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OVERVIEW OF SINGLE-INPUT SINGLE-OUTPUT DISTILLATION CONTROL

Khairiyah Mohd. Yusof
Department of Chemical Engineering

ABSTRACT

Distillation is a very important operation in the chemical industry. Distillation columns are notoriously known for being difficult to control. This paper presents an overview of distillation control for a general understanding of the important aspects that influence single-input single-output control of a column.

INTRODUCTION

The past three decades have seen active research on distillation control because of rising energy costs and stringent demands on product purity. Distillation columns are among the most difficult chemical processes to control. This is because overall, distillation columns are high order systems that are non-linear. Numerous factors influence the behavior of these columns. Among them are the number of trays, operating pressure, vapor-liquid equilibrium (including relative volatility) and chemical equilibrium between components, enthalpy-composition relationships, etc.

This paper discusses single-input single-output (SISO) direct product composition control of conventional distillation columns, which is typically found in industry. Control of non-conventional columns, such as azeotropic or heat-integrated columns, and complex or decoupled control are not discussed.

INFLUENCE OF PRODUCT PURITY

In general, distillation columns can be separated into three categories, based on product purity:

1. low purity columns that behave linearly,
2. moderate purity columns that have nonlinear gains while the time constants and dead-times are approximately constant over the region, and
3. high purity columns that are nonlinear in gains, time constants and dead-times.

Low to moderate purity columns usually can easily be controlled using simple control structures as mentioned in the previous section. Nevertheless, the higher the

purity of the products, the more difficult it becomes to control the column. This has been reported in works by Mountziaris and Georgiou (1988) and Fuentes and Luyben (1983).

PRODUCT COMPOSITION MEASUREMENT

When product composition is measured directly, a typical composition analyzer adds a dead-time ranging from three to twelve minutes, with the average value at about five minutes. Dead-time causes serious problems in control systems and should be avoided when possible. Since plate temperatures in a column are related to composition, it is common practice in industry to measure plate temperatures to infer product composition. Usually, this can be done in a column with moderately pure products and has a relative volatility of about two or more.

Nevertheless, there are several types of columns in which temperature measurement is not feasible for composition measurement. For example, if there is a problem of pressure fluctuations (which often occur in either very low pressure or high pressure columns), temperature measurement is inadequate because temperature is also a strong function of pressure. In addition, temperature mesurement is not accurate and not sensitive enough to indicate small changes in compostion that is important for high purity columns.

SISO CONTROL CONFIGURATIONS

For distillation columns, controlling one composition, either the distillate or the bottoms composition, is called single-end control. If the distillate composition, xd, is controlled, the manipulated variable is usually either the distillate rate, D, or the reflux rate, R. The bottom of the column then has a fixed vapor boil-up to bottoms rate ratio (VB) or a fixed vapor boil-up to feed ratio (VF). Figure 1 shows a schematic diagram of single-end control of xd by manipulating D, while VB is kept constant. If the bottoms composition, xb, is controlled, the bottoms rate , B, or the steam (or heat input) rate, S, is usually the manipulated variable. The distillate end then has a fixed reflux to feed ratio (RF) or reflux to distillate ratio (RR).

In dual-composition or two-point control, the compositions at both ends of the column are controlled. This is often significantly more complex than single-end control because of interaction between the two control loops. Consequently, if the conventional PI controllers are used, at least one of the controllers has to be loosely tuned to avoid closed-loop instability. However, significant savings, especially in energy consumption, can be achieved by employing two-point control (Luyben, 1975). Various control structures exist for implementing dual-composition control. The most commonly found control structure is direct product control, where either the distillate or the reflux rate and the bottoms or steam rate are manipulated. Figure 2 shows the R-B control structure, where xd is controlled by manipulating the reflux rate, R, and xb is controlled by manipulating B, the bottoms rate. The liquid level in the reflux drum and the reboiler are controlled by manipulating the distillate rate, D, and the steam rate, S, respectively.

EFFECT OF RELATIVE VOLATILITY ON HIGH PURITY COLUMNS

For a high purity column, the relative volatility of the system influences the type of control structure that is suitable. For example, Fuentes and Luyben (1983) reported that a simple product control structure is sufficient to control a high purity distillation column with a relative volatility of two. However, they found that with a relative volatility of four, the controller failed because the compositions changed too fast for the composition analyzer (average dead-time for an analyzer is five minutes), because of large composition separations between the liquid and vapor phases.

In an earlier paper, Tyreus and Luyben (1976) also reported difficulties in controlling a methanol-water column, with 99.9 mole percent methanol at the distillate end and 0.1 mole percent at the bottoms. The average relative volatility of the system throughout the column is 4.47. On the other hand, Finco (1987) was able to control a propane-propylene column (relative volatility very close to one) with 99.5 mole percent propylene at the distillate and 0.5 mole percent propylene at the bottoms using a simple SISO control structure with PI controllers.

The actual cases examined by Finco, and Tyreus and Luyben confirmed that the relative volatility of the components in a column heavily influence the control system. The larger the relative volatility, the faster the change in compositions throughout the column. This presents a problem in the presence of composition analyzer dead-time because large changes would have occured during the time delay, resulting in erronous control action. On the other hand, compositions change slowly in low relative volatility systems. Consequently, the compositions do not change much during the analyzer time delay, making the control action quite effective.

INTERACTION ANALYSIS

Interaction between the variables in a distillation column presents another difficulty in controlling the product composition, especially in two-point control. For example, for the structure shown in Figure 2, when xd is controlled by manipulating R, the liquid flow into the reboiler also changes, causing the vapor boil-up rate to also change. This, in turn, affects xb. On the other hand, when xb is controlled by manipulating B, the vapor rate changes, resulting in a change in the distillate rate, affecting xd. Therefore, the interactions between the variables in the column must first be analyzed before determining a control structure.

To perform interaction analysis, several methods exist. Among them are relative gain analysis (Bristol, 1966; McAvoy, 1983), singular value decomposition (Moore, 1986), and the Niederlinski Index (Niederlinski, 1971).

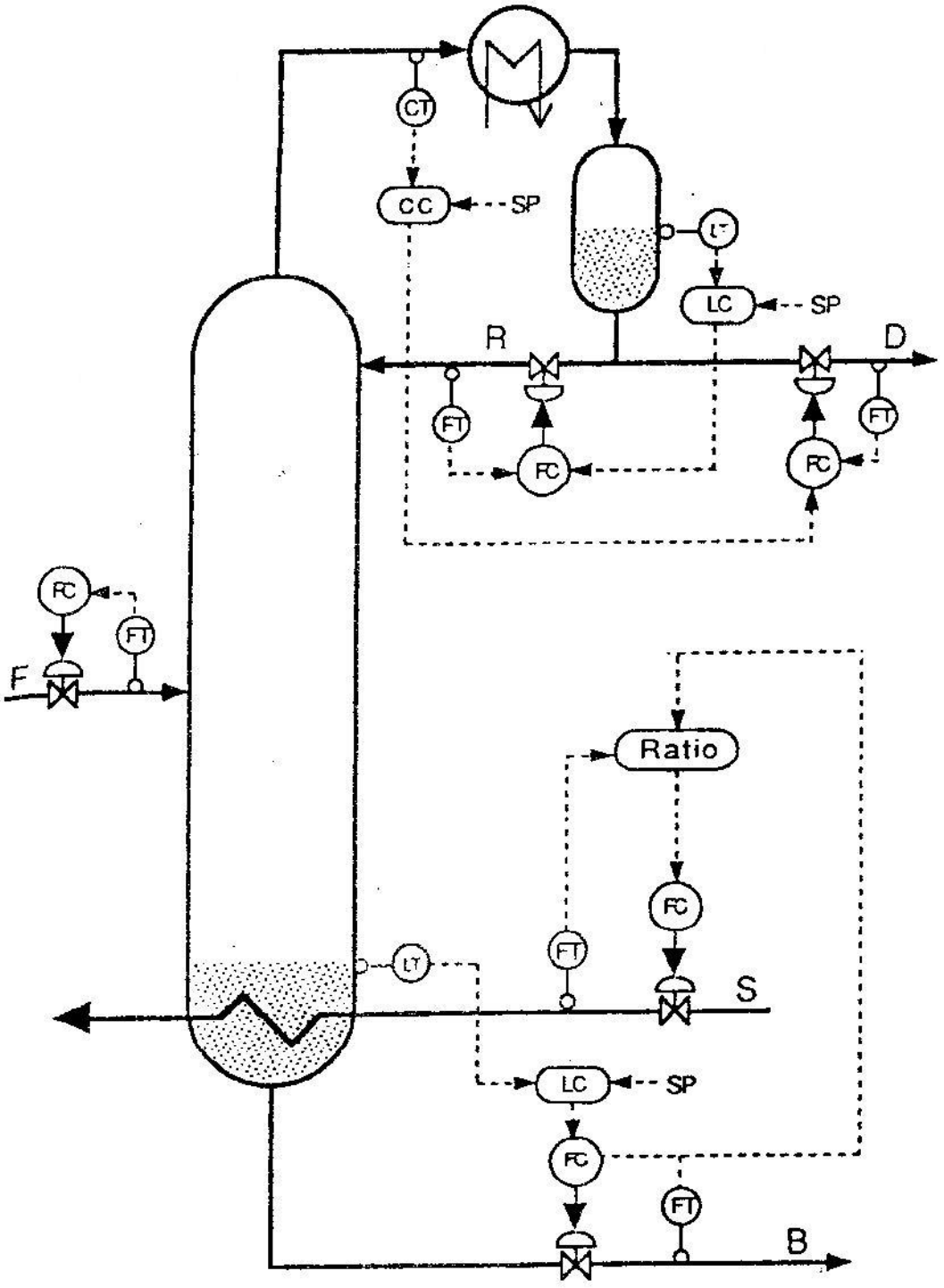

Figure 1. Single-end control of xd by manipulating D (constant VB)

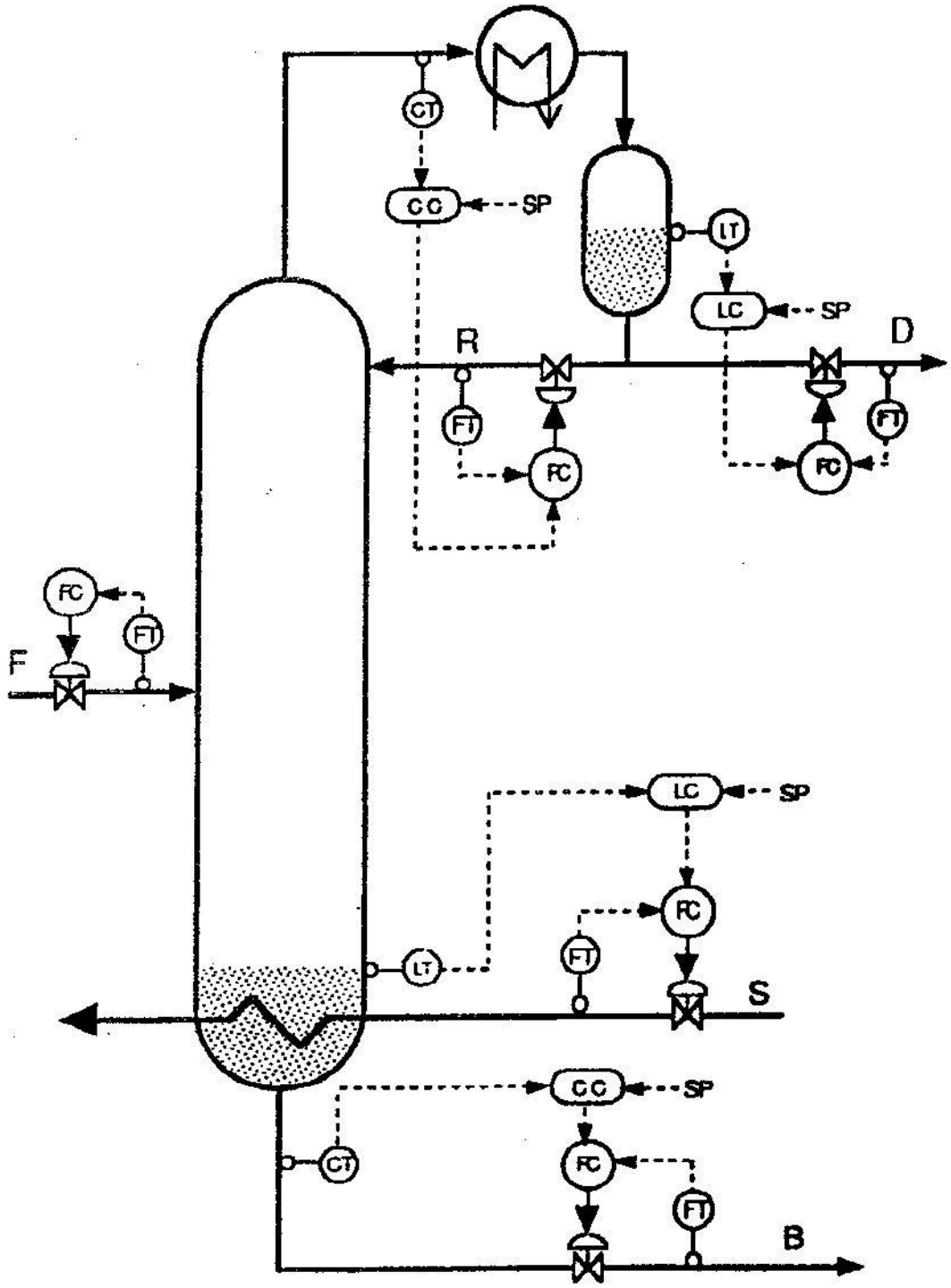

Figure 2. R-B structure

CONCLUSION

Distillation control is a wide and challenging area of research for which many questions remain unanswered. For such a commonly found operation, the need for a greater depth in understanding distillation control is definately important.

REFERENCES

1. Bristol, E. H., IEEE Trans. Auto. Control AC-11, 133 (1966).
2. Finco, M. V., M. Sc. thesis, Lehigh University (1987).
3. Fuentes, C., and Luyben, W. L., IEC Process Des. Dev. 22(3), 361 (1983).
4. Luyben, W. L., IEC Fundam. 14(4), 321 (1975).
5. McAvoy, T. J., AICHE J. 27, 613 (1981).
6. Moore, C. F., Proc. Am. Control Conf., 643 (1986).
7. Mountziaris, T. J., and Georgiou, A., IEC Res. 27(8), 1451 (1988).
8. Niederlinski, A., Automatica 7, 691 (1971).
9. Tyreus, B. D., and Luyben, W. L., Chem. Eng. Prog., 59 (Sept. 1976)