

Diabatic Distillation – Comments on the influence of Side streams

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Abstract

In diabatic distillation the internal flows of vapour and liquid vary along the column and in the design calculations of such columns the diameter of the column has been allowed to change accordingly. However, if the column is fixed the variations in internal flows will influence the performance of the trays and thus the efficiency and separation. The configuration studied was based on a distillation pilot plant and compared with the simulations in PROII. The column used was a tray column with 12 sieve trays with 20 cm inner diameter and 6 m height.

In this study simulations were made to include the effect of changing tray efficiencies due to varying internal flow and to see its influence on the separation and other measures of performance. It was found that under certain diabatic conditions the tray efficiencies changed in favour of an increased total separation and including also improved thermodynamic efficiency. A comparison was made between experimentally and theoretically (based on the Chan & Fair model) determined tray efficiencies. Both experimental and simulation results showed the same trend but with a slight difference.

Keywords: Process Simulation, diabatic distillation, efficiency

1. Introduction

Distillation is the most common separation process in industry. The chemical process industries, including the petroleum and chemical industries, consume about 27% of the energy demand in the United States. Separation processes to recover and purify products account for over 40% of this energy demand (Humphrey *et al.*, 1991).

Distillation is a process, which is using considerable amount of energy. This is because the separation uses heat as the main separating agent. To improve the energetic situation in distillation, many methods have been discussed in the literature e.g. King, (1980), Mullins *et al* (1984), Rivero *et al* (1994), and diabatic distillation is one of these.

Evaluation of diabatic distillation can be made using different measures. One of these measures has been based on the entropy production of the system e.g. Tondeur *et al* (1987), Mullins *et al*, (1984), Björn *et al*, (2002), De Koejer *et al.*, (2002) and De Koejer *et al.*, (2004) and the entropy production in the whole system could be minimised as well with this method. The entropy production rate could be reduced by

30-50% compared to the adiabatic operation for the same column. By proper location of interstage heating/cooling the entropy production can be minimized. According to the isoforce principle, minimum entropy production rate is obtained in distillation when the driving forces are uniformly distributed over the column.

It is often concluded that the improvement obtained with intermediate heat exchange requires an increase of the number of trays in the distillation column to yield the same product quality as in the conventional case. This can be illustrated as a change in the slope of the operating lines resulting from the varied flow of the liquid and vapour streams in the column. The driving force as well as the entropy production is affected by the change in operating lines. However, when applied to a column with fixed number of stages and in order to fulfil the purity requirements, the gross heating and cooling duties will have to increase. It is therefore interesting to use a heat pump connection here.

The *aim* of the study was to investigate the introduction of intermediate heating and cooling to a column. Especially the consequences of the side stream return and its influence on the tray efficiency and different measures of effectiveness of separation. The variance of the driving forces was considered as a practical method of evaluating the equipartitioning of the driving forces for the different cases studied. The number of trays and the product purities were kept constant as compared to conventional distillation.

2. Background

In order to have equal partitioning of the driving force for mass transfer the concentration difference between the concentration y in the vapour phase and the equilibrium concentration, y^* should be evenly distributed along the column. The evaluation parameter of a good simulated system is therefore the variance (σ^2) of this driving force. Taking the vapour mol fraction distance between the operating line and the equilibrium line, the variance can be expressed as

$$\sigma^2 = \left[N * \sum (y^* - y)^2 - \left(\sum (y^* - y) \right)^2 \right] / (N * (N - 1)) \quad (1)$$

where N is the number points. When calculating the tray efficiency the method of Chan and Fair was chosen (Chan et al, 1984) Based on an evaluation by Ilme (1997).

3. Simulation Procedures and Experiments

The simulations were performed by using a computer steady state simulation programme, PRO II 5.11 from Simulations Sciences. In the simulations the physical dimensions of the studied column will be taken into consideration, such as tray size and active area.

In order to study the type of side stream return and withdrawal it was decided to simulate a real fixed-distillation column with twelve (12) sieve trays as a basis for the simulations. The column diameter is 0.2 m and the total height is 6 m. The column is

equipped with a reboiler and a total condenser^d. The equipment was designed to separate ethanol from n-propanol at atmospheric pressure.

The separation requirements were based on a certain feed rate, which was entered to the middle of the column of ethanol and n-propanol. The purity of the distillate and bottom products was kept constant. The basic equilibrium model is Non Random Two Liquid (NRTL). The algorithm for the solution is inside out.

The rectifying section is the upper part of the column, from the feed-tray above. Therefore, in this section, in order to make changes on the operating lines, some vapour was withdrawn and returned back to the column after phase change. At the bottom part of the column, stripping section, it is the other way around by withdrawing a liquid and returning back it back as vapour to the column. These changes in the operating lines were intended to make an equal distribution of the driving force possible.

The optimal way to return the side stream is to return it to a plate above in the rectifying section and to a plate below in the stripping section. For the system studied this actually means that phase and composition will coincide. A flow chart of the interconnected system is shown in Figure 1.

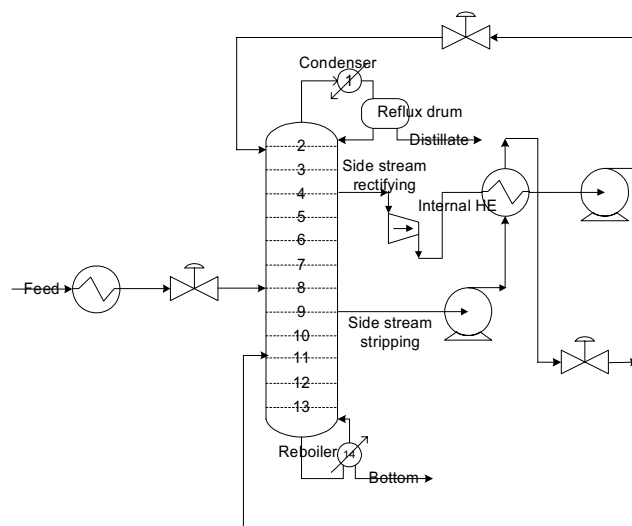


Figure 1. Flow chart of interconnected system.

4. Results and discussion

The improvements that can be obtained with diabatic distillation in comparison with adiabatic distillation are related to a thermodynamically better separation and thus also a better energy utilisation. The discussions have focused on the possible improvements that could be obtained often assuming ideal conditions or using infinite number of trays. These results show that there is a large potential of improvement to be obtained using

^d The trays in the simulation program are numbered 1 to 14, with 1 as the condenser and 14 as the reboiler.

efficiency calculated according to Chan & Fair model indicates that the vapour flow rate is the most important factor, Figure 4.

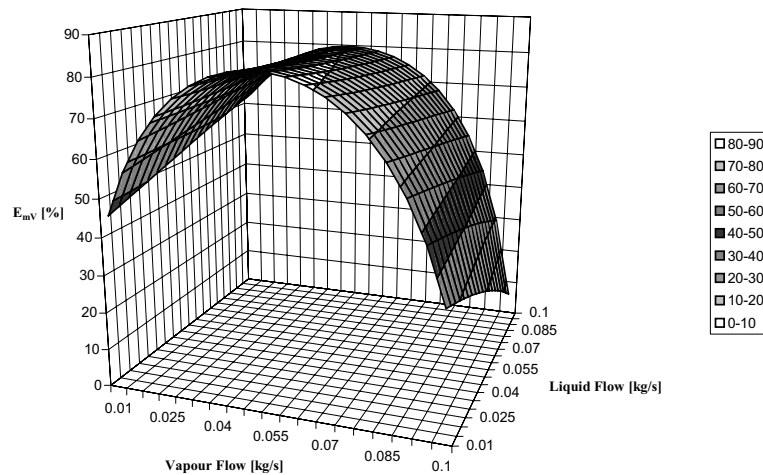


Figure 4. Variation of tray efficiency with varying vapour and liquid flow rate.

At flow rates around 50 – 60 % of flooding there may be an improvement of the tray efficiency by increased vapour flow and the result of changing the flow profile can be an overall improvement of the tray efficiency when going diabatic, Figure 5. However, each separation case should be analysed separately.

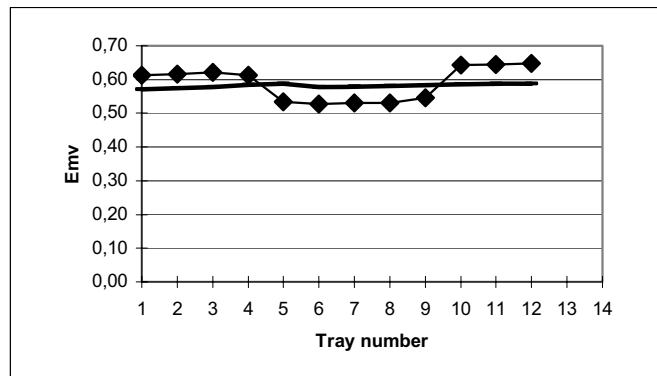


Figure 5. Variation of tray efficiency along the column

A comparison with experimentally determined tray efficiencies in the pilot plant show that the tray efficiency is dependant on the vapour flow rate and was found to vary around 50 – 60 %. Experiments included the introduction of liquid and vapour side

streams and extraction of liquid side streams. Simulations of the temperature and concentration profile in PROII gave an acceptable fit using a tray efficiency of 60 %. Using the Chan Fair model gave predicted tray efficiency slightly higher, around 70%, which is probably due to the relative small size of the tray.

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