CHAPTER 1

1. INTRODUCTION

1.1. Batch Processes

In the 1950s, chemical engineers might have the impression that the ultimate mission of the engineers was to transform old-fashioned batch processes into modern continuous ones (Rippin, 1983). With such a perspective it is surprising to find that, today, fifty years later a significant proportion of the world's chemical production by volume and a much larger proportion by value is still made in batch plants and it is unlikely that this proportion will decline in the near future. Parakrama (1985) reported that 99 batch processes were in operation in 74 UK manufacturing companies. Among these, 80% plants were producing chemicals in steady or growing markets. Moreover, many more products, which could be manufactured continuously, are in fact made in batch plants on economic grounds (Rippin, 1991).

Batch production is usually carried out in relatively standardised types of equipment, which can easily be adapted and if necessary reconfigured to produce many other different products. It is particularly suitable for low volume, high value products such as pharmaceuticals, polymers, biotechnologicals or other fine chemicals for which annual requirement can be manufactured in few days or few batches in an existing plant. The flexibility of the production arrangements can also cope with the fluctuations or rapid changes in demand, which is often characteristic of products of this type. Other factors (Shah, 1992) which favours batch processing are:

- increased global competition in the bulk chemicals sector
- need to produce customer specific products
- seasonal demands of certain products

Where small amounts of different products must be produced, it is usually more economically efficient to manufacture them in a common facility such as multipurpose batch plant, rather than operating one plant per product.

1.2. Distillation

Distillation separates two or more liquid components in a mixture using the principle of relative volatility or boiling points. The greater the difference in relative volatility the greater the nonlinearity and the easier it is to separate the mixture using distillation. The process involves production of vapour by boiling the liquid mixture in a still and removal of the vapour from the still by condensation. Due to differences in relative volatility or boiling points, the vapour is rich in light components and the liquid is rich in heavy components.

Often a part of the condensate is returned (*reflux*) back to the still and is mixed with the outgoing vapour. This allows further transfer of lighter components to the vapour phase from the liquid phase and transfer of heavier components to the liquid phase from the vapour phase. Consequently, the vapour stream becomes richer in light components and the liquid stream becomes richer in heavy components. Different types of devices called plates, trays or packing are used to bring the vapour and liquid phases into intimate contact to enhance the mass transfer. Depending on the relative volatility and the separation task (i.e. purity of the separated components) more *trays* (or more packing materials) are stacked one above the other in a cylindrical shell to form a *column*.

The distillation process can be carried out in *continuous*, *batch* or in *semi-batch (or semi-continuous)* mode.

1.3. Continuous Distillation

Figure 1.1 shows a typical continuous distillation column. The liquid mixture (*feed*), which is to be separated into its components, is fed to the column at one or more points along the column. Liquid runs down the column due to gravity while the vapour runs up the column. The vapour is produced by partial vaporisation of the liquid reaching the bottom of the column. The remaining liquid is withdrawn from the column as *bottom product* rich in heavy components. The vapour reaching the top of the column is partially or fully condensed. Part of the condensed liquid is refluxed to the column while the remainder is withdrawn as the *distillate product*. The column section above the feed tray rectifies the vapour stream with light components and therefore is termed as *rectifying* section. The column section below the feed tray strips heavy components from the vapour stream to the liquid stream and is termed as *stripping* section.

The readers are directed to Smith (1963), Seader and Henley (1998), Perry et al. (1997), McCabe et al. (2001), Gani and co-workers (1986a, 1986b, 1988, 2000), Perkins and co-workers (1996, 1999, 2000, 2001) for detailed account of modelling, design, operation, control and synthesis of continuous distillation processes.

1.4. Batch Distillation

Batch distillation is, perhaps the oldest operation used for separation of liquid mixtures. For centuries and also today, batch distillation is widely used for the production of fine chemicals and specialised products such as alcoholic beverages, essential oils, perfume, pharmaceutical and petroleum products. It is the most frequent separation method in batch processes (Lucet et al., 1992).

The essential features of a conventional batch distillation (CBD) column (Figure 1.2) are:

- A bottom receiver/reboiler which is charged with the feed to be processed and which provides the heat transfer surface.
- A rectifying column (either a tray or packed column) superimposed on the reboiler, coupled with either a total condenser or a partial condenser system.

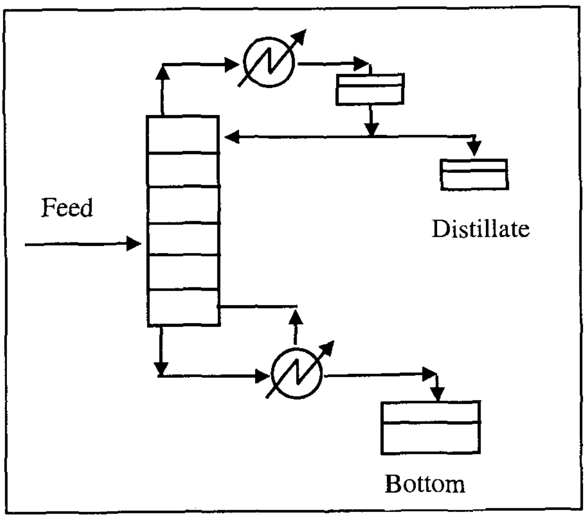

Figure 1.1. Continuous Distillation Column

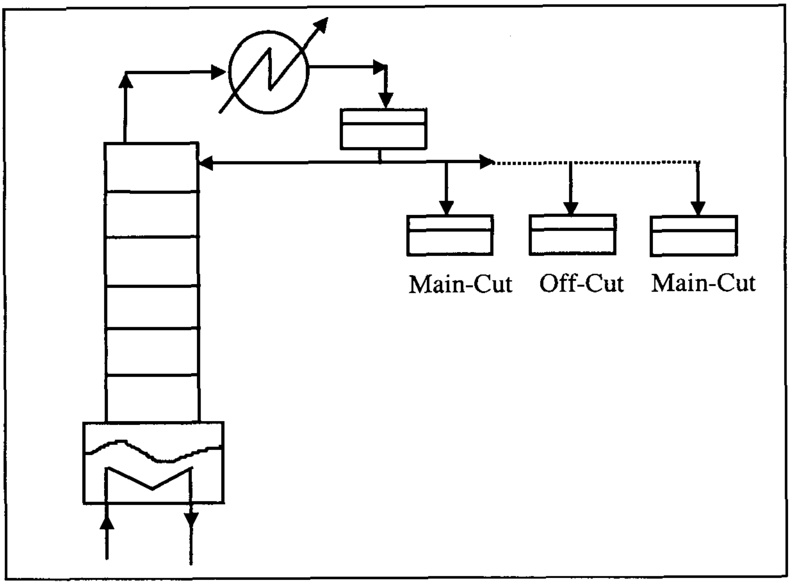

Figure 1.2. Conventional Batch Distillation (CBD)

- A series of product accumulator tanks connected to the product streams to collect the main and or the intermediate distillate fractions.

Operation of such a column involves carrying out the fractionation until a desired amount has been distilled off. The overhead composition varies during the operation and usually a number of cuts are made. Some of the cuts are desired products (main-cuts) while others are intermediate fractions (off-cuts) that can be recycled to subsequent batches to obtain further separation. A residual bottom fraction may or may not be recovered as product (Mujtaba, 1989).

Further details on batch distillation are provided throughout this book.

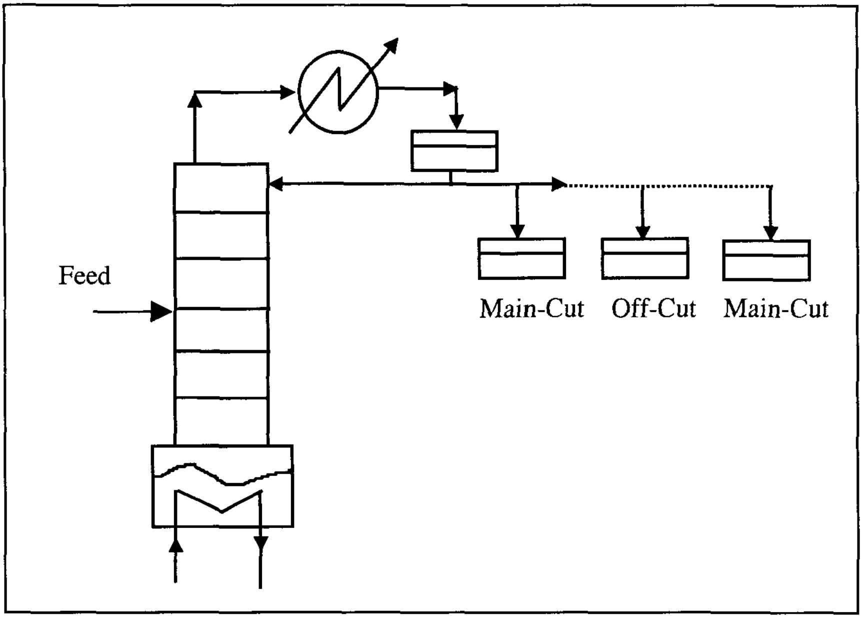

Figure 1.3. Semi-batch (Semi-continuous) Distillation Column

1.5. Semi-batch (semi-continuous) Distillation

Figure 1.3 shows a typical semi-batch (semi-continuous) distillation column. The operation of such columns is very similar to CBD columns except that a feed is introduced to the column in a continuous or semi-continuous mode. This type of column is suitable for extractive distillation, reactive distillation, etc. (Lang and co-workers, 1994, 1995; Mujtaba, 1999). Further details of semi-batch distillation in extractive mode of operation are provided in Chapter 10.

1.6. Advantages of Batch Distillation

The main advantages of batch distillation over a continuous distillation lie in the use of a single column as opposed to multiple columns and its flexible operation.

For a multicomponent liquid mixture with n_c number of components, usually (n_c-1) number of continuous columns will be necessary to separate all the components from the mixture. For a mixture with only 4 components and 3 distillation columns there can be 5 alternative sequences of operations to separate all the components (Figure 1.4). For a mixture with only 5 components, 4 distillation columns can be sequenced in 14 different ways. The number of alternative operations grows exponentially with the number of components in the mixture. These alternative operations do not take into account the production of off-specification materials or provision for side streams (this would further increase dramatically the number of columns and or operational sequences).

On the other hand with CBD, only one column is necessary and there is only one sequence of operation (with or without the production of off-specification materials) to separate all the components in a mixture (Figure 1.2). The only requirements here are to divert the distillate products to different product tanks at specified times.

The continuous distillation columns are designed to operate for longer hours (typically 8000 hrs a year) and therefore each column (or a series of columns in case of multicomponent mixture) is dedicated to the separation of a specific mixture.

However, a single mixture (binary or multicomponent) can be separated into several products (***single separation duty***) and multiple mixtures (binary or multicomponent) can be processed, each producing a number of products (***multiple separation duties***) using only one CBD column (Logsdon et al., 1990; Mujtaba and Macchietto, 1996; Sharif et al., 1998).

Finally, in pharmaceutical and food industries product tracking is very important in the face of strict quality control and batch wise production provides the *batch identity* (Low, 2003).

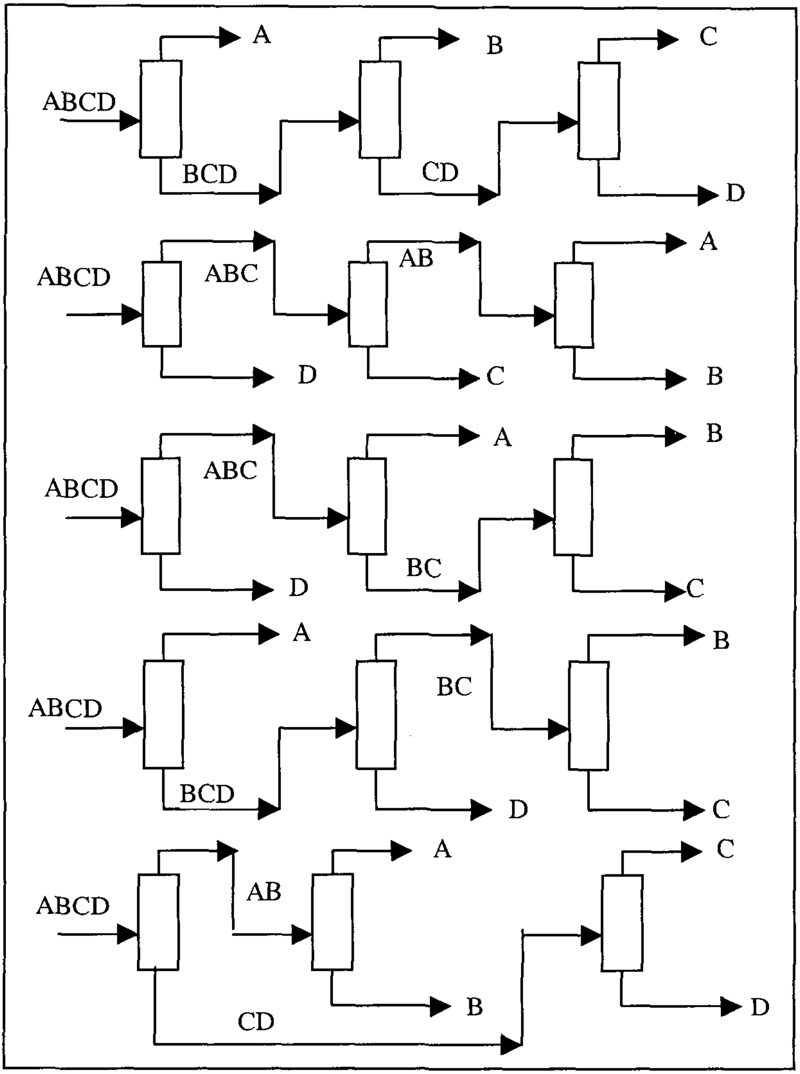

Figure 1.4. Alternative Separation Sequences for Quaternary Mixture Using Continuous Distillation Columns

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