ISSN 2250-3153

Challenges and Prospect for the Development of Parabolic Trough Solar Collectors (PTC's) in Malaysian Environment

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Abstract- The demand of energy, global warming and greenhouse gas emission have forced the world to look into alternative sources of energy. Solar thermal technologies are regarded as the most promising technology that can supplement the usage of fossil fuels in power generation. Among the solar thermal technologies, parabolic trough solar collectors (PTC's) from the concentrated solar power (CSP) technology are the most matured application for the production of electricity and steam generation. The development of parabolic trough solar collectors has been carried out throughout the world for different thermal applications ranging from industrial heat process to generation of electricity. In Malaysia, the use of solar thermal technology for the generation of electricity and industrial heat process is not given much attention. Therefore, the objective of this paper is to review the development of parabolic trough solar collectors (PTC's) for different thermal applications and pointing out some challenges and prospects associated with the development of PTC in Malaysian environment.

Index Terms- Solar radiation, Thermal energy, parabolic trough collector, Development, Concentrated solar power

I. Introduction

Energy demand, global warming from the fossil fuels and move to minimize greenhouse gas emission have put the focus on how making use of an alternative sources of energy such as renewable energy technology. Fig. 1.0: Shows that 78.4% of the world energy consumptions is supplied from the fossil fuels and only 19% of the supplied energy is from renewable energy while nuclear energy carries 2.6% [18]. However, the global energy demand is expected to increase to 53% by the year 2030 according to the international energy Agency [23], and 70% of the estimated growth energy demand is expected to come from the developing countries. Malaysia is one of the most developing countries that currently uses fossil fuel as its primary source of energy. The power generated from the fossil fuels in Malaysia reads 91.9 % [9] and is expected to reach to 38.9 metric tons by the year 2030 [19]. Although, there is a plan in the 10th Malaysian plan to increasing the renewable energy power generation to 5.5% by the year 2015 [].

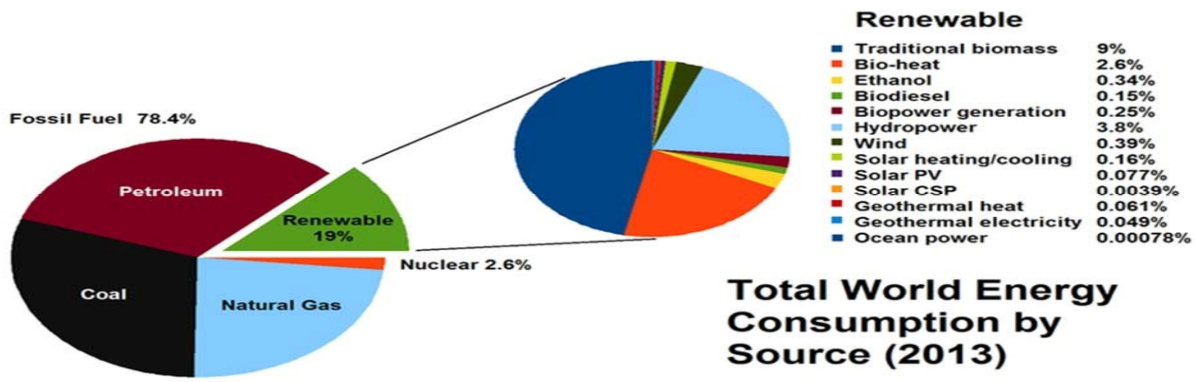

Fig: 1.1.: World energy consumption [18]

Solar thermal technology is an alternative source of the renewable energy technology that can supplement/replace fossil fuels. Concentrating solar power (CSP) Technologies is one of solar thermal technology that is suitable for the generation of electricity. Among the CSP technology, a parabolic trough solar collector (PTC) is the most matured application for the production of electricity as well as steam generation. Though, CSP technologies were not given much attention in the Malaysian context as reported by [17], this is due to the climatic nature of the country that characterize by the high formation of clouds, humidity and heavy rainfall. However, the awareness on how making use of solar thermal technology, to real life applications among Malaysian is also very little [5] and in addition the parabolic trough solar collectors are not available in the Malaysian market [9].

The conversion of solar energy radiation is divided into two types: the thermodynamic cycle and photovoltaic, but the thermodynamic cycle method of conversion will be focused in this paper.

The first type of converting solar energy is the thermodynamic circle or thermodynamic solar technologies. This type of conversion divided into two groups: the first group is the one operating at medium (about 500^0C) and higher temperatures (about 1000^0C) which have become one of the most attractive fields of solar thermal technology for the generation of electricity. The other group is the one operating at medium (about 100^0C) and higher temperatures (about 250^0C) and are regarded as the most suitable applications for steam generation, such as hot water production, cooking, drying, refrigeration, cooling, etc.

The CSP systems that can be used to generate electricity from solar energy are: power tower, linear Fresnel reflector, parabolic dish and parabolic trough solar concentrators [27].

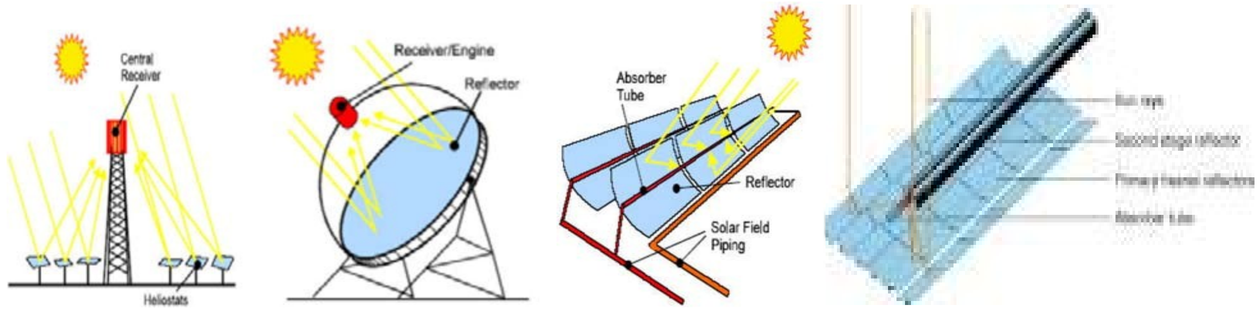

Fig: 1.3: Diagrams of the four CSP Systems (Power Tower, Dish, Trough and Fresnel), [14]

1.2 Parabolic Trough Solar collectors (PTC'S)

PTC's are the most matured, low-cost and most efficient source of energy of the CSP technology. The trough contractor uses reflectors curved around one axis using a linear parabolic shape to reflect solar energy directly onto the receiver tube located along the focal line of the parabolic trough concentrator. The collector will continuously track the sun with the help of the tracking system to ensure the maximum reflection of the solar radiation on the receiver [Ahmad, 2012].

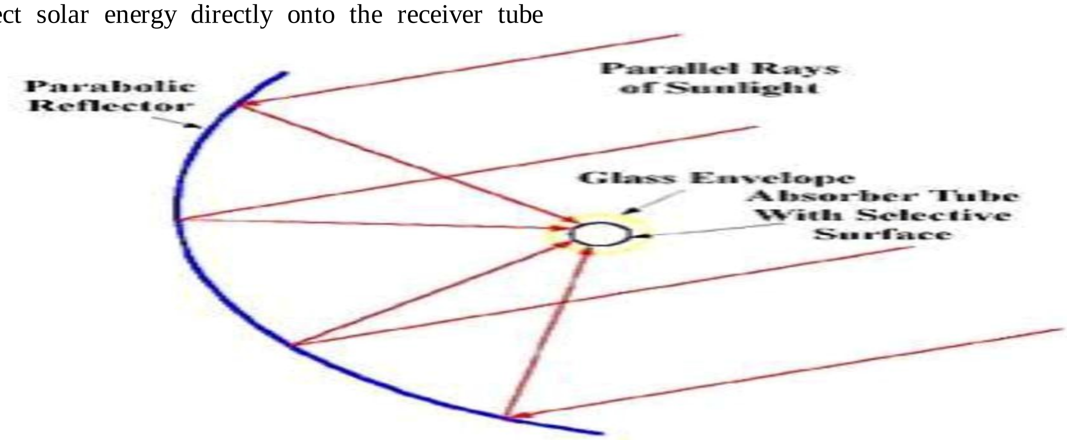

Fig 1.4: Parabolic solar trough collector [1]

Currently PTC is the most established and attractive aspect of the CSP technology for electricity and steam generation.

1.3 Solar Energy Potentials in Malaysia

Malaysia is an equatorial country of 1^0 and 6^0 N, 101^0 and 118^0E. The tropical environment has been characterized by a heavy Rainfall, winds, high level of clouds, high temperature and high humidity. With all these characteristics, Malaysia receives a huge amount of solar irradiation every year. However, the daily solar irradiation in Malaysia is around 4.7 to 5.8 kWh/m^2 with 6.8kWh/m^2 in August and November while monthly solar irradiation of Malaysia is 133.0kWh/m^2 and yearly value is around 1596.5kWh/m^2 to 1643kWh/m^2/year [19]. Furthermore, Malaysia has averagely about 6h sunshine per day and the annual, varying temperature of 26 to 28^0C [17]. Meanwhile, northern Malaysian states and few places in east Malaysia receive high amount of solar irradiation throughout the year. More so, Malaysia is considered as one of the wet climate countries where the annual rainfall is about 2250mm/year and the cloud cover is normally high throughout the year, even in the dry season [16]. The rate of humidity in Malaysia varies from 80% to 90%. Therefore, from the given solar radiation data in Malaysia, northern states and several places in east Malaysia can be considered as suitable places for CSP technology compared to other places in Malaysia [16]. Though, for the CSP technology to be economically feasible it requires direct solar irradiation (DNI) of atleast1900-2000kwh/m^2/day or daily solar irradiation value of at least 5kwh/m^2/day [17]. Therefore, with the given data above, we can conclude that the parabolic trough solar concentrator for thermal heat applications can be applied in Malaysian environment.

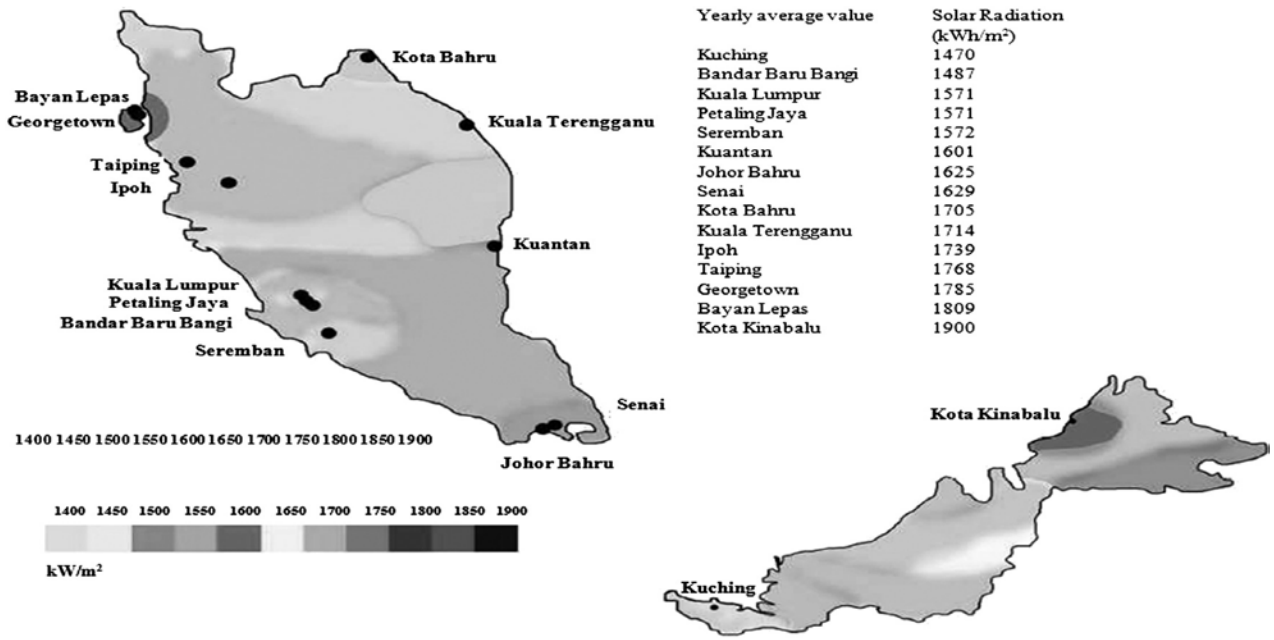

Fig: 1.5: Annual average solar radiation in Malaysia [21]

1.4 Application of Parabolic Trough Solar Concentrators (PTC's)

The application of PTC's divided into two groups: namely,

1. The parabolic trough solar power generation that requires temperatures ranging from 300^0C to 400^0C which is the main application of the concentrated solar power (CSP) technology, and
2. The industrial process heat applications for refrigeration, space heating, cooling and drying, which requires temperatures ranging from 100^0C to 250^0C

The water heating parabolic solar trough is one of the several applications of solar energy technologies. This type of technology can be used on a commercial scale to produce high pressure steam for power generation as well on a small scale industries and residential applications. For small factories processing, a moderate temperature ranging from 100^0C to 250^0C is required for food canning, paper production, air conditioning, refrigeration, sterilization [35].

1.5 Development perspective of parabolic trough solar collectors

PTC is the most established and low-cost aspect of the CSP technology for the electricity and steam generation.

The first experience with the PTC^s goes back to 1870 (30), when a Swedish engineer, John Ericsson, design and construct a $3.5m^2$ aperture collector that operates the small engine of 373-W called direct steam generation (DSG). Steam produces directly from the solar collector. The world attention on concentrating solar thermal technology was negligible for almost 60 years [8]. But, in reaction to the oil crisis, global warming and greenhouse gas emission, international interest were drawn towards alternative energy sources to supplement fossil fuels. PTC is an alternative means from CSP technology that can generate electricity and steam production [34]. Many parabolic trough solar thermal concentrators have been designed, manufactured, developed, constructed, operated and evaluated throughout the world, but a few will be discussed in this literature.

The most common and recent application of PTC for power generation is the nine commercial solar energy generating systems (SEGS) that has aperture of a black silvered mirror area of $2.32x10^6m^2$ and a receiver of 70mm diameter steel tube which have been developed, installed and in operation in Mojave desert Area of southern California that has a total installed capacity of 354MWe [24]. However, the power generating system consists of two subsystems that uses two heat exchangers with the oil as thermal heat transfer fluid, the function of the two subsystems is to obtain superheated steam and to convert the thermal energy into electricity while rejecting the waste heat.

Fiberglass trough parabola for parabolic trough concentrators of a 90^0 Rim angle for hot water application was designed, manufacture and tested in [39]. The thermal performance of the fiberglass reinforced parabolic trough collector of aperture area $1m^2$ that manufactured by a lay hand method was determined according to the ASHRAE standard 93 method of testing the thermal performance of the PTC's. However, copper tube of 12.8mm diameter was used as a receiver coated with a resistance black paint and enclosed by a glass envelope with the water as a heat transfer fluid. Furthermore, the standard deviation of the parabolic trough surface error of 0.0066 rad indicates that the parabolic trough surface was accurately constructed and the manufactured. However, the developed fiberglass reinforced parabolic trough can be used for low-cost production as well as the batch production for all collectors' size.

Tadahamum Ahmed Yassen, (2012) conducted an experimental and theoretical study of a parabolic trough solar collector to determine the thermal efficiency of the parabolic trough solar collector during winter and summer climatic conditions of Takrit-Iraq. The study was done by performing theoretical calculation of the solar radiation of Takfir-University and programming the theoretical result into the FOTRAM 90 program where the solar collector's parameters were entered into the program so as to determine the thermal efficiency of the collector theoretically. Furthermore, experimental studies was carryout with the same dimension and parameters of the PTC during the winter and summer climatic conditions, and in addition a comparison was made between the experimental and theoretical study of the parabolic trough solar collector. The result of the comparison shows that the theoretically determined thermal efficiency of the concentrator is greater than the actual thermal efficiency by 15%- 7% and the thermal efficiency of the parabolic trough concentrator in winter is greater than that of summer by 5%-2% respectively [37].

Design, test and mathematical modelling of a two prototypes PTC's of aperture area 1.85 and 5.78 m^2 and 180^0 rim angle was developed in [29]. Two Univpm.01 and Univpm.02 composite fiberglass materials with extruded polystyrene was used for the two prototypes and the mathematical model was developed in order to predict the thermal losses and optical efficiency of any parabolic trough concentrator (PTC) which was validated through comparison with the two developed prototypes experimental results. However, the two prototypes built was tested with oil and water as a heat transfer fluid and have a working temperature ranging from 10 - 150^0C. Furthermore, a simulation environment was developed for the yearly simulation of the PTC field and heat demand profile. A PTC uses a mirror as a reflecting surface to reflect and concentrate solar radiation onto the receiver tube at the focal line of the parabolic cylinder was designed and manufactured in [11]. The incoming solar radiation will be absorbed by the receiver and then transformed into thermal energy. This method of solar collection has the advantage of high efficiency and low cost, and can be used either for thermal energy collection, for generating electricity or for both.

The design and fabrication of PTSC for thermal energy application were presented in [16]. He uses two axis solar tracking system, and this method has proved the reception of higher energy gain and improved collector efficiency, the results obtained from this study show that the maximum thermal efficiency of the PTSC is 44%, 59% and 67% using non coating, coating metallic and evacuated receivers respectively. It was reported that the evacuated receivers are suitable for obtaining high temperature of about 130^0-140^0C. However, the fabricated PTSC is suitable for space heating and hot water loads, because of the higher temperature of storage that reaches 135^0C.

Kawira et al., (2012) reported the study of the potential of solar thermal concentrators for the steam produced from three parabolic trough solar concentrators (PTSC). The collector dimensions are: aperture width 1.2m, collector length 508m, and aperture area of 6.95m^2, the receiver was made from a copper tube which carried water as the heat transfer fluid. Furthermore, the concentration ratio of the collectors is 128. Testing was carryout for each of the concentrators and the maximum temperature of the steam obtained was 248.3^0C while the average temperature of the steam produced was 150^0C. The result indicates that the concentrators can be used in providing electricity to the rural areas which are far away from the electricity transmission grid [25].

The Designing, construction and testing of a miniature PTC was carryout in [10]. The trough was constructed with aluminum sheet as a reflector and copper for the receiver, the concentrator was designed to utilize the energy provided by the sun to heat water, though, the testing result showed consistency with initial mathematical modelling, but due to the small scale of the project the actual use of the parabolic trough to heat water would not be feasible.

Design and Testing of solar parabolic trough concentrating collector were reported [7]. In this type of study, a small type PTC was fabricated with the aim to carry out an experimental study by testing the parabolic trough collector under Darfur climatic condition, Sudan. A PTC of the aperture width 1m stainless steel reflector and a receiver of 3.8cm diameter galvanized steel pipe was fabricated locally with a water as a working heat transfer fluid. The results from the experimental study indicates that the collector's orientation North-South will prevent solar radiation end loss and can increase the thermal performance of the collector. However, the average collector's efficiency of the experimental testing was found to be 37% and hence, using stainless steel pipes enclosed by evacuating glass envelope round the absorbing tube can increase the thermal performance of the parabolic trough solar collector.

An educational single tracking PTC was designed and developed in [35] for moderate heat purposes and for instruction and demonstration purposes. The solar collector was designed and developed as a self- powered solar tracking collector that can operate remotely and independently under moderate radiation levels with a minimum technical supervision. The average thermal efficiency of the solar collector determined from this type of study was 60% using stainless steel reflector of aperture area of. However, Umar, et. al. (2013) Conducted experiments for the performance evaluation of PTC under climatic condition of the Dundaye Area of the usmanu Danfodio university energy research Centre Sokoto, Nigeria. The experimental performance evaluation was carryout using PTC constructed with an aperture area of 2.85$m^{2,}$ focal distance 1.82 and collector's lengths of 1.82m using locally available materials. Copper pipe of 28.5mm diameter was used as a receiver which was painted with a black paint in order to increase the thermal conductivity of the receivers. Furthermore, the result obtained from this experimental study indicates that the maximum outlet temperature of 110^0 attained can fairly be acceptable, even though, that some problems were encountered during the experiment with the tracking inaccuracy due to the manual tracking of the PTC [38]. Similarly, the development of small scale concentrating PTC for drying purpose was reported in [36]. In this study, a concentrating PTC was developed using steel sheet reflector of aperture area of 2.9m^2 and a steel pipe receiver of 0.05m diameter connected to steel drying box with the aim to determine the performance of the PTC for drying fruits and consequently to study the thermal efficiency of the concentrating collector. However, results from this study using two air mass flow rate indicates that the average temperature of the month and the mass air flow rate affected the thermal efficiency of the concentrating solar collector, and in addition the solar collector's efficiency of drying increases with increased in mass flow rate.

Macedo, et., al., (2014) Presented the designed, construction and evaluation of a prototype PTC for demonstrative purposes. The prototype was designed by considering the parabolic aperture of 0.5m wide and 0.95m long using computer aided design device. The result obtained during the evaluation of the thermal performance of the prototype was a maximum of 47.3^{0}C outlet temperature for 783w/m^2 direct solar irradiation at rate flow of 0.200L/min. Furthermore, the thermal efficiency and the useful energy obtained from this study was not the one expected, this is due to the optical properties of the coated pipe absorber but the collector's thermal efficiency was related to the room temperature, cloudiness and atmospheric conditions [28]. However, the concept of combining a parabolic dish concentrator with the thermo-electric (TE) module to produce electricity and thermal energy from the sun was explored with a simple prototype and some preliminary experimental measurement [27]. It was found in this study that the solar parabolic concentrator couple with a thermo-electric (TE) generator can produce a maximum power output of 1.38W at 0.42m^2/min of the air flow (pushing air).

Gianluca, et., al., (2015). Reported the design, manufacture and testing of a prototype PTC for industrial process applications. The main features of this prototype are its cost-effectiveness, low weight, high mechanical resistance, and easy to manufacture. Testing results indicate that the equation of the thermal efficiency is comparable with other similar thermal collectors for industrial heat process applications ranging from 70 to 250^{0}C. The PTC was presented with 90^0 rim angle and a lower concentration ratio of 9.25 build in fiberglass and extruded polystyrene with the cross-sectional aluminum pipe receiver contained within a low-iron glass envelope [15]. Recently, the experimental study of the performance of PTC for hot water generation was carryout [31]. The PTC was designed and fabricated using aluminum sheet reflector of aperture area of 1.82m^2 and aluminum tube as a receiver surrounded by a glass and metal pipe in order to minimize the thermal heat loss. However, the experiment from this study indicates the maximum outlet temperature of 65^{0}C with a collector thermal efficiency of 32%.The maximum value of temperature obtained at noon and hence the manually tracking parabolic trough solar collector can be a better option for hot water generation during the winter season for rural and remote areas.

2.2 Parabolic trough solar concentrators in Malaysia

Among the PTC's developed in Malaysia based on the literature available where the solar thermal organic Rankin circle studied [9]. The objective of the research project is to study the feasibility of an organic Rankin circle (ORC) as a renewable thermal energy source for the generation of less than 10MW for small and medium scale commercial purposes. However, there are two cycles in the power generating systems of the organism Rankin cycle (ORC): the solar thermal cycle that circulates heat transfer fluid in the circle and subsequently converts the solar thermal energy from the sun via a heat exchanger into the organic compound in the Rankin cycle (ORC) and the power cycle which is the organic Rankin cycle that generates electricity. Furthermore, the two organic materials R123 and isobutene used as a thermal fluid were examined for power generation and it was found that the R123 gives higher thermal efficiency, more suitable for high temperature applications and less thermal efficiency when superheating than the isobutene.

Fauziah Sulaiman, et, al. (2012). Presented the simulated design and analysis of a solar thermal PTC using several meteorological data in different parts of Malaysia using the software writing in MATLAB environment. The study was carryout by changing three parameters: Aperture Area, Receiver diameter and working fluid in order to optimize the simulated design. However, three different types of working fluids were investigated for this study and the results obtained from this simulation shows that the receiver's diameter of 0.03m and concentration ratio of 10 are the optimum parameters to achieving the highest efficiency of this model. More so, the study shows that equilibrium between the thermal losses increment due to the increases in the aperture must be achieved [13].

Alhassan et al., (2014) reported the Simulation analysis of thermal losses of PTC in Malaysia using computational fluid dynamics. The study investigates the thermal loses (Radiation and Convection) of the PTC by simulation with aim to investigates the wind speeds velocity and mass flow rate of the heat transfer fluid (HTF) on the thermal loses of the parabolic trough solar collector. However, the receiver of the parabolic trough collector (PTC) was modelled with the CDF Code ANSYS commercial heat transfer Software. it was revealed from the numerical analysis of the study that the effect of both the radiation and convection heat loses are not affected by the changes in wind speed, and in addition 64% of the convection heat loss was contributed to the total heat loss of the glass envelope were 'as radiation contributes 36% of the total heat loss for wind speed velocity of 2m/s [4].

1.6 Comparison between developed PTC in Malaysia and other collectors

Type of PTC	Aperture Area	Aperture width	Rim-Angle	Country	Ref.
Design & Construction	$6.95m^2$	1.2m	-	Kenya	[25]
Design & Dev. of	-	1.8m	74^0	-	[35]
Design, manufacture & testing	$1.85m^2$	1.00m	-	Italy	[15]
Design, construction and evaluation	-	0.5m	96^0	Mexico	[28]
Design & Construction	$1m^2$	0.8m	90^0	India	[39]
Design, test &Math. Modelling	$5.78m^2$	1.85	180^0	-	[27]
Design, fabrication &testing	$5.04m^2$	2.8m	67.8^0	Iraq	[14]
Design, construction& testing	$1m^2$	-	90^0	Dafur	[7]
Experimental performance	$2.85m^2$	-	-	Nigeria	[38]
Performance evaluation	$1.82m^2$	1.2m	-	India	[31]
Development for drying purpose	$2.9m^2$	2.4	-	Pakistan	[36]
Simulation Study	-	0.8m	90^0	India	[11]

II. Challenges and Prospects for the Development of Parabolic Trough Solar Collectors (PTC's) in Malaysia.

The major challenge associated with the development of PTC's in Malaysia is the climatic nature of country that characterizes by the heavy rainfall, formation of clouds, winds and high humidity. Other challenges are: lack of technical expertise locally for the PTC [17], inadequate funding of research and development in the field of solar thermal technology among the Malaysian universities. It was reported from [30] that areas like PV concentrators, inverters, solar cell fabrication and characterization, hybrid system and solar tracking system are the only areas of research and development among local universities in Malaysia. More so, lack of public awareness among Malaysian on how to use solar thermal technologies, particularly PTC into real life applications such as, cooking, refrigeration, cooling, drying, hot-water generation, electricity generation, etc. is also a great challenge with development of PTC in Malaysia. Basically, this challenges can be overcome if the government gives adequate encouragement on research and development in the field of solar thermal technology, this is specifically by funding researches on solar thermal technologies among the local universities in Malaysia. However, creating public enlightenment/awareness on how to use solar thermal technology in real life applications such as in industrial and domestic houses among others will definitely solve most of the challenges facing the implementation of solar thermal technologies in Malaysia environment.

III. Conclusion

From the literature, it was found that many PTC's have been reportedly designed, develop, evaluated and some are in operation for either industrial heat applications, generation of electricity, or for the research purpose. However, the performance of those reported developed concentrators was evaluated mostly under normal environmental weather where there is uninterrupted high degree of solar irradiation. However, there is need to develop and evaluate the performance of PTC's under a tropical environment like Malaysia where the availability of solar irradiation is varying throughout the day. Similarly, installation of parabolic trough solar concentrator for power generation has to be given priority by the Malaysian government so as to supplement the reliance on the fossil fuel.

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