Applied Thermal Engineering 70 (2014) 1189–1194

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

An innovative methanol synthesis process based on self-heat recuperation

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HIGHLIGHTS

- Application of self-heat recuperation to the methanol synthesis was investigated.
- A new process for methanol synthesis was developed for energy saving.
- A new process design methodology has further energy saving potential for other processes.

ARTICLE INFO

Article history:
Received 14 January 2014
Received in revised form
24 April 2014
Accepted 1 May 2014
Available online 10 May 2014

Keywords:
Methanol synthesis
Energy
Self-heat recuperation
Process design

ABSTRACT

The demand for methanol will continue to increase since methanol is an attractive fuel for fuel cells in addition to being an intermediate raw material for hydrogen and dimethyl ether (DME), which are categorized as green energy sources. To produce methanol with a minimum amount of energy, it is necessary to investigate and reconsider a whole methanol synthesis process from energy saving point of view. Recently, we developed an innovative process design technology referred to as self-heat recuperation technology for saving energy. To apply this technology, whole-process heat is recirculated within the process without heat addition leading to large energy savings. In this paper, the feasibility of applying self-heat recuperation technology to the methanol synthesis process is investigated and an innovative process for methanol synthesis is developed from an energy saving point of view. The use of this self-heat recuperation technology in the methanol synthesis process greatly reduces the energy consumption.

1. Introduction

The demand for methanol will continue to increase since methanol is attractive as a fuel for fuel cells and is an intermediate raw material in the production of hydrogen [1] and dimethyl ether (DME) [2], which are categorized as green energy sources [3]. In addition to other chemical processes, many methanol synthesis processes have reactant recycle systems with a product separation step because of the low conversion ratio of the reactor. For product separation from the reactant recycle stream, a gas–liquid separator or distillation process is often used in many chemical processes. However, these gas–liquid separator and distillation processes are well known energy-consuming processes because of the latent heat of condensation.

Currently, most methanol is produced from fuel, especially natural gas, coal and biomass by steam reforming and gasification reactions [4]. At first, methane from the fuel is mixed with steam and reformed to carbon monoxide and hydrogen with a catalyst [5]. Then, a methanol and water mixture is produced from carbon monoxide and hydrogen [6]. The methanol synthesis reactions are mainly the following three reactions: CO and CO_2 hydrogenation and the reverse water–gas shift reaction [7]

$$CO(g) + 2H_2(g) \leftrightarrow CH_3OH(g)\ \Delta H_{298} = -90.55\ \mathrm{kJ\ mol^{-1}} \quad (1)$$

$$CO_2(g) + 3H_2(g) \leftrightarrow CH_3OH(g) + H_2O(g)\ \Delta H_{298} = -49.43\ \mathrm{kJ\ mol^{-1}} \quad (2)$$

$$CO_2(g) + H_2(g) \leftrightarrow CO(g) + H_2O(g)\ \Delta H_{298} = +41.12\ \mathrm{kJ\ mol^{-1}} \quad (3)$$

where ΔH_{298} is the heat of reaction at standard temperature and pressure, i.e. 298 K and 1 atm. From a thermodynamic equilibrium point of view, Eqs. (1)–(3) indicate that suitable conditions for this

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http://dx.doi.org/10.1016/j.applthermaleng.2014.05.002
1359-4311/

methanol synthesis reaction are low temperature and high pressure. Therefore, many chemical engineers and investigators have managed to produce a catalyst that achieves high conversion from reactant to product under low temperature and high pressure conditions in the reactor [8] thus reducing the recycle flow rate because of an increase in the operation's energy [9] or integration of the methanol plant with other plants for whole process optimization [10] of the economics [11] or the operational energy [12].

Recently, we [13] developed self-heat recuperation technology in which the latent heat as well as the sensible heat of the process stream can be circulated without any heat addition, leading to a reduction in the energy requirement of several chemical processes [14]. This self-heat recuperation technology is suitable for thermal and separation processes and can be applied to several chemical processes for energy savings. These include petrochemical distillation [15] such as separation of a benzene–toluene mixture [16], bioethanol distillation, crude oil distillation [17], drying, gas separation [18], and CO_2 capture process [19].

In this research, we investigated the feasibility of applying self-heat recuperation technology to the methanol synthesis process and we developed an innovative process for methanol synthesis from an energy savings point of view. Using self-heat recuperation technology in the methanol synthesis process greatly reduces the energy consumption of the process. Thus, we expect that the use of self-heat recuperation technology in methanol synthesis is a new process design option that achieves high conversion in the reactor.

2. Application of self-heat recuperation technology to methanol synthesis

Self-heat recuperation technology [13] facilitates the recirculation of latent heat and also sensible heat in a process. It helps to reduce the energy consumption of the process using compressors and self-heat exchangers based on exergy recuperation. In this technology, i) a process unit is divided on the basis of functions to balance the heating and cooling loads by performing enthalpy and exergy analyses and ii) the cooling load is recuperated by compressors and exchanged with a heating load [20]. As a result, the heat of the process stream is perfectly circulated without heat addition, and thus exergy loss during heat transfer is minimized [21]. The energy consumption of a process can be greatly reduced.

Methanol is produced from reformed carbon monoxide and hydrogen from a fuel mixture together with a catalyst. After the

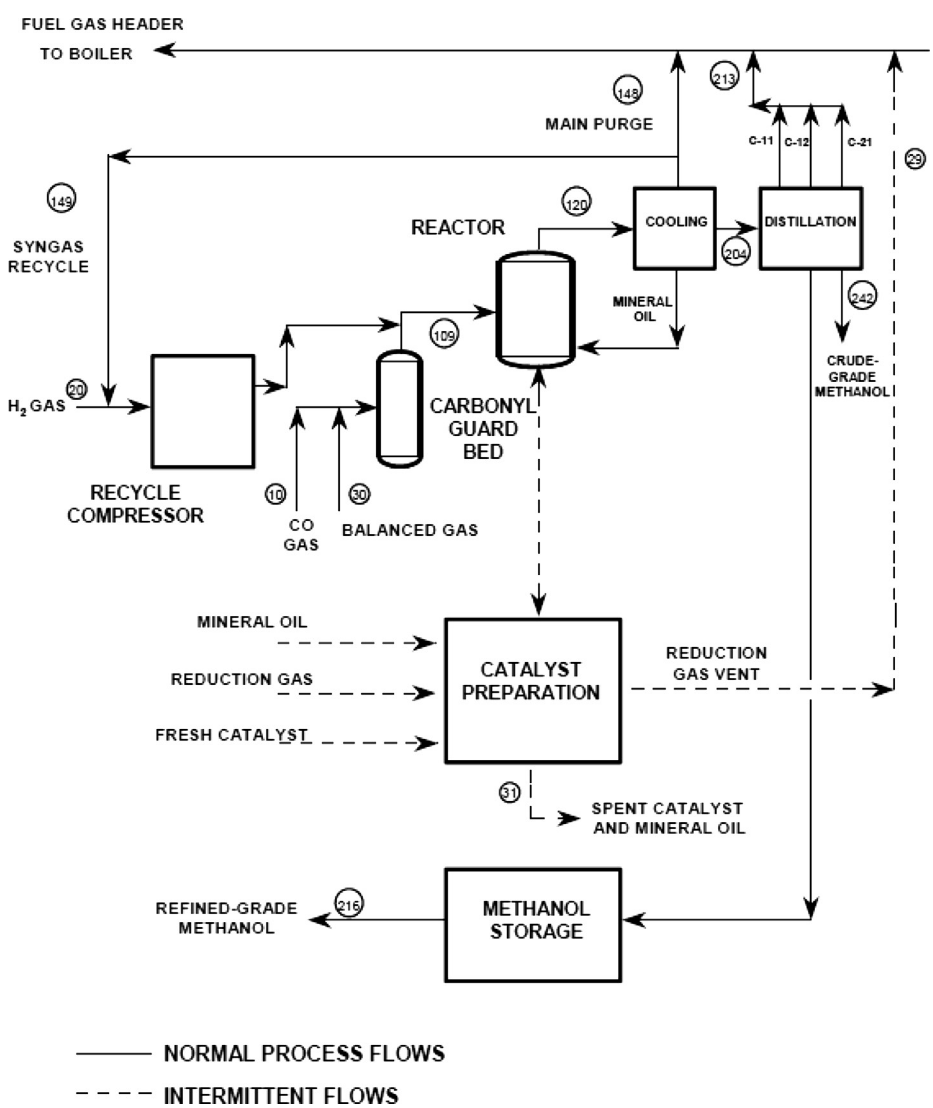

Fig. 1. LPMEOH™ demonstration unit process flow diagram [23].