정류보조탑이 있는 분리벽형 증류탑을 이용한 천연가스 공정의 에너지 절감

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Energy Saving in LNG Plant Using Side-Rectifier DWC

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1. Introduction

Two conventional distillation columns in sequence are combined into a single Petlyuk distillation column, implemented as a DWC (divided wall column) in practice [1], and three products are yielded from the column. When the DWC is employed in an offshore LNG (liquefied natural gas) plant utilizing three conventional distillation columns, the DWC replaces last two columns [2-4]. If a rectifying column is connected to the prefractionator of the Petlyuk column, four products are processed from the single column DWC as illustrated in Fig. 1 and the three columns in the conventional system are replaced with it. In this configuration most of the lightest component is separated in the rectifier, which significantly reduces the separation load of the next column.

For the practical implementation of the proposed Petlyuk column, a side-rectifier DWC can be constructed. Considering the space limitation and the harsh condition of operation of the offshore LNG plant, the single-reboiler distillation column is suitable to the LNG plant. Though new separation techniques were developed recently, distillation has been the most reliable process for the natural gas separation. In addition the side-rectifier DWC has high distillation efficiency, because it has the same column structure as the common DWC. The extended DWC having three walled sections in the middle is known to produce four products, but the control of product specification is more difficult than the common DWC of two sections. The difficulty explains why the extended DWC has not been commercialized, while the common DWC is being utilized in many field operations.

In this study a single reboiler distillation column, side-rectifier DWC, producing four products is proposed, and its application to the floating LNG plant is evaluated in the separation performance and heat duty requirements. The characteristics and design procedure of the side-rectifier DWC are addressed, and its cost and thermodynamic efficiency are examined.

2. Process description

Raw natural gas from gas well contains liquid components of oil and water, which are separated through the multiple separators having successively reduced pressures up to 20 kPa to maximize gas recovery and to stabilize the crude oil. The processed gas is compressed to high pressure to minimize the number of processing equipments in the next stage. A typical gas mixture contains various components. The feed components are of wide variation of volatility, but methane is more than 86 %. The first column in the distillation system processes the most of the feed because of the large amount of methane, and therefore a specially designed distillation system can be applied in the processing. Though the onshore separation system utilizes five columns, the number of the columns is limited in the offshore operation. A three-column offshore process is conventionally utilized. The first two columns with recycle produce the mixture of methane and ethane as a typical LNG fuel. The last column produces LPG and C_5 plus heavier components to be fed to hydrocarbon chemical processes.

When the prefractionator of the Petlyuk column accommodates a small column on its top, the pretreatment column for the common DWC used in the previous studies can be eliminated to make the whole distillation system a single-reboiler column. In practice the proposed column becomes a side-rectifier DWC. Because the offshore operation requires the compactness of equipment due to limited space and harsh environment, the side-rectifier DWC is a good candidate for the LNG plant if the column operating pressure is properly selected. Due to the single operating pressure in the DWC unlike the conventional system of multiple column pressures, the condenser temperature is lower than that of the conventional system and its reboiler temperature is higher. Therefore, the in-tray heat exchangers are installed to reduce the consumption of high cost utilities for the condenser and reboiler. The distribution of the in-tray heat exchangers is explained in the next section.

3. Design of the side-rectifier DWC

In the design of a conventional distillation column using a commercial program the operating pressure is determined first, and the number of trays and operating conditions are optimized for the minimum of total annual cost. The design of the side-rectifier DWC limits the number of trays due to the harsh condition of offshore operation. The numbers of trays were set to 20 and 25 for the rectifier-prefractionator and main column, respectively, considering the results of previous studies. Because the number of trays was limited in the offshore operation of distillation column due to the harsh environment at sea, the maximum number was set at 25 and the number was not optimized. Instead the location of feed and interlinking trays was iteratively optimized in the simulation by checking the product composition. The difference of tray numbers between the rectifier DWC and the conventional system is five, of which the difference of the pressure drop is 5 kPa. The difference was not significant to affect the column performance, because the column operating pressure was 0.8 MPa. The location of feed and side draw and the interlinking stages between the prefractionator and main column are found from the iterative computation for the minimum heat duty at the given product specification. Though the conventional offshore LNG plant operates three columns having different pressures between 0.8 MPa and 7 MPa, the operating pressure of the side-rectifier DWC has to be unique. The pressure was set at the lowest pressure of 0.8 MPa, because low pressure operation gives high thermodynamic efficiency and requires no extra cost for high pressure equipment. In addition, the compression of the raw gas from the well is not necessary to feed to the column.

The design of a distillation column using the commercial software requires two input data: column operating pressure and the number of total trays, and they are determined as explained above. Because the HYSYS was used in this study, the locations of feed, side draw and interlinking streams were iteratively computed for the minimum use of utilities. The operating condition for a given set of product specification from a feed was also found from the iterative computation. The product specifications are 0.89, 0.98 and 0.99 for the methane, LPG and C5+ product, respectively. The nominal amount of overhead product from the main column is mixed to the overhead product of the rectifier.

Because three columns used in the conventional LNG plant are combined to the single-reboiler column, the temperature difference of condenser and reboiler is very large almost equal to the boiling point difference between the lightest and heaviest components in feed, methane and C5+ in this study. Therefore, high-cost utility is required, and the operating cost is more than the conventional system. The same problem has been indicated in the previous studies of the DWC application.

Primary reason to install the in-tray heat exchangers is to reduce the cost of utility by using less-cost refrigerant and steam. The in-tray heat exchangers near to the condenser and reboiler have less temperature difference with them than others. Because the theorem of equipartition of entropy production requires even distribution of heat transfer through the trays, the in-tray heat exchangers are installed including near to the condenser and reboiler. In addition, the diabatic operation of a distillation column improves thermodynamic efficiency.

4. Results and Discussion

Because the main column of the DWC produces three products, five more trays are necessary than the tallest debutanizer in the conventional system. As indicated above the column pressure is set to the lowest pressure among the conventional three columns, which gives the condenser temperature much lower than the conventional system. However, its heat duty is minimized for the reduced use of high-cost refrigerant by employing in-tray heat exchangers. The amount of C_{5+} product was 15 % more than the conventional system, while LPG was produced 15 % less. The feed pressure in the DWC is much lower than the conventional system, and therefore the cooling load is about half of the conventional system due to less temperature elevation from the feed compression. In addition the compression of recycle stream from the depropanizer is not necessary giving less investment and utility costs in the DWC. The small amount of overhead product from the main column is mixed to the overhead product of the rectifier. Due to the improved thermodynamic efficiency of the DWC, the heating and cooling duties of the side-rectifier DWC including the in-tray heat exchangers are 5.9 % and 5.1 % less than the conventional system, respectively.

The composition variation of the lower 20 stages in the DWC is similar to that of the debutanizer. It indicates that the addition of 5 stages to the debutanzer is sufficient to separate the mixture of methane and ethane from the top of the DWC. Because of the limitation of column height in the offshore operation and large boiling point difference between the mixture and LPG products, the small number of stages is added to the DWC. Because a partial condenser is used in the adiabatic DWC, its vapor composition at top tray is lower than others. The LPG is produced as side cut in the DWC, and their composition profiles are different from the debutanizer of the conventional system. The mixture of methane and ethane is produced from the top of the DWC, and therefore the top temperature of the DWC is lower than that of the debutanizer producing the LPG. The in-tray heat exchangers in the diabatic DWC lead to the stepwise variation of vapor and liquid flow rates.

The economics between the conventional distillation system and the side-rectifier DWC is compared in terms of investment and utility costs. The investment cost includes the costs of column, trays, and heat exchangers, which are calculated from the cost equations given in Appendix. The utility costs of steam and refrigerant depend on temperature. The correlation of the costs and temperature was derived from the reference data. The investment of the rectifier DWC is less than 43 % of the conventional system. The large difference comes from the high pressure operation at the demethanizer in the conventional system. The pressure requires additional cost in the construction of column and heat exchangers, and the investment of the compressor used for recycling the overhead product of the depropanizer is added. The utility cost of the DWC is 10 % more than that of the conventional system because of the lower cooling temperature requiring high-cost refrigerant. The significant reduction of the investment cost compensates the utility cost increase. The critical issue in the economics between the conventional system and the rectifier DWC is the column operating pressure. Employing high column pressure of 7 MPa in the conventional system requires a feed compressor of the cost more than 5.1 times the total investment of other equipment in the conventional system and the electricity cost of 1.8 times the total utility cost. While the feed pressure in the conventional system is 7 MPa, the pressure of the rectifier DWC is 1 MPa. As the production of raw natural gas from the well continues, the gas pressure drops significantly and the compression of the raw gas is required in the conventional system. When a payback time of 5 years is applied, the TAC (total annual cost) of the compressor is 2.5 times that of the conventional system.

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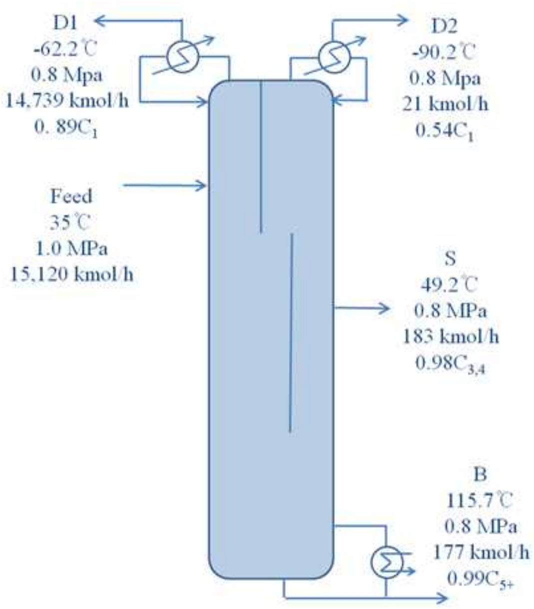

Fig. 1. Schematic diagram of single column DWC for LNG plant.