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Research Article

Parabolic Trough Solar Concentrators: A Technology which can Contribute towards Pakistan's Energy Future

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Abstract: The utilization of solar thermal energy has got prime importance in Pakistan due to the current energy scarcity and escalating cost scenario in the country. Parabolic Trough Solar Concentrator is one of the most reliable technologies for utilization of solar thermal energy. In solar thermal power generation, Parabolic Trough Solar Concentrators are most successful as almost 96 percent of total solar thermal power is generated across the world by utilizing this technology. Its high reliability, operational compatibility, comparative low cost and high efficiency adds to its high value among other resources. Fortunately, Pakistan lies in the high Solar Insolation Zone; thus, a huge potential exists to benefit from this technology. This technology may cater to the Pakistan's seasonal increased electricity demand. Apart from electric power generation, this technology may also have cost-effective solutions for Pakistan's other industries, like steam generation, preheating of boiler make-up water, air-conditioning, and hot water production for food, textile, dairy and leather industries. However, economic justification of such projects would be possible only on accomplishing an indigenous technology base. Globally, this is a proven technology, but in Pakistan there is hardly any development in this field. In this study, an effort has been made by designing and fabricating an experimental Parabolic Trough Solar Water Heater by utilizing locally available materials and manufacturing capabilities. On achieving encouraging results, a solar boiler (steam generator) is proposed to be manufactured locally.

Keywords: Pakistan's energy future, solar thermal energy utilization, solar concentrators

1. INTRODUCTION

A solar concentrator captures sunlight over a large aperture area and concentrates this energy onto a much small receiver area, multiplying intensity of the solar radiation by a concentration ratio in the range of 10–80. It is the process of concentration that allows troughs to deliver high temperature thermal energy. However, to achieve such concentration, a trough tracks the sun in one axis continually throughout the day.

A Parabolic Trough Solar Concentrator is a one-dimensional parabola that focuses solar beam (parallel) radiation onto a line. Physically, this line is a pipe (absorber) with a flowing liquid inside that absorbs the heat transmitted through the pipe wall and delivers it to the thermal load. Primarily, the heat transfer fluid (some high boiling-point liquid) is heated by passing it through the concentrator's absorber tube and then this heated fluid exchanges absorbed heat with some thermal load, mostly with water, to make steam that can run the steam turbine to produce electricity.

2. COMPARISON WITH OTHER SOLAR ENERGY UTILIZATION TECHNOLOGIES

Parabolic Trough Solar Concentrator is one of the most reliable technologies for utilization of solar thermal energy. There are many power plants running on solar energy across the world by using parabolic trough solar concentrators. After the successful commissioning of a huge commercial power plant in 2007 (68 MW) in Nevada, USA, this technology got a exponential growth, as currently

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almost 1700 MW of electricity is being produced by utilizing this technology and by the end of 2014 it will reach 3800 MW by the completion of under-construction projects [9, 10].

2.1. Comparison with Photo-Voltaic Technology

Both Photo-Voltaic (PV) and Concentrated Solar Panel (CSP) technologies are being used to generate electricity by utilizing solar energy but CSP is more reliable as compared with photovoltaic power generation. Solar energy is available only in day time but energy demand is for 24 hours a day. So, energy storage provides an option to increase grid reliability and there are many storage options available or under development. The main difference between CSP and PV technologies is energy storage efficacy. The ability of CSP to utilize high-efficiency thermal energy storage (TES) makes its more reliable technology (Fig. 03). The addition of TES produces additional value by shifting solar energy to periods when sun is not available. This enables CSP systems to supply solar-generated electricity during periods of cloudy weather or at night.

2.2. Comparison with other Solar Thermal Technologies

Parabolic Trough Solar Concentrators are most successful in solar thermal technologies. It is because of high reliability, operational compatibility, low cost (comparatively) and high efficiency as parabolic troughs are being utilized in different applications around the world. There are many power plants running on solar thermal energy, across the world and producing almost 1750 MW of electricity out of which 1682 MW (96% of total) are being produced by using parabolic trough solar concentrators [9, 10].

3. PROSPECTS OF THE TECHNOLOGY IN PAKISTAN

Currently, the country is experiencing a severe energy crisis, and its energy requirement over time is increasing rapidly. Over the past 15 years, the primary energy consumption in Pakistan has grown by about 80%, i.e., from 34 million tons oil equivalent (MTOE) in 1994-95 to 63 MTOE in 2009-10. The energy requirement is expected to be doubled in the next few years; by 2015 it is likely to cross 120 MTOE and by 2030 the requirement would reach 360 MTOE [8]. The country's primary energy supply currently comes mainly from fossil fuels, which is 88% of energy mix (47.5% indigenous natural gas, 0.7% LPG, 30.5% imported oil and 9.2% of energy mix). The rest 10.9% comes from hydropower and 1.2% from nuclear power [7]. Natural resources haven't been utilized effectively due to which our natural gas reservoirs are depleting and on the other hand oil prices in international market is also increasing.

Pakistan's current energy scenario demands extensive utilization of renewable energy resources in a cost effective manner. At present, hydropower is the only renewable energy resource, being utilized partially, and a 48 MW wind power project is in the erection phase as yet; all other renewable resources in the country are almost untapped.

Utilization of solar energy has got prime importance in current energy scarcity and cost inflating scenario. Parabolic Trough Solar Concentrator is one of the most reliable technologies in solar thermal technologies and developed countries are benefiting by utilizing this proven technology. Pakistan's geographical position & climate favors this technology but Economical justification for utilization of this technology may only be possible by accomplishing an indigenous technology base. Manufacturing, installation and operational excellence in this technology may contribute significantly in Pakistan's energy future.

3.1. Geographical Position and Solar Radiation Data

Pakistan's geographical position and climate has made this technology one of the reliable energy options as Pakistan lies in high Solar Insolation Zone and because of this there is a huge potential to get benefitted from this technology. Pakistan lies in between 25^o-37^o latitude which is one of most favorable regions for solar thermal energy utilization. In the fig.4 the regions in dark orange color are high Direct Solar Insolation (5.0-6.5kWh/m2/day) regions and most area of Pakistan lies in this region.

If we see the average monthly solar radiation

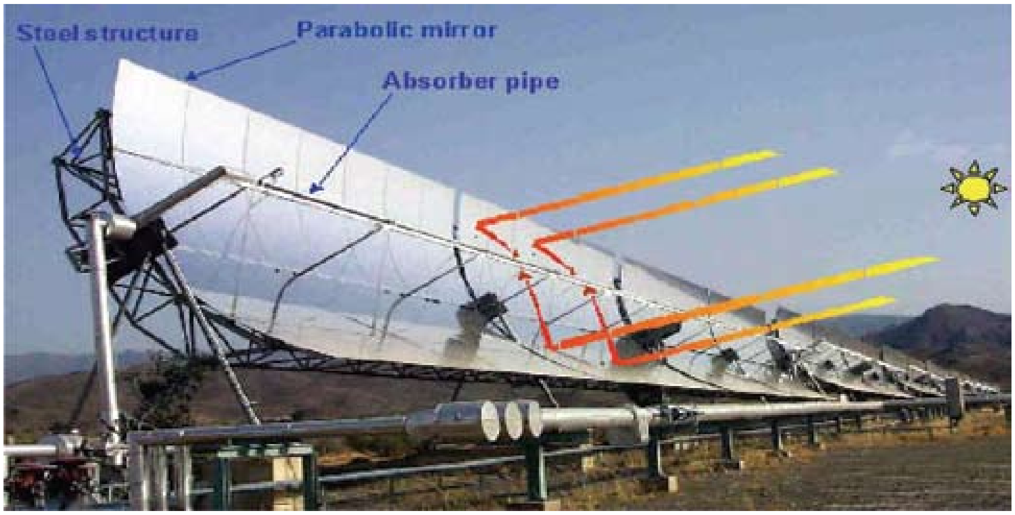

Fig.1. Schematic of a parabolic trough [2].

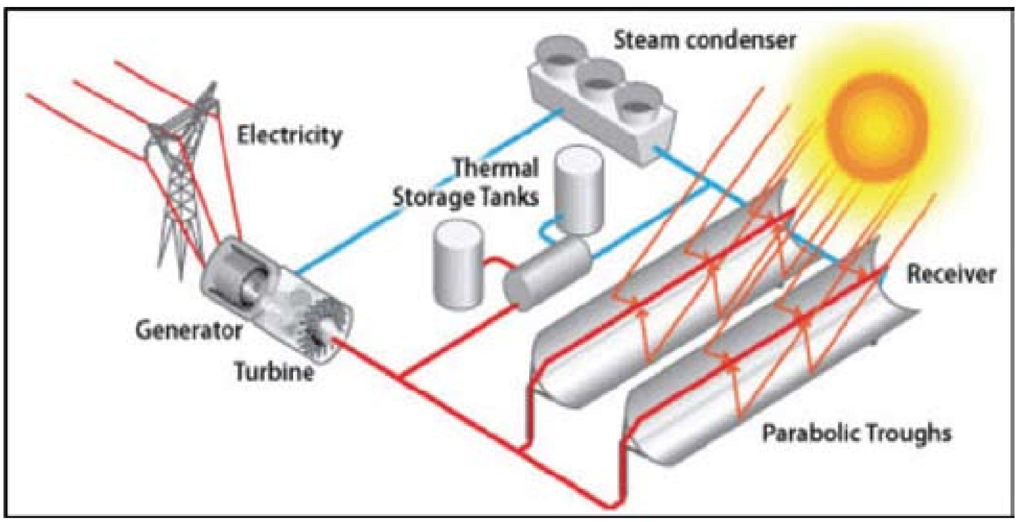

Fig. 2. Schematic of solar-thermal power plant [5].

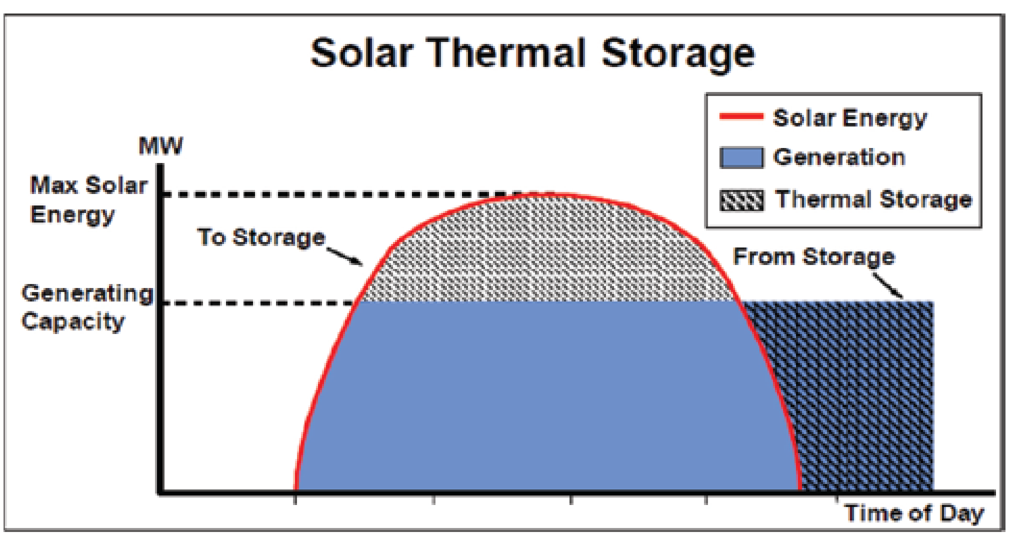

Fig. 3. TES extends the power production period [4].

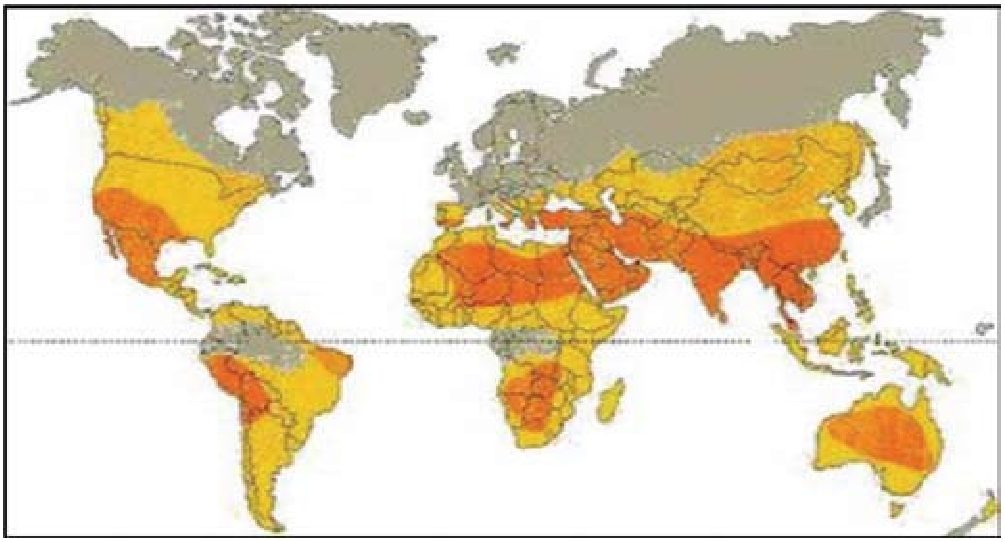

Fig. 4. Map for Solar Insolation region-wise [2].

data and day length for Lahore (Table.1) it can be observed that for the six months (i.e. Apr, May, Jun, July, Aug and Sep) high solar flux is available for more than 12 hr daily and these are the most troubled months for power shortage in Pakistan.

3.2 Applications for Pakistan's Local Industry

Parabolic trough solar concentrators have many cost effective solution for Pakistan's local industries, in addition to steam and power generation [6]. This technology may be utilized in:

i. Preheating of boiler make-up water.
ii. Utility hot water production in foods industry.
iii. Utility hot water production in dairy industry, as hot water is extensively used in dairy industry for cleaning purpose.
iv. Hot water production for leather industry (tanneries)
v. Hot water production for textile industry.
vi. In air-conditioning.

3.3. Socioeconomic Benefits

Solar thermal technologies have great potential to benefit our nation. They can not only diversify our energy supply by reducing our dependence on natural gas and imported fuels but also improve the quality of the air we breathe and offset greenhouse gas emissions. It can also stimulate our economy by low cost power generation and creating new jobs

Table 1. Monthly average radiation data on horizontal surface for Lahore [3].

Month	Day length (hr)	*Rad (cal/cm².day)*	*Rad (cal/m².day)*	*Rad (J/cm².day)*	*Rad (j/m².day)*	*Flux (W/m²)*
JAN	10.2	256	2560000	1075.2	10752000	292.81
FEB	10.9	333	3330000	1398.6	13986000	356.42
MAR	11.8	435	4350000	1827	18270000	430.08
APR	12.8	499	4990000	2095.8	20958000	454.81
MAY	13.6	545	5450000	2289	22890000	467.52
JUN	14	533	5330000	2238.6	22386000	444.16
JUL	13.8	491	4910000	2062.2	20622000	415.09
AUG	13.1	448	4480000	1881.6	18816000	398.98219
SEP	12.2	436	4360000	1831.2	18312000	416.93989
OCT	11.2	361	3610000	1516.2	15162000	376.04167
NOV	10.4	297	2970000	1247.4	12474000	333.17308
DEC	10	244	2440000	1024.8	10248000	284.66667

in the manufacturing, installation and operations of solar energy systems.

4. TECHNOLOGY INCUBATION (EXPERIMENTAL RIG)

A parabolic trough concentrator system was designed and fabricated on experimental scale, for hot water production, under the research chair of SNGPL, at Chemical Engineering Department, University of Engineering & Technology, Lahore under the supervision of Drs. A.R. Saleemi and A.H. Delawari.

4.1. Parts, Construction and Materials

The experimental setup (Fig. 5) mainly consists of following components:

i. Reflecting surface
ii. Absorber
iii. Support structure
iv. Tracking system
v. Circulation system

The experimental rig was fabricated by utilizing locally available materials and local manufacturing capabilities. Brief description of components is as follow.

4.1.1 Reflecting Surface

It is the one of the most crucial parts of solar concentrator as efficiency of concentrator greatly depends on the reflectivity of reflector material.

Stainless steel sheet was used for this purpose. Although the value of reflectivity is not very good, however results obtained were encouraging (Fig. 06).

4.1.2 Absorber

Absorber is basically a metallic tube, which is usually coated black to enhance absorbance. The tube is jacketed with glass to reduce the convective heat losses. Absorbed solar radiation delivers heat energy to fluid moving inside pipe.

Copper tube has been used for the purpose. Absorber tube was fixed in glass jacket by the means of Teflon rings and mounting ends. The system was not evacuated due to cost constrains (Fig. 07).

4.1.3 Support Structure

This is the structure required to hold and support the absorber/reflector assembly at correct positions. It must be moveable in horizontal axis so that concentrator may track sun throughout the day. For this purpose trough was mounted on stand structure with the help of bearing (Fig. 08).

4.1.4 Tracking System

To achieve continuous delivery of concentrated solar energy, trough tracks the sun in one axis continually throughout the day.

Timer based tracking system has been used. It consists of two analog timers, on/off switches, electric motor and worm gear arrangement (Fig. 09). The system was calibrated with the movement of sun and the time based tracking was achieved.

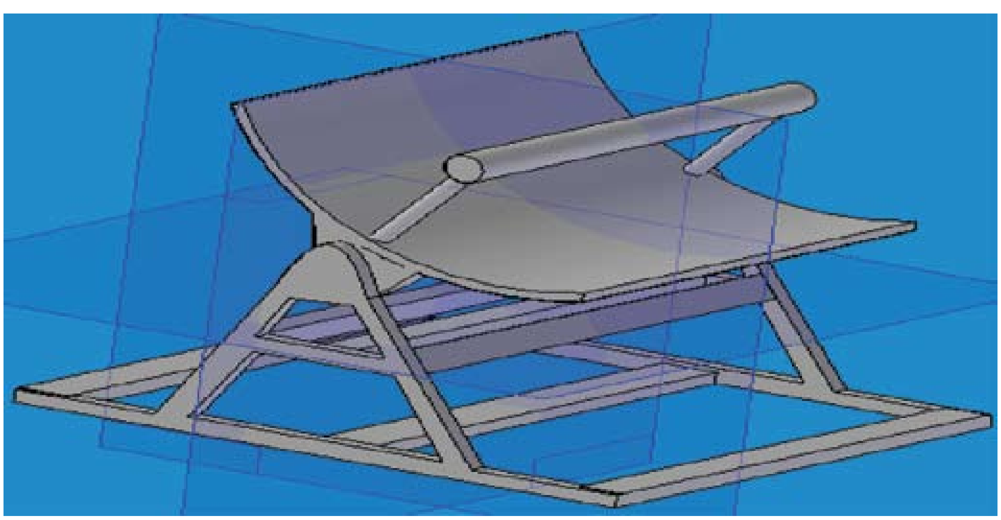

Fig. 5. Three dimensional model of the experimental rig.

Fig. 6. Reflecting Surface of the experimental rig.

Fig. 7. Absorber of the experimental rig.

Fig. 8. Support Structure of the experimental rig.

Fig. 9. Tracking system structure of experimental rig.

4.1.5 Circulation System

Circulation system is a wide term, used here for complete circuit of heat transfer fluid including pumps hot fluid reservoir and circulation pattern.

Centrifugal pump was used along with rota-meter, online thermometer and valve arrangement for in circulation system (Fig. 10).

Fig. 10. Circulation System of the experimental rig.

4.2. Dimensions of the Experimental Rig

The fabricated experimental rig has the following dimensions

Length of trough, L = 2.133 m
Length of aperture, L_a = 1.1 m

Aperture area, A_{ap} = 2.133 x 1.1 = 2.346 m^2

Outside dia of glass envelop, D_{og} = 0.033 m

Inside dia of glass envelop, D_{ig} = 0.03 m

Outside dia of absorber tube, D_{or} = 0.014 m
Inside dia of absorber tube, D_{ir} = 0.013 m

Outside surface area of absorber tube, A_{or} = .Л Dor L = 0.0938 m^2

Inside surface area of absorber tube, A_{ir} = Л Dir L = 0.087 m^2

Outside surface area of glass envelop , Aoe = .Л Doe L = 0.221 m^2

Now the Concentration Ratio for these dimensions may be calculated as:

C.R. = Aperture area / Absorber area = A_{ap} / A_{or}

C.R. = 25.0106 = 25

4.3. The Experiment and Its Results

An experiment was designed to study the performance of the fabricated experimental rig. As the rig have two temperature sensors, one on outlet and other on inlet of absorbing tube and no heat storage was available so the focus was on investigating the change in temperature of circulating water in one pass at different flow rates. The flow rate was optimized on the basis of heat transfer coefficient.

Volumetric flow rate of water,

F_w = 75 L/hr

= 2.08 x 10^{-5} m^3/sec and

Mass flow rate, m_0 = 0.0206 kg/sec

Water was circulated by means of pump and the flow rate was adjusted with the help of bypass valve on the rig. Temperatures of both points, inlet and outlet of absorber, were noted. The experiment was carried out when the direct solar radiation intensity was 480.5 W/m^2. The increase in temperature in one pass achieved was 9^{o}C and in multi-pass

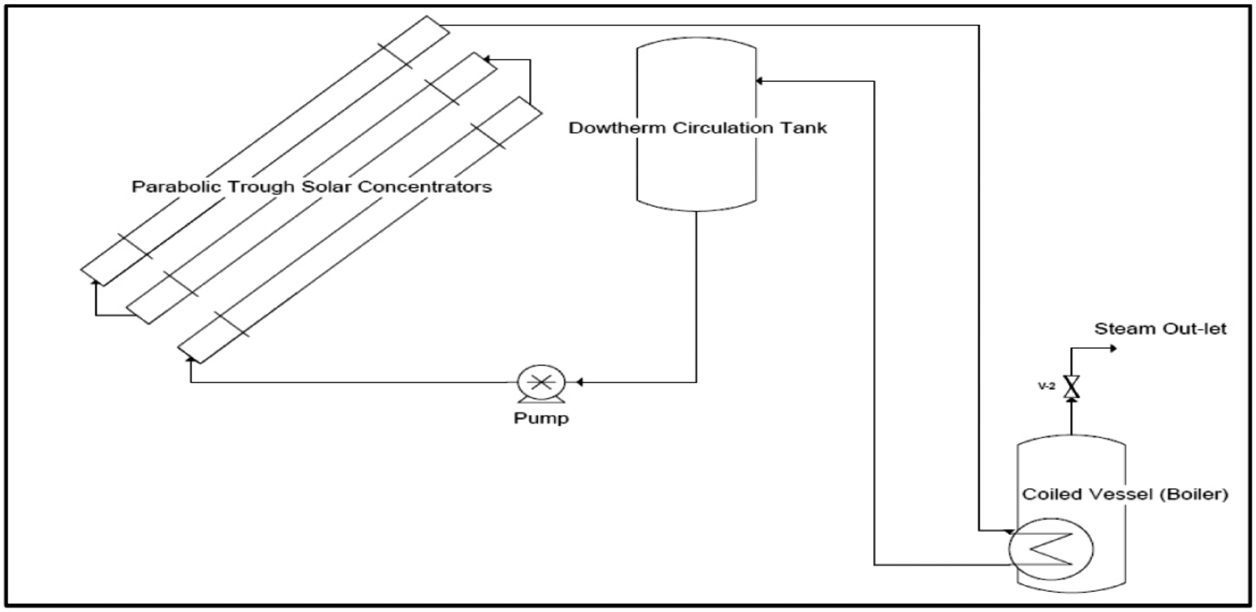

Fig. 11. Schematic of the proposed solar boiler.

arrangement 85°C temperature of water reservoir was archived.

4.4. Efficiency and Performance

Overall efficiency of a parabolic trough solar concentrator is based on two types of performance: (i) optical performance; and (ii) thermal performance.

4.4.1 Optical Performance

Absorbed radiation per unit area of un-shaded aperture is given by:

$$S=I_b\rho(\gamma\tau\alpha)\,K_{\gamma\tau\alpha} \qquad [1]$$

Where I_b is effective incident beam radiation on the plane of aperture, ρ is the reflectance of the concentrator, γ is intercept factor, τ is transmittance, and α is absorptance. $K_{\gamma\tau\alpha}$ is an incidence angle modifier that can be used to account for deviations from the normal of the angle of incidence of the radiation on the aperture.

4.4.2 Thermal Performance

$$Q_u = A_a F_R\left(S - \frac{A_r U_L}{A_a}\left(T_i - T_a\right)\right) \qquad [1]$$

where A_a is the un-shaded area of the concentrator aperture and A_r is the area of the receiver, S is the absorbed solar radiation per unit of aperture area, T_i and T_a are inlet fluid temperature and ambient temperature F_R is the collector heat removal factor.

$$F_R = \frac{m_o Cp}{A_r U_L}\left(1 - \exp^{\left(-\frac{A_r U_L F}{m_o Cp}\right)}\right) \qquad [1]$$

4. THE WAY FORWARD

To get our nation benefited by this technology, we must have to develop technical expertise in manufacturing and operations of Parabolic Trough Solar Concentrator systems. Initially, we should focus on commercialized thermal application especially for water heating and hybrid (fossil fuels-CSP) steam generation. This will make us able to run infrastructure level projects.

Development of a Parabolic Trough Solar Boiler is purposed (Fig. 11). The heating mechanism of purposed setup is indirect heating i.e. primarily the heat transfer fluid (some high boiling point liquid) will be heated, by passing it through concentrator's absorber tube, and then this heated fluid passes through coiled heat exchanger and exchanges its heat with water and water will make steam that can run steam turbine.

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