CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
 ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021006

Advanced energy saving in distillation process with self-heat recuperation technology

Kazuo Matsuda*[a], Kenichi Kawazuishi[a], Yasuki Kansha[b], Chihiro Fushimi[b], M. Nagao[c], H. Kunikiyo[c], F. Masuda[c], and Atsushi Tsutsumi[b]

[a] Chiyoda Corporation, 2-12-1, Tsurumichuo, Tsurumi-ku, Yokohama 230-8601, Japan
[b] Collaborative Research Center for Energy Engineering, Institute of Industrial Science, The University of Tokyo, Japan
[c] Nippon Oil Corporation, 1-3-12 Nishi Shimbashi, Minato-ku, Tokyo, Japan
kmatsuda@ykh.chiyoda.co.jp

In the distillation process, heat is supplied at a feed heater and a reboiler, and cooled at an overhead condenser. In the conventional distillation process, the supplied heat at the reboiler is discarded in the overhead condenser. Energy savings were fundamentally attained as a result of the maximized heat recovery duty in the feed heater using the heat of the bottom stream and then, the utility steam rate to the feed heater is managed to be reduced. To achieve further energy saving in the process, “self-heat recuperation technology” (SHRT) was adopted. In this technology, two compressors are installed in the overhead vapor line, which consists of the reflux stream and the overhead product stream. The compressor-1 treats the reflux stream and the compressor-2 treats the overhead stream. The reboiler duty is satisfied by the recuperated heat of a discharged stream from the compressor-1 and the feed heater duty is recuperated by a discharged stream from the compressor-2 by adiabatic compressions. Process-simulation (PRO/II^{TM} ver.8.1, Invensys) case study confirmed that despite there being almost no more energy saving potential in the conventional process, the advanced process with SHRT could reduce the energy consumption significantly by using the recuperated heat of the overhead vapor.

1. Introduction

In the distillation process, there are a feed stream and two product streams that are the overhead product stream and the bottom product stream. The heat input to the distillation process is provided by a feed heater and a reboiler. The feed heater is heated by the heat of the bottom product stream and then is additionally heated by a steam. The reboiler is also heated by a steam. For conventional energy saving method, the heat recovery in the feed heater was maximized but no consideration for the reboiler.
For further energy saving, heat integration methods for distillation column such as vapor recompression distillation columns (VRC: Annakou and Mizsey, 1995) and heat

Please cite this article as: Matsuda K., Kawazuishi K., Kansha Y., Fushimi C., Nagao M., Kunikiyo H., Masuda F. and Tsutsumi A., (2010), Advanced energy saving in distillation process with self-heat recuperation technology, Chemical Engineering Transactions, 21, 31-36 DOI: 10.3303/CET1021006

integrated distillation columns (HIDiC: Campbell *et al*., 2008) have been developed. In these methods, latent heat (condensation heat) is recovered by vapor compression to reduce the heating load by exploiting energy cascading. However, in both VRC and HIDiC, only the heating by the reboiler in the distillation column is considered and the heat during preheating is not considered for heat recovery. Recently, Kansha *et al*. (2009, 2010) have developed a novel self-heat recuperation technology that utilizes not only latent heat but also sensible heat in the process by compressors and self-heat exchangers based on exergy recuperation. As a principle of this technology, i) a process unit is divided on the basis of functions to balance the heating and cooling load by performing enthalpy and exergy analysis, ii) the cooling load is recuperated by compressors and exchanged with the heating load. The overhead vapor is pressurized by compressors and its temperature is increased due to adiabatic compression. The duties of reboiler and feed heater are satisfied by the heat of the discharged streams from compressors. As a result, the heat of the process stream is circulated without any heat addition, and thus, the energy consumption of a process can be greatly reduced. In their study (2010), a distillation process that separates benzene from a mixture of benzene (50 mol%) and toluene (50 mol%) at standard temperature (25^{o}C) and pressure (1 atm) for the exergy standard is used as a case study for developing a basic design for a distillation process by using SHRT.
In this paper, we used the actual operation data of the distillation process in the heavy chemical industrial field as an industrial application and initially undertook a feasibility study by applying SHRT. We could develop the advanced industrial distillation process in which all the recuperated heat in the process was recirculated without any additional heat. Furthermore, we conducted the case study from the point of cost saving, when a compressor was introduced.

2. Study approach for conventional and advanced processes

2.1 Conventional process

A conventional distillation process flow diagram is shown in Figure1. The heats to the distillation tower are supplied by a feed heater and a reboiler, which are heated by utility steam. The overhead vapor is subcooled by an overhead condenser and the condensed liquid is routed into the overhead drum. One of the liquid

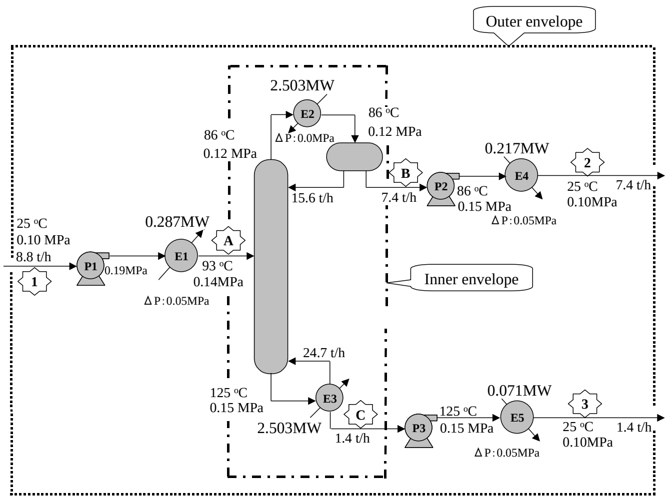

Figure :1 Conventional process (Base case) streams from the overhead drum is the reflux stream, which is sent back to the top tray of the distillation tower, and the other is the overhead product stream. The overhead product stream is further cooled by the rundown cooler. The bottom product stream from the bottom of the distillation tower is cooled by another rundown cooler.

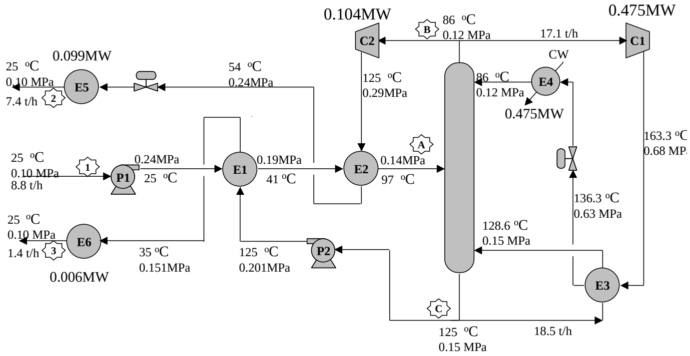

Figure 2: Advanced process
(Advanced case with self-heat recuperation technology)

To provide the bench mark process for comparison, the operating condition of the conventional process was arranged. We divided the distillation process into the two envelopes, inner one and outer one. In the inner envelope, the enthalpy of stream A matched the sum of enthalpy of stream B and C. The overhead cooling duty became same as the reboiler (E3) duty. Here, the overhead vapor was cooled to the bubble point condition. In the outer envelope, the enthalpy of stream 1 matched the sum of enthalpy of stream 2 and 3. Streams 1 to 3 were set in the standard condition, such as 25°C and 0.10MPa.

2.2 Advanced process

We have applied the self-heat recuperation techonology to a distillation process and made it an advanced process. In the advanced process, two compressors were installed in the overhead vapor line as shown in Figure 2. The overhead vapor consisted of two streams, the reflux stream and the overhead product stream. It is noted that the compressor-1 (C1) treated the reflux stream and the compressor-2 (C2) treated the overhead product stream. The temperature of the discharged stream could be increased by the compressor due to adiabatic compression. The reboiler (E3) duty was supplied by the heat of the compressed stream discharged from the compressor-1 (C1). After the reboiler (E3), the heat input was adjusted by the cooler (E4) in the return line to the distillation tower. And the feed heater (E2) duty was supplied by the heat of the compressed stream discharged from the compressor-2 (C2). In the feed line, another feed heater (E1) was exchanged with the bottom product stream. Finally the overhead product stream and the bottom product stream were cooled to the standard condition (25°C

Table 1: Component balance in the streams

	Feed	Overhead	Bottom
Component	**wt%**	**wt%**	**wt%**
C8H18	0.20	0.06	0.95
Benzene	85.02	0.00	4.07
Toluene	12.83	99.94	82.38
Et-Benzene	0.14	0.00	0.89
p-Xylene	0.63	0.00	4.08
m-Xylene	1.12	0.00	7.19
o-Xylene	0.06	0.00	0.44

and 0.10MPa) by the coolers.

3. Results

We studied the benzene distillation process as an industrial application. In operating conditions, the feedstock was a mixture of benzene, toluene and the other constituents. Feed rate was 8.8 t/h. The overhead product was 7.4 t/h and the bottom product was 1.4 t/h. For those three streams, the component balance was specified as shown in Table 1. We used the commercial process simulator, PRO/II^{TM} (Invensys, Ver. 8.1). The Soave-Redlich-Kwong equation of state (SRK) was applied.

We calculated the material and energy balances of the conventional process (base case) and the advanced process (advanced case). For comparison purpose, we simulated a heat recovery system (case-1) in which the heat recovery duty at the feed stream was increased compared with the base case.

3.1 Conventional process

As shown in Figure1, the feed heater required 0.287 MW. The overhead condenser and the reboiler required 2.503MW. Here, the overhead vapor was cooled to bubble point condition of 86 ^{o}C and routed into the overhead drum. Table 2 shows the exergy and energy input to the conventional process (base case). The sum of exergy input to the conventional process (a feed heater, a reboiler) was 2.790 MW and the sum of energy input was also 2.790 MW. In the base case, there were several pumps, which consumed the electricity power. However, those power consumption were negligible small.

For comparison, we calculated the material and energy balances of the case-1 as shown in Figure 3. The feed heaters (E1 and E2) were exchanged with the overhead product

Table 2: Study results of conventional and advanced processes

	Conventional process		Advanced process		Remarks
Case	Base	Case-1 (heat recovery improved)	Advanced	Economical (single compressor)	
1. **Exergy Input MW**					
Feed heater	(E1) 0.287	(E3) 0.069	--	--	
Reboiler	(E3) 2.503	(E5) 2.503	--	--	
Compressor-1	--	--	0.475	0.682	
Compressor-2	--	--	0.104	--	
Total	2.790 (100%)	2.572 (92.2%)	0.579 (20.7%)	0.682 (24.4%)	
2. **Energy Input MW**					Efficiency
Feed heater	(E1) 0.287	(E3) 0.069	--	--	
Reboiler	(E3) 2.503	(E5) 2.503	--	--	
Compressor-1	--	--	1.298	1.863	All: 65%
Compressor-2	--	--	0.284	--	(Power efficiency 36.6%)
Total	2.790 (100%)	2.572 (92.2%)	1.582 (56.7%)	1.863 (66.8%)	

stream and the bottom product stream, respectively. As a result, the feed heater duty (E3) by steam is reduced to 0.069MW. The reboiler duty (E5) was equal to that of the base case. Both the sum of exergy and energy inputs into the case-1 were 2.572 MW. This energy input was 92.2% of the energy input in the base case.

3.2 Advanced process

In advanced case as shown in Figure 2, two compressors were installed in the overhead vapor line. Compressor-1 required 0.475 MW and Compressor-2 required 0.104 MW, providing a compressor efficiency of 65%. Table 2 shows the exergy and energy input to the advanced process (advanced case). The sum of exergy input to the advanced process (Compressor-1 and -2) was 0.579 MW that was 20.7% of the base case. And the sum of energy input was 1.582 MW that was 56.7% of the base case. Note that the primary energy input was calculated based on the power generation efficiency (36.6%) in Japan.

4. Discussion

In the self-heat recuperation technology (SHRT) the heat of the streams are recuperated by using compressors and the recuperated heat of the pressurized stream is supplied to the cold stream by heat exchange. This means that SHRT utilizes not only latent heat but also sensible heat in the process by using a compressor.

In the distillation process of the heavy chemical industrial field, we integrated the two types of SHRT. One is the self-heat recuperation distillation. A partial heat of the overhead vapor (the reflux stream) is recuperated and the recuperated heat is supplied to the reboiler. The other is the heat circulation system for heating, which means that the remaining partial heat of the overhead vapor (the overhead product stream) is recuperated and the recuperated heat is supplied to the feed heater. As a result, the whole heat is recirculated in the process without external heat and the only electric power for the compressors are required.

As shown in Table 2, despite improving the heat recovery in the case-1, the energy consumption could be 92.2% of the base case. However, by applying SHRT, the energy consumption of the advanced case could be substantially decreased to 56.7% of the base case.

From the economical process design point of view, the related cost of installing compressors raises the total project cost of the advanced

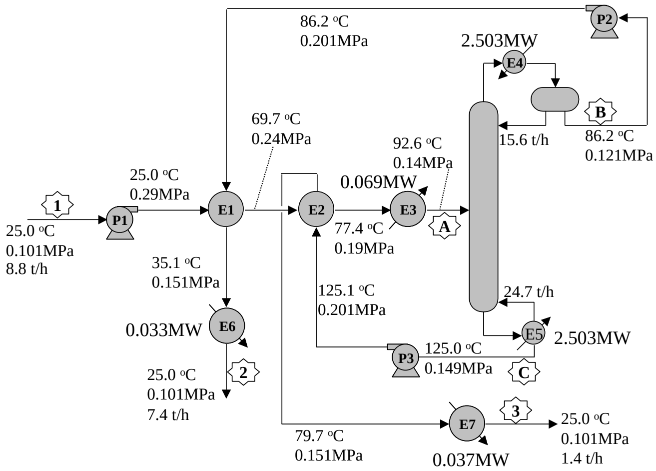

Figure 3: Conventional process (Case-1: heat recovery improved)

process as compared with the conventional process. We have developed and investigated the economical case when designing the advanced process. Instead of the two compressors in the advanced case, only one compressor was installed. The compressor treated all the overhead vapor and the compressed vapor was divided into the reboiler and the feed heater. Although the economical case could not be a minimal energy consumption due to the increase of the discharged stream temperature and pressure from the compressor, the energy consumption of this process is slightly increased compared with the advanced process The sum of exergy input to the economical case (Compressor-1) was 0.682 MW that was 24.4% of the base case and the sum of energy input was 1.863 MW that was 66.8% of the base case.

5. Conclusion

Applying the self-heat recuperation techonology to the distillation process of the benzene column could reduce the exergy input drastically, 21% of the conventional process (base case). In the conventional process, the external input (2.503 MW) is supplied to the reboiler and simultaneously the same amount heat duty (2.503 MW) of overhead vapor is disposed as waste heat. In contrast, introducing self-heat recuperation technology, the overhead vapor is compressed and the enthalpy of the overhead vapor is increased due to adiabatic compression in the advanced process (advance case). This increased enthalpy can be utilized to both the reboiler duty and the feed heater duty throughly. Eventually, the heat of the overhead vapor is re-circulated in the process without any external heat input. According to these simulation studies, the self-heat recuperation is a promissing technology to the industrial application for energy saving.

References

Annakou O. and Mizsey P., 1995, Rigorous Investigation of Heat Pump Assisted Distillation, Heat Recovery Syst. CHP 15, 241–247.

Campbell J.C., Wigal K.R., Van Brunt V. and Kline R.S., 2008, Comparison of Energy Usage for the Vacuum Separation of Acetic Acid/Acetic Anhydride Using an Internally Heat Integrated Distillation Column (HIDiC), Sep. Sci. Technol. 43, 2269–2297.

Kansha Y., Tsuru N., Sato K., Fushimi C. and Tsutusmi A., 2009, Self-Heat Recuperation Technology for Energy Saving in Chemical Processes, Ind. Eng. Chem. Res. 48, 7682–7686.

Kansha, Y., Tsuru N., Fushimi C., Shimogawara K. and Tsutsumi A., 2010, An Innovative Modularity of Heat Circulation for Fractional Distillation, Chem. Eng. Sci. 65, 330–334.