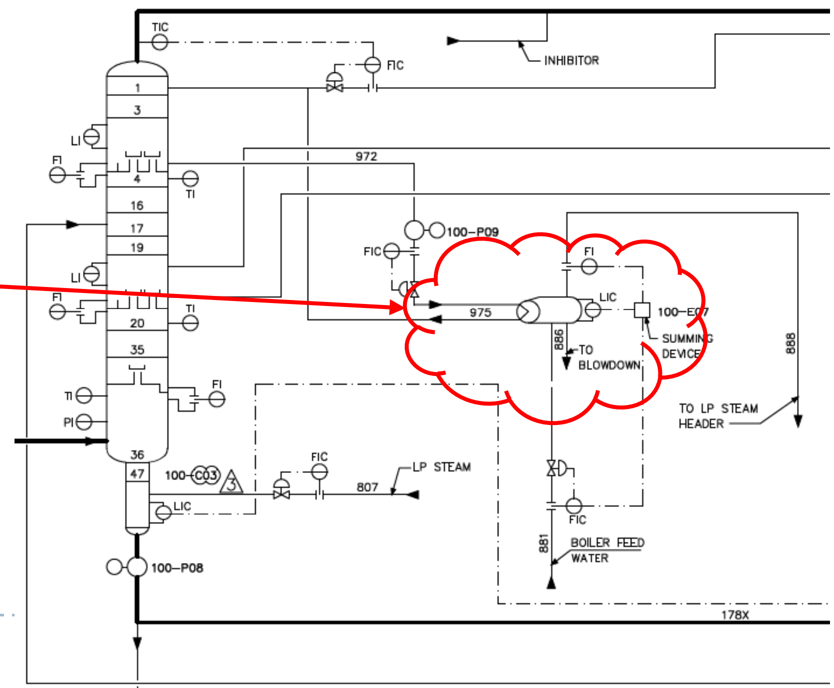
Set pressure = Pressure at which PSV is set to open

Design Code & Standard (Unfired Boiler)

ASME Section I

Contingency	Single-Valve Installations: Maximum Set Pressure (percent)	Single-Valve Installations: Maximum Accumulated Pressure (percent)	Multiple-Valve Installations: Maximum Set Pressure (percent)	Multiple-Valve Installations: Maximum Accumulated Pressure (percent)
First valve	100	106	100	106
Additional valve(s)	—	—	103	106

Kerosene Pumparound
LP Steam Generator



PROCEDURES FOR PSV CALCULATION

LOCATE PSV and SPECIFY RELIEF PRESSURE

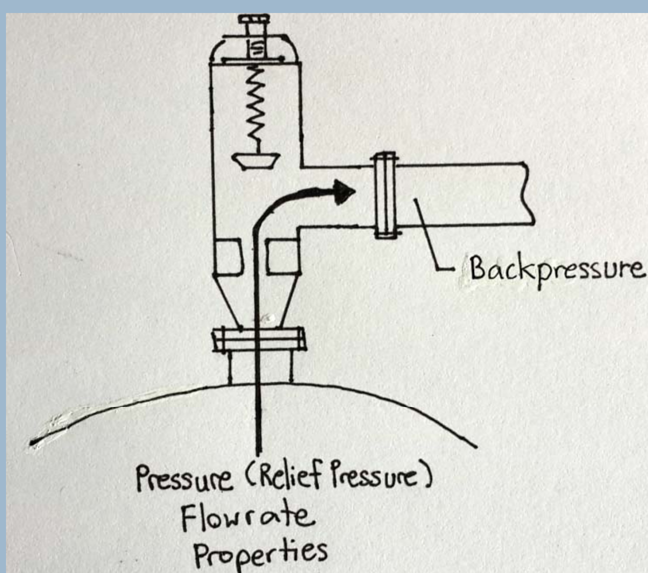
DEVELOP SCENARIOS (WHAT CAN GO WRONG?)

CALCULATE PSV SIZE

CHOOSE WORST CASE

DESIGN OF RELIEF SYSTEM (Flare Header, etc)

Required Information



PSV SCENARIOS (Refer API 521)

FOCUS ON COMMON CASES :

- Closed Outlets on Vessels
- External Fire
- Failure of Automatic Controls
- Hydraulic Expansion
- Heat Exchanger Tube Rupture

- Total Power Failure
- Partial Power Failure
- Cooling Water Failure
- Reflux Loss
- Failure of Air-Cooled Heat X

DOUBLE JEOPARDY NOT CONSIDERED
(Simultaneous occurrence of two or more unrelated causes of overpressure)

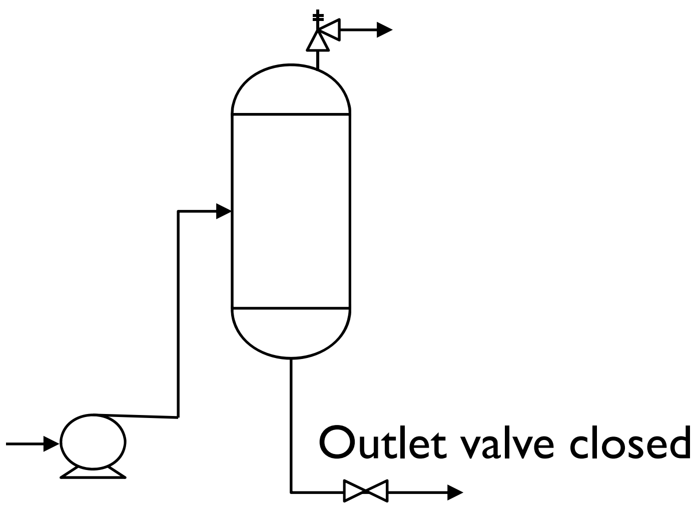
Item No.	Condition	Liquid-relief guidance [a]	Vapour-relief guidance [a]
1	Closed outlets on vessels	Maximum liquid pump-in rate	Total incoming steam and vapour plus that generated therein at relieving conditions
2	Cooling-water failure to condenser	—	Total vapour to condenser at relieving conditions
3	Top-tower reflux failure	—	Total incoming steam and vapour plus that generated therein at relieving conditions less vapour condensed by sidestream reflux
4	Sidestream reflux failure	—	Difference between vapour entering and leaving equipment at relieving conditions
5	Lean-oil failure to absorber	—	None, normally
6	Accumulation of non-condensables	—	Same effect in towers as found for Item 2; in other vessels, same effect as found for Item 1
7	Entrance of highly volatile material	—	—
	Water into hot oil	—	For towers, usually not predictable
	Light hydrocarbons into hot oil	—	For heat exchangers, assume an area twice the internal cross-sectional area of one tube to provide for the vapour generated by the entrance of the volatile fluid due to tube rupture
8	Overfilling storage or surge vessel	Maximum liquid pump-in rate	—
9	Failure of automatic controls	—	Analyse on a case-by-case basis
10	Abnormal heat or vapour input	—	Estimated maximum vapour generation including non-condensables from overheating
11	Split exchanger tube	Liquid entering from twice the cross-sectional area of one tube	Steam or vapour entering from twice the cross-sectional area of one tube; also same effects found in Item 7 for exchangers
12	Internal explosions	—	Not controlled by conventional relief devices but by avoidance of circumstances
13	Chemical reaction	—	Estimated vapour generation from both normal and uncontrolled conditions; consider two-phase effects
14	Hydraulic expansion:		
	Cold-fluid shut in	See 5.14	—
	Lines outside process area shut in	See 5.14	—
15	Exterior fire [b]	See 5.15.3.3	Estimated by the methods given in 5.15.2.2 or 5.15.3.2
16	Power failure (steam, electric, or other)	—	Study the installation to determine the effect of power failure; size the relief valve for the worst condition that can occur
	Fractionators	—	Loss of all pumps, with the result that reflux and cooling water would fail
	Reactors	—	Consider failure of agitation or stirring, quench or retarding stream; size the valves for vapour generation from a runaway reaction
	Air-cooled exchangers	—	Fan failure; size valves for the difference between normal and emergency duty
	Surge vessels	—	Maximum liquid inlet rate

[a] Consideration can be given to the reduction of the relief rate as the result of the relieving pressure being above operating pressure.

[b] Guidance on fire relief is given in Annex A.

Source : API 521

Closed outlets on vessels



Pressure source (pump, compressor, high pressure header)

Cause

Outlet valve is blocked while there is continuous inlet from high pressure source

Effects

Pressure built-up in vessel

Calculation

Can PSV be opened in Closed Outlet Case?
(Is maximum inlet pressure > PSV set pressure?)

For pump :
Is maximum pump shut-off pressure ≥ PSV set pressure?

No → **Relief case not considered**

Yes → **Relief rate = maximum inlet flow**

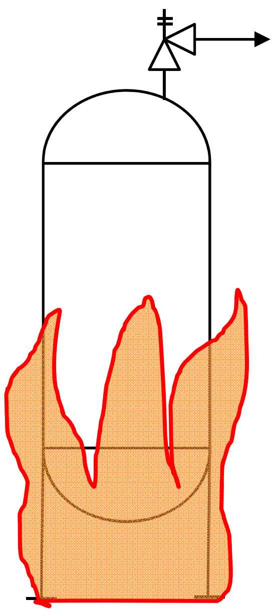
External Fire (1/4)

Cause

External pool fire caused by accumulated hydrocarbon on the ground or other surfaces

Effects

- Vaporization of liquid inside the vessel, leading to pressure building up within the vessel

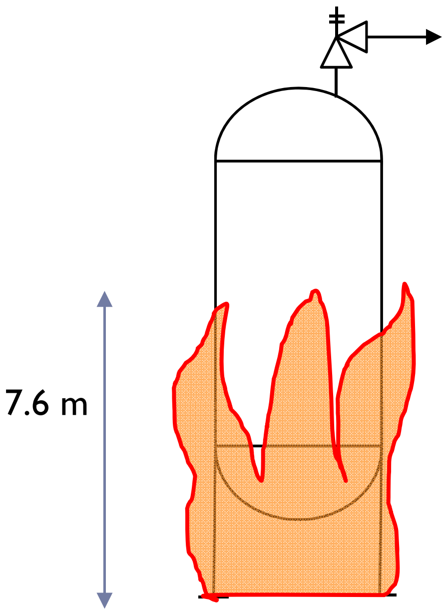


Calculation

Refer next slides

External Fire - Liq. Vessel (2/4)

$$\text{Relief rate (W)} = \frac{\text{Heat absorbed by liquid from external fire (Q)}}{\text{Latent Heat of Vaporization of liquid } (\lambda)}$$



Case 1 :

If adequate drainage necessary to control the spread of major spills from one area to another and to control surface drainage and refinery waste water.

$$Q = 43{,}200 \times F \times A^{0.82}$$

Case 2 :

If adequate drainage and firefighting equipment do not exist.

$$Q = 70{,}900 \times F \times A^{0.82}$$

Q = Heat absorbed by liquid from external fire(W)

F = Environment Factor

A = Wetted Surface Area (m^2)

External Fire - Liq. Vessel (3/4)

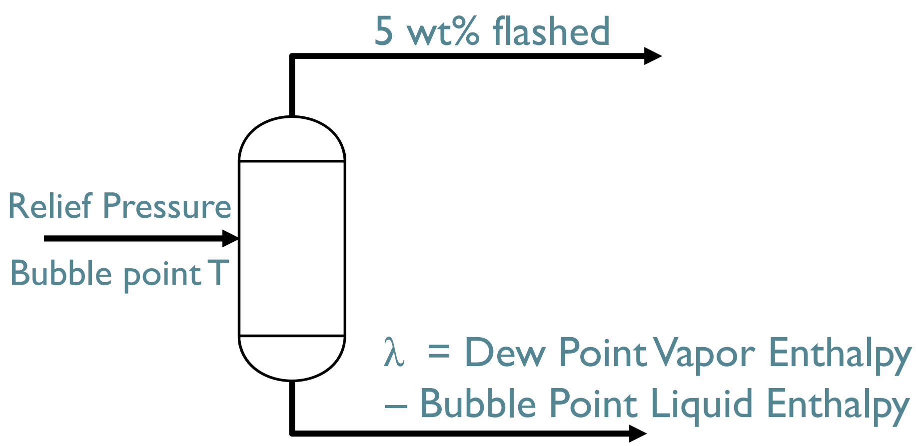
Wetted Surface Area (A)

Class of vessel	Portion of liquid inventory	Remarks
Liquid-full, such as treaters	All up to the height of 7,6 m (25 ft).	—
Surge drums, knockout drums, process vessels	Normal operating level up to the height of 7,6 m (25 ft).	—
Fractionating columns	Normal level in bottom plus liquid hold-up from all trays dumped to the normal level in the column bottom; total wetted surface up to the height of 7,6 m (25 ft).	Level in reboiler is to be included if the reboiler is an integral part of the column.
Working storage	Maximum inventory level up to the height of 7,6 m (25 ft) (portions of the wetted area in contact with foundations or the ground are normally excluded).	For storage tanks and process tanks, see API Std 2000 or prEN 14015.
Spheres and spheroids	Up to the maximum horizontal diameter or up to the height of 7,6 m (25 ft), whichever is greater.	—

Source : API 521

External Fire
Liq. Vessel (4/4)

Latent Heat of Vaporization of liquid (λ) for multi-component mixture



For column, use composition of

1. Second tray from top (or reflux composition if unavailable)
2. Bottoms

Choose one that require larger PSV size

Environment Factor (F)

Type of equipment		Environment factor [a] *F*
Bare vessel		1,0 [c]
Insulated vessel [b], with insulation conductance values for fire exposure conditions in $W/m^2 \cdot K$ ($Btu/h \cdot ft^2 \cdot °F$)	22,71 (4)	0,3
	11,36 (2)	0,15
	5,68 (1)	0,075
	3,80 (0,67)	0,05
	2,84 (0,5)	0,037 6
	2,27 (0,4)	0,03
	1,87 (0,33)	0,026
Water-application facilities, on bare vessel [c]		1,0 [e]
Depressurizing and emptying facilities [d]		1,0 [e]
Earth-covered storage		0,03
Below-grade storage		0,00

NOTE Local instantaneous pool fire heat fluxes as high as 190 kW/m^2 (60 000 $Btu/ft^2 \cdot h$) have been reported. When designing pressure-relief systems, consideration is generally given to the use of time-weighted average fire heat fluxes rather than instantaneous peaks as some time is required for the contents to reach relieving conditions.

[a] These are suggested values for the conditions assumed in 5.15.2. If these conditions do not exist, engineering judgment should be exercised either in selecting a higher factor or in providing means of protecting vessels from fire exposure as suggested in 5.15.4 and 5.15.5.

[b] Insulation should resist being dislodged by firehose streams (5.15.5.2). For the examples, a temperature difference of 871 °C (1 600 °F) was used. These conductance values are computed from Equation (13) and are based upon insulation having thermal conductivity of 0,58 W/m·K (4 $Btu \cdot in/h \cdot ft^2 \cdot °F$) at 538 °C (1 000 °F) and correspond to various thicknesses of insulation between 25,4 mm (1 in) and 304,8 mm (12 inches). See Equation (13) to determine the environment factor, *F*.

[c] See 5.15.4.2.

[d] See 5.15.4.3.

[e] The environment factor, *F*, in Equations (6) and (7) does not apply to uninsulated vessels. The environment factor should be replaced by 1,0 when calculating heat input to uninsulated vessels.

Source : API 521

Failure of Automatic Control (1/3)

Cause

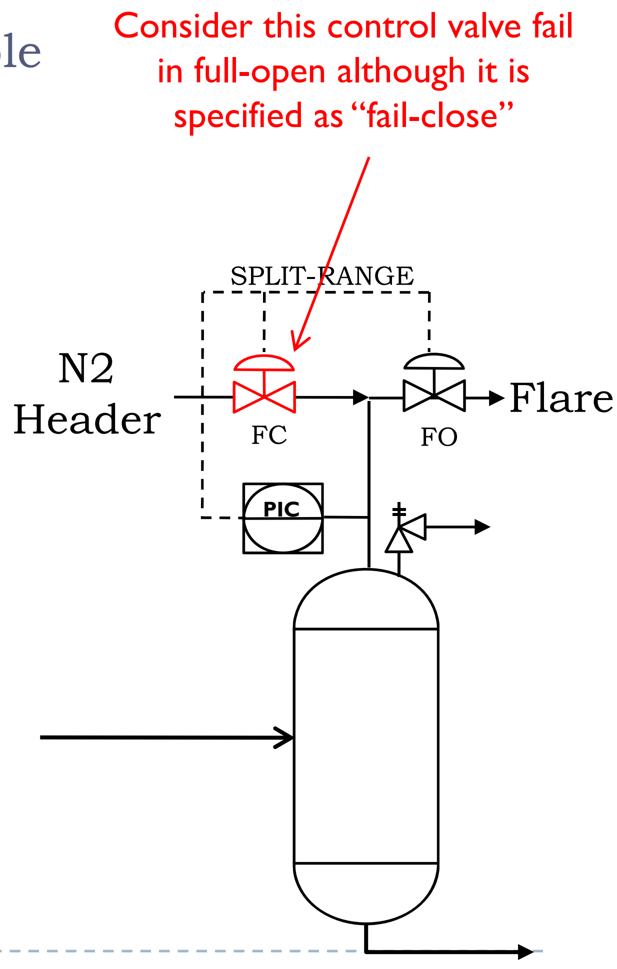
- Failure of a single automatic control valve
- Control valves are assumed to fail to non-favorable position (not necessarily to their specified fail position).

Effects

- Control valve fail open : maximum fluid flow through valve
- Control valve fail close : no fluid flow
- Effect of control valve fail open or close to be considered on case-by-case basis

Calculation

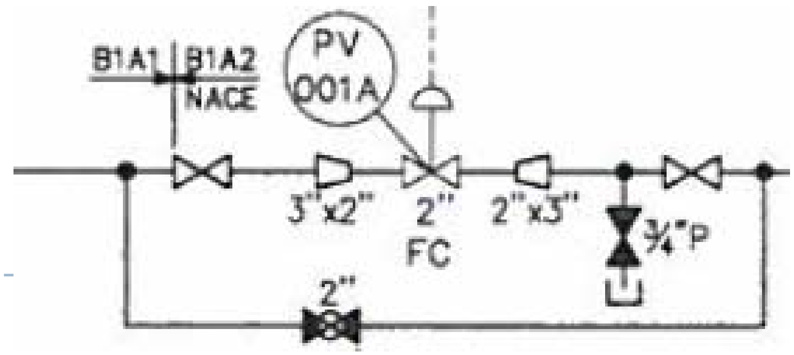
Calculation of maximum fluid flow in control valve fail open case, refer next slide



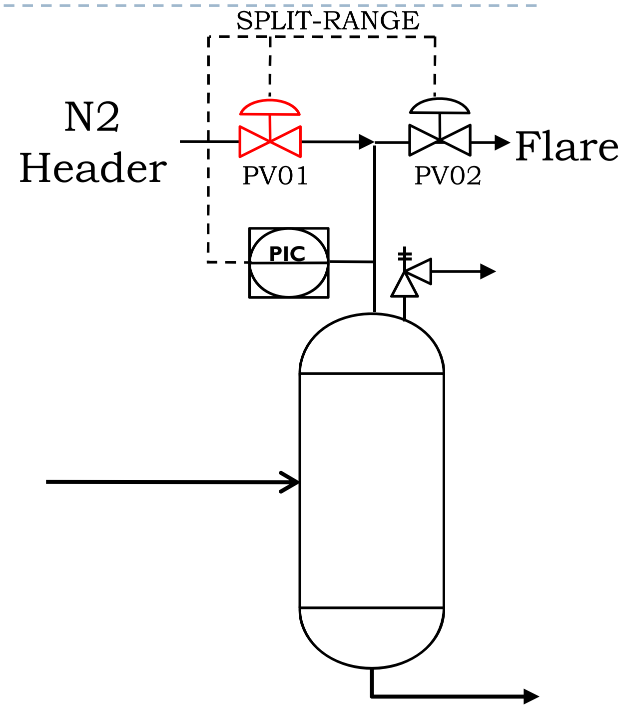
Failure of Automatic Control (2/3)

CALCULATION OF MAX. FLOW THROUGH CONTROL VALVES

1. Find Valve CV value (from manufacturer).
2. If by-pass valve is installed, consider possibility that by-pass valve may be partially open. Add 50% margin to CV value in 1.
3. For Calculate maximum flow through control valve (refer calculation sheet)
4. Find relief rate (to consider on case-by-case basis)



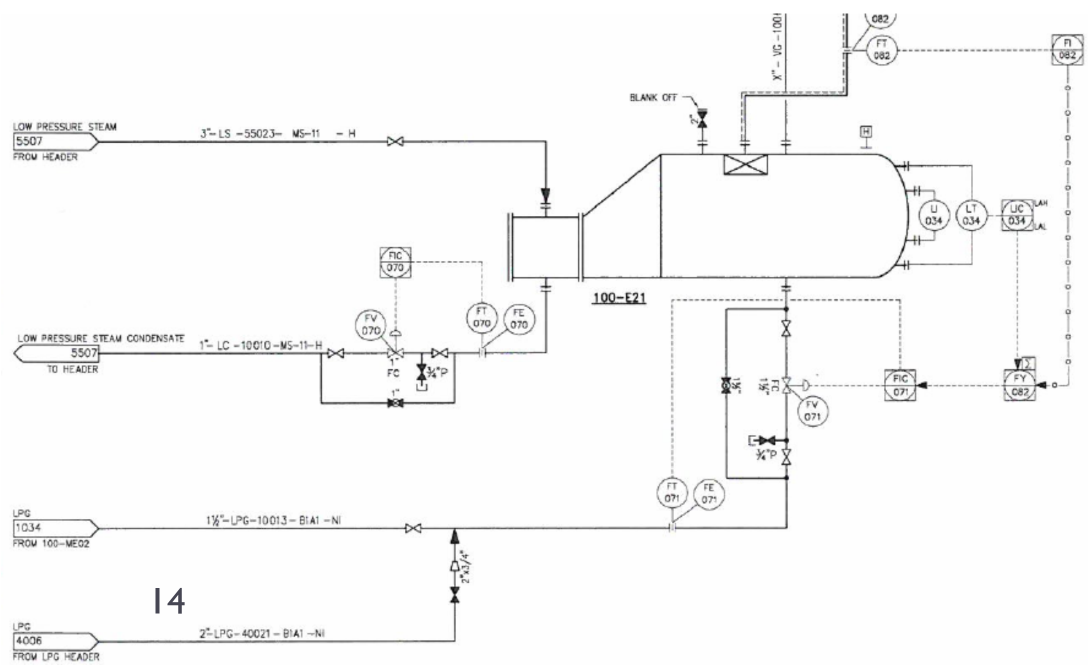
Failure of Automatic Control (1/3)



EXAMPLE :

1. FEED SURGE DRUM

Relief rate = maximum flow through PV01 –
flow through PV02



2. LPG VAPORIZER

Relief rate =
LPG Generated by max. steam flow
– normal LPG outlet flow

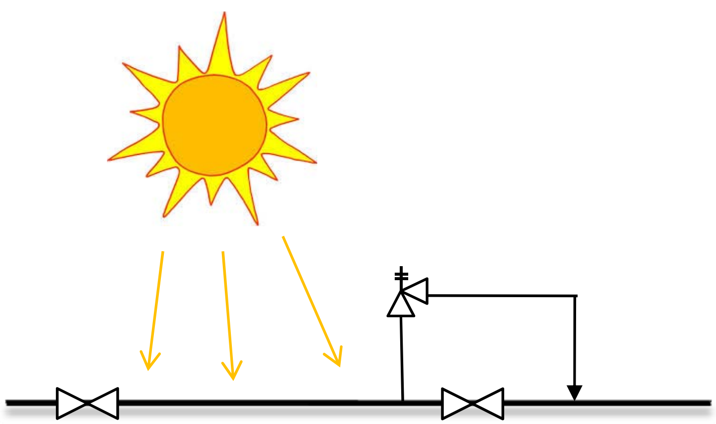
Hydraulic expansion (1/2)

Cause

Liquid is blocked-in and later heated up (by hot fluid, steam tracing / jacket or by solar radiation).

Effects

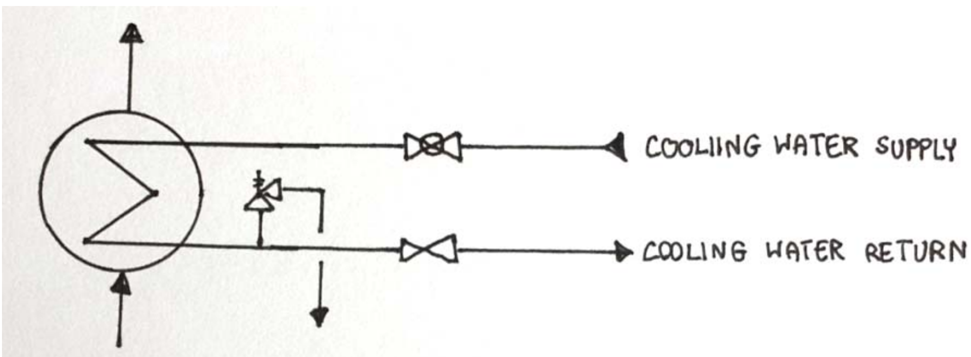
Liquid expands upon heating, leading to pressure build-up in vessel or blocked in section of piping/pipeline.

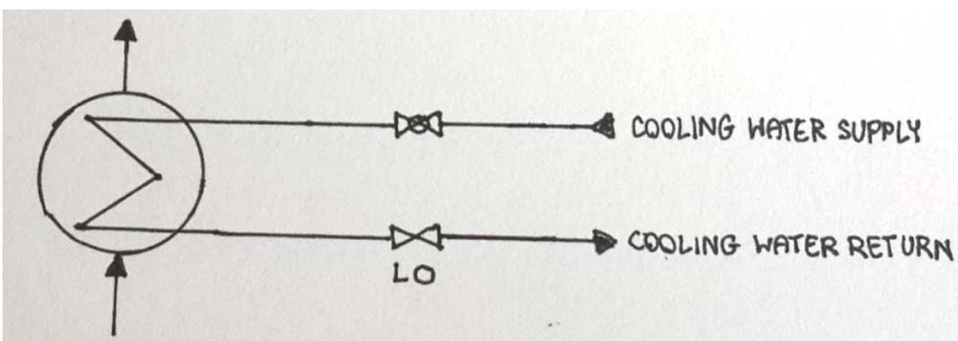


Hydraulic expansion (1/2)

Calculation

Refer calculation sheet for relief rate calculation





If applicable (e.g. in cooling circuit), consider administrative control in place of relief valve.

Heat Exchanger Tube Rupture (1/3)

Cause

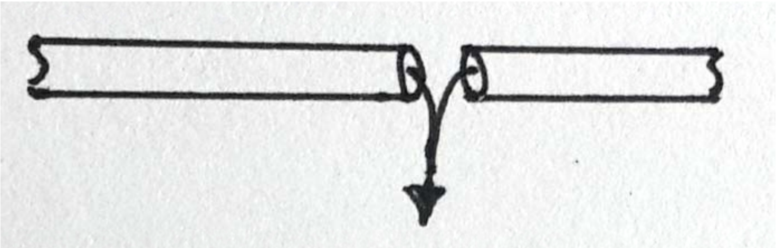
Tube rupture in shell & tube heat exchanger, exposing lower pressure side to high pressure fluid.

Effects

Lower pressure side is exposed to high pressure fluid
Note : No need to consider if design pressure of lower pressure side is 10/13 or more of design pressure of high pressure side.

Calculation

Use orifice equation with double cross-sectional area.



Heat Exchanger Tube Rupture (2/3)

1. Liquid flow and conventional (conservative) equation for vapor flow:

$$W = 0.7\,A\sqrt{2 \times (P_1 - P_2) \times \rho_1} \quad \text{.........................}(Eq.07)$$

2. Critical vapor flow: $P_2 \leqslant 0.5 \times P_1$

$$W = 0.7\,A\sqrt{P_1 \times \rho_1 \times k\left(\frac{2}{k+1}\right)^{\left(\frac{k+1}{k-1}\right)}} \quad \text{............}(Eq.08)$$

W	:	Mass flow rate	kg/s
A	:	1. For STHE: Cross sectional area of one side of ruptured tube **x** 2 2. For PLHE: (**)	m^2
P_1	:	Absolute upstream pressure based on maximum operating pressure	pa a
P_2	:	Absolute downstream pressure (PSV set pressure)	pa a
r	:	P_2 / P_1	-
k	:	Ratio of specific heat, Cp/Cv	-
ρ_1	:	Density at upstream pressure	kg/m^3

Heat Exchanger Tube Rupture (3/3)

3. Non critical vapor flow $W = 0.7 \times 0.685 \times A\sqrt{P_1 \times \rho_1}$

$$W = 0.7 \times Y \times A\sqrt{2(P_1 - P_2)\rho_1} \quad \text{............(Eq.10)}$$

$$Y = \sqrt{r^{\left(\frac{2}{k}\right)}\left(\frac{k}{k-1}\right)\left(\frac{1-r^{\left(\frac{k-1}{k}\right)}}{1-r}\right)}$$

W	:	Mass flow rate	kg/s
A	:	1. For STHE: Cross sectional area of one side of ruptured tube **x** 2 2. For PLHE: (**)	m^2
P_1	:	Absolute upstream pressure based on maximum operating pressure	pa a
P_2	:	Absolute downstream pressure (PSV set pressure)	pa a
r	:	P_2 / P_1	-
k	:	Ratio of specific heat, Cp/Cv	-
ρ_1	:	Density at upstream pressure	kg/m^3

Total Power Failure (1/5)

Cause

Disruption in power supply, leading to electrical power failure of the whole site.

Effects

- Loss of operation for pumps, air-cooled heat exchangers, all electrically-driven equipments
- For Fractionating Column worst case design, assume steam system continues to operate

Calculation

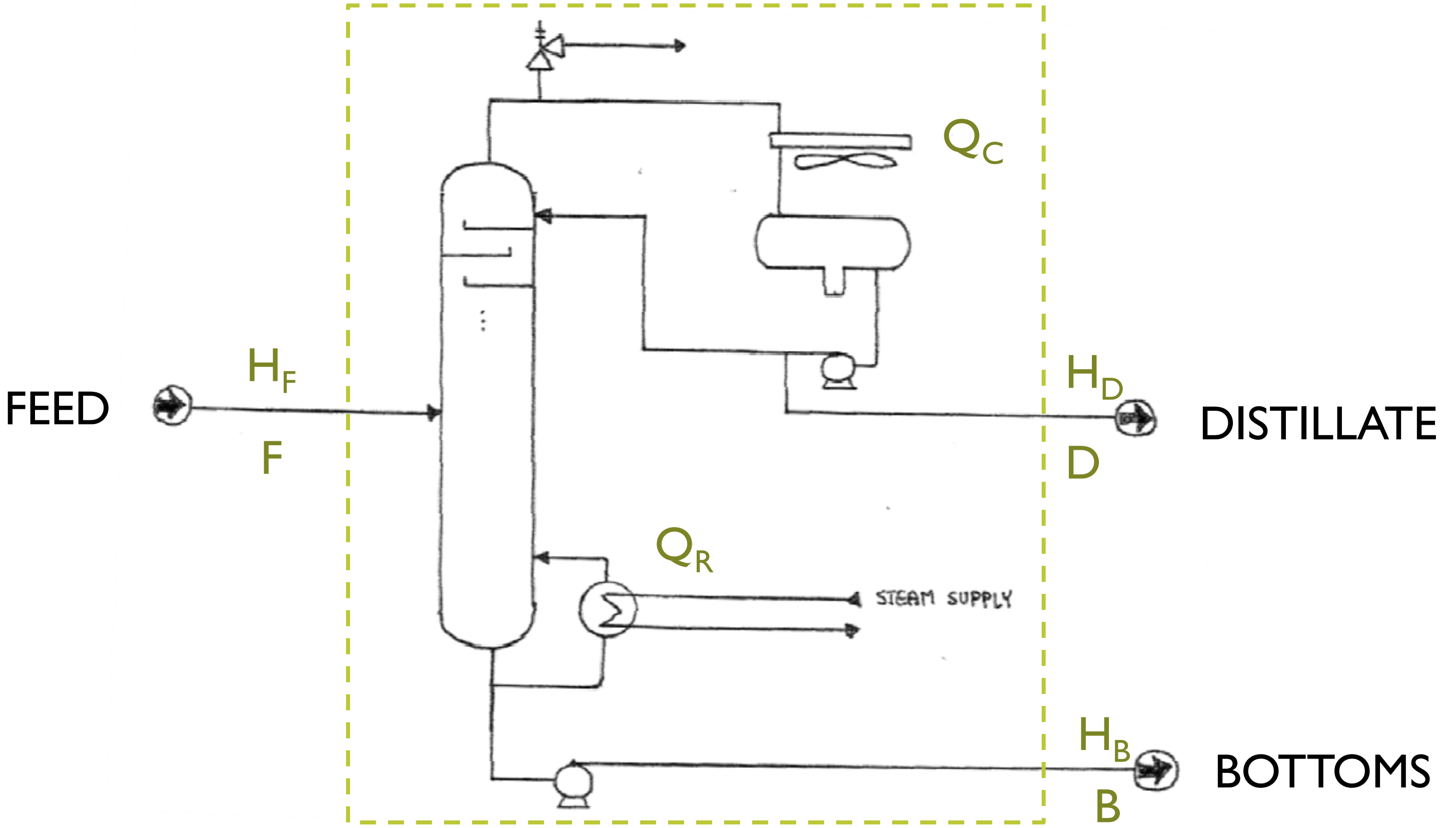
For Fractionation Column : Enthalpy Balance Method

Note

Usually controlling case for flare capacity

Total Power Failure (2/5)

Enthalpy balance around Fractionator Column to find excess heat (Q), which would cause vapor generation.



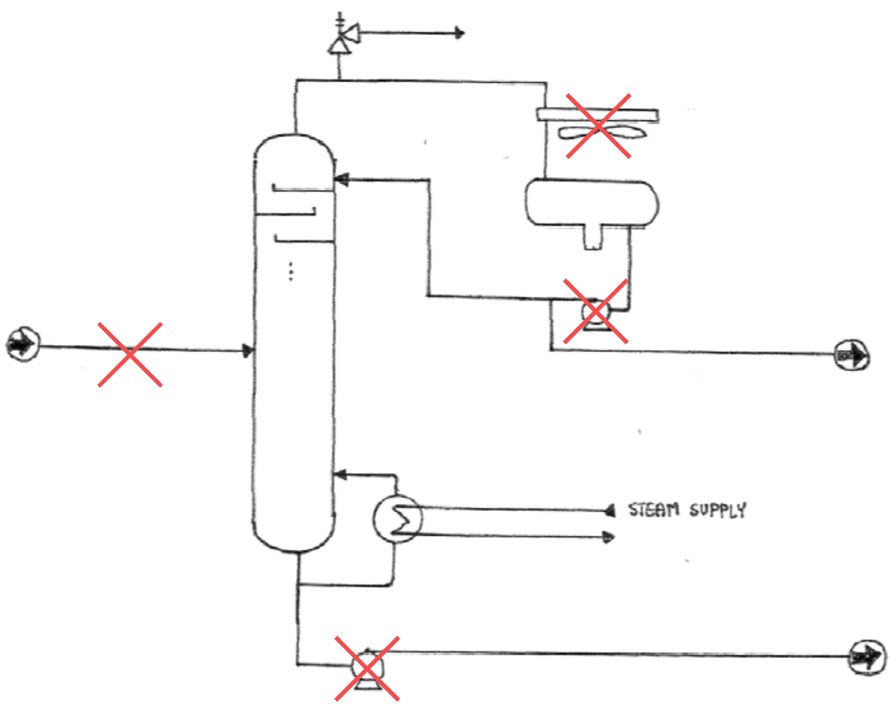
$$\text{Excess Heat (Q)} = H_F F - H_D D - H_B B - Q_C + Q_R$$

- Note : All values are taken from relieving condition

Total Power Failure (3/5)

Excess Heat (Q) $= H_F\cancel{F} - H_D\cancel{D} - H_B\cancel{B} - Q_C + Q_R$

All pumps stop → loss of feed, distillate and bottoms



Condenser Duty (Q_C)

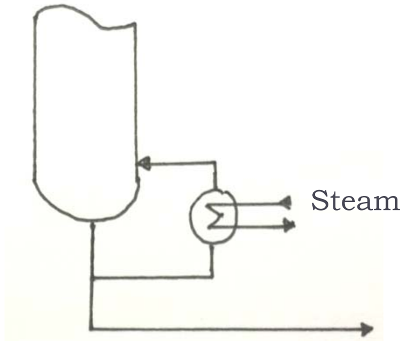
1. Water-cooled (Q_C = 0)
2. Air-cooled

May consider credit for natural draft effects (20-30% of normal duty)

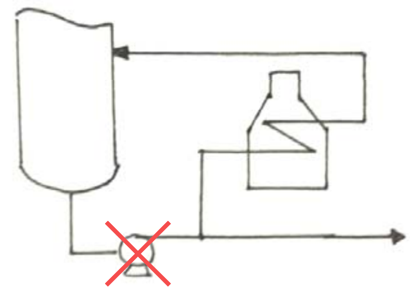
Total Power Failure (4/5)

Reboiler Duty (Q_R)

1. Thermosyphon using steam
   (Q_R = Normal Duty)

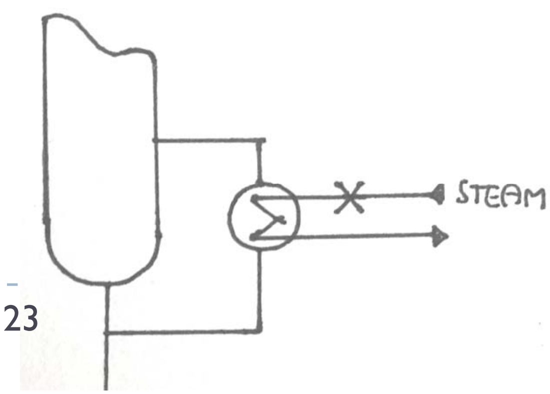


2. Fired Heater
   No flow to fired heater, but consider the possibility that remaining fluid inside tube is heated up by heat from refractory surfaces
   (Q_R = 30% of normal duty)

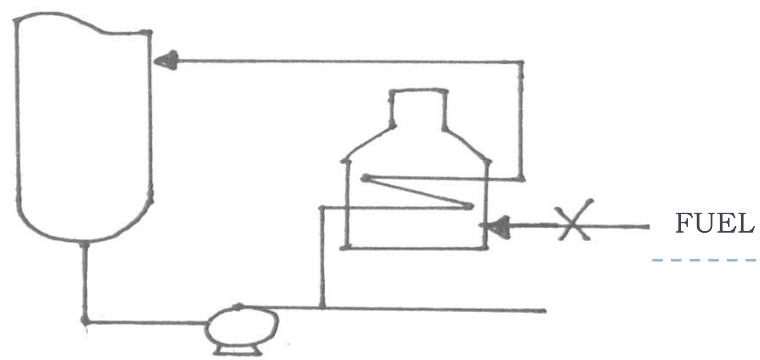


High Integrity Pressure Protection System (HIPPS)

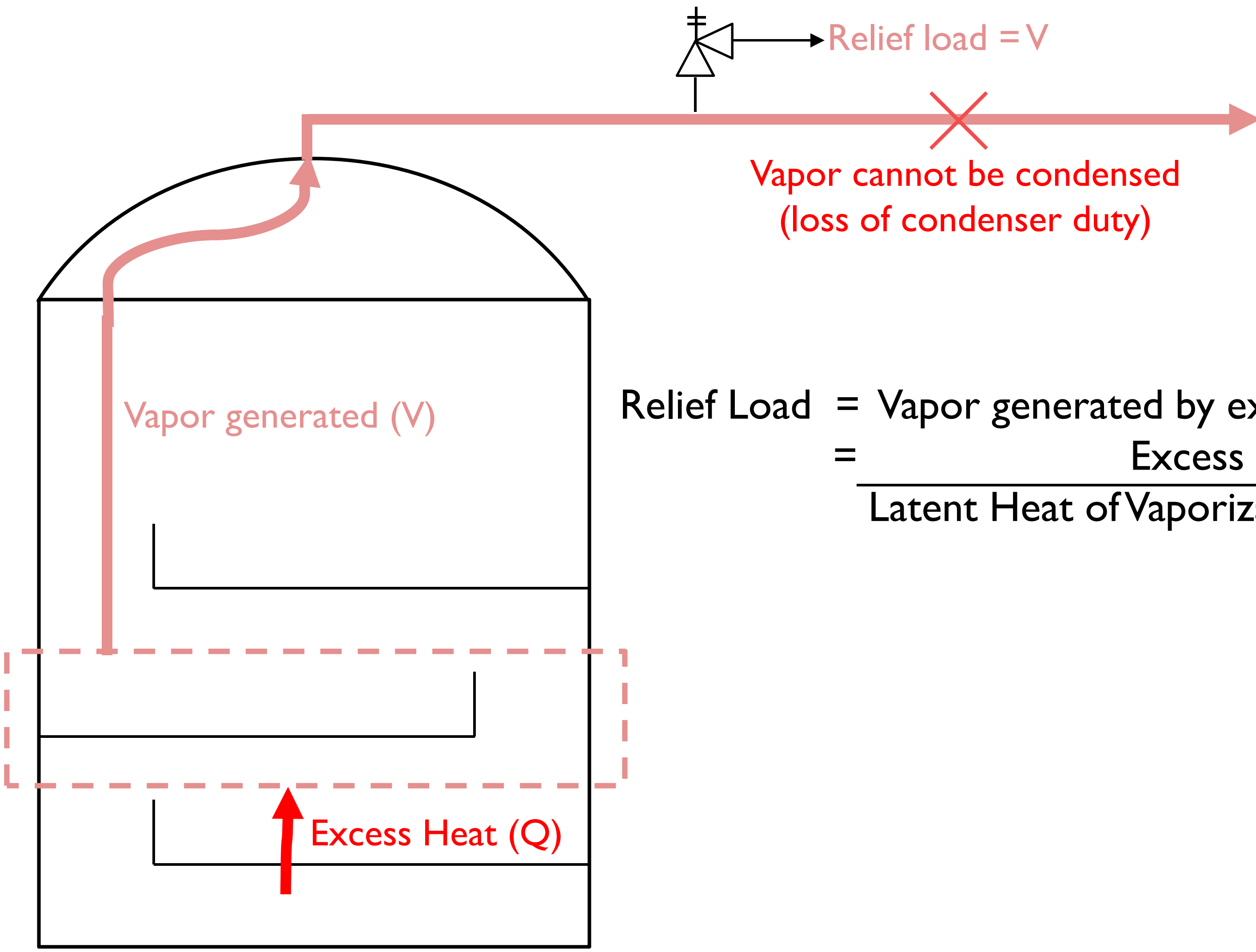
1. Thermosyphon using steam
   (Q_R = 0)



2. Fired Heater
   Heat from refractory surfaces
   (Q_R = 30% of normal duty)



Total Power Failure (5/5)



$$\text{Relief Load} = \text{Vapor generated by excess heat} = \frac{\text{Excess Heat (Q)}}{\text{Latent Heat of Vaporization of } 2^{nd} \text{ tray liquid}}$$

Partial Power Failure (1/3)

Cause

Disruption in a single feeder, bus, circuit or line, leading to partial power failure

Effects

- Varies, pending on power distribution system
- For Fractionating Column, worst case considered for Partial Power Failure is simultaneous loss of reflux pump and air-cooled condenser, while there is continuous heat input into column.

Calculation

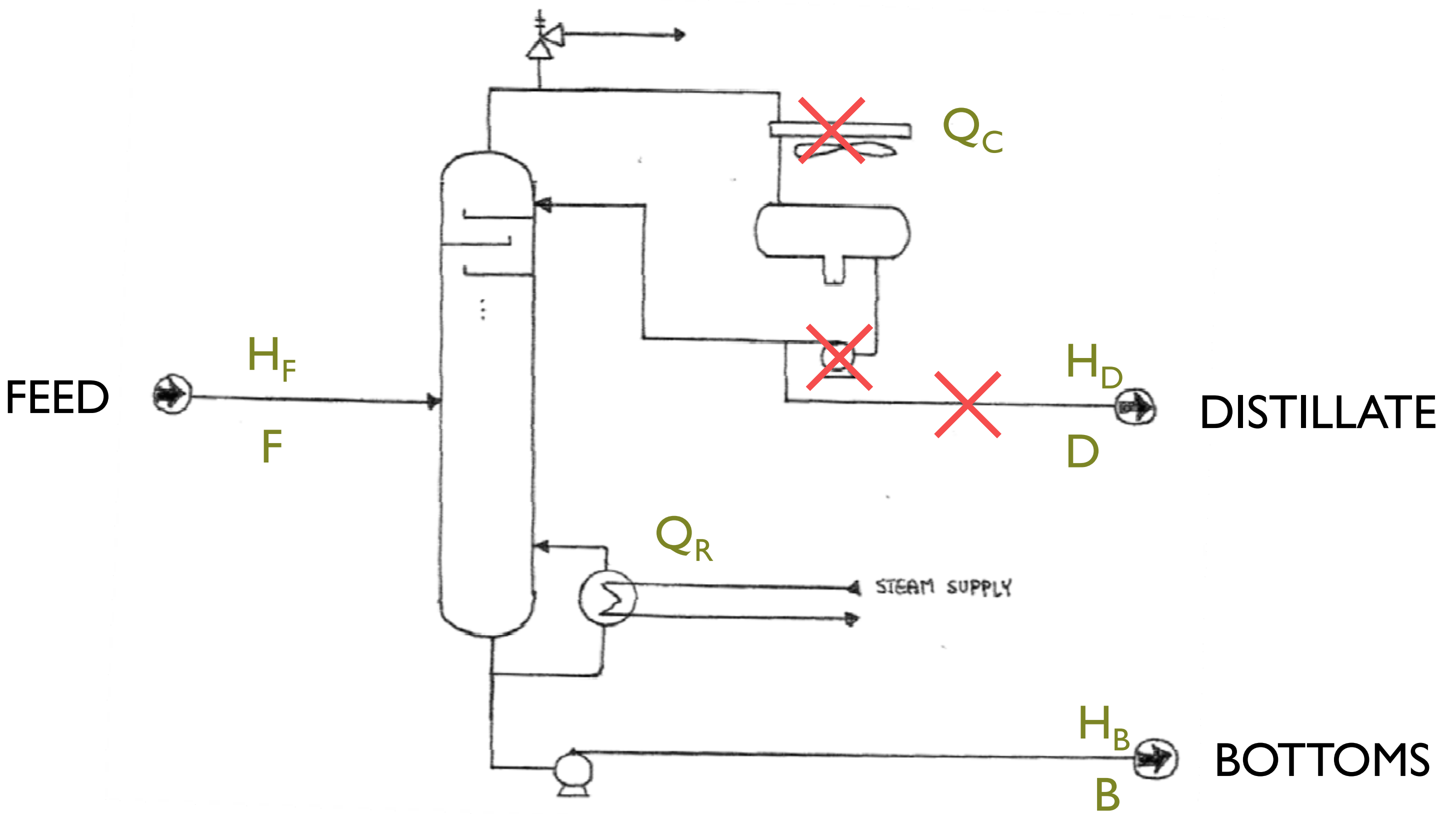
For Fractionating Column : Enthalpy Balance Method
Internal Reflux Method (alternative)

Note

Usually controlling case for column PSV sizing

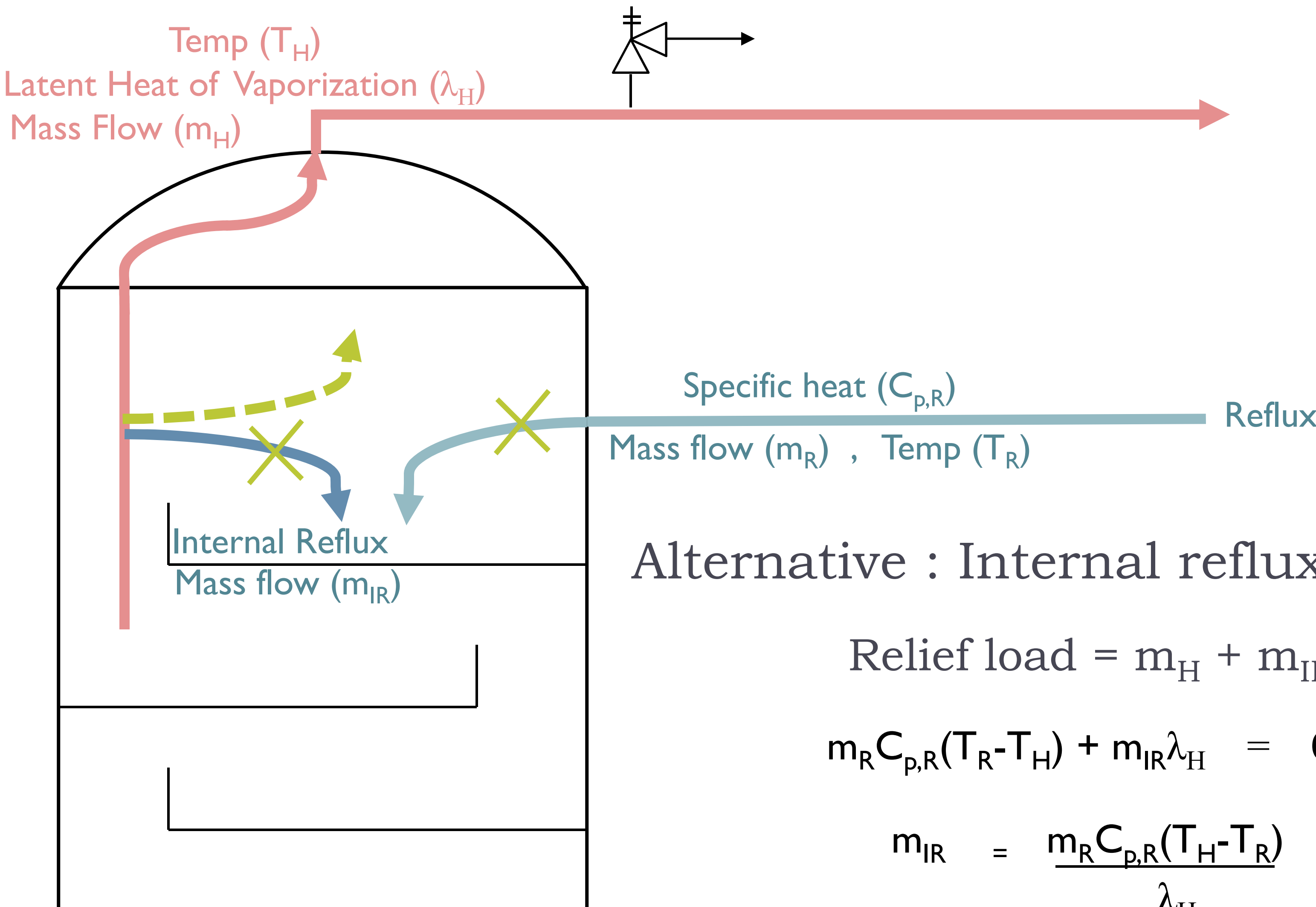
Partial Power Failure (2/3)

Worst case : simultaneous loss of reflux pump and air-cooled condenser



$$\text{Excess Heat (Q)} = H_F F - H_D \cancel{D} - H_B B - Q_C + Q_R$$

Partial Power Failure (3/3)



Alternative : Internal reflux method

$$\text{Relief load} = m_H + m_{IR}$$

$$m_R C_{p,R}(T_R - T_H) + m_{IR}\lambda_H = 0$$

$$m_{IR} = \frac{m_R C_{p,R}(T_H - T_R)}{\lambda_H}$$

Cooling Water Failure (1/3)

Cause

Cooling Water Pump failure, loss of make-up water, etc.

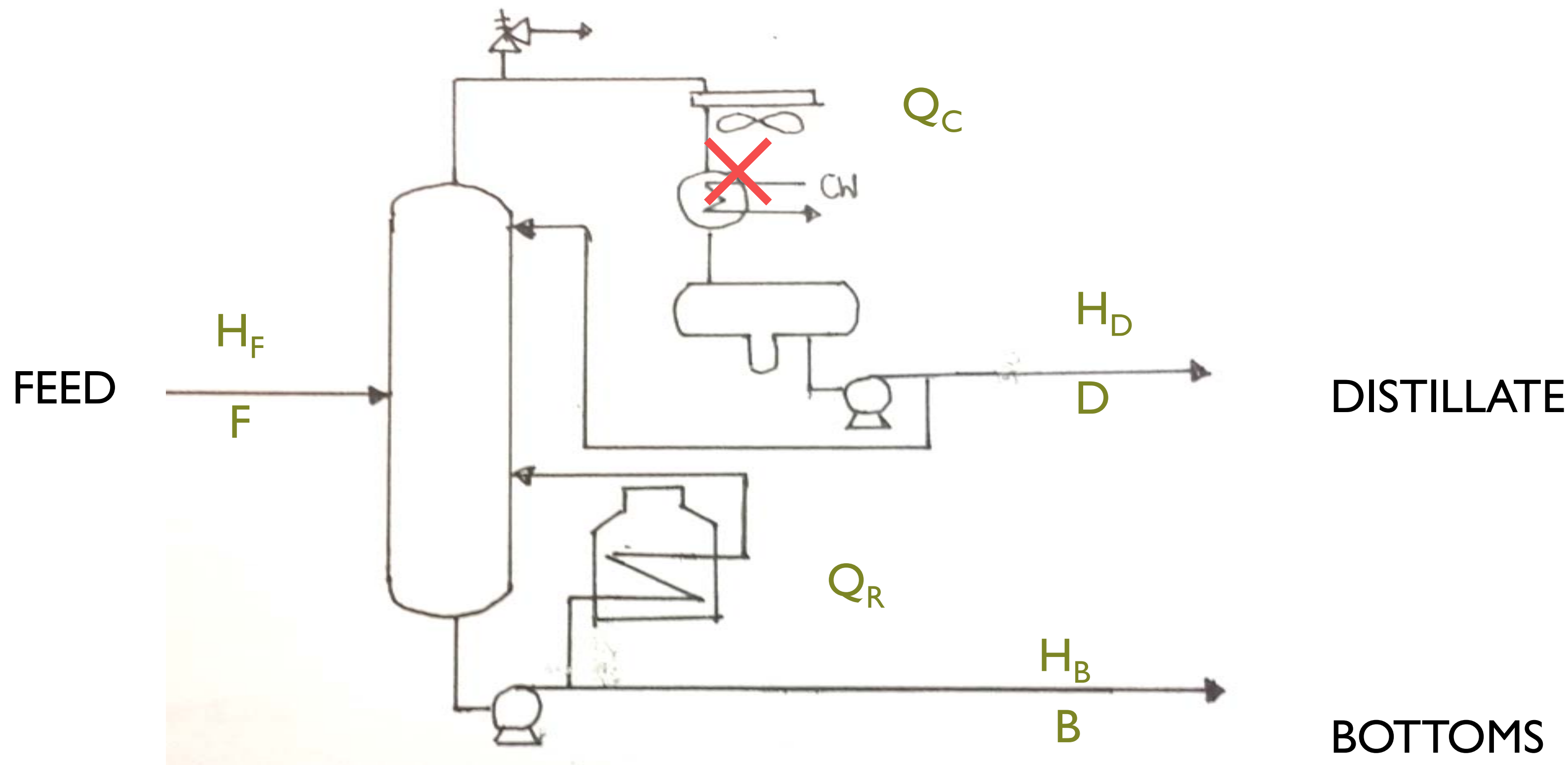
Effects

- Loss of duty for water-cooled heat exchangers
- Operation of pumps that require cooling water for lube oil cooling may also be effected

Calculation

For Fractionating Column : Enthalpy Balance Method
Internal Reflux Method (Alternative)

Cooling Water Failure (2/3)

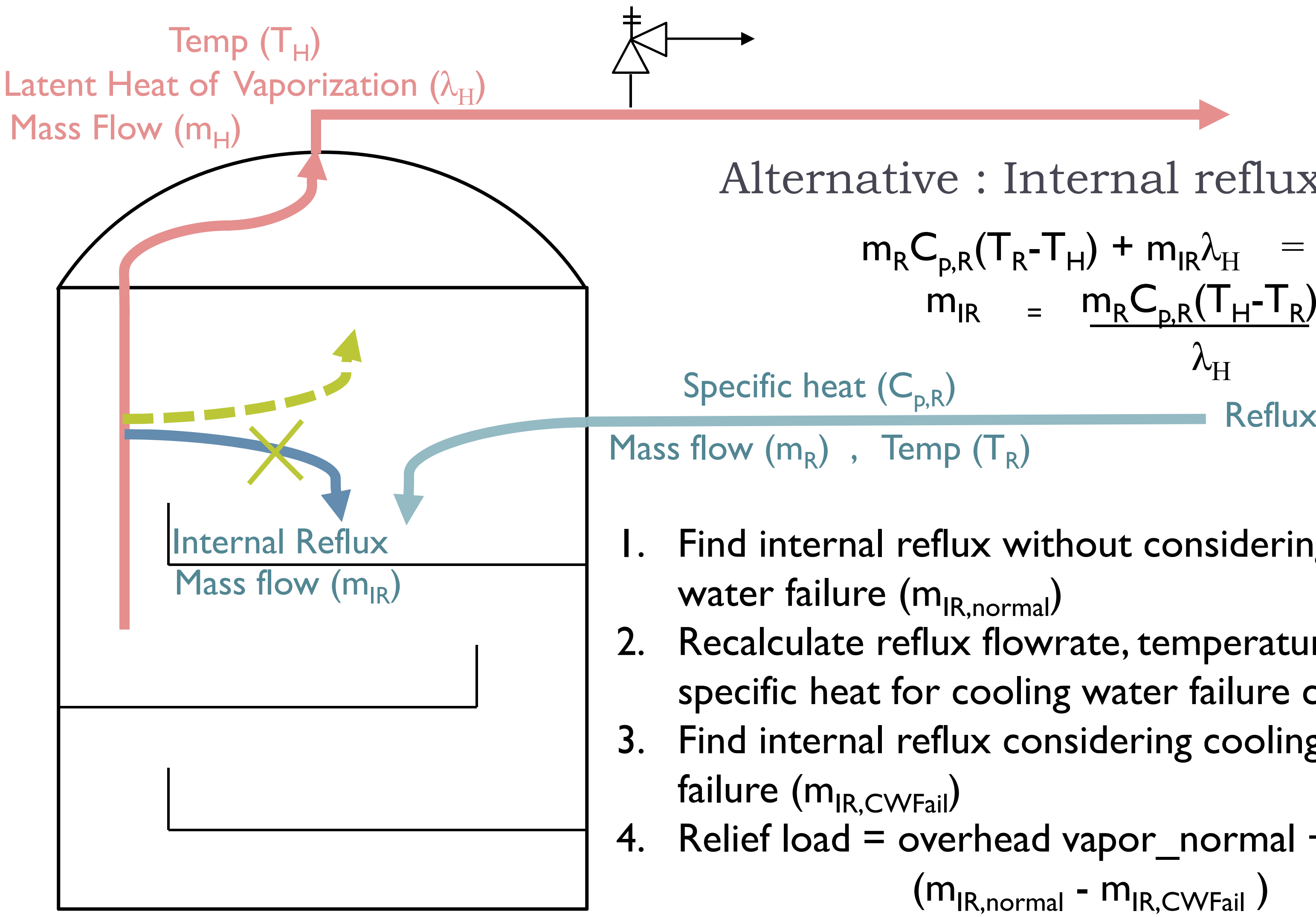


Excess Heat (Q) $= H_F F - H_D D - H_B B - Q_C + Q_R$

Note : Need to recalculate D and H_D

<u>Alternative</u> : Internal Reflux Method (refer Partial Power Failure case with re-calculated reflux temp, flowrate and specific heat)

Cooling Water Failure (3/3)



Alternative : Internal reflux method

$$m_R C_{p,R}(T_R - T_H) + m_{IR}\lambda_H = 0$$

$$m_{IR} = \frac{m_R C_{p,R}(T_H - T_R)}{\lambda_H}$$

1. Find internal reflux without considering cooling water failure ($m_{IR,normal}$)
2. Recalculate reflux flowrate, temperature and specific heat for cooling water failure case
3. Find internal reflux considering cooling water failure ($m_{IR,CWFail}$)
4. Relief load = overhead vapor_normal + ($m_{IR,normal}$ - $m_{IR,CWFail}$)

Reflux Loss(1/2)

Cause

Failure of reflux pumps

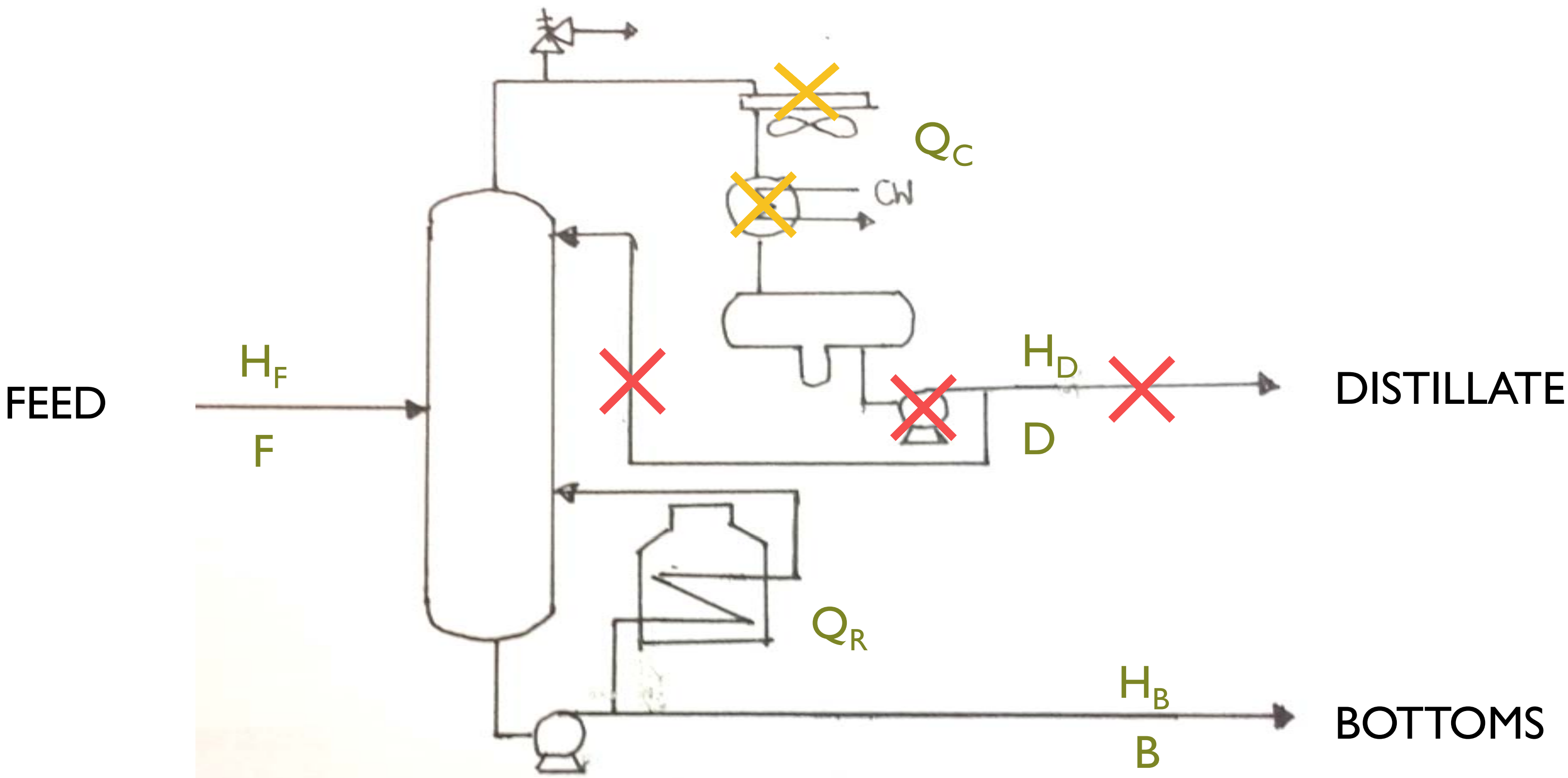
Effects

- Loss of reflux to column
- Liquid level in overhead receiver rises, ultimately flooding the condenser, causing loss of condensing duty

Calculation

For Fractionating Column : Enthalpy Balance Method
Alternative : Internal Reflux Method

Reflux Loss (2/2)



$$\text{Excess Heat (Q)} = H_F F - H_D \cancel{D} - H_B B - Q_C + Q_R$$

Alternative : Internal Reflux Method (refer Partial Power Failure case)

Failure of air-cooled heat exchanger (1/2)

Cause

Failure of individual air-cooled heat exchanger

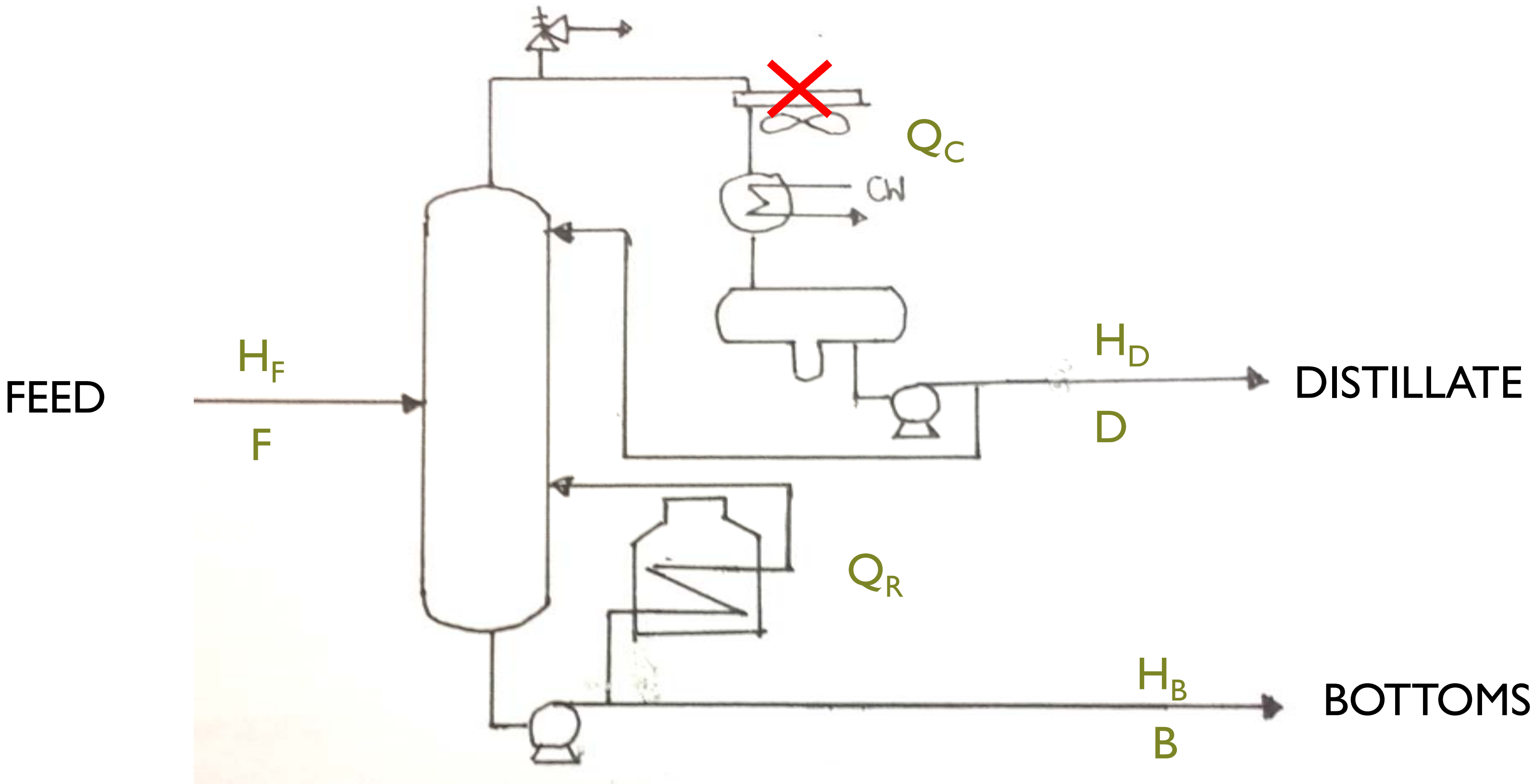
Effects

- Loss of condensing duty in fractionating column

Calculation

For Fractionating Column : Enthalpy Balance Method
Internal Reflux Method (Alternative)

Failure of air-cooled heat exchanger (2/2)



Excess Heat (Q) = $H_F F - H_D D - H_B B - Q_C + Q_R$

Note : Need to recalculate D and H_D

<u>Alternative</u> : Internal Reflux Method (refer cooling water failure case)

THANK YOU

February 3, 2014