CHEMICAL ENGINEERING TRANSACTIONS Volume 25, 2011
Editors Jiří Jaromír Klemeš, Petar Sabev Varbanov, Hon Loong Lam
Copyright © 2011, AIDIC Servizi S.r.l., ISBN 978-88-95608-16-7 ISSN 1974-9791
DOI: 10.3303/CET1125162

Heat Integration Analysis of Gasification Process for Hydrogen Production from Oil Palm Empty Fruit Bunch

Abrar Inayat, Murni M Ahmad*, M I Abdul Mutalib, Suzana Yusup

Chemical Engineering Department, Universiti Teknologi PETRONAS,
Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia
murnim@petronas.com.my

A heat integrated flowsheet has been designed for hydrogen production from oil palm empty fruit bunch (EFB) via steam gasification with in-situ CO_2 capture. The process energy requirement and cost are calculated from the mass balances, energy balances and the economic model of flowsheet. The flowsheet calculation and cost minimization are carried out using MATLAB. The flowsheet under investigation includes steam generation unit, gasification unit and gas cleaning unit. For heat integration studies on the flowsheet, the pinch analysis is employed to obtain the energy efficient and self-sustained system. The heat integration study is carried out using SPRINT software. The analysis shows that considerable saving can be obtained for steam production using heat integration application as there is a large amount of available waste heat from the gas cleaning and cooling units. The results show that the minimum hot utilities required is 601.85 kJ/h and the minimum cold utilities is 13.82 kJ/h for the case of minimum temperature difference of 10 K. Furthermore, a feasible heat exchanger network that fulfills these requirements has been presented. Moreover, the cost of hydrogen production decreases from 1.91 to 1.84 US$/kg of H_2 by applying heat integration approach in the flowsheet.

1. Introduction

Malaysia is the largest exporter of palm oil with the production of empty fruit bunch (EFB) with more than 17 million tones/year (Shuit et al., 2009). Biomass steam gasification for hydrogen production is not only in favor of more hydrogen but also economical than other conventional gasifying methods and pyrolysis (Balat, 2008). Furthermore, hydrogen purity can be increased in the product gas with in situ CO_2 capture technique using CaO as sorbent (Florin and Harris, 2008). The hydrogen production cost can be reduced with energy efficient system through increasing thermal integration of the system (Eljack et al., 2005).

Luterbacher et al., (2009) presented a model for hydrothermal gasification of biomass for upgrading of biomass to synthetic natural gas (SNG). The model incorporated the flowsheet mass, energy balances and heat and power integration. The thermo economic analysis showed that high efficiency process could be attained using heat integrated configurations. Heyne et al., (2010) also reported a study on SNG production from gasified biomass using integrated flowsheet design using ASPEN PLUS. They used pinch analysis method for the calculation of optimal internal heat recovery within the

Please cite this article as: Inayat A., Ahmad M.M., Abdul Mutalib M.I. and Yusup S., 2011, Heat integration analysis of gasification process for hydrogen production from oil palm empty fruit bunch, Chemical Engineering Transactions, 25, 971-976
DOI: 10.3303/CET1125162

flowsheet design. Fu and Gundersen, (2010) applied heat integration using pinch analysis on heat exchangers in an oxy-combustion process of coal fired power plant. Smejkal et al., (2009) presented a new modern unit for energy production from biomass using process integration approach. The technology provided high efficiency and low operating cost. Pavlas et al., (2010) applied process integration methodology for a biomass gasification process design to deal with the heating and cooling streams involved in energy recovery.

The objective of the present work is to apply process integration in the flowsheet design for enriched hydrogen production from EFB via steam gasification with CO_2 capture in a single pass fluidized bed gasifier. The feasibility of the process is investigated via parametric studies of energy recovery on the hydrogen cost using MATLAB. Pinch analysis approach is employed to integrate heat sources and sinks, to determine energy targets and to identify potential improvement in the flowsheet to obtain lower production cost and increased energy efficiency and self-sustainability.

2. Process Development

The process flowsheet diagram was presented by authors in earlier work (Inayat et al., 2010). EFB is used as the feedstock biomass and is pretreated i.e. dried and grinded. The gasifier operates at atmospheric pressure and assumed to be at steady state condition (Inayat et al., 2010). Steam is used as the gasification agent, produced in a steam generator and superheated using super heaters. The product gas from the gasifier is cooled down by passing it through a scrubber, and hydrogen recovered and purified using a pressure swing adsorption (PSA) unit. The steam gasification process is an endothermic process which requires external energy that is supplied using heaters.

3. Cost Minimization

The minimum hydrogen production cost is solved subject to the process constraints (Inayat et al., 2010) as formulated below.

$$Minimize\ hydrogen\ production\ \cos t = \frac{\sum Total\ \cos t}{\sum Total\ hydrogen\ p} \quad (1) \quad \frac{}{ed}$$

Subject to: Total Cost
Total Hydrogen Produced
Reaction Kinetics
Mass Balances
Energy Balances
H_2 mol% > 80 %
H_2 yield > 15 g/h (0.015 kg/h)
H_2 Efficiency > 80 %
Thermodynamic Efficiency > 80 %

Bounds: 850 < Temperature (K); < 1150; 2.0 < Steam/biomass ratio < 4.0;
0.2 < Sorbent/biomass ratio < 1.6

The optimization is carried out using MATLAB optimization solver named fmincon. The minimum production cost of 1.91 US$/kg is obtained at 1150 K, steam/biomass ratio of 4 and sorbent/biomass ratio of 0.87. The hydrogen yield and purity at the optimal condition are 0.0179 kg/h and 79.91 mol% respectively.

4. Heat Integration

Heat integration study using SPRINT software is next applied to improve the system's energy efficiency and self-sustainability. The SPRINT is commercial process heat integration software developed by University of Manchester, United Kingdom. For heat integration studies on the flowsheet, the pinch analysis is employed to obtain the required minimum utilities.The stream data are extracted from the energy balance of the flowsheet at the optimum conditions with minimum hydrogen production cost calculated in the previous section. The energy balance on the flowsheet is shown in Figure 1.

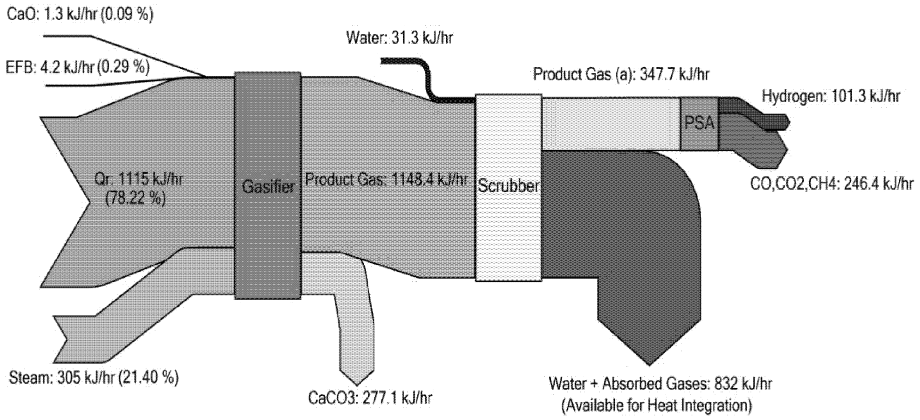

Figure 1: Sankey diagram of energy balance for the flowsheet. Temperature: 1150 K; Steam/biomass ratio: 4; Sorbent/biomass ratio: 0.87

The stream data are shown in Table 1. The table shows that energy required for cold streams C1 and C2 are 305 and 1115 kJ respectively. C1 is the stream for super heated steam generation and C2 is the energy required to the gasification process. H1 is the hot stream from scrubber.

Table 1: Stream data

Stream	Name	Supply Temp. (K)	Target Temp. (K)	Energy (kJ/h)	Heat Capacity Flowrate (kW/K)
1	H1	900	298	832	1.38206
2	C1	298	523	305	1.35556
3	C2	298	1150	1115	1.30869

There is 832 kJ of energy available for heat integration as shown in Figure 1. The calculation is performed with the minimum temperature difference of 10 K. The composite curves for hot streams and cold streams are generated using SPRINT, given in Figure 2. It can be calculated based on the composite curves that the minimum hot utilities required is 601.85 kJ/h and minimum cold utility is 13.82 kJ/h.

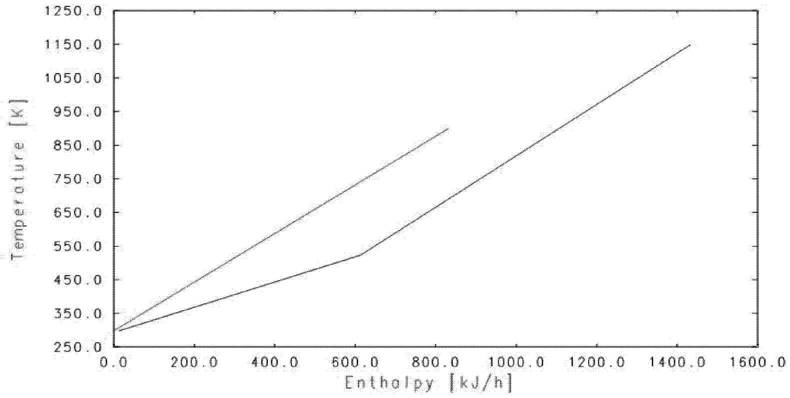

Figure 2: Composite curves for hot streams (red) and cold streams (blue)

Furthermore, Heat Exchanger Network (HEN) has been developed and optimized using SPRINT as shown in Figure 3. There are three heat exchangers required to fulfil minimum amount of hot and cold utilities with the temperature difference of 10 K.

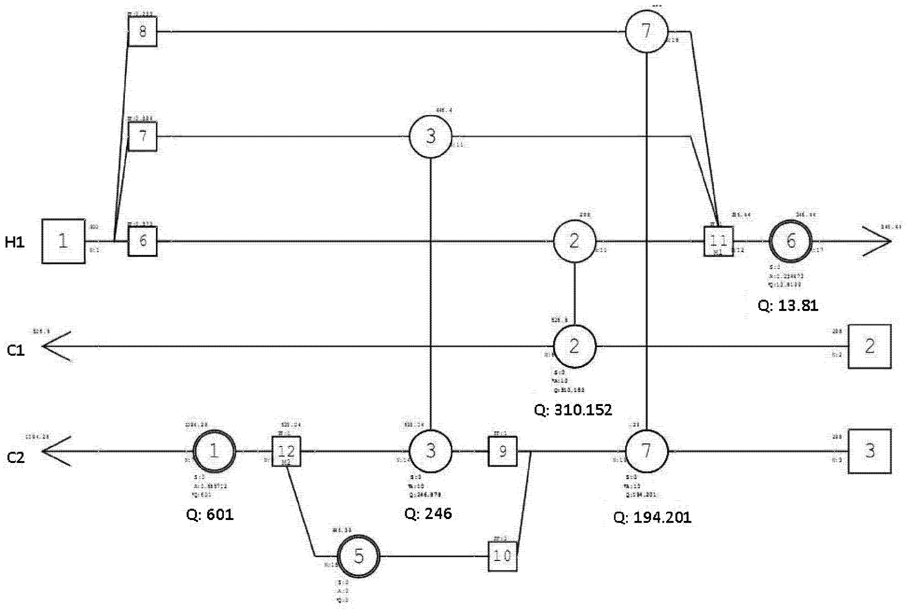

Figure 3: Optimized heat exchanger network

Based on the matching in the developed HEN, the heat integrated process flowsheet design as shown in Figure 4 is proposed. The production cost of hydrogen is recalculated for the heat integrated flowsheet. It is observed that by using heat integration, the hydrogen cost decreases from 1.9105 to 1.8405 US$/kg of H_2. So, using heat integration application, the flowsheet not only becomes energy efficient and self-sustained but also offers lower hydrogen production cost.

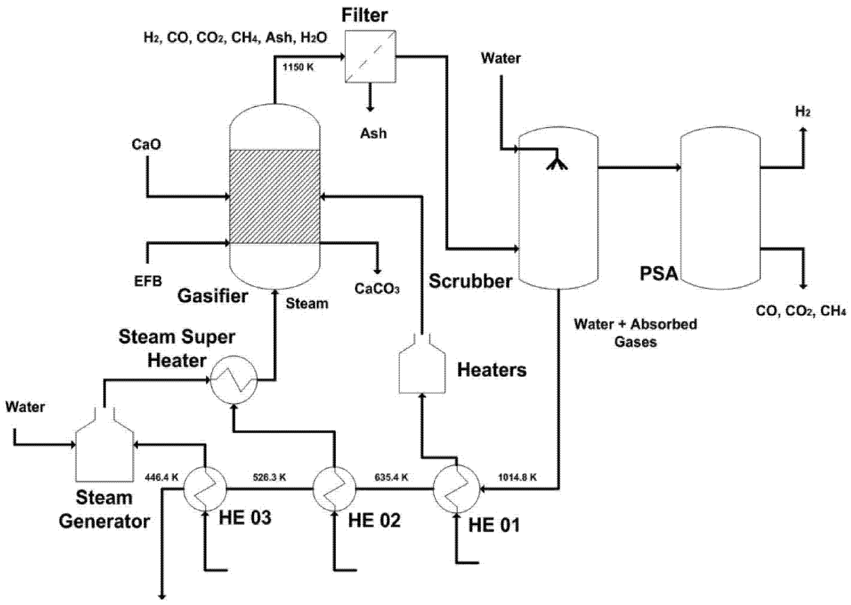

Figure 4: Integrated process flowsheet design

A comparison of hydrogen production cost between the current study and others on similar processes is shown in Table 2. The results indicate that this system has the potential to offer low production cost for hydrogen production from EFB in Malaysia.

Table 2: Comparison of hydrogen production cost

H_2 cost (US$/kg)	Process	Reference
10	Electrolyzed hydrogen	Georgi, (2002)
4.60	Japanese cedar pyrolysis and CO-shift	Iwasaki, (2003)
4.29	Solar electrolysis	Norman, (2007)
1.69	Pine wood blocks gasification and CO shift	Lv et al., (2008)
1.91	Palm oil empty fruit bunch steam gasification with in-situ CO_2 capture	(Current study)
1.84	Palm oil empty fruit bunch steam gasification with in-situ CO_2 capture using integrated flowsheet	(Current study)

5. Conclusion

A heat integration study has been carried out on the flowsheet design for H_2 production from EFB via steam gasification with in-situ CO_2 capture. The minimum production cost is solved to be 1.9105 US$/kg of H_2. For heat integration studies on the flowsheet, the pinch analysis is employed to obtain the energy efficient and self-sustained system using SPRINT software. The analysis shows that considerable saving can be obtained for steam production using heat integration application. Moreover, using the heat integration the H_2 production cost can be reduced to 1.8405 US$/kg.

References

Balat M., 2008, Hydrogen-Rich Gas Production from Biomass via Pyrolysis and Gasification Processes and Effects of Catalyst on Hydrogen Yield, Energy Sources, A: Recovery, Util. Environ. Eff., 30, 552 - 564

Eljack F.T., Cummings R.M., Abdelhady A.F., Eden M.R. and Tatarchuk B.J., 2005. Process integration and optimization of logistical fuels processing for hydrogen production, Comput. Aided Chem. Eng., 20, 1609-1614

Florin N.H. and Harris A.T., 2008, Enhanced hydrogen production from biomass with in situ CO_2 capture using calcium oxide sorbents, Chem. Eng. Sci., 63, 287-316

Fu C. and Gundersen T., 2010, Heat integration of an oxy-combustion process for coal fired power plants with CO_2 capture by pinch analysis, Chem. Eng. Trans., 21, 181-186

Georgi D., 2002. Hydrogen extraction, more than one way to skin the cat, Batteries Digest Newsletter

Heyne S., Seemann M.C. and Harvey S., 2010, Integration study for alternative methanation technologies for the production of synthetic natural gas from gasified biomass, Chem. Eng. Trans., 21, 409-414

Inayat A., Ahmad M.M., Mutalib M.I.A. and Yusup S., 2010, Flowsheet development and modeling of hydrogen production from empty fruit bunch via steam gasification, Chem. Eng. Trans., 21, 427-432

Iwasaki W., 2003, A consideration of the economic efficiency of hydrogen production from biomass, Int. J. Hydrogen Energy, 28, 939-944

Luterbacher J.S., Fröling M., Vogel F.d.r., Maréchal F.o. and Tester J.W., 2009,Hydrothermal gasification of waste biomass: Process design and life cycle asessment, Environ. Sci. Technol., 43, 1578-1583

Lv P., Wu C., Ma L. and Yuan Z., 2008, A study on the economic efficiency of hydrogen production from biomass residues in China, Renew. Energy, 33, 1874-1879

Norman K., 2007. Interim report:feasibility of microscale glucose reforming for renewable hydrogen, Technical Report, SAND2007-1713; TRN: US200717494

Pavlas M., Stehlík P., Oral J., Klemes J., Kim J.-K. and Firth B., 2010, Heat integrated heat pumping for biomass gasification processing, Appl. Therm. Eng., 30, 30-35

Shuit S.H., Tan K.T., Lee K.T. and Kamaruddin A.H., 2009, Oil palm biomass as a sustainable energy source: A Malaysian case study, Energy, 34, 1225-1235

Smejkal Q., Sarlej M. and Stehlik P., 2009, New unit for clean energy production from contaminated biomass (1 to 3 MW_t)-example of process design, Chem. Eng. Trans., 18, 57-62