A Pre-Feasibility Study to Implement Solar Hot Water (SHW) System to Reduce the CO_2 Emissions

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***Abstract*— The world Green House Authorities are encouraging the industrial sector to use green energies since last two decades to reduce the CO_2 Emissions. Hot water and steam are one of the significant requirements in the industries, and to fulfill this requirement, natural gas boilers are commonly used by the industries. However, due to the vast usage of conventional boilers, the emission of CO_2 increases in the environment. Therefore, Solar Thermal Collectors (STC) gain the importance over natural gas boilers as green energy products in the industry to generate hot water and steam. The performance of STC depends on the different factors such as solar irradiation, non-shading area, cost, and heating capacity. The objective of this pre-feasibility study is to see the technical viability of the Solar Hot Water (SHW) system in order to fulfill the industrial hot water requirement. It can be observed from the result that SHW system is capable of generating averagely 614.75kW/day which can save 123.93 KG of CO_2. Furthermore, the performance of the different type of solar collectors is also analyzed comprehensively. It is observed that the evacuated tube collector performs better as compared to the flat plate collector.**

***Keywords*— Renewable Energy (RE), Solar Hot Water (SHW) System, Solar Thermal Collector (STC), CO_2 Emissions.**

I. SOLAR HOT WATER SYSTEM

In the industrial sector, the use of the Solar Hot Water (SHW) System is advantageous in many situations, the demand is constant throughout the year, and current storage facilities may be used. Nevertheless, only a few SHW systems have been installed in industrial companies around the world, and their capacity is around 0.02% compared to the installed capacity of the conventional boiler system. Possible research on the use of the SHW system for industrial processes has been carried out in the past for different countries and regions. In addition to low - temperature applications, there are several possible areas of use for solar thermal energy at medium and medium-high temperatures (80° C - 240° C). The most significant of these is the generation of steam and production of heat for industrial processes, desalination of seawater, and solar drying [1]–[3].

In comparison to fossil fuel heating systems, the SHW system is primarily designed to reduce pollution and preserve fossil fuel reserves. On the other hand, solar energy is a renewable zero-carbon energy stream, ; therefore it can be used to displace non-renewable or carbon-emitting fuels. With the development of a more dynamic range of energy sources, it is also benefited energy security. However, the typical SHW system uses a collector of 2 - 5 m^2 and this system is capable of fulfilling the requirement of annual hot water between 40% to 50% while considering a minimum storage temperature of 60^o C. To achieve maximum carbon savings, the optimal size of SHW system need to be installed [4], [5]. As shown in Fig. 1, a typical SHW system consists of solar thermal collectors, storage tanks and a conventional boiler. The other related elements of SHW include a heat exchanger, water pump, and a control system.

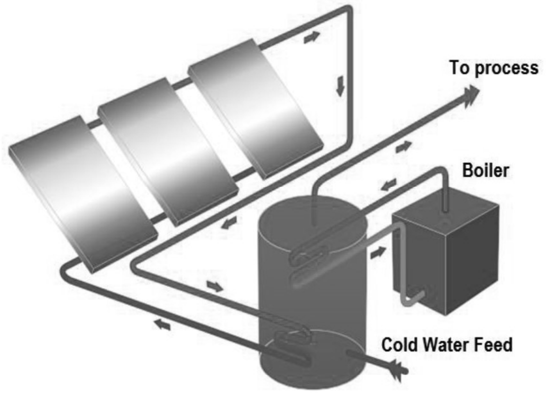

Fig. 1 A typical SHW System

II. SOLAR THERMAL COLLECTORS

Solar thermal collectors (STCs) are different types of heat exchangers that collects the incoming solar radiation, transforms it into heat, and transfers the heat to a fluid (such as air, water, or oil) which flows through the collector. Thus, obtained solar energy can be transferred to circulate the fluid either directly to the hot water or space-conditioning equipment or to the thermal energy storage tank from which it can be drained for a night and/or rainy days usage.[3]

The mechanism of solar thermal systems may be defined as natural or forced diffusion. This system is typically used for the processing of hot water or zone heating, but it can also be used for different purposes. Many types of solar thermal collectors used for various applications are available nowadays, and it can be classified as non-concentrating and concentrating solar thermal collectors. In residential and commercial buildings, non-concentrating collectors are commonly used, while concentrating collectors are usually used in solar power plants. Fig. 2 shows the key categories of solar thermal collectors[6].

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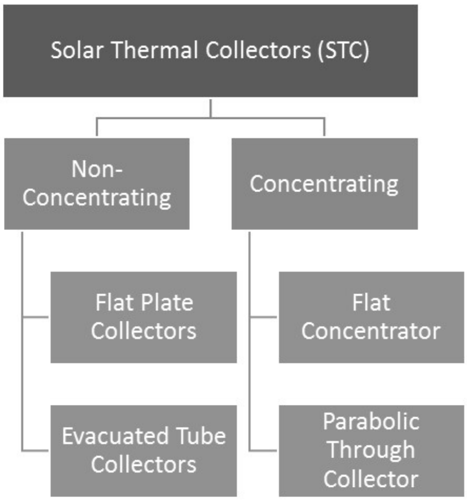

Fig. 2 Major Types of STC

A. *Flat Plate Collectors*

Flat Plate Collectors (FPCs), a type of non-concentrating solar thermal collector, are widely used in low-temperature solar thermal systems, especially for domestic hot water and solar district heating systems. It is broadly acknowledged that the thermal performance of FPCs has been significant from improving energy efficiency. Commonly FPCs are based on metal structure, transparent sheet, an absorber plate attached to the risers and tubing, and thermal insulation. One of popular design of FPCs is tube-on-sheet, which connects the absorber plate and the header riser tube. [7].

Fig. 3 (a) Flat Plane Collector [8]

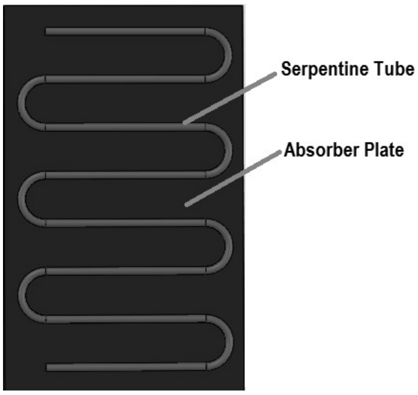

Fig. 3 (b) Flat Plate Collectors (Internal Structure)

B. *Evacuated Tube Collectors*

The Evacuated Tube Collector (ETC) is designed to use a vacuum shield that reduces absorber heat losses, which boosts solar radiation to improve energy efficiency. Evacuated solar tube collectors that use heat pipe technology function differently than other collectors on the market. A limited amount of work fluid (often pure water) is stored in the lower part of the heat pipe, which, as heat is absorbed from the air, evaporates and falls into the heat pipe to the top (condenser). Solar pipe collectors currently have become a common component of high temperature solar thermal systems. The vacuum shield around the heat pipe prevents heat loss through convection and conductivity, and allowing the collectors to work at higher temperatures than the Flat Plate Collectors (FPC)[9].

Fig. 4 (a) Evacuated Tube Collector [10]

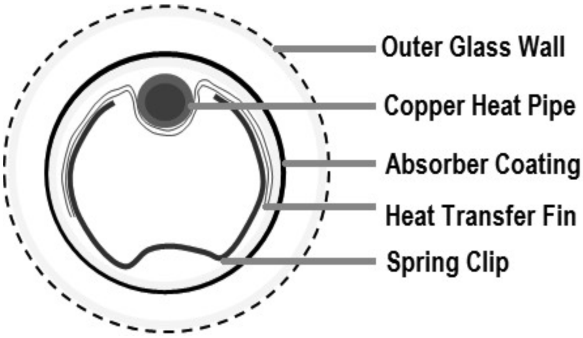

Fig. 4 (b) Evacuated Tube Collector (Internal Structure)

C. *Comparison of Flat Plate and Evacuated Tube*

Table I summarizes the comparison between the Evacuated tube and Flat plate solar collector. From the Table, it can be observed that the flat plate suffers more by corrosion effect as compared to the evacuated tube. On the other hand, flat plate collectors require more area, but the price of the collector is lesser than an evacuated tube because of its simple design and easy to manufacture. In addition to that, it is capable of producing lean-to snow even with the less intensity of radiance. However, the evacuated tube is lighter in weight and contains more heating capacity as compared to flat plate collectors. Therefore, efficiency of the evacuated tube collector is higher than the flat plate collector.

TABLE I. COMPARISON OF FLAT PLATE AND EVACUATED TUBE SOLAR THERMAL COLLECTORS

Comparison of Flat Plate and Evacuated Tube		
Parameter	***FPC***	***ETC***
Required Installation Area	More	Less
Corrosions Effect	More	Less
Cost	Less	More
Weight	More	Less
Heating Capacity	Less	More
High Temp Effect on Efficiency	More	Less

III. DESIGNING OF SHW SYSTEM

A. Project Location and Radiation

The location of this project is one of the factories in Johor, Malaysia. The coordinates of the city are 01°29'14", 103°46'52". According to the [11], the annual average of Global Horizontal Irradiation (GHI) is 1553 kWh/m^2 and the daily average of GHI is 4.26 kWh/m^2. This radiation is considerable for the pre-feasibility of SHW system. In Fig. 5 (a) & Fig. 5 (b) below, the daily average according to months and hourly profile are shown base on-peak hours (7AM-5PM:UTC+08).

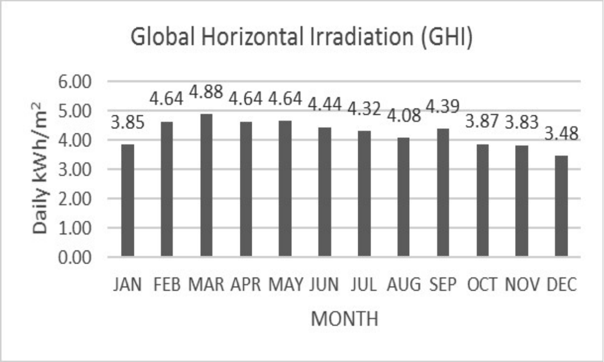

Fig. 5 (a) Monthly GHI of project location

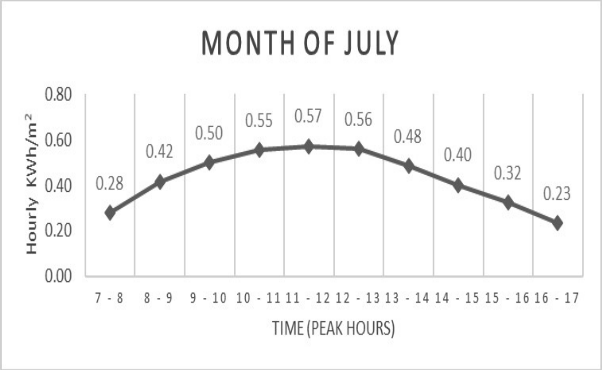

Fig. 5 (b) Hourly GHI of Project Location

B. STC Selection

Among various types of STC, ETC have several characteristics that make them more efficient. To meet the factory hot water requirement, several elements was considered to select STC, e.g. temperature requirement, radiation and shading effect, area, and price. According to the factory area, there is no place to mount the panels on the ground.

A roof-top of 15.05 x 38.95 meters has been selected on-site without shading effect, but a new structure is required for the installation of the selected STC. Base on the available space, the energy calculation of both STC was executed, which is shown in Table II. The Evacuated Tube Collector (ETC) can produce 614.75 kW energy. In contrast, Flat Plate Collector (FPC) can generate only 396.62 kW energy in the same area as ETC. The major specifications of selected ETC can be seen in Table III. It comes with a different number of evacuated tubes and sizes. In this study, 18 evacuated tubes ETC is used for the energy calculation base on its energy output and size.

TABLE II. GHI CALCULATION BASE ON FPC & ETC

GHI Calculation base on FPC & ETC			
Description	***Unit***	***FPC***	***ETC***
Gross Area	m^2	2.00	3.41
Aperture Area	m^2	1.88	3.00
GHI / Day / STC	kW	7.52	12.77
Efficiency	%	41.20	61.20
Energy / Day / STC	kW	3.10	8.20
No. of STC	piece	128.00	75.00
Energy / Day / STC System	kW	396.62	614.75

TABLE III. EVACUATED TUBE COLLECTOR [10]

ETC with CPC Reflector		
Description	***Unit***	***Value***
Model		CPC-1518
No. of Evacuated Tubes		18.00
Efficiency	%	64.20
Yield forecast (per annum)	kWh/m²	651.00
Grid dimensions (l x h x d)	Meter	2.08x1.64x0.1
Gross surface area	Meter squre	3.41
Aperture area	Meter squre	3.00
Collector capacity	Liter	2.40
Weight	Kilogram	54.00
Maximum pressure	Psi	145.04
Maximum temperature	°C	272.00
Connection dia	Millimeter	15.00
Sensor sleeve	Millimeter	6.00

According to the space availability, 75 Evacuated Tube Collectors (ETC's) can be installed in the given place. Each panel is a 3-meter square (3 m^2), which offers 64.2% efficacy in the average of the Global Horizontal Irradiation (GHI) system. The design system of 75 ETC's generates 614.75 kWh in average (during peak hours), which is equivalent to 2213.09 Megajoules (MJ). The average GHI per day of 10 hours (07AM to 05PM) is 4.26 kW/m^2 or 15.32 MJ/m^2. The ETC size is 3 meters, and it provides an average efficiency of 64.2%. The each ETC drive average daily energy of 8.20 kW/3m^2 or 29.51 MJ/3m^2. The GHI calculation can be visualized in Table II below. The average daily system energy, according to months are displayed in Fig. 6.

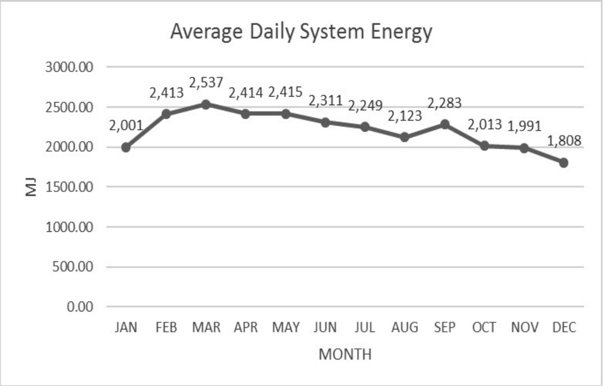

Fig. 6 Average Daily System Energy

C. *Process Design*

The hot water required by the factory process is nearly 5.80 Matric Ton (MT) to be stored in a reserved water tank with a size of 20.00 MT. The hot water process is a closed-loop, which circulates through the different factory processes. The return process temperature is 55°C compared with the supplied temperature of 85°C. This shows that the temperature is critically needed to be raised by SHW or conventional gas-fired boilers. The process operated 24 hours daily and the SHW system only can supply the hot water during peak hours from 07AM to 05PM.

The ETC elevation from the ground is 8.35 meter or 27.40 Feet. For the water circulation from the storage tank to ETC through heat exchanger, a pump is required. The nominal flowrate of selected ETC is 6.5m^3/hour, compared with the higher range (8m^3/hour) of centrifugal pump with one (1) inch of suction and discharge diameter.

Remote Monitoring is done through Industrial Internet of Things Technology/Technique. The monitoring system will include the auxiliary sensors, Programmable Logic Controller and Industrial IoT Data Gateway. A cloud-based dashboard will be developed to monitor and analyze the data after the successful implementation of the project.

IV. PRE-FEASIBILITY RESULTS & ANALYSIS

The above-proposed design for the SHW system will contribute to supplying hot water to the process plant throughout the year. In this pre-feasibility studies, three major variables were considered,

i. Project Location & Radiation
ii. STC Selection
iii. Process design.

From the initial study, it was found that the Global Horizontal Irradiation (GHI) is sufficient at the factory side based on the available area for Solar Thermal Collector (STC) Installation. The energy calculation of the two major STC has been conducted (can be seen in Table II). The Evacuated Tube Collector (ETC) produces more energy at the required temperature level as compare to Flat Tube Collector (FTC). Finally, in the process, the pump (s) are required to circulate the water from the cold-water tank to the hot water tank through Evacuated Tube Collectors & heat exchanger. Pressure and Flowrate were considered as major parameters for the pump selection. Two centrifugal pumps are chosen with the 8m^3/hour capacity.

Energy generation has been simulated for peak hours only (7AM to 5PM). The required energy is 7273.20 MJ/day for 58.00 MT/day hot water to raise and maintain the temperature at 85°C. The SHW system can provide 2213.09 MJ/day for 17.65 MT/day hot water to meet the temperature demand. The conventional boiler generates the rest of the energy to meet the factory's hot water requirement.

The analysis of Energy and hot water generation from the SHW system and conventional boiler can be seen in Table IV. In the early hour (7-8) and last hour (16-17) the energy production by the SHW system is low. On the other hand, production is high during 09-13 hours. The boiler contributes to the energy more at the begging and end of the day. But during 09-13 hours the boiler is on less energy production as low as 414.80 MJ/hour.

The average hourly energy produced by the system is 221.31 MJ, which provides 17.65 MT/ hour in average. In Fig. 8, we can see that the SHW System is contributing 30.43%, and the conventional boiler offers the rest of the 69.57% energy. This shows a good SHW system efficiency (30.43%) during peak hours (07 AM to 5 PM) and the viability of the proposed project. The SHW system provides a maximum of 42.97% efficiency during 10-11 hours. The least contribution from the SHW system is 13.84 during the last hours (16-17) of the peak day. The conventional boiler is running partially for 10 hours and 14 hours fully to produce the required hot water for the factory process. The overall efficiency of the system for 24 hours is 12.68%, in which the SHW System runs for only 8 hours.

TABLE IV. ENERGY AND HOT WATER GENERATION FROM SHW SYSTEM AND CONVETIONAL BOILER

Time	***Required Energy Generation***	**Energy Generated**		***Requirement of Hot Water***	**Supply of Hot Water**	
		SHW System	***Conventional Boiler***		***SHW System***	***Conventional Boiler***
Hour	MJ	MJ	MJ	MT	MT	MT
7 – 8	727.32	151.51	575.81	5.80	1.21	4.59
8 – 9	727.32	239.92	487.40	5.80	1.91	3.89
9 – 10	727.32	283.73	443.59	5.80	2.26	3.54
10 - 11	727.32	312.52	414.80	5.80	2.49	3.31
11 - 12	727.32	306.90	420.42	5.80	2.45	3.35
12 - 13	727.32	272.66	454.66	5.80	2.17	3.63
13 - 14	727.32	220.79	506.53	5.80	1.76	4.04
14 - 15	727.32	177.53	549.79	5.80	1.42	4.38
15 - 16	727.32	146.85	580.47	5.80	1.17	4.63
16 - 17	727.32	100.67	626.65	5.80	0.80	5.00
Total/Day	**7273.20**	**2213.09**	**5060.11**	**58.00**	**17.65**	**40.35**

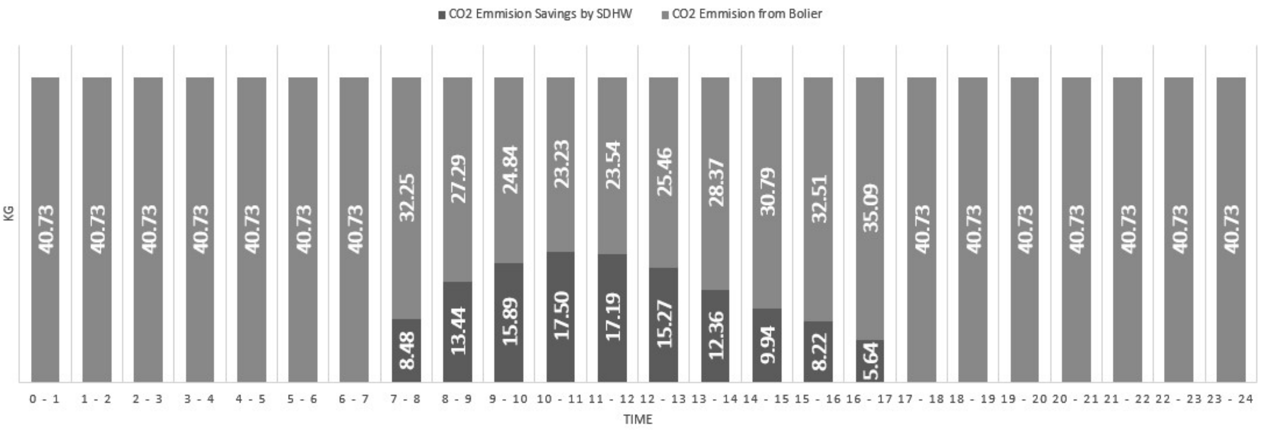

Fig. 7 CO_2 Emission after SHW System

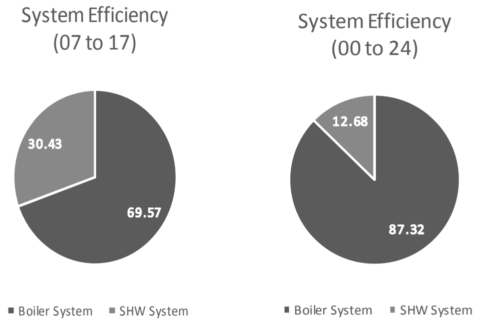

Fig. 8 SHW System Efficiency

In line with the results illustrated in Table IV, the carbon dioxide (CO_2) emission has been calculated and shown in Fig. 7. Without the SHW system, the boiler emits around 1 Ton of CO_2 in 24 hours. But with the SHW system it will come down to 0.85 Ton/day. If we look at only peak hours (07-17), we can reduce 0.125 tons of CO_2 emission which is equal to 30% of total CO_2 emission in 10 hours.

V. CONCLUSION

This pre-feasibility study shows the viability of implementing the Solar Hot Water (SHW) system in the process factory to reduce the CO_2 Emission. Solar Thermal Collectors (STC) are the major element of the SHW system, and energy generation capacity from two major STC's are evaluated in this research. The result from the observed evaluation proves that Evacuated Tube Collector (ETC) gives the 35.48% high energy as compare to Flat Tube Collector (FTC). The SHW system offers a 30.43% supply of hot water to the factory process in the peak hours (07-17); however full day (00-24) efficiency of the proposed system is 12.68%. On the other hand, CO_2 emission by Boiler is 40.73KG/hour in off-peak hours, and with the integration of SHW system, during peak hours it saves 12.39KG/hour. It can be concluded that the use of a solar hot water system is recommended for the factory to reduce the CO_2 Emission to enhance the quality of life and health standards.

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