Energy 57 (2013) 663–670

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A novel NGL (natural gas liquid) recovery process based on self-heat recuperation

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A R T I C L E I N F O

Article history:
Received 3 December 2012
Received in revised form
27 March 2013
Accepted 30 April 2013
Available online 27 June 2013

Keywords:
CGCC
Distillation process
Self-heat recuperation
Heat pump
NGL (natural gas liquid) process
Energy saving

A B S T R A C T

This study examined an innovative self-heat-recuperation technology that circulates latent and sensible heat in the thermal process and applied it to the NGL (natural gas liquid) recovery process. A CGCC (column grand composite curve) was used to assess the thermodynamic feasibility of implementing the heat pump system and self-heat-recuperation technology into a conventional distillation column. The proposed distillation based on self-heat recuperation reduced the energy consumption dramatically by compressing the effluent stream, whose temperature was increased to provide the minimum temperature difference for the heat exchanger, and circulating the stream heat in the process. According to a simulation of the proposed sequence, up to 73.43 and 83.48% of the condenser and reboiler energy, respectively, were saved compared to a conventional column. This study also proposes heat integration to improve the performance of self-heat recuperation. The results showed that the modified sequence saves up 64.35, 100.00 and 31.60% of the condenser energy requirements, reboiler energy requirements and OP (operating cost), respectively, compared to a classical heat pump system, and 90.24, 100.00, and 67.19%, respectively, compared to a conventional column. The use of these sequences to retrofit a distillation column to save energy was also considered.

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1. Introduction

Separation by distillation columns consumes the largest portion of energy in industry, making this process a major concern for sustainable development in industrially developed countries [1]. Distillation is the most widely used separation process in industry, and its large-scale equipment makes it one of the most capital-intensive industrial processes. With global industrial growth, distillation is increasing in both the variety and size of applications. Therefore, sustainable and economically feasible, i.e. industrially viable, distillation systems are required [2].

In the distillation process, heat is supplied to the feed heater and reboiler, and the overhead stream is cooled in a condenser. Most of the heat supplied to the reboiler in the conventional distillation process is discarded in the overhead condenser [3]. Heat pumps in distillation allow the heat of condensation released at the condenser to be used for evaporation in the reboiler [4]. This is an economic way of conserving energy when the difference in temperature between the overhead and bottom of the column is small and the heat load is high [5]. Heat pumps can also be used in grass-root or retrofitting designs because they are easy to introduce and the plant operation is normally simpler than heat integration [6]. On the other hand, the high capital expenditure needed for compressors make them industrially viable only for high-capacity end-of-train (practically binary) separations of substances with similar boiling points, which require minimal compressor/compression cost [7]. This is the case mainly in the separation of light hydrocarbons, such as C_2–C_4 components [1], where the adiabatic exponents of the substances are sufficiently large to enable significant increases in temperature with relatively low compression efforts [8]. Furthermore, in heat pumps, only the heat recovery duty to the reboiler in the distillation column is considered but the heat during preheating is not well recognized [3].

Self-heat-recuperation technology facilitates the recirculation of both latent and sensible heat in a process, and helps reduce the energy requirements of the process using compressors and self-heat exchangers based on energy recuperation [9]. To recirculate the self heat in the process, the cooling load is recovered by compressors and exchanged with the heating load. As a result, the heat of the process stream is circulated perfectly without heat addition, and the energy consumption for the process can be reduced considerably [10].

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0360-5442/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2013.04.078

To evaluate the industrial applications of these self-heat-recuperative distillation processes, Kansha et al. compared the energy saving efficiency of an integrated bioethanol distillation process using an azeotropic distillation method with conventional azeotropic distillation processes [11]. They also applied it to a cryogenic air separation process and compared the energy requirements with the conventional cryogenic air separation in an industrial feasibility study [12]. Their study indicated a potential energy reduction of 40% using self-heat-recuperative distillation. Kansha et al. recently proposed a novel integrated process module based on self-heat recuperation that facilitates heat circulation for use in distillation processes [13]. By dividing the distillation process into two modules (heat circulation and distillation modules), the heat of condensation and the cooling heat can be recuperated by compressors and exchanged with the heat of vaporization and heating heat using heat exchangers in each module without the addition of heat.

Liquid hydrocarbons recovered from NGL (natural gas liquid) are typically separated into relatively pure ethane (C_2), propane (C_3), isobutane (iC_4), normal butane (nC_4) and gasoline products (C_{5+}). This is performed conventionally by distilling C_2–C_4 from gasoline in sequence, followed by the distillation of iC_4 from nC_4. The final distillation of iC_4 from nC_4 is energy and capital intensive because of the low relative volatility of these compounds [14]. This study applied self-heat-recuperation technology to reduce the energy requirements of the deisobutanizing fractionation step of NGL processing. A CGCC (column grand composite curve) was used to indicate the thermodynamic feasibility of implementing the heat pump system and self-heat-recuperative technology into a conventional column. Furthermore, heat integration was proposed to improve distillation based on self-heat recuperation. The effects of utility prices on the OP (operating cost) saving of the proposed integrated distillation process were investigated. The use of those sequences to retrofit a distillation column to save energy was also considered.

2. Thermal heat pump integration

Standalone unit operations, such as distillation columns are thermodynamic systems comprising a heat source (condenser) and heat sink (reboiler). These systems can also be represented graphically on a temperature–enthalpy diagram known as the CGCC [15]. At a fixed product composition, number of stages and reflux ratio, this diagram shows the steady state thermodynamic operating profile of the column and corresponding condenser as well as the reboiler heat duties. As in the case of the background processes, the thermodynamic division between the two zones is called the column pinch point.

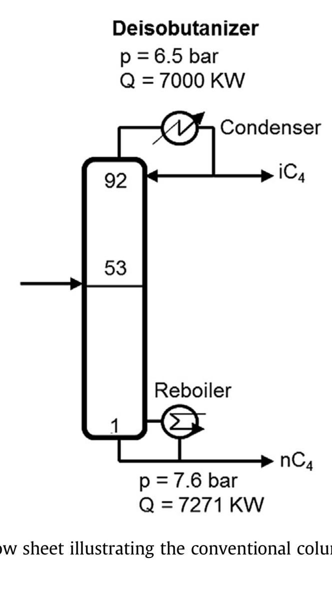

Fig. 1. Simplified flow sheet illustrating the conventional column – deisobutanizer.

Table 1
Feed mixture conditions.

Feed conditions		
Component	Mole flow (kg mol/h)	Mole fractions (%)
Propane	0.48	0.00
i-Butane	116.58	0.29
n-Butane	288.70	0.71
i-Pentane	2.13	0.01
n-Pentane	0.07	0.00
Temperature (°C)	46.83	
Pressure (bar)	8.0	

To make heat pump installation a profitable option in distillation processes, the system must operate between small temperature differences [15]. A heat pump operates by extracting a given amount of heat from a source to a relatively low temperature and delivering a larger quantity of heat to a sink with a higher temperature by consuming electrical or mechanical energy to achieve the task. The shape of the CGCC determines the opportunities for implementing a heat pump on the top of the column or an intermediate heat pumping system. A flat profile on both sides above and below the pinch point indicates that the process is suitable for recovering the waste heat from the rectification section and reusing it in the stripping section of the column.

If an inspection of the CGCC confirms that the column energy requirements can be met by a heat pump operating between the stages above and below the CGCC pinch point across a relatively small temperature difference, there is a strong possibility of improving the energetic efficiency of the system.

3. Conventional distillation column – deisobutanizer

A deisobutanizer, possessing 92 theoretical trays [16], was designed and operated at 6.5 bar (Fig. 1) because commercial isobutane can be condensed with cooling water under this pressure [17]. Table 1 lists the feed composition, temperature and pressure. The maximum flooding of the modeled columns was determined using a rating mode simulated using the internal specifications of the columns, such as the type of trays, column diameter, tray spacing and number of passes. The simulations were performed using the simulator, ASPEN HYSYS V7.3. The Peng–Robinson equation of state was used to predict the vapor–liquid equilibria of these simulations [18]. Table 2 lists the conditions and product specifications of the columns in the existing sequence. The base case simulation model showed that the energy consumption of the deisobutanizer was 7271 KW.

All columns were designed with loads of *ca.* 85% of the flooding point load to prevent flooding. Furthermore, for all sequences using

Table 2
The existing columns' hydraulics, energy performance, and product specifications.

Number of trays	92
Tray type	Sieve
Column diameter (m)	2.4
Number of flow paths	1
Tray spacing (mm)	457
Max flooding (%)	83.63
Energy requirement of condenser (KW)	7000
Energy requirement of reboiler (KW)	7271
	Purity (mol%)
iC_4	99
nC_4	95

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