Reduction of Diesel Fuel Consumption in Boiler by Application of Solar Thermal Energy: A case study of Radisson Hotel

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Abstract: Efficient solar water heaters can replace water boilers in hotels, dyeing, and carpet-washing industries almost completely. Efficient solar water heaters can be a potential alternative to replace diesel and kerosene fuel for heating water in boilers. The research analyses the fraction of total load that can be supplied by solar thermal technology using flat plate collectors in Radisson Hotel, Kathmandu. It was determined that use of Solar water heating system with 50×15 square meter of collector area , can reduce the diesel fuel consumption by 102,320 .0 liters annually for the size of the hotel considered i.e. of capacity of 50,000 liters hot water processing per day. The Carbon dioxide emission will be reduced by 274,217.6 kg annually. The project is financial viable since its Net present value is positive.

Keywords: solar water heater, solar thermal, boiler, emission, efficiency

1. Introduction

The development of solar thermal conversion devices started in Nepal in early 1960s, a locally made Solar Water Heating installed on the premises of the department of Mines and Geology was the first in Nepal. Continuous improvements in design, fabrication and installation as well as through a combination of efforts of private companies and technical institutions, the efficiency of SWHs were greatly improved. The market of SWH manufacturers are emerging in Kathmandu. Until 1992, there was record of thirty five solar SWHs manufacture registered with the department of Cottage and Small Industries. There were Ninety unregistered manufacturers in Kathmandu valley alone. It is estimated that presently there are more than 200 workshop making SWHs in Nepal. Likewise, more than 30000 households in Nepal have already installed SWHs in their home and out of them about 80% are said to be installed within Kathmandu valley alone (Shrestha et. at, 2003). Most industries in Nepal use diesel and kerosene boilers to meet their hot water requirements. Some of the industries that heavily depend on fossil fuel boilers for hot water are; hotel, dyeing factories, carpet-washing factories, breweries, and dairies. Efficient solar water heaters can replace in fossil fuel water boilers completely. Solar water heaters can be used to preheat water up to 60 degree centigrade which is sufficient temperatures in breweries, dairies and hotel industries. With these industries using diesel and kerosene for heating water, large amounts of GHGs are emitted every day. Under the recent energy scenario where fossil fuel prices are skyrocketing, using high efficiency solar water heaters can be a potential alternative. Meanwhile, the solar water heating technologies are getting more efficient and affordable. The upfront investments required installing a locally assembled high quality solar water heating system that can be paid back within three to four years from the savings made through avoided use of fossil fuels. Solar water heating systems are available with twenty years of “trouble free” guarantees. This proves solar water heating system to be much more economical than diesel and kerosene boilers in terms of life-cycle cost. A part from being economical, solar water heaters are environment friendly. They zero emission energy providers and contribute towards cleaning the local air as well as reducing GHG emissions.

2. Methodology

- Survey and relevant data collection of Radisson Hotel in Kathmandu
- Detail study of the existing boilers at Radisson Hotel.
- To design for integration of solar thermal heating system into the existing diesel boilers.
- Calculation and Analysis
- Result and Conclusion

3. Simulation of the solar thermal system

The performance of the system as shown in figure 3 below was modeled by a simulation program written in the MATLAB programming .The program calculates the solar gain for the specified system based on the insulation, ambient temperature, the latitude, the parameters specifying the solar collector system and the volume of storage tank. Since the daily hourly radiation data is not available, average monthly insulation and similarly average monthly ambient temperature is used for calculation. The simulation gives the maximum temperature that the storage tank water can attain at end of each day of each month in average.

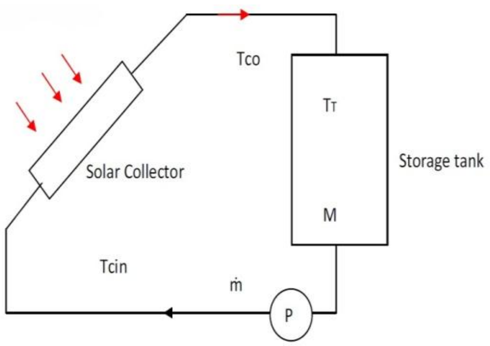

Figure 3: General Solar Thermal Systems

3.1 Mathematical modeling of simple collector and storage tank

During a particular instant energy balance equation of solar collector relating the temperature 'Tco' of the circulated water at the solar collector exit and inlet temperature 'Tcin' can be given from equation:

(Tco-Tcin) ×m× Cw = I ×Area×η

Where,

η = collector efficiency

$Area$ = Area of collector

I = Irradiance

m = mass flow rate

Cw = specific heat of water

From which we can calculate temperature 'Tco'of water exit from collector as given

$$\text{Tco} = \text{Tcin} + \frac{I*Area*\eta}{m*Cw} \quad \text{.............. (1)}$$

The collector efficiency can be calculated using the equation:

$$\eta = Fr(\tau\alpha) - (Fr.Uc)\left[\frac{Ti-Ta}{I}\right] \quad \text{...... (2)}$$

Ti = Tcin = inlet water temperature to the collector

Ta = Ambient temperature around the collector

From select collector type and its efficiency (η) plot against ($\frac{Ti-Ta}{I}$), we can get

Fr ($\tau\alpha$) = intercept of the plot

(FrUc) = slope of the plot

Energy balance equation between collector and storage tank with water:

$$\dot{m}(\text{Tco-Tcin})\times\text{Cw} = \text{M(TT- Tcin)}$$

Solving we get:

$$\text{TT} = \text{Tcin} + \frac{\dot{m}*(Tco-Tcin)}{M} \quad \text{.......} \quad (3)$$

4. Diesel consumption scenario analysis

Among four boilers installed in Radisson hotel, only three are used at a time. Two of these boilers are used for hot water and one is used for steam generation. The graph below shows that monthly diesel consumption in year 2013. When we used solar flat plate collector for preheating of water at 60°c then 47 % of diesel demand will reduce, as shown in figure 4.

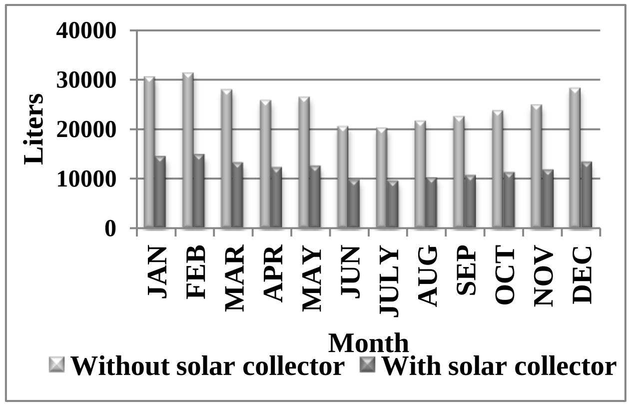

Figure 4: Monthly diesel consumption of boilers.

4.1 Solar Thermal Energy Applications

Table 4.1 below shows different industrial process and temperature ranges which can be easily obtained by using solar thermal technology.

Table 4.1 Industrial process and Temperature Range.

Industrial sector	Process	Temperature level (° C)
Food and Beverages	Drying	30-90
	Washing	40-80
	Pasturing	80-100
	Boiling	95-105
	Heat treatment	40-60
Textile Industries	Washing	40-80
	Bleaching	60-100
	Dying	100-160
Chemical Industries	Boiling	95-105
	Distilling	110-300
	Various chemical process	120-180
All Sector	Preheating of boiler feed	30-100
	Water heating of production hall	30-80

Source: European solar Thermal Industry Federation

4.2 Carbon emission scenario analysis

The graph below shows that monthly Carbon emission before and after the project in year 2013.When we used solar flat plate collector for preheating of water at 60°c as shown in figure 4.2.

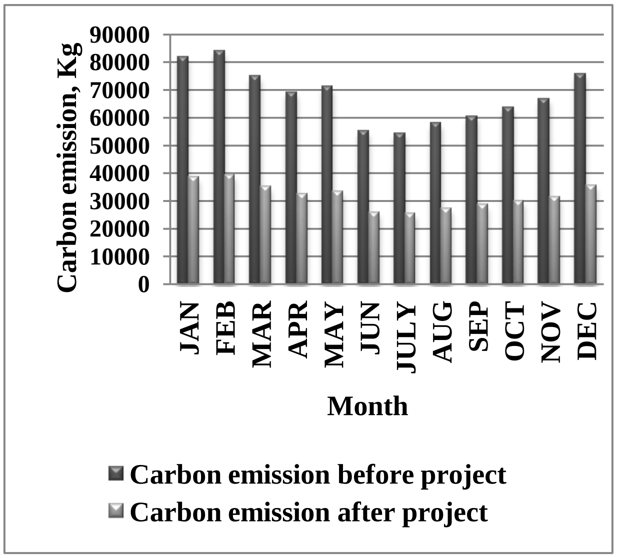

Figure 4.2: Carbon emission scenario

5. Complete Arrangement of Solar Thermal System

The design is done under the consideration that certain amount of water is heated in a day by solar thermal system is stored in highly insulated tank which is used next day as feed water to the boiler . The selected collector has following data.

Table 5.1: Selected collector data

Collector type	Glazed Flat plate
Model	Alternate energy AE -40
Gross area	3.696 m^2
Net aperture Area	3. 481 m^2
Dry weight	69.4kg
Operating temperature	30-100 °c
Efficiency	0.691
Flow rate	42 ml/s

Figure below shows that complete arrangement system of solar flat plate collector.

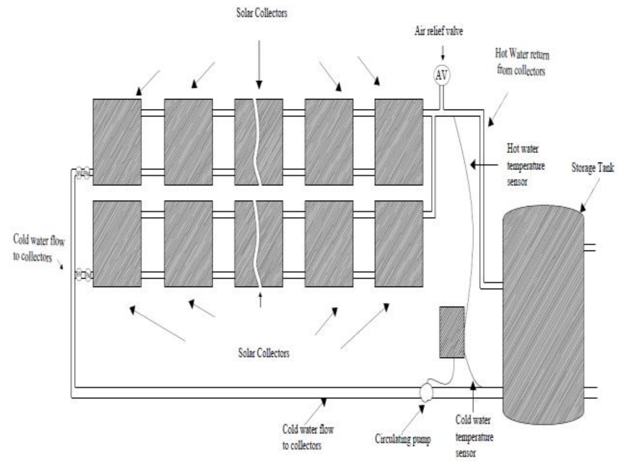

Figure 5 .1: Solar Thermal Arrangement System

6. Maximum Energy Supplied by Solar System

6.1 Calculation of Energy Delivered by temperature Basis.

A sample calculation for January:

Average ambient temperature = 8^0C

Mass of water per day = 50,000 kg

Specific heat capacity of water = 4,200J/kg^{0}C

Final simulated temperature that can be achieved at the each month = 60.69^{0}C

Energy per day in January = 50,000×4,200× (60.69 - 8) =11,064.9MJ

Average monthly energy collected = 30× 11,064.9 MJ

= 331, 947 MJ

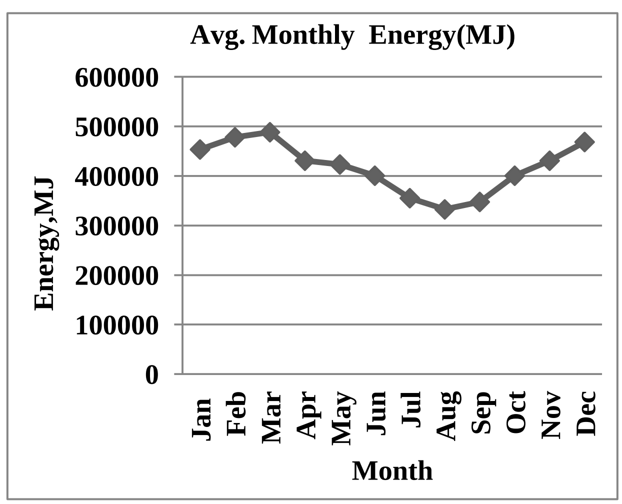

Figure 6.1: Energy delivered by temperature basis

Now calculating the equivalent quantity of diesel saved per year by using the fact that per litre of diesel provide 36.4 MJ of energy. It is found that 108,478 litre of diesel is being saved annually. Similarly the CO2 emission reduced annually is calculated to be 290,721.04 kg by knowing the fact that 2.68 kg of CO2 is emitted per litre diesel burned (Source : IEA).

6.2 Calculation of Energy Delivered by Area Basis

We calculated energy that can be produced by considered system on the basis of maximum temperature that can be achieved at the end of each average day per month. Now in this section we again calculate the same maximum energy that can be provided by the system considered but on the basis of area.

We have average daily per month insulation data Efficiency of a typical collector can be taken 0.6 on average.

A sample calculation for January:

Average daily insulation = 5.81kW/m^2.day = $\frac{5.81\times60\times60}{1000}$ MJ/m^2 =20.916MJ/m^2

Aperture Area = 750 m^2

Efficiency (η) =0.65

Average Daily Energy per month = $20.91\times0.6\times750 = 10{,}193.62$MJ

Average Monthly Energy Obtained = 30×10193.62 =305,808.75 MJ.

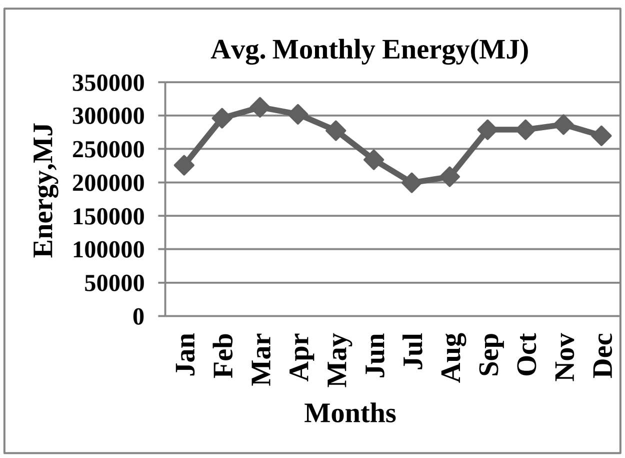

Figure 6.2: Energy delivered per month area basis

Figure 6.2 shows the graph of energy produced verses month which clearly tells that worst energy production months are: June, July, August and September.

7. Result and discussion

The solar water heating system with 50×15 square meter of collector area and five insulated hot water storage tanks of 10,000 liters capacity each was implemented in a hotel with a capacity of 50,000 liters hot water processing per day. The results are listed below:

Fractional contribution by temperature basis and area basis differs by 5.67% due to the fact that losses in pipes and storage tank were not accounted while calculating by area basis.

Fractional contribution by area basis and F-chart method differed by only 1.7% which can be concluded that the approach was in right direction.

- It was found that 102,320 liters of diesel would be saved annually where in present annual consumption is 216,180 liters of diesel.
- It was found that 274,217.6 kg of carbon dioxide emission would be reduced annually.

8. Conclusion

- In industrial sector any investment is taken as attractive if NPV value comes positive with IRR greater than MARR.

  NPV = NRs. 91, 36,100.00 (positive), IRR= 40%, when I = 10% and time period =10 years.
- Thus the project is feasible.
- It is beneficial from financial point of view and net present value is also positive during life span of the project.
- Above findings led to the conclusion that solar thermal technology using flat plate and evacuated collector can be used to fulfill the heat requirement of low temperature for small to medium scale hotel industries.
- Concentrated solar power should be used for large solar fraction contribution especially for large scale hotel industries.

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