DESIGN AND OPTIMIZATION OF HEAT EXCHANGER NETWORK IN OLEFIN UNIT OF OIL REFINERY

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To my beloved parents and brothers

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ABSTRACT

The design of heat exchanger network (HEN) is an important part of the synthesis process. Optimum design of HEN can cause significant reduction in the total cost of the plant. In the mid 80’s, famous industrial companies started using a systematic approach to HEN design, called “PINCH METHOD”. This method, which is based on thermodynamic concept, is now the most applicable technique for HEN design. The superiority of this method over other techniques has encouraged industries to use it not only for grass root design, but also to retrofit their existing plants. This study investigates the systematic approach to retrofit an existing plant using the “Pinch Method”. The method was applied on the distillation unit of Isfahan refinery preheat train. Increasing crude oil of Isfahan refinery up to 50% has caused heat load increase at atmospheric furnace (H-101). This in fact, has created a serious operational problem. Retrofitting the preheat train network, however, makes the temperature of the crude oil entering the furnace to rise and, therefore reduces the heat load of the atmospheric furnace. Results show that it is possible to reduce the load of the atmospheric furnace up to 25% and restore the normal operational condition, only by USD 1 million investments. This implies a payback time of 9 months. On the other hand, applying the retrofitting technique to both nominal capacity (100,000 barrel) and increase capacity (150,000 barrel) show that despite significant increase, the key retrofitting variables remain almost unchanged. Therefore, the suggested retrofitting procedure for Isfahan refinery will be applicable to all capacities ranging from 100,000 barrel to 150,000 barrel. However, at a capacity higher than 150,000 barrel, the chance of inducing bottlenecks, for example at atmospheric tower hydraulic should be taken into consideration.

ABSTRAK

Rekabentuk rangkaian penukar haba (RPH) adalah satu bahagian penting dalam proses sintesis. Rekabentuk optimum RPH yang optimum boleh menyumbang kepada pengurangan yang tinggi dalam keseluruhan kos operasi di pelantar. Pada pertengahan 80-an, kebanyakan syarikat yang terkenal mula menggunakan pendekatan yang sistematik untuk merekabentuk RPH yang dinamakan “PINCH METHOD". Kaedah ini yang berdasarkan konsep termodinamik merupakan teknik yang kerap dipilih untuk rekabentuk RPH. Kelebihan kaedah ini telah menggalakkan pihak industri menggunakannya bukan sahaja untuk asas rekabentuk, tetapi juga untuk pemulihan peralatan pelantar kilang yang sedia ada. Kajian ini menyiasat pendekatan yang menggunakan kaedah optimum yang sistematik untuk pemulihan peralatan pelantar. Penerapan kaedah ini melibatkan pelantar minyak Isfahan. Peningkatan minyak mentah di seluruh kilang Isfahan sehingga 50 % telah menyebabkan beban panas yang teruk meningkat pada relau atmosfera (H- 101). Ini telah menyebabkan masalah besar dalam operasi pelantar minyak. Pembaharuan pemulihan peralatan terhadap jaringan pemanasan awal bagaimanapun, membuatkan suhu minyak mentah melalui relau meningkat dan seterusnya mengurangkan beban haba relau atmosfera. Hasil kajian menunjukkan bahawa pengurangan beban relau atmosfera sehingga 25 % dan memulihkan semula keadaan operasi pada keadaan asal boleh dilakukan hanya dengan pelaburan USD 1 juta. Justeru, pengembalian modal dianggarkan akan mengambil masa 9 bulan. Penggunaan teknik pemulihan peralatan untuk kedua-dua kapasiti nominal, iaitu 100,000 tong dan peningkatan kapasiti 150,000 tong menunjukkan bahawa walaupun berlaku peningkatan yang mendadak, pembolehubah pemulihan peralatan, utama hampir kekal tidak berubah. Oleh itu, prosedur pemulihan peralatan yang dicadangkan untuk kilang Isfahan boleh digunakan untuk semua kapasiti antara 100,000 tong sehingga 150,000 tong. Walaubagaimanapun, pada kapasiti yang lebih tinggi daripada 150,000 tong, kebarangkalian berlakunya ganguan kesesakan lain misalnya menara hidraulik atmosfera perlu dipertimbangkan.

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LIST OF SYMBOLS

a	-	Price of exchangers
A	-	Surface temperature for exchange energy
A_t	-	Minimum surface temperature chosen for network
$A_\propto$	-	Minimum surface temperature in one year for the network
A_X	-	Existence surface temperature
A(i)	-	The surface temperature of exchanger (i)
A_{tr} (i)	-	Minimum surface temperature for remaining problem for exchanger
b	-	Parameter for price of exchangers
C	-	Parameter for price of exchangers
CP	-	The flow in power of temperature
CP_c	-	The cold flow in power of temperature
CP_h	-	The hot flow in power of temperature
C_p	-	Capacity of the temperature
E	-	Energy need for the refinery
E_t	-	Minimum energy needed for refinery
E_{tx}	-	Minimum energy needed for refinery in the normal temperature
E_x	-	Energy usage of the existence refinery
F	-	Mass flow rate
h	-	Temperature value
NS	-	Number of the layers in the exchanger
Q	-	Temperature value on the exchangers
Q_{cmin}	-	Minimum cold utility needed for refinery
Q_{hmin}	-	Minimum hot utility needed for refinery
T_c	-	Temperature of the cold flow
T_h	-	Temperature of the hot flow
T_{ci}	-	Entrance temperature of the cold flow
T_{co}	-	Exit temperature of the cold flow

T_h - Temperature of the hot flow

T_{hi} - Entrance of the hot flow temperature

T_{ho} - Exit temperature of the hot flow

T_{in} - Entrance temperature of the flow

T_{out} - Exit temperature of the flow

$T_{pinch,c}$- Temperature of the cold flow on pinch point

$T_{pinch,h}$- Temperature of the hot flow on pinch point

U - The power of the full temperature

α - Random of the surface temperature on the refinery

$\propto_{max}$- Maximum of the surface temperature on the refinery

β - Random of the energy on the refinery

Δα - Random of the surface temperature on the refinery at α-constant

ΔA - The extra surface temperature needed

ΔA_{min}- Minimum surface temperature needed

ΔE - Optimize on energy

ΔN - The extra needed layer at refinery

ΔP - Pressure drops

ΔT - Difference in temperature

ΔT_c - Difference of the temperature at the end of cold exchanger

ΔT_h - Difference of the temperature at the end of hot exchanger

ΔT_{LM} - Difference of the temperature

ΔT_{min}- Minimum of the temperature at exchangers

$\Delta T_{min}r$- Minimum of the temperature at exchangers in remaining problem

CHAPTER 1

INTRODUCTION

1.1 Research Background

Since olden days, optimization of energy has been common among researchers. During the 1970s, it started gaining popularity as energy became a scarce resource and started getting expensive and every company was trying to find ways to reduce the cost in the refinery until they came up with the rule of heat transfer. (Gundersen.T, 2007)

As observed from the Onion diagram, the energy is used in the HEN layer.

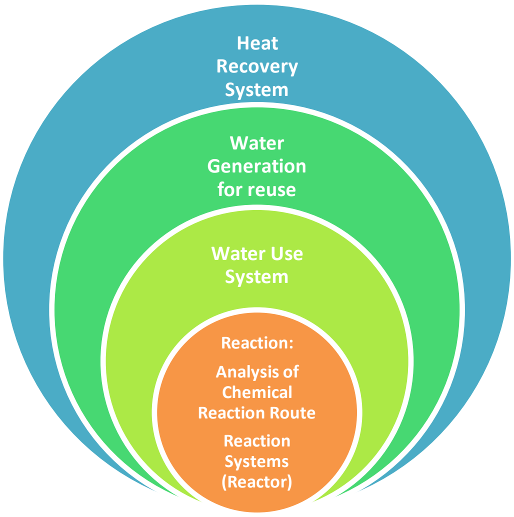

Figure 1.1: Onion diagram, Heggs, 2010

The heat transfer process is explained in Figure 1.1, developed by researchers. The core of the system is known as the reactor and the second layer is called a separator. This layer separates the reactor from the other layers and also separates the materials. The third layer is called Heat Exchanger Network (HEN), in which all the separation of hot and cold process is done. The last layer is referred to as utilities, which consist the water, electricity, smoke, and fuel. The onion diagram shown below includes reactor, separator, HEN and utility.

Figure 1.1 illustrates the role of Pinch Technology in the overall process design. The design of a process starts with the reactors which represents the analysis of chemical reaction route. Once feeds, products, recycle concentrations and flowrates are known which the water use system is the separators can be designed. Water generation for reuse represents the Heat Exchanger Network (HEN) where the basic process of heat and material balance is in place. Finally the heat recovery system represents the utility system to perform heating and cooling duties.

One of the steps to start the optimization is to check the energy use of cold and hot streams from the HEN to utility. In this process, the movement can be either from the first layer to the last layer or from the last layer to the first layer with the purpose of achieving the optimization results in the system. After the establishment of this analysis, researchers started to develop a new process that is called process integration. In this system, all the processes are integrated into a system to calculate and optimize the use of energy. The prerequisite of this process was a preliminary research on the following two subjects which are pinch technology and energy analysis.

These terms are similar in meaning but can be used in a different given context. The pinch technology works on the basis of the first law of thermodynamics, which is heat balance, whereas the energy analysis works on the basis of the second law of thermodynamics which is process energy exchanges (Gundersen.T, 2007). This process of optimization started 40 years ago and has proven its value by saving energy by 10% to 80%. This process was founded by

Linnhoff, 1984 at the University Manchester Institute of Technology (UMIST). Over one thousand projects have been done and a lot of different consulting companies have been established to provide optimization advice services based on the technique. Moreover, UMIST has introduced a new faculty under the name of integrated energy that focuses mainly on energy optimization. (Linnhoff, 2012)

The two reasons that have made this integration process very popular among chemical engineers are the support from the UK because at the time of research, the oil industry was controlled by the UK and all the major chemical engineering companies pooled in funds to form a community to work on this process. Due to these reasons, this process has gained an important place in the engineering industry after research of over 20 years. The purpose of this work, Process Integration (PI), is to give engineers the knowledge and techniques for optimization. This method shall enable exchangers to use energy in the best possible ways. The process integration can mean a number of things to different people. It may be applied in a simple heat exchanger to recover the heat from a process of steam or to recover waste heat from a gas turbine. It can be used for optimizing the reactor usage or for the integration of a number of production units in an oil refinery. In the proposed research, the PI is applied to analysis and optimization of large and complex industrial processes. Therefore, PI may be defined as the process integration, combined with other tools such as process of simulation.

PI can be used in the following industrial applications in the petrochemical engineering field:

- Energy saving and GHG emission reduction
- Debottlenecking of the critical area in a given process
- Optimization of process
- Optimization of hydrogen use
- Reactor design and operation improvements
- Minimization of water use and waste reduction
- Optimization of separation sequences

- Waste minimization (how much energy is wasted in the other parts or network)
- Utility system optimization
- Investment cost reduction (to reduce the cost of energy and come up with a lower cost)

This process has added more values to the industry, compared to the older approaches. It is better for big industrial and large complex facilities because the more complex the process, the harder it is to achieve savings without using systematic approaches such as PI. One of the best tools to use in the field of process integration in the past 20 years has been optimization analysis, which comes up with the best way of utilizing energy, water and hydrogen in companies' processes. This technique will be used in industrial fields such as:

- Chemical
- Petrochemical
- Oil refining
- Pulp and paper
- Food and drinks
- Steel and metallurgy

Over the past years, this process (PI) technique has worked perfectly. It provides a way to investigate the usage of energy in the process, and gives the most economical ways of maximizing heat recovery and minimizing the demand of external utilities (Linnhoff, 1994). The technique is used to identify energy saving projects within a process or utility system. This process helps to recover energy from the heat transfer in the refinery.

1.2 Problem Statement

Companies are always under pressure to meet new environmental limits and to work at higher efficiency to improve the capacity of the company. Therefore, there is an inevitable need to develop an optimum system and, simultaneously prevent a huge capital investment for its implementation. Hence, the problem is highly complex, primarily because the targets set by legislation or industry benchmarks are to be met, while on the other hand, investment has to be minimized. This demands an expert solution to keep costs under control while achieving high quality standards.

It is possible to achieve the goal in several ways without following any specific methodology. One of the solutions is by identifying utility infrastructure improvements that meet immediate needs as well as saving the operating costs. However, the effectiveness of such solutions is a challenge. For example, there might be other different relevant ways or projects that might solve the immediate problem, but they need bigger savings, or lower capital investment. It needs to be ascertained that all such options are considered and evaluated. The solution might be identified but making future improvement is more expensive or impossible to justify. On the country, a project that meets all such goals is needed.

Every project has to work in a longer-term perspective; structuring a solution that can also minimize operating cost, minimize the capital plan investment and minimize engineering time and effort.

1.3 Research Justification

Iran (Isfahan) refinery has not made any changes after the war in the country since 1970. This research is very important to solve the problem in the refinery, in order to save energy and save money for the refinery. Because the production line is very important for the country no changes have been made to it. As a results, researcher can show and prove that the refinery production line can be increased and better efficiency can be achieved in the refinery.

This research is expected to make a big change in the refinery, which can save much time and money. It also enhances the refinery and it can be done without sacrificing efficiency. As is known, fuel consumption is essential in everybody’s life. Therefore, this research can help to stabilize the price of fuel, increase production (line) and eventually benefit the city and the government. Several issues would prevail if the refinery does not apply the method. First, there is a probability that this refinery might stop its operation at any time because of high temperature. Second, the production cannot be maximized and would incur more cost to the government. With this study, the researcher has achieved the optimization in the refinery, reduced the heat on the exchanger and reduced the temperature on the main tower. The money that can be saved is approximately about 1, 337, 200 US dollars per year.

1.4 Research Objectives

The objectives of this research are:

1. Identify the network and exchangers that use more than the required energy in an existing oil refinery company.
2. Analyse exchangers required energy saving techniques and apply the process of optimization in refinery.
3. Propose a new design that shall be more efficient for oil refinery.

1.5 Scope of Research

The scope of the study shall encompass reducing consumption of different elements that consist of:

1. Saving energy consumption by 10% to 30%
2. Saving water consumption by 20% to 40%
3. Saving fuel consumption by up to 20%

The analysis will be done by formulating the problem and generating mathematical formula to get the best optimization result, which is known as a ΔT_{min}. This is a method to conduct optimization in the network and reduce the cost of energy in the system.

1.6 Summary of Research Methodology

Many researchers have studied this problem and introduced different methods to solve it. However, until now there is no study that has applied the method of optimization. Hence, this study works on solving the problem with the optimization method.

The methodology in this research is divided into 6 steps. The first method is “targeting”. It is designed to find out how much is needed to invest and how long it takes to get the return of the investment. The second step is philosophy of optimization, and it is to check the system based on the optimization process. This means whole refinery has to be checked well and it is essential to see how the system is working. The third step is “targeting”. This step will give optimized result in this project and the number of years of payback. The fourth step is estimating the value of investment and energy saving. This step is to estimate the value of the temperature needed and determine how much energy is going to be saved. Fifth, explaining the saving based on the investment. That can help to calculate the amount of investment and how much energy is going to be saved. The sixth step is to find out the optimized design which can reduce the cost of energy.

1.7 Research Significant

In this research a case has been studied and the limitation has been explained. The limitations are mostly to control the capital cost which is going to be used in the refinery. Next, to make changes in the refinery is difficult because the refinery is sensitive and making changes might affect other areas. This research will mostly will be applied on the refineries that have problems such as high temperature, high cost in production lines and waste of energy. Most of these refineries have been built long time ago and no changes have been made on those refineries since they were built.

1.8 Conclusion

This research is to work on an Iranian refinery (Isfahan refinery) and investigate all the exchangers and places which need to be fixed or changed. Researcher will go through all the exchangers, pipe lines, and the refinery to come up with the optimized solution to solve the current problems and increase the production line from 100,000 barrels per day to 150,000 barrels per day. The researcher has achieved the sufficient results by combining all the methods together which have been used to do optimization in refineries and come up with the optimized refinery which can increase the production line by up to 50,000 extra barrels per day. It will be shown that this refinery can increase the production line.

REFERENCES

A, K., H. Z and B. M. (2010). "Nickel/magnesium-lanthanum mixed oxide catalyst in the Kumada-coupling." Org Biomol Chem 21(8): 331-335.

Ahmed, S. and Dr, Linnhoff. (1984). overall cost target for heat exchanger. *IchemE* . 10 (2), 5.

Akdim, O., U. B. Demirci and P. Miele (2009). "Acetic acid, a relatively green single-use catalyst for hydrogen generation from sodium borohydride." international journal of hydrogen energy 34(17): 7231-7238.

Balakos, M. W. and E. E. Hernandez (1997). "Catalyst characteristics and performance in edible oil hydrogenation." Catalysis Today 35(4): 415-425.

Basagiannis, A. C. and X. E. Verykios (2007). "Catalytic steam reforming of acetic acid for hydrogen production." international journal of hydrogen energy 32(15): 3343-3355.

Bhosale, R. R., R. V. Shende and J. A. Puszynski (2012). "Thermochemical water-splitting for H2 generation using sol-gel derived Mn-ferrite in a packed bed reactor." international journal of hydrogen energy 37(3): 2924-2934.

Bimbela, F., M. Oliva, J. Ruiz, L. García and J. Arauzo (2007). "Hydrogen production by catalytic steam reforming of acetic acid, a model compound of biomass pyrolysis liquids." Journal of Analytical and Applied Pyrolysis 79(1–2): 112-120.

Blok, k., r. H. Williams, r. E. Katofsky and c. A. Hendriks (1997). "hydrogen production from natural gas, sequestration of recovered co2 in depleted gas wells and enhanced natural gas recovery." energy 22: 161-168.

Bulushev, D. A. and J. R. H. Ross (2011). "Catalysis for conversion of biomass to fuels via pyrolysis and gasification: A review." Catalysis Today 171(1): 1-13.

Cabo, M., E. Pellicer, E. Rossinyol, M. Estrader, A. Lopez-Ortega, J. Nogues, O. Castell, S. Surinach and M. D. Baro (2010). "Synthesis of compositionally graded nanocast NiO/NiCo2O4/Co3O4 mesoporous composites with tunable magnetic properties." Journal of Materials Chemistry 20(33): 7021-7028.

Chen, Y., H. Xu, Y. Wang and G. Xiong (2006). "Hydrogen production from the steam reforming of liquid hydrocarbons in membrane reactor." Catalysis Today 118(1–2): 136-143.

Dr, linnhoff, B. and Tjoe . (1984). pinch technology. *IchemE* . 10 (5), 3.

Gundersen .T (2000) process integration primer, 2nd edn., Canada : international energy agency.

Heggs, P. (1989). Minimum temperature difference approach concept in heat exchanger networks, J Heat Recov Syst CHP, 9(4): 367–375.

Howell, R. L (2000) 'Hydroprocessing Routes to Improved Base Oil Quality and Refining Economics', 6th Annual Fuels and Lubes Conference, Singapore, pp

Iwasa, N., T. Yamane, M. Takei, J.-i. Ozaki and M. Arai (2010). "Hydrogen production by steam reforming of acetic acid: Comparison of conventional supported metal catalysts and metal-incorporated mesoporous smectite-like catalysts." International Journal of Hydrogen Energy 35(1): 110-117.

J.geldermann, M.treitz and O.rentz (May 2007) 'toward sustainable production network ', international journal of production research, 45(18-19), pp.

Jimmy D. kumana (22 jun 2009) 'pinch analysis for process energy optimization', energy engineering, (), pp. e.g.18-41.

Kennedy, J. F. and J. Shimizu (1995). "Chemical fixation of carbon dioxide methods for recycling co2 into useful products: M.M. Halmann, CRC Press Inc., Boca Raton, Florida, 1993. 172 pp. Price £56.00. ISBN 0-8493-4428-X." Carbohydrate Polymers 26(1): 81-82.

Kobayashi, J., K. Yoshimune, T. Komoriya and H. Kohno (2011). "Efficient hydrogen production from acetate through isolated Rhodobacter sphaeroides." Journal of Bioscience and Bioengineering 112(6): 602-605.

Kwan-Soo Leea,Balaram Kundua, b (November 2014) 'Sustainable Development of Energy, Water and Environment Systems', , 76(SDEWES 2013), pp. Pages 733–748 [Online]. Available at:http://www.sciencedirect.com/science/article/pii/S0360544214010251 (Accessed:).

Li, J., Y. Yin, J. Liu and R. Yan (2009). "Hydrogen-rich gas production from steam gasification of palm oil wastes using the supported nano-NiO/γ-Al2O3 catalyst." International Conference on Energy and Environment Technology.

Lima da Silva, A. and I. L. Müller (2011). "Hydrogen production by sorption enhanced steam reforming of oxygenated hydrocarbons (ethanol, glycerol, n-butanol and methanol): Thermodynamic modelling." international journal of hydrogen energy 36(3): 2057-2075.

Linhoff. B (1994) User guide on process integration for the efficient use of energy, 1st edn., UK: The institution of chimerical engineering.

Masuda, T., Y. Kondo, M. Miwa, T. Shimotori, S. R. Mukai, K. Hashimoto, M. Takano, S. Kawasaki and S. Yoshida (2001). "Recovery of useful hydrocarbons from oil palm waste using ZrO2 supporting FeOOH catalyst." Chemical Engineering Science 56(3): 897-904.

Mazaheri, H., K. T. Lee, S. Bhatia and A. R. Mohamed (2010). "Subcritical water liquefaction of oil palm fruit press fiber for the production of bio-oil: Effect of catalysts." Bioresource Technology 101(2): 745-751.

Medrano, J. A., M. Oliva, J. Ruiz, L. Garcia and J. Arauzo (2008). "Catalytic steam reforming of acetic acid in a fluidized bed reactor with oxygen addition." international journal of hydrogen energy 33(16): 4387-4396.

Mohammed, M. A. A., A. Salmiaton, W. A. K. G. Wan Azlina, M. S. Mohammad Amran, A. Fakhru’l-Razi and Y. H. Taufiq-Yap (2011). "Hydrogen rich gas from oil palm biomass as a potential source of renewable energy in Malaysia." Renewable and Sustainable Energy Reviews 15(2): 1258-1270.

Mohan, D., C. U. Pittman and P. H. Steele (2006). "Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review." Energy & Fuels 20(3): 848-889.

National Petroleum Refiners Association, “1999 Lubricating Oil and Wax Capacities of Refiners and Re-Refiners in the Western Hemisphere,” January 1999.

Neiva, l. s and g. l (2010). "A study on the characteristics of the reforming of methane: a review." brazilian journal of petroleum and gas 4(3): 119-127.

Ozawa, M. and M. Kimura (1991). "Preparation and characterization of zirconium dioxide catalyst supports modified with rare earth elements." Journal of the Less Common Metals 171(2): 195-212.

P, B. G. E. and W. K.B (1951). "The Experimental Attainment of Optimum Conditions (with discussion)." Royal Statistical Society Series B 13(1): 1-45.

Patil, P. S. (1999). "Versatility of chemical spray pyrolysis technique." Materials Chemistry and Physics 59(3): 185-198.

Rahkamaa, K., Tolonen, T. Salmi, D. Y. Murzin, L. B. Dillon, H. Karhu, R. L. Keiski and J. V¨ayrynen (2002). "Investigation of NO Reduction by H2 on Pd Monolith with Transient and Isotopic Exchange Techniques." Journal of Catalysis 210: 17–29.

Ribeiro and J. e. al (2010). "Burning of coal waste piles from Douro Coalfield." International Journal of Coal Geology 81(4): 359–372.

Ryan. V (2009) Basic concept of heat exchange, Available at:http://www.technologystudent.com/energy1/solar2.htm (Accessed: 1 october 2013).

Seman, C. H. (2011). http://www.wisegeek.com/what-is-space-velocity.htm. (adopted with some minor modifications).

Sequeira, A., Jr. 2006, “Lubricant Base Oil and Wax Processing,” Marcel Dekker, Inc., Chemical Industries Series, August 1994.

Spath, P., A. Aden, T. Eggeman, M. Ringer, B. Wallace and J. Jechura (2005). "Biomass to Hydrogen Production Detailed Design and Economics Utilizing the Battelle Columbus Laboratory Indirectly-Heated Gasifier." National Renewable Energy Laboratory.

Stormont, D. H., “New Process Has Big Possibilities,” The Oil and Gas Journal, 57, 44, 1959, pp. 48-49.

Sumathi, S., S. P. Chai and A. R. Mohamed (2008). "Utilization of oil palm as a source of renewable energy in Malaysia." Renewable and Sustainable Energy Reviews 12(9): 2404-2421.

Suzuki, T., K. Miyamoto, S. Kobayashi, N. Aratani and T. Yogo (2008). "R&D on Hydrogen Production by Autothermal Reforming." 2.3.

Takanabe, K., K.-i. Aika, K. Seshan and L. Lefferts (2004). "Sustainable hydrogen from bio-oil—Steam reforming of acetic acid as a model oxygenate." Journal of Catalysis 227(1): 101-108.

Third Intl.Sym.Fuels & Lubricants ISFL (Oct.7-9, 2002) 'Sym.Fuels ', Sym.Fuels, (, New Delhi), pp.

Tjoe and Dr, linnhoff, B... (1984). heat exchanger network. *IchemE* . 8 (7), 6.

Townsend and Dr, linnhoff, B... (1984). surface area target for heat exchanger network. *IchemE* . 6 (2), 7.

Vagia, E. C. and A. A. Lemonidou (2010). "Investigations on the properties of ceria–zirconia-supported Ni and Rh catalysts and their performance in acetic acid steam reforming." Journal of Catalysis 269(2): 388-396.

Wanga, J., G. Cheng, Y. You, B. Xiao, S. Liu, P. He, D. Gua, X. Guo and G. Zhang (2012). "Hydrogen-rich gas production by steam gasification of municipal solid waste (MSW) using NiO supported on modified dolomite." international journal of hydrogen energy 37: 6503 - 6510.

Wilhelm, D. J., D. R. Simbeck, A. D. Karp and R. L. Dickenson (2001). "Syngas production for gas-to-liquids applications: technologies, issues and outlook." Fuel Processing Technology 71(1–3): 139-148.

Xiao, L., S.-Y. Wu and Y.-R. Li (2012). "Advances in solar hydrogen production via two-step water-splitting thermochemical cycles based on metal redox reactions." Renewable Energy 41(0): 1-12.

Zheng, X.-x., C.-f. Yan, R.-r. Hu, J. Li, H. Hai, W.-m. Luo, C.-q. Guo, W.-b. Li and Z.-y. Zhou "Hydrogen from acetic acid as the model compound of biomass fast-pyralysis oil over Ni catalyst supported on ceria–zirconia." international journal of hydrogen energy (0).