OPTIMAL SOLAR THERMAL DESIGN OF PALM OIL REFINERY

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ABSTRACT

One of the main contributors to global warming and climate change is the use of fossil fuels, such as coal and oil to generate electricity. Energy demand continues to grow, and the fossil fuel consumption will most likely increase, resulting in a further increase in CO2 emissions. Solar energy has many benefits over other options and is the most promising alternative energy. Solar energy is a safe and renewable source of energy originating from the sun that can be directly used to produce electricity. Solar thermal energy (STE) is a type of renewable energy and technology that can be used in manufacturing, residential and commercial sectors to harness solar energy to produce thermal or electrical energy. In Malaysia in particular, electricity is much cheaper, so it is not as attractive as other countries to switch to renewable energy. The challenger relies on the implementation of solar thermal heat systems in industrial processes and the use of solar thermal heat applications based on energy demand, consumption, and climatic conditions in Malaysia. However, the capital investment on solar thermal is not cheap and solar thermal system efficiencies varies upon multiple technical specifications and environment factors. Therefore, solar thermal potentials had to be studied and the optimum specification had to be determined for installing the solar thermal system in industrial processes. This study will be conducted by firstly familiarize the process flow, proposed the solar thermal system design, data collection and finally, solar thermal integration. The case study will be conducted in an oil palm refinery which known as Mewaholeo Industries Sdn Bhd. The best collector type, number of collectors, and solar thermal design was generated using an excel tool named Solar Heat Industry Process (SHIP) to conduct a performance and financial analysis.

ABSTRAK

Salah satu penyumbang utama pemanasan global dan perubahan iklim adalah penggunaan bahan bakar fosil, seperti arang batu dan minyak untuk menjana elektrik. Permintaan tenaga terus meningkat, dan penggunaan bahan bakar fosil kemungkinan besar akan meningkat, mengakibatkan peningkatan pelepasan CO2. Tenaga suria mempunyai banyak kelebihan berbanding pilihan lain dan merupakan tenaga alternatif yang paling menjanjikan. Tenaga suria adalah sumber tenaga yang selamat dan boleh diperbaharui yang berasal dari matahari yang boleh digunakan secara langsung untuk menghasilkan elektrik. Tenaga terma solar (STE) adalah sejenis tenaga dan teknologi yang boleh diperbaharui yang dapat digunakan dalam sektor pembuatan, kediaman dan komersial untuk memanfaatkan tenaga suria untuk menghasilkan tenaga termal atau elektrik. Di Malaysia khususnya, elektrik jauh lebih murah, jadi tidak semenarik negara lain untuk beralih kepada tenaga boleh diperbaharui. Pencabarnya bergantung pada implementasi sistem haba terma suria dalam proses industri dan penggunaan aplikasi panas terma suria berdasarkan permintaan tenaga, penggunaan, dan keadaan iklim di Malaysia. Walau bagaimanapun, pelaburan modal pada haba solar tidak murah dan kecekapan sistem terma solar berbeza-beza berdasarkan beberapa spesifikasi teknikal dan faktor persekitaran. Oleh itu, potensi haba suria harus dikaji dan spesifikasi optimum harus ditentukan untuk memasang sistem termal suria dalam proses industri. Kajian ini akan dilakukan dengan terlebih dahulu membiasakan aliran proses, mengusulkan reka bentuk sistem termal suria, pengumpulan data dan akhirnya, penyatuan termal suria. Kajian kes akan dilakukan di kilang minyak kelapa sawit yang dikenali sebagai Mewaholeo Industries Sdn Bhd. Jenis pemungut terbaik, jumlah pengumpul, dan reka bentuk terma solar dihasilkan dengan menggunakan alat excel bernama Solar Heat Industry Process (SHIP) untuk melakukan persembahan dan analisis kewangan.

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LIST OF ABBREVIATIONS

CO_2	-	Carbon Dioxide
RE	-	Renewable Energy
GW	-	Giga Watt
PV	-	Photovoltaic
STE	-	Solar Thermal Energy
CBS	-	Cocoa Butter Substitute
HVAC	-	Heating, ventilation, and air conditioning
NEM	-	Net Energy Metering
kWh	-	Kilo-watt Hour
SWH	-	Solar Water Heater
EWH	-	Electric Water Heater
SHIP	-	Solar Heat Industrial Process
INTEC	-	Institute for Sustainable Technologies
MWh	-	Mega-watt Hour
MHI	-	Mewaholeo Industries Sdn. Bhd
CPKO	-	Crude Palm Kernel Oil
CPKST	-	Crude Palm Kernel Stearin
CPKOL	-	Crude Palm Kernel Olein
FPC	-	Flat Plate Collector
ETC	-	Evacuated Tube Collector
LCOH	-	Levelized Cost of Heat
GAMS	-	General Algebraic Modelling System
LINDO	-	Linear, Interactive, and Discrete Optimizer
PCM	-	Phase Change Material

CHAPTER 1

INTRODUCTION

1.1 Problem Background

One of the main contributors to global warming and climate change is the use of fossil fuels, such as coal and oil to generate electricity. Energy demand continues to grow, and the fossil fuel consumption will most likely increase, resulting in a further increase in CO_2 emissions. Governments around the world have since taken steps to tackle this issue by promoting the introduction of renewable energy (RE) through different national program (IEA, 2017). Although renewable and alternative energy offer great potential to replace fossil fuel reliance, progress has been slow in most developed countries in getting it into the mainstream (Malahayati, 2020). Governments and businesses around the world are constantly looking for ways to reduce their operations' greenhouse emissions, with a significant emphasis on the use and deployment of sustainable renewable energy systems (Abdelaziz et al., 2011).

Iceland, Sweden, and Costa Rica are the top three countries that use renewable energy to sustain their economies rather than non- renewables. These countries can implement a renewable energy very well. Renewable sources of energy include wind, hydro, solar, biomass, geothermal energy, and tidal energy, among other things. Every renewable energy has its own benefits and drawbacks and a global preference for consumption. Between 2019 and 2024, renewable power will grow by 50%, led by solar photovoltaics. This 1 200 GW rise is equal to today 's total US installed power capacity. In figure 1.2, it shows that Solar PV alone accounts for nearly 60 percent of the projected rise, with one-quarter of onshore wind. Renewable capacity growth could be 26 per cent (1 500 GW) higher than in the main forecast of the study in the accelerated case of Renewables 2019.

The accelerated case needs policymakers to address three major challenges such as, policy and regulatory uncertainty, high investment risks in developed countries, and wind and solar energy integration in some countries. Solar PV is the single largest source of capacity for additional expansion followed by onshore wind and hydropower.

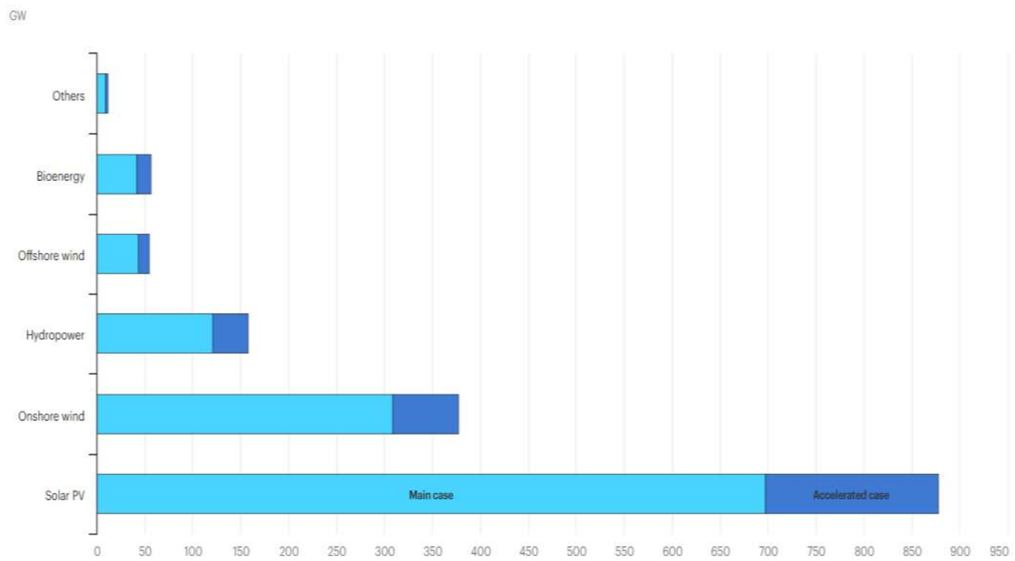

Figure 1.1 Renewable capacity growth between 2019 and 2024 by technology (Source: IEA, 2019)

Solar energy has many benefits over other options and is the most promising backup energy. Solar energy is a safe and renewable source of energy originating from the sun that can be directly used to produce electricity (Saidur, 2010). With some remarkable developments in the recent past the solar energy sector is rapidly developing. Reviews published recently concentrate widely on RE integration research and the enhancement of grid criteria with control methods. Other aspects recently published include effect and status of RE in Malaysia , public opinion-influenced policies, sustainable ideas for RE development, climate change mitigation in Malaysia and feasibility studies on solar use in Malaysia (Vaka et al., 2020).

Solar thermal energy (STE) is a type of renewable energy and technology that can be used in manufacturing, residential and commercial sectors to harness solar energy to produce thermal or electrical energy. Solar thermal technology mechanism is by collecting the heat energy from the sun and using it for heating and electricity output. By comparison, this solar thermal is different from photovoltaic solar panels which directly convert the radiation from the sun into electricity.

There are two major types of solar thermal systems which are active and passive systems used in energy production. Active systems require moving components such as pumps to move heat carrying fluids while passive systems do not have mechanical components and rely on design features to absorb heat (e.g. greenhouses) only. Solar thermal technologies can be categorized by applications of low, medium, or high temperature defined as follows:

(a) Usually systems with low temperatures (less than 100° C) use solar thermal energy for hot water. Many active systems consist of a flat plate collector mounted on the roof, from which liquid circulates. The collector receives heat from the air, and it is transported by the liquid to the desired destination, such as a home heating device. Intelligent building design practices include passive heating systems which reduce the need for heating or cooling systems by better capturing or reflecting solar energy.

(b) Medium-temperature applications (ranges from 100° C to 250° C) are not popular. An example of this would be a solar oven, which uses a specially shaped reflector to concentrate the rays of the sun on a central pot. Similar systems could be used but are not widely used for industrial processes.

(c) Solar thermal systems with high-temperature (more than 250° C) use mirror groups to focus solar energy on a central collector. These concentrated solar power (CSP) systems can reach temperatures that are high enough to produce steam, which then turns a turbine and drives a generator to generate electrical power.

In the case of solar thermal technology , solar energy is used to satisfy the demands of the various end users in the various industries, such as construction, industry and the domestic sector (Heng et al., 2019). In industrial applications, it represents a range of applications ranging from low to high temperatures. The category of HVAC needs a significant allocation of total energy demand to satisfy heat ventilation and air conditioning requirements (Vaka et al., 2020). In Malaysia, for example, HVAC needs 59% and 29% of overall energy consumption in buildings and industry. According to the IRENA study, the overall energy demand and use of buildings and factories is 90% and 24% as shown in figure 1.2.

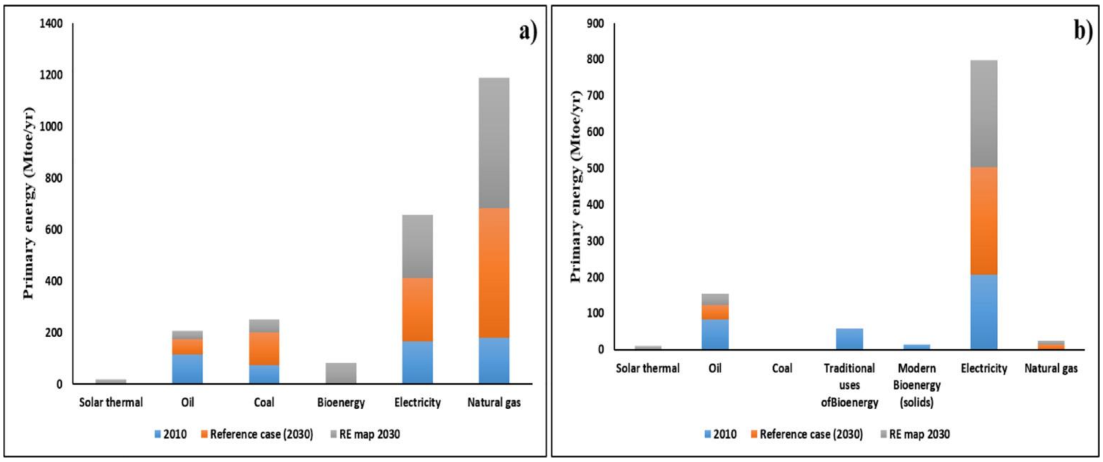

Figure 1.2 Total energy demand from different renewable sources a) For industry, b) for buildings (Source: IRENA Report)

Malaysia is experiencing hot and humid weather due to its geographic location, with a decent amount of rainfall all year round. It receives an abundance of solar radiation during the year, with an average solar radiation mean of 4.7 - 6.5 kWh/m^2 in most places (Petinrin and Shaaban, 2015). Applications involving solar energy therefore also gained popularity in Malaysia due to favourable climate conditions in the region.

Minister Yeo Bee Yin had implemented the Net Energy Metering (NEM) scheme in Malaysia, the Ministry of Energy, Science, Technology, Environment and Climate Change, with a view to growing Malaysia's renewable energy mix from 2% to 20% by 2030. Following the trend of global demand for solar panel technology and local interest in renewable energy, this study will thus assist with research data on solar system optimization in terms of cost to any location provided that the technological and environmental data are recognised as capital expenditure for such a larger target is not inexpensive.

1.2 Problem Statement

Conventional fossil fuel like oil, gas, and coal has growing environmental issues such as the carbon emission from their activities. It was important to discover a new green and renewable energy source to replace the current method of obtaining energy through combustion of fossil fuel which generates tons of CO_2 emissions, which is the main culprit of greenhouse warming. Solar thermal energy could be used as a substitute for fossil fuel because it could be produced in an environmentally friendly way that almost did not damage our climate. The challenger relies on the implementation of solar thermal heat systems in manufacturing processes and the use of solar thermal heat applications based on energy production, usage, and climatic conditions in Malaysia.

In Malaysia in particular, electricity is much cheaper, so it is not as attractive as other countries to switch to renewable energy. However, there is huge potential to harvest solar energy for industrial heating demand, below than 100 °C. Complex case of solar optimization model by understanding and considering all environmental data and costs per used technical specification had not been investigated in any research in Malaysia. The challenger relies on the implementation of solar thermal heat systems in industrial processes and the use of solar thermal heat applications based on energy demand, consumption, and climatic conditions in Malaysia. Lack of detailed model design optimization results in implemented oversized installation system which ultimately costs more than it should.

Therefore, in Malaysia, solar thermal potentials had to be studied and the optimum conditions had to be determined for installing the solar thermal system in industrial processes.

1.3 Objectives

The objectives of this study are:

a. To determine the best solar thermal system design

b. To identify the best type of solar thermal collectors

c. To determine the optimum number of solar thermal collectors within the specified area

1.4 Scope of Study

The scope of study includes:

a. Case study is an oleo chemical industry, Cocoa Butter Substitute (CBS) refinery plant.

b. The selection of solar thermal collectors based on heating demand temperature of an oleo chemical industry; Cocoa Butter Substitute (CBS) refinery plant is ranged from 40 to 100 °C.

c. Given the specified area, Solar Heating for Industrial Processes (SHIP) will be used as a tool to calculate energy and cost saved by applying solar thermal system in an oleo chemical industry.

d. Economic parameters needed to determine the best design (LCOH, Payback, and Annual savings).

REFERENCES

ABDELAZIZ, E. A., SAIDUR, R. & MEKHILEF, S. 2011. A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews, 15, 150-168.

ABIKOYE, B., ČUČEK, L., ISAFIADE, A. J. & KRAVANJA, Z. 2019. Integrated design for direct and indirect solar thermal utilization in low temperature industrial operations. Energy, 182, 381-396.

ALLOUHI, A., AGROUAZ, Y., BENZAKOUR AMINE, M., REHMAN, S., BUKER, M. S., KOUSKSOU, T., JAMIL, A. & BENBASSOU, A. 2017. Design optimization of a multi-temperature solar thermal heating system for an industrial process. Applied Energy, 206, 382-392.

BANY MOUSA, O., TAYLOR, R. A. & SHIRAZI, A. 2019. Multi-objective optimization of solar photovoltaic and solar thermal collectors for industrial rooftop applications. Energy Conversion and Management, 195, 392-408.

BIROL, F., BROMHEAD, A., IKEYAMA, S., BLASI, A., FRANK, M., KIM, S., KURNIADI, C., LEE, J. & SUEHIRO, S. 2013. Southeast Asia energy outlook. World Energy Outlook.

EL KAFAZI, I., BANNARI, R., ADIBA, E. B. E. I., NABIL, H. & DRAGICEVIC, T. 2017. Renewable energies: modeling and optimization of production cost. Energy Procedia, 136, 380-387.

EVANGELISTI, L., DE LIETO VOLLARO, R. & ASDRUBALI, F. 2019. Latest advances on solar thermal collectors: A comprehensive review. Renewable and Sustainable Energy Reviews, 114, 109318.

FARJANA, S. H., HUDA, N., MAHMUD, M. A. P. & SAIDUR, R. 2018. Solar process heat in industrial systems – A global review. Renewable and Sustainable Energy Reviews, 82, 2270-2286.

FUDHOLI, A. & SOPIAN, K. 2019. A review of solar air flat plate collector for drying application. Renewable and Sustainable Energy Reviews, 102, 333-345.

GARG, H. P. & DATTA, G. 1993. Fundamentals and characteristics of solar radiation. Renewable Energy, 3, 305-319.

GOSWAMI, D. Y., KREITH, F. & KREIDER, J. F. 2000. Principles of solar engineering, CRC Press.

HENG, S. Y., ASAKO, Y., SUWA, T., TAN, L. K., SHARIFMUDDIN, N. B. & KAMADINATA, J. O. 2019. Performance of a small-scale solar cogeneration system in the equatorial zone of Malaysia. Energy Conversion and Management, 184, 127-138.

HEREZ, A., EL HAGE, H., LEMENAND, T., RAMADAN, M. & KHALED, M. 2020. Review on photovoltaic/thermal hybrid solar collectors: Classifications, applications and new systems. Solar Energy, 207, 1321-1347.

IEA 2017. Southeast Asia Energy Outlook 2017.

IEA. 2019. Renewable capacity growth between 2019 and 2024 by technology [Online]. Available: https://www.iea.org/data-and-statistics/charts/renewable-capacity-growth-between-2019-and-2024-by-technology [Accessed 11 Aug 2020].

KASAEIAN, A., NOURI, G., RANJBARAN, P. & WEN, D. 2018. Solar collectors and photovoltaics as combined heat and power systems: A critical review. Energy Conversion and Management, 156, 688-705.

KIM, J., HONG, T., JEONG, J., LEE, M., KOO, C., LEE, M., JI, C. & JEONG, J. 2016. An integrated multi-objective optimization model for determining the optimal solution in the solar thermal energy system. Energy, 102, 416-426.

KUMAR, L., HASANUZZAMAN, M. & RAHIM, N. A. 2019. Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. Energy Conversion and Management, 195, 885-908.

KYLILI, A., FOKAIDES, P. A., IOANNIDES, A. & KALOGIROU, S. 2018. Environmental assessment of solar thermal systems for the industrial sector. Journal of Cleaner Production, 176, 99-109.

MALAHAYATI, M. 2020. Achieving renewable energies utilization target in South-East Asia: Progress, challenges, and recommendations. The Electricity Journal, 33, 106736.

MAURER, C., CAPPEL, C. & KUHN, T. E. 2017. Progress in building-integrated solar thermal systems. Solar Energy, 154, 158-186.

MEKHILEF, S., SAFARI, A., MUSTAFFA, W. E. S., SAIDUR, R., OMAR, R. & YOUNIS, M. A. A. 2012. Solar energy in Malaysia: Current state and prospects. Renewable and Sustainable Energy Reviews, 16, 386-396.

PELDA, J., STELTER, F. & HOLLER, S. 2020. Potential of integrating industrial waste heat and solar thermal energy into district heating networks in Germany. Energy, 203, 117812.

PETINRIN, J. O. & SHAABAN, M. 2015. Renewable energy for continuous energy sustainability in Malaysia. Renewable and Sustainable Energy Reviews, 50, 967-981.

ROMMEL, M., KOVÁCS, P. & KRAMER, K. 2011. Solar thermal technology update [Online].Available:http://www.renewableenergyfocus.com/view/17067/solar-thermal-technology-update/ [Accessed 1 September 2020 2020].

SAIDUR, R. 2010. A review on electrical motors energy use and energy savings. Renewable and Sustainable Energy Reviews, 14, 877-898.

SAIDUR, R., RAHIM, N. A., PING, H. W., JAHIRUL, M. I., MEKHILEF, S. & MASJUKI, H. H. 2009. Energy and emission analysis for industrial motors in Malaysia. Energy Policy, 37, 3650-3658.

SCOLAN, S., SERRA, S., SOCHARD, S., DELMAS, P. & RENEAUME, J.-M. 2020. Dynamic optimization of the operation of a solar thermal plant. Solar Energy, 198, 643-657.

SHARMA, N., VARUN & SIDDHARTHA 2012. Stochastic techniques used for optimization in solar systems: A review. Renewable and Sustainable Energy Reviews, 16, 1399-1411.

VAKA, M., WALVEKAR, R., RASHEED, A. K. & KHALID, M. 2020. A review on Malaysia's solar energy pathway towards carbon-neutral Malaysia beyond Covid'19 pandemic. Journal of Cleaner Production, 273, 122834.

WAGH, M. M. & KULKARNI, V. V. 2019. Thermal energy demand fulfillment of Kolhapur through modeling and optimization of integrated renewable energy systems. Renewable Energy Focus, 29, 114-122.

YıLMAZ, İ. H. & MWESIGYE, A. 2018. Modeling, simulation and performance analysis of parabolic trough solar collectors: A comprehensive review. Applied Energy, 225, 135-174.