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A novel multi-effect methanol distillation process

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ABSTRACT

Crude methanol distillation is an energy-intensive separation process and contributes significantly to the cost of methanol production. Although a number of energy-efficient distillation systems have been proposed, there is potential for energy savings in methanol distillation. To further reduce the energy consumption of methanol distillation, a novel five-column multi-effect distillation process is proposed in this work, which is essentially an improved version of an existing four-column scheme. The four-column scheme is made up of a pre-run column, a higher-pressure column, an atmospheric column and a recovery column. The new five-column scheme adds a medium-pressure column after the original higher-pressure column. In this way, the load of the original higher-pressure and atmospheric columns can be decreased by about 30%. The five-column arrangement creates a multi-effect distillation configuration involving efficient heat integration between higher-pressure and medium-pressure columns, atmospheric and recovery columns, and recovery and pre-run columns. Steady-state process simulation results indicate that temperature differences at two sides of each heat exchanger are appropriate, allowing effective heat transfer. Economic analysis shows that the energy consumption of the five-column scheme can be reduced by 33.6% compared to the four-column scheme. Significant savings in operating costs can therefore be achieved, resulting in an economically viable process for methanol distillation.

1. Introduction

Distillation, which is the most widely used separation technique in the chemical process industries, accounts for about 3% of the world energy consumption [1,2]. Although mature and well optimized, distillation remains an energy-intensive operation. To reduce its energy consumption, the concept of heat integration was first introduced almost 70 years ago. The basic idea of heat integration is that the hot process streams exchange heat with cold process streams. So far, various heat integrated distillation schemes have been proposed, which have been described in some detail in a recent review article [3]. Today, economic factors coupled with environmental concerns (e.g. CO_2 emissions) are playing a role in reviving interest in the thermal efficiency of distillation columns.

In methanol production, distillation is the standard separation method. Currently, a significant proportion of industrial methanol is manufactured from synthesis gas produced from natural gas. In the original Low Pressure Methanol Process with Cu-based catalyst in the methanol synthesis reactor, a typical two-column methanol distillation scheme (see Fig. 1) was commonly adopted to purify crude methanol containing water and organic impurities. This basic arrangement is widely reported in the literature [4,5].

With the sharp rise in energy costs since the mid-1970s, methanol technology licensors and operators have focused considerable attention on alternatives to this standard two-column arrangement. So far, many energy-saving alternative schemes have been proposed [5–11], among which the double-effect three-column scheme invented by Lurgi [6] is perhaps the most widely applied in industry. A number of these alternative schemes involve splitting the refining column of two-column scheme into two separate columns operating at different pressures, such that the overheads of the higher pressure column can be used to reboil the lower pressure column. Several novel energy-saving three-column schemes have been explored in the literature [12].

Lurgi's three-column methanol distillation scheme is made up of a pre-run column, a higher-pressure column and an atmospheric column. To further reduce the methanol content in wastewater and fusel oil leaving the process, an improved scheme [13], which adds one recovery column after the atmospheric one in Lurgi's three-column scheme, is being presently used in large-scale methanol plants. This improved scheme, designated as four-column scheme, is considered as the base case in this work. Its flowsheet is shown in Fig. 2.

It is shown in this work that there is potential for saving energy in methanol distillation based on the four-column scheme. Steady-state process simulation results suggest that a novel five-column

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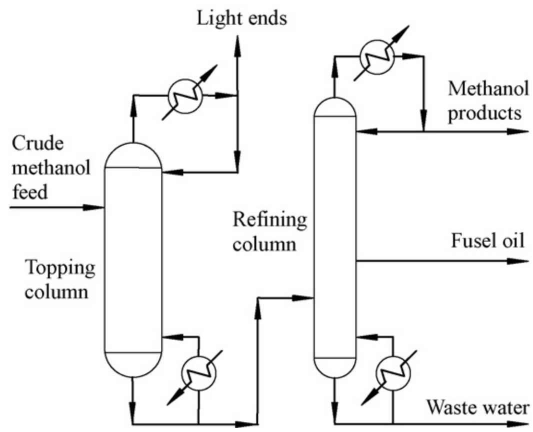

Fig. 1. Typical two-column methanol distillation scheme.

multi-effect methanol distillation scheme, proposed in the present work, can have significantly lower energy requirements than the four-column base case.

2. Base case: four-column multi-effect distillation scheme

With the four-column arrangement, as shown in Fig. 2, crude methanol is purified via pre-run column C1′, higher-pressure column C2′ and atmospheric column C4′. Columns C1′ and C4′ operate at pressure slightly higher than atmospheric pressure, while column C2′ operates at pressure of 0.5–0.8 MPaG. Column C1′ is for light ends removal. The crude methanol after being pre-heated enters column C1′ at near the top stage and methanol vapor generated in the reboiler acts to strip the light ends (such as DME, methyl formate and acetone) and residual dissolved gases from the crude methanol.

After the bottom product of column C1′ is pressurized and heated, it is sent to column C2′, where approximately 40–50% of the methanol product can be produced as the overhead product or the side stream close to the top stage. Then the bottom product of column C2′ flows into column C4′, from which the remaining methanol product is obtained as overhead product, while wastewater is withdrawn as the bottom product. Middle boiling impurities (principally ethanol, but also higher alcohols) are withdrawn as a side stream below the feed stage. To reduce energy consumption, the overhead vapor of the higher-pressure column C2′ heats the sump of the atmospheric column C4′.

Generally speaking, the methanol content of the waster water drawn from the atmospheric column bottom is in the range of 0.01–0.1%, which fails to meet typical effluent standards. Besides, the side stream drawn from the atmospheric column C4′ also contains a large amount of methanol. A majority of the methanol remaining in the bottom and side stream leaving from the atmospheric column C4′ is recovered at the recovery column C5′ as the overhead. The fusel oil is withdrawn as a side stream, while the waster water meeting the effluent standards is withdrawn as a bottom product of column C5′.

Compared with the typical two-column scheme, the four-column scheme can save energy by around 30% [14]. However, there still exist some deficiencies in the four-column scheme, as described below.

(a) The temperature at the bottom of the pre-run column C1′ is lower than that at the bottom of the atmospheric column C4′. Whereas column C4′ uses the overhead vapor of the higher-pressure column C2′ as the heat source, column C1′ by contrast uses the 0.5 MPaG steam as the heat source.
(b) The energy consumption of column C2′ accounts for about 40% of the total consumption, and the steam consumption of its reboiler is a little too great.
(c) The separation is somewhat difficult because of the stringent requirement for methanol content in the wastewater of the atmospheric column C4′ and recovery column C5′.

3. Five-column multi-effect distillation scheme

A novel five-column multi-effect methanol distillation process proposed in this work is shown in Fig. 3. The main differences between the five-column and four-column schemes are outlined below.

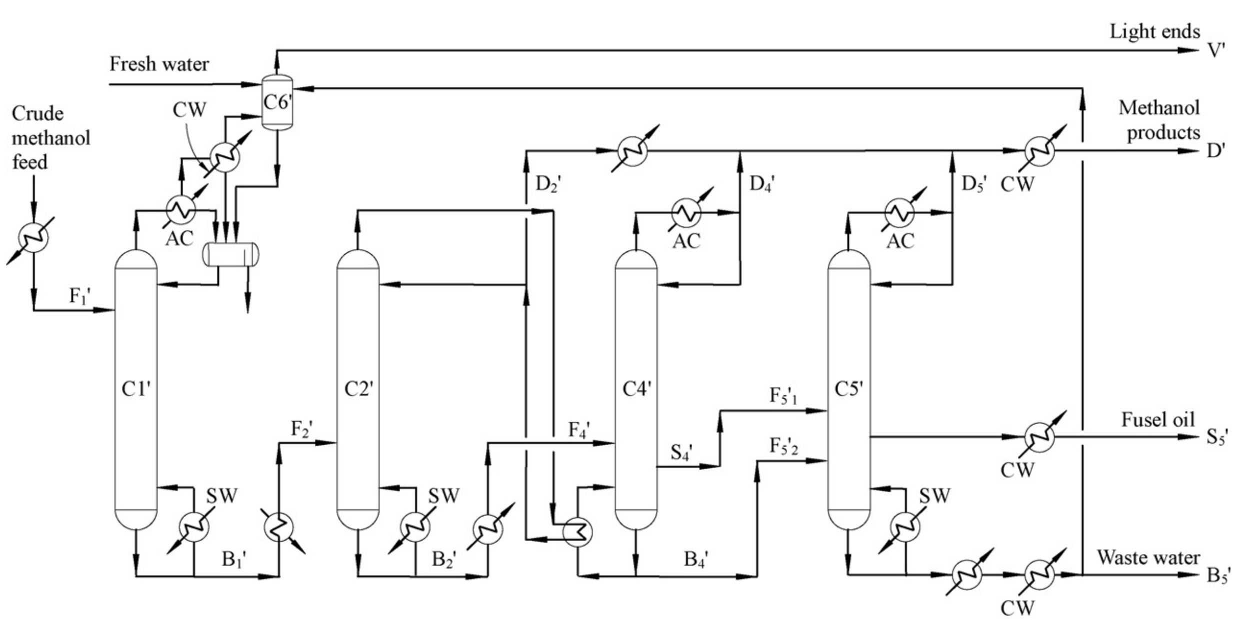

Fig. 2. Schematic of the four-column double-effect methanol distillation schemes (C1′, pre-run column; C2′, higher-pressure column; C4′, atmospheric column; C5′, recovery column; C6′, water wash column; AC, air-condenser; SW, saturated steam; CW, cooling water; F′, feed; D′, overhead product; B′, bottom product; S′, side-draw; V′, light ends).