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Effect of Downcomers Sizes on Tray Column Performance

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The performance of industrial plants such as petroleum refineries, gas processing installations, etc. depends to a large extent on the operation of distillation columns which are considered as one of the most critical components, since they have a direct influence on the quality of the product.

The present work is mainly concerned with the performance of tray columns as well as the investigation of the effect of design parameters on their operation, focusing on downcomers which are very important elements in plate columns, because they ensure the passage of the liquid from one plate to the other as well as the degasification of the liquid in order to reduce the vapor entrainment. In fact a poor downcomer design may lead to flooding and hence a low performance of the column. Therefore it is proposed to study the effect of downcomers sizes on columns performance, finding the optimal dimensions which will ensure a satisfactory operation of the column.

First, the HYSYS software was used with actual data collected from a local refinery and concerning distillation columns, to obtain flowrate profiles, physical properties and compositions according to plates. The obtained results were used as input data for a Mathcad program elaborated to calculate values of certain parameters such as liquid residence time in downcomers, flooding, entrainment, weeping, liquid velocity, liquid load, and pressure drop, making it possible to control the downcomer operation. The obtained results for each plate were used to quantify and locate the problem in order to adapt an optimal solution. The developed program can be used for the control of similar plate columns, introducing just the operating conditions and real dimensions of the considered column.

1. Introduction

In a given separation, the plate is the stage which ensures the contact between the two phases, and the better this contact is, the more effective is the plate. A good performance of the column depends upon on how well is designed the plate in order to avoid any bad operation.

A great number of chemical and petrochemical industries are showing a great interest in using the gamma ray scanner for improving design, operation, optimization and troubleshooting of industrial processes (Wilson et al., 2009). However a column scan is able to analyze and then identify failures in industrial processes (Laraki et al., 2007). In this perspective the present work describes the procedure for checking column performances by means of a computer code where the results are obtained, plate by plate in order to locate and quantify the problem before suggesting and adopting any solution.

Constructing a plate is not an easy process since its dimensions and areas have a direct influence on its performance. The gas flows through the holes, and the downcomer ensure the flow of the liquid down from one plate to the other. The weir is the element which retains a liquid quantity on the plate in order to ensure the contact between the two phases before flow into the next plate. The downcomer area is fixed by the length of the weir the effect of which on the performance column is considered in the present work.

2. Checking procedure of the good performance of the column

The check up of the column is carried out through hydrodynamic calculations which make it possible to avoid problems such as: flooding, entrainment and weeping. A good performance of the downcomers must

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also be ensured in order to avoid flooding or vapor entrainment by the liquid, in case it was not well degassed (Kister, 1993). Downcomer checking is performed through calculations of the liquid residence time, downcomer velocity and liquid load. Excessive pressure drop can also generate flooding of the column or the downcomers. All the checking factors do have the following limiting criteria:
-The height of the liquid above the weir must remain higher than 5 mm to ensure a correct distribution of the liquid, (Cecile,1991).

$$h_{OD} = 1.04\left(\frac{q_{vl}}{L_D} K_0\; g^{0.5}\right)^{2/3} \tag{1}$$

-The liquid velocity in the downcomer must be lower than a maximum velocity (Cecile,1991) :

$$UlDm = \left[\sigma\; g\; \frac{(\rho l - \rho v)}{\rho l^2}\right]^{1/4} \tag{2}$$

-The residence time of the liquid in the downcomer must be higher than 5s, in order to ensure its degasification (Kister, 1991). For a one pass plate:

$$t = \frac{T\, A_D}{q_{vl}} \tag{3}$$

-The liquid load in the downcomer is given by (Cecile,1991) :

$$hq = hL + \left[\frac{(\Delta p + \Delta pf)}{(\rho l - \rho v)\, g}\right] \tag{4}$$

This load is subject to the following constraint in order to avoid downcomer flooding:

$$hq < (T+h_D)/2 \tag{5}$$

-In order to allow a good plate operation, it is necessary that the bypass sections planned for the liquid and the vapour, allow indeed a regular flow. A flooding factor which must be in the range of 0.8 and 1.2 (Wuithier, 1972) is defined as follows:

$$f = \sqrt{\left(\frac{A_{CT}}{1.2\, A_{CR}}\right)^2 + \left(\frac{A_{DT}}{1.8\, A_{DR}}\right)^2} \tag{6}$$

-The operation of the column is also limited by the entrainment where the amount of liquid entrained in $m^3/m^2/$ min is given graphically by Wuithier, (1972) with a maximum value of 1.025 m/min. Graphical values were interpolated by an intrinsic function of Mathcad to use it in the developed program.
-The weeping is the passage of the liquid through the openings. Lockett established the following limit as Fr=0.68± 0.12 (Cecile,1991), with the Froude number in the holes:

$$Fr = U_{GO}\left(\frac{\rho v}{(\rho l\; g\; hc)}\right)^{1/2} \tag{7}$$

-The total pressure drop on the plate includes the dry pressure drop, the pressure drop due to the liquid and those due to splashing (Cecile,1991):

$$\Delta p = \Delta ps + \Delta p\sigma + \Delta p_b \tag{8}$$

- Dry pressure drop: $\Delta ps = \left[\frac{1}{(2\, K_0{}^2)}\right] U_{G0}{}^2\; \rho v\, (1 - por^2)$ (9)

- Pressure drop due to the liquid: $\Delta p\sigma = 4\, \frac{\sigma}{d}$ (10)

- Pressure drop due to the splashing: $\Delta p_b = \rho l\; g\; \beta hL$ (11)

3. Results and discussion

HYSYS simulation with the real data of the column led to the flowrate profiles, physical properties and compositions at each plate. These results are used as input data for the Mathcad program, to calculate all dimensions and values which make it possible to check the operation of the plate and the downcomers, and this, according to the weir length. The checking is done through the factors mentioned above, introducing the limit to be respected to obtain the satisfactory L_D for each plate.

The studied column is a depropaniser of the refinery of Skikda in the Algerian eastern coast. It has 30 valve plates, 45.7 cm tray spacing and 1.98 m diameter. The feed is introduced on the 13th plate with the following composition (Skikda refinery, 2010):

Table 1. Feed composition

	Components	Mass Fraction	Mass flowrate (kg/h)
1	Ethane	$0.05\ 10^{-2}$	15.62
2	Propane	$21.23\ 10^{-2}$	7000.00
3	i-Butane	$12.63\ 10^{-2}$	4163.84
4	n-Butane	$65.71\ 10^{-2}$	21663.00
5	i-Pentane	$0.38\ 10^{-2}$	124.86
	total	1.00	32970.00

First, the length of the weir was varied within a range of 50 % D to 90 % D, in order to study the effect on the various factors of checking and then deduce the limiting values to respect. The results are obtained for each plate.

The height of the liquid above the weir is higher than the limit of 5 mm, the good distribution of the liquid is ensured, not depending on the weir length. A clear difference is noticed between the stripping and the enrichment sections.

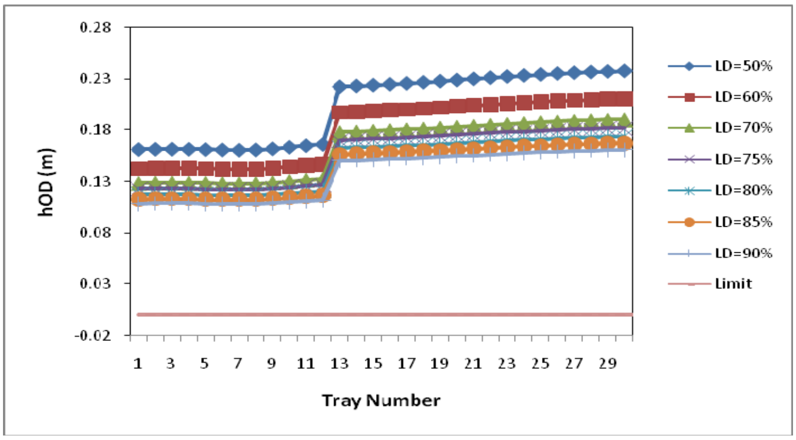

Figure1. Variation of the liquid height above the weir

- For the entrainment also, we obtain a much lower values from the limit, not depending on the weir length.

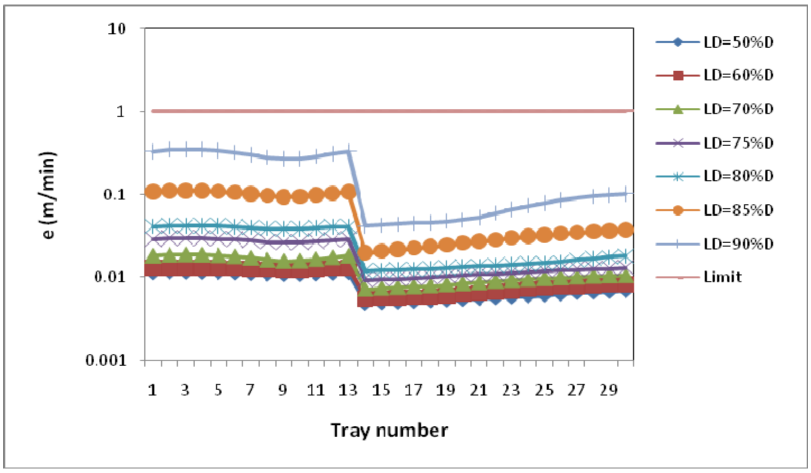

Figure2. Entrainment variation

For all the other studied factors, we find limiting values of the weir length to be respected to avoid a bad operation. The established program makes it possible to give for each studied factor, these limiting values according to the plates. The obtained results are summarized on the following figure:

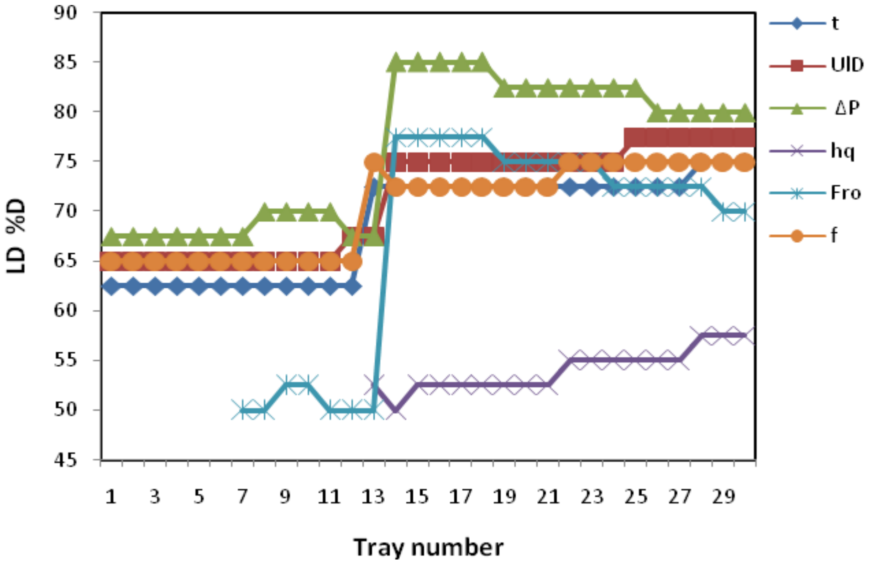

Figure3. Limiting weir length for studied factors according to the trays

According to the case for which the limit to be respected is higher or lower, we delimits a zone which covers all the studied limits, and Figure 3 is summarized in the following graph :

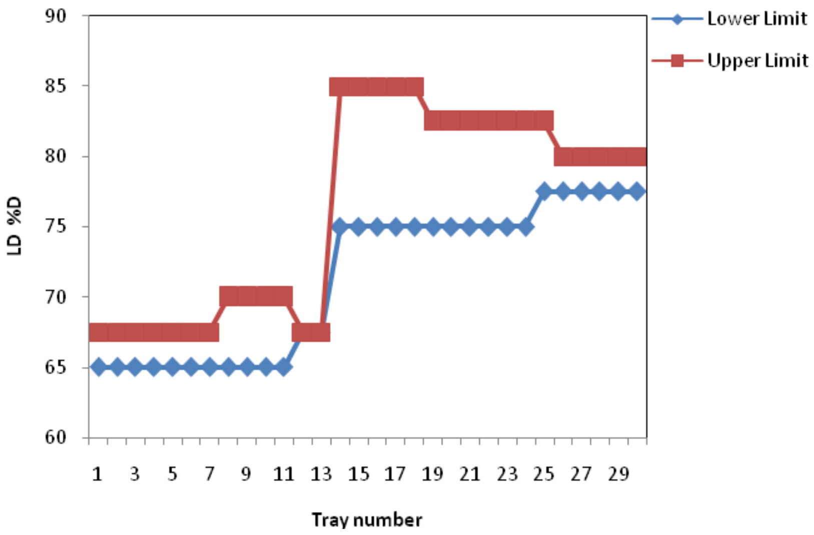

Figure 4. Zone limits to respect

It is noticed that there are several stages for which the optimal weir length is very different. In practice it is difficult to design a column with functional areas which differ much between the plates. We thus propose two constructions of plates with median values for each zone of the column: 67.5 % and 77.5 % in the stripping and in the enrichment zones, respectively (figure 5).

An execution of the program with these optimal values of weir length, led to an operation in the security zone (avoiding all the dysfunctions referred above) for the entire column.

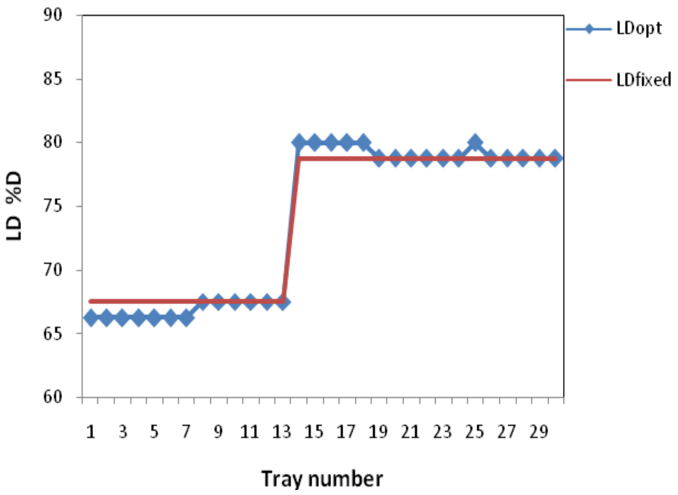

Figure 5. Optimal L_D for each zone of the column

4. Conclusion

The checking was carried out plate by plate for better detecting those having problems. We also found a direct relation between problem and weir length, from where adjustment of this one in the sections with problems.

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The length of the weir which fixes the section of the downcomers was varied from 50 % to 90 % of the diameter. The results show the effect of this factor on the stability of the plate (security operation). For each column plate we can find an optimal of L_D, which would ensure an operation in the security zone. In the studied case, we propose to adopt a weir length for each section from the column: stripping and enrichment.

We recommend to combine the procedure of calculation presented above with a gamma ray scanning of the column (which was not available for the one that was studied) in order to validate the results.

Notation

A_{CR} : the real surface allocated to the holes (m^2).
A_{CT} : theoretical free section of passage offered to the vapor flowrate (m^2)
A_{DR} : the effective section of the downcomer (m^2)
A_{DT} : downcomer theoretical section necessary to run out the liquid flowrate(m^2)
d: hole diameter (m)
e : entrainment (m^3/m^2 min)
f: flooding factor
Fr : Froud number
g : the acceleration of gravity (m/s^2)
hc : the height of clear liquid (m)
h_D: weir height (m)
h_L: liquid height (m)
h_{OD} : height of the liquid above the weir(m)
h_q: liquid load in the downcomer (m)
K0: hole coefficient
L_D : the length of the weir (m)
por: tray porosity (entire surface of the holes/effective surface of the plate)
q_{vl} : liquid volume flowrate (m^3/h)
q_{mv} : vapor mass flowrate (kg/s)
T : tray spacing (m)
t: residence time of liquid in the downcomers(s)
U_{g0} : gaz velocity through the holes (m/s)
UlDm: maximum liquid velocity in the downcomer (m/s)

Greek letters

ρl : liquid density (kg/m^3)
ρv : vapor density (kg/m^3)
β : factor of ventilation
Δp : Total pressure drop on the plate (Pa)
Δpj : **P**ressure drop under the downcomer (Pa)
σ : Interfacial tension (N/m)

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