Simple Hydraulic Rule, Wide Application Range

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Introduction

We all have done the hydraulic calculation of connected vessels on the third or may be fourth semester in the university. The first time I faced some difficulties in using this principle in my job, I realized that how applying such a simple concept can be troublesome in reality especially when you are not given enough time to remember, put it into practice and produce a deliverable with an acceptable quality.

I made reference to the university textbook (which is not always easy), checked the calculations produced from the previous stage of the project and found out that the system had not been correctly designed. A mutli-million dollar process equipment was not going to work as it was expected because small details were overlooked!

This notes reviews the basic fundamentals of hydraulic of connected vessels and studies two possible arrangements for a column with the kettle reboiler as a typical application where this rule is applied.

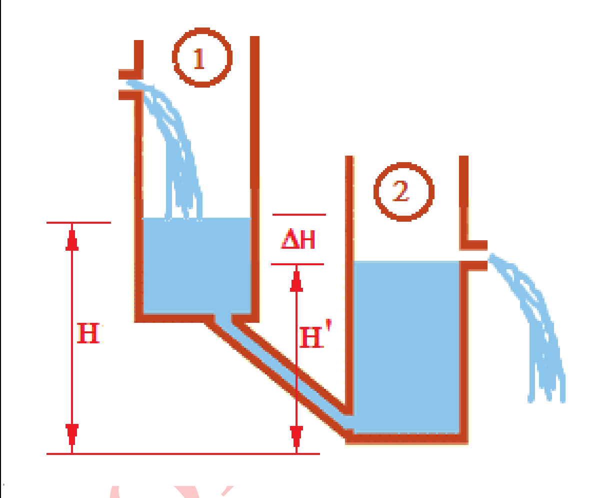

Figure 1 – Typical Liquid Circuit

Hydraulic Rules

Figure 1 shows a typical system in steady state condition where the incoming and outgoing liquid flows are identical, the liquid levels are constant (or slightly level fluctuating) and the fluid velocity in vessels' body is negligible so that there is no frictional pressure drop in the vessels. For such system, the following rules are applicable:

- **Static Head**

The pressure due to static head increases as you move downward and decreases when you go upward. For example in Figure 1, pressure at bottom of vessel-1 is equal to gas pressure at the surface of liquid (P_{V-1}) PLUS the static pressure of liquid column in vessel-1.

Pressure at the surface of liquid in vessel-2 is equal to the pressure at the bottom of vessel-2 MINUS the static pressure of liquid column in that vessel.

- **Frictional Loss Head**

For the section of the system where liquid is flowing, the pressure of fluid decreases as you move in the direction of flow and increases when you move opposite to the flow direction. The amount of pressure change is corresponding to the frictional pressure drop of line.

Abbreviation	
d	Pipe diameter
g	Gravity acceleration
H	Static height
P	Pressure
ΔP	Pressure drop
ρ	Density
Subscript	
1, 2, 3	Pipe number
C	Column (below bottom tray)
L	Liquid
G	Gas
R	Reboiler

For example in Figure 1 where liquid is flowing from vessel-1 to vessel-2, the pressure at the bottom of vessel-2 is equal to the gas pressure at the surface of liquid in vessel-1(P_{V-1}) PLUS the static pressure corresponding to the liquid column (H) (as you move downward) MINUS the frictional pressure drop of the interconnecting pipe (as you move in the direction of flow).

- **Reference Level**

Reference line for static head calculation can be any level however selecting a proper reference line can significantly simplify the calculation. One of the most convenient reference lines is the ground level because the equipment elevations are usually specified from the ground. On the other hand, sometime using another reference line than ground level can be more suitable. For example, if the liquid level in the vessel-2 is taken as a reference line, the static head difference between vessel-1 and vessel-2 is corresponding to ΔH as the static head of remaining liquid in vessel-1 cancels out the effect of identical liquid column in vessel-2.

- **Rules in Practice**

Applying the above mentioned hydraulic rules on the liquid circuit is always the best approach to specify the loop. For example, the process system shown in Figure 1 can be represented with the following equations:

$P_{V\text{-}1} + \rho_L\, g\, H - \Delta P_{\text{frictional of interconnecting pipe}} - \rho_L\, g\, H' = P_{V\text{-}2}$ (when reference line is the bottom of vessel-2)

A typical application is the degassing vessel upstream of an atmospheric storage tank where the vessel elevation is determined using the same approach. Another example is the kettle reboiler where the height of bottom section of the column and the elevation of equipment are specified based on a similar calculation.

Case Study

CASE A: Figure 2 depicts one the possible arrangements for the bottom of column equipped with a kettle reboiler in which liquid to reboiler is supplied from the column sump, passes through the tube side of the reboiler where the light components are vaporized and heavy components flows over the reboiler weir as the final product. The gas is then sent to below the column bottom tray via vapor return line.

Reboiler Elevation from Ground: The elevation of reboiler bottom line from ground is specified based on the process requirement. For example, NPSH requirement of pump if the bottom product is pumped out or piping requirements if there is no pump.

NLL Setting: In this configuration, the column product can be taken from the reboiler where the normal liquid level (NLL) is maintained via a control system. On the other hand, the NLL inside the column is set by the reboiler circuit hydraulic described below.

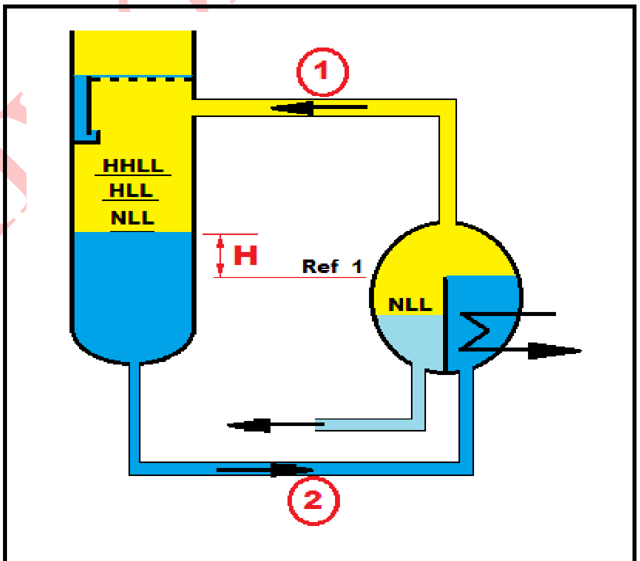

Figure 2 – Bottom Draw off Configuration

Circulation Differential Head: To ensure that there is enough differential head to drive the liquid in the reboiler circuit, the minimum elevation difference between column NLL and top of the reboiler weir (H) is specified based on the following relation. The weir height is set based on heat exchanger thermal rating calculations.

$P_C + \rho_L\, g\, H - \Delta P_2 - \Delta P_R - \rho_G\, g\, H - \Delta P_1 = P_C$ (Where top of the reboiler weir is the reference line)

Column Elevation from Ground: The column Tangent Line (TL) elevation from ground is calculated by use of the following relation:

Column elevation from ground = Reboiler elevation from ground + reboiler weir height + H - the elevation difference between column NLL and TL based on the project philosophy for the liquid hold up time inside the column

If the elevation of column TL from ground from this equation is turned out to be less than what piping department need to accommodate piping underneath the column (typically 2000mm to 2500mm), you need to increase the reboiler elevation from ground to meet the piping requirement.

Vapor Return Nozzle Elevation from Ground: Since column and reboiler elevations have been fixed in the previous stages, an additional check is required to ensure that the bottom section of column has been designed to accommodate the vapor return piping from the reboiler outlet nozzle to the column. Therefore, considering the reboiler diameter and vapor return line routing, the elevation of vapor return nozzle from ground should be at least equal to reboiler elevation + reboiler diameter + 3 times of vapor return line diameter. Factor 3 is just a rule of thumb for a relatively short and straight pipe with one 90° long radius elbow. However, the actual height of vapor return pipe can be higher depending on its routing (check with piping engineers even if they can offer a preliminary piping route).

This is important because accommodating the vapor return line may govern the length of bottom section on column between HHLL and the bottom tray as there is usually a typical requirement is to keep minimum one tray spacing between top of this nozzle and bottom tray.

CASE B: Figure 3 shows the other possible arrangement for the bottom of column equipped with a kettle reboiler in which the liquid is taken from the draw off tray, passes through the reboiler shell side where the light components are vaporized and heavy components overflows over the reboiler weir. The gas and liquid are then returned to the column via two separate lines.

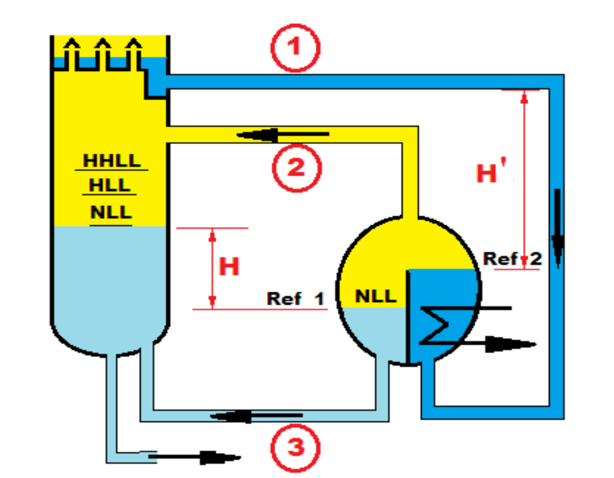

Figure 3 – Side Draw off Configuration

Column Elevation from Ground: In this configuration, the column product is taken from the column sump, therefore the column tangent line elevation from ground is determined based on the process requirement. For example, NPSH requirement of pump if the bottom product is pumped out or piping requirements if there is no pump.

NLL Setting: The liquid levels inside the column are set based on the project philosophy for liquid hold up time between different levels and the normal liquid level (NLL) is maintained via a control system.

The NLL inside the reboiler is set by the reboiler circuit hydraulic and according to the following relation:

$P_C + \Delta P_2 + \rho_G\, g\, H - \Delta P_3 - \rho_L\, g\, H = P_C$ (Where reboiler NLL is the reference line)

Reboiler Elevation from Ground: The reboiler elevation from ground can be calculated based on the selected NLL in the reboiler (which is typically 50% of weir height obtained from the reboiler thermal rating calculations) and by use of the following relation:

Reboiler elevation from ground = column TL elevation from ground + the elevation difference between column NLL and TL based on the project philosophy for the liquid hold up time inside the column – H - 50% of reboiler weir height

If the elevation of reboiler from ground from this equation is turned out to be less than what piping department need to accommodate piping underneath the reboiler (typically 2000mm to 2500mm), you need to increase the column elevation from ground to meet the piping requirement.

Circulation Differential Head: To ensure that there is enough differential head to drive the liquid in the reboiler circuit, the minimum height of liquid draw off nozzle is specified based on the following relation:

$P_C + \rho_L\, g\, H' - \Delta P_1 - \Delta P_R - \rho_G\, g\, H' - \Delta P_2 = P_C$ (Where top of the reboiler weir is the reference line)

Vapor Return Nozzle Elevation from Ground: see above

Contact

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