분리벽형 증류탑의 효율향상과 응용

장대진, 김병철, 김영한*
동아대학교 화학공학과
(yhkim@mail.donga.ac.kr*)

Efficiency improvement and application of divided wall column

Dae Jin Jang, Byoung Chul Kim and Young Han Kim*
Dept. of Chemical Engineering, Dong-A University
(yhkim@mail.donga.ac.kr*)

1. Introduction

When two conventional distillation columns in sequence are combined into a single divided wall column (DWC), the operating pressure of the DWC has to be compromised between those of the conventional columns if they are different. In addition the operating temperatures of the condenser and reboiler of the DWC are quite distant: the condenser temperature is the overhead temperature of the first column and the reboiler temperature is the bottom temperature of the second.

The gas separation in liquefied natural gas (LNG) plant has unique characteristics requiring cryogenic separation and having large difference of boiling points among the feed components. The large difference of volatility among the components gives easy separation with distillation, but cryogenic cooling and high temperature boiling are necessary due to the large boiling point difference. For the gas separation, multi-column distillation reduces the utility cost by adjusting operating pressure between 3 bars and 30 bars to set the product temperature near to ambient temperature[1]. Therefore, a five-column plant is operated in the conventional onshore gas separation. However, the number of columns is limited in offshore operation. While five columns are employed in the onshore processing of the gas separation, three columns are used in the offshore operation with recycle[2].

In this study a diabatic DWC is proposed for the floating liquefied natural gas plant requiring a compact distillation process. The usual DWC is modified for the process handling the mixture of wide distribution of boiling points. The characteristics and design procedure of the proposed DWC are explained along with cost evaluation and the investigation of thermodynamic efficiency improvement.

2. Process description

The raw natural gas from well contains liquid components of oil and water, which are separated in the pre-treatment units. The processed gas mixture contains various components of largely different volatilities making their separation easy, but a series of distillation columns is used in the separation due to the large number of components. A typical onshore separation plant utilizes five columns as described in Lee et al. [2]. When the gas is processed offshore, the number and height of the columns are limited due to the nature of the harsh offshore operation. A three column plant of the offshore gas separation is given in the reference. Because the composition of methane in the natural gas feed is over 86 mol % as listed in Table 1, the first two columns with recycle readily separate the methane and ethane from the feed.

The offshore operation requires the compactness of equipments due to limited space and harsh environment. A conventional gas separation process in the FLNG plant is demonstrated in Figure 1 adopted from Lee et al. [3]. The introduction of the DWC to the offshore LNG plant will give the compactness, and consumes less energy compared with the conventional FLNG process. Figure 2 shows the replacement of the last two columns of the conventional system with the DWC. In the gas separation process, the component volatilities vary widely making the separation easy, but the temperature distribution through the columns is wide leading to cryogenic condensation and high pressure steam heating for the condensers and reboilers. To minimize the utility cost the operating pressure of the columns is considerably raised for the first column and the second column as well. The application of the DWC makes the utility problem even worse by combining last two columns into one. Its condenser temperature is the lower one between two condensers of the conventional system, and its reboiler temperature is the higher one.

3. DWC design

When a distillation column is designed the operating pressure is determined first, the number of trays and liquid flow rate are adjusted to find the optimum values for the given product specification from a known feed. The structural design and operating conditions of the conventional offshore gas separation process are demonstrated in Figure 1, and the feed composition is found in Table 1. The proposed DWC The numbers of trays of the main column and prefractionator of the proposed DWC are matched to the numbers of the conventional system. The number in the prefractionator was set to 5, and that of the mid-section of the main column was 15 after considering the difference of tray composition distributions. The distribution of the prefractionator requires less number of trays than the mid-section of the main column, because the composition of middle component in feed is much lower than that in the side draw from the main column. The trays of interlinking between the prefractionator and main column are determined from the iterative simulation to give the minimum reflux flow for the given product specification. The design result of the adiabatic DWC is listed in Table 2.

From the comparison of the design results of the DWC and the conventional two-column distillation system, it is noted that the cooling duty and reboiler duty of the DWC are less than those of the conventional distillation system composed of depropanizer and debutanizer.

4. Results and discussion

The design results of the diabatic DWC were analyzed, and the cost evaluation and thermodynamic efficiency of the DWC were presented below.

1. Diabatic Column Design

Because the structural information and column operating pressure were determined from the beginning of the design, the adiabatic DWC design using the commercial design software was simple except the determination of the interlinking trays between the prefractionator and main column. The trays were found from the iterative computation for the minimum reflux flow. Though the operating pressure of the debutanizer in the conventional system was 0.8 MPa, the pressure was set to 0.4 MPa considering high thermodynamic efficiency of the low operating pressure and low temperature at the bottom of the column. The temperature of the DWC is about 20 °C less than the conventional system as shown in Table 2. The theorem of equipartition of entropy production in trays for the optimal design indicates that the installation of heat exchangers needs to be every tray, but installing that many heat exchangers is not practical in the DWC, which has a dividing wall in the middle of the column. The selection of one in three trays is a proposed compromise between the efficiency and the practicality in this study.

2. Exergy Loss and Thermodynamic Efficiency

Because the column profile of the DWC is more favorable than the conventional distillation column, not only less utility is necessary but its thermodynamic efficiency is higher than the conventional system. In this section the efficiency is compared using the exergy analysis of the systems.

The exegy loss associated with the inter-coolers and inter-heaters used in the diabatic DWC is included in the exergy loss of trays. While the exergy loss in trays varies not much between the different distillation systems in terms of percent variation, the differences in the condenser and reboiler are significant because of the high distillation efficiency of DWC. Note that the column profile of the DWC is close to the ternary profile of equilibrium distillation having the maximum efficiency. Because the composition and amount of feed and products of the systems are similar, their minimum work is close. The thermal efficiency of the diabatic DWC calculated from the exergy loss and the minimum work is the highest among three systems as expected. The proposed DWC requiring the least utility cost proves its high thermal efficiency.

4. Conclusion

An offshore floating liquefied natural gas (FLNG) plant requires small number of distillation columns with limited height for its gas separation due to its harsh condition of process operation. The divided wall column (DWC) provides the reduction of required column number and investment and utility costs. When the DWC was utilized in the FLNG plant, its design and column efficiency were examined from the simulation results using the HYSYS. In addition the cost evaluation and column operation were also discussed. When the same number of trays in the depropanizer and debutanizer of the conventional distillation system was implemented to a single DWC, 12.5 % less investment cost was required. While the saving of 25 % in steam cost was expected, the total reduction of utility cost was 20.2 % due to the lower reduction of refrigeration cost in the DWC. The operation difficulty associated with the DWC implementation can be solved by using a wide margin of product specification in the design of the DWC system.

References

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Table 1. List of feed conditions

Name	Value	Name	Value
Temperature(℃)	35		
Pressure(MPa)	7.1		
Flow rate(kmol/h)	15,120		
Composition(% mol fraction)		Composition(% mol fraction)	
Nitrogen	1.54	Ethane	6.47
Methane	86.39	Propane	2.87

Table 2. Structural information, operating conditions and compositions in the conventional and divided wall column distillation systems for the FLNG plant. Tray numbers are counted from top.

Name	Conventional DeC1	DeC3	DeC4	DWC Adiabatic Prefract	Adiabatic Main	Diabatic Prefract	Diabatic Main
Structural							
Number of trays	10	10	20	5	25	5	25
Feed/Side draw tray	8	7	13	2	9	2	9
interlinking trays				2/16			2/16
Operating							
feed (kmol/h)	15,120/349	718	369	715		715	
Product (kmol.h)							
Overhead	14,750	349	215.5		349		349
Bottom	718	369	153.5		151.3		151.3
Side					214.7		214.7
Reflux (kmol/h)	101.5	178	183.2	50	320	23	25
Vapor boilup (kmol/h)	1.14	526.5	352.6	150	501.7	60	22.2
Composition (mol frac.)							
feed	0.93/0.04/0.01	0.46/0.32/0.18	0/0.58/0.42	0.46/0.33/0.21		0.46/0.33/0.21	
Product -$C_{1,2}$	0.95	0.95			0.93		0.93
-LPG	0.32	0.58	0.99		0.98		0.98
-C5+			0.99		0.99		0.99

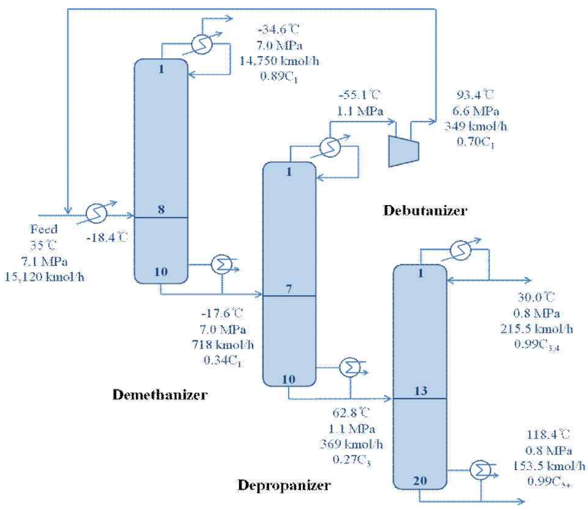

Fig. 1. Schematic diagram of the conventional FLNG plant. The first column is demethanizer, the second is depropanizer and the third is debutanizer.

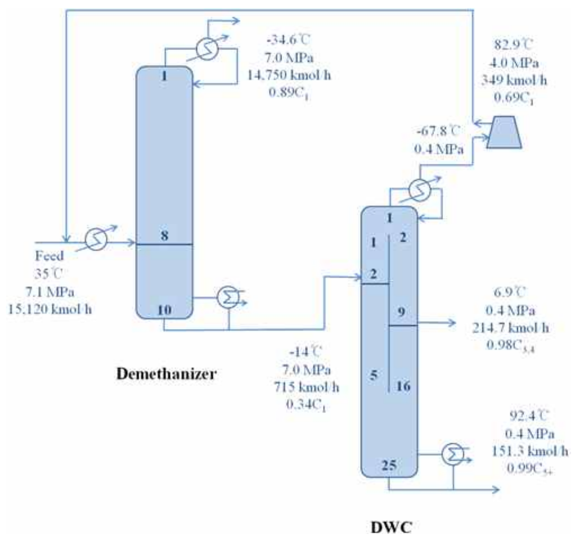

Fig. 2. Schematic diagram of the divided wall collumn (DWC) applied to gas separation process.