Analysis and Suitability of Concentrating Solar Thermal Technology for Waste Oil Treatment in Lubricant Industry

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Abstract - *The increasing cost of fossil fuels and concerns of climate change necessitates an increasing dependence on renewable energy. Solar energy is a solution to curb the increasing energy imports and the current trade deficit. While most renewable energy sources provide energy in the form of electricity, Concentrated Solar Thermal (CST) technologies are considered as a source of thermal energy production for heating and cooling application. Industries such as automotive, paper and pulp, textile manufacturing, food and beverage, dairy sectors require a minimum process for heating, as the energy is not being converted into power, these systems usually have higher efficiency can meet heating demands of different sectors for temperatures up to 250°C. Majority of the heating needs in the commercial sector come from the industrial sector.*

The paper aims to examine the process and potential of application of the CST technologies in the industrial sector, especially in the lubrication industry. The processes in the lubrication industry that have heating needs that can be met by CST technologies are first selected. Minimum collector area is calculated for each type of CST technologies based on meeting at least 5% of heating needs for that process through CST technologies. The most suitable CST technologies for meeting the heating needs of the lubrication industry are identified through their cost-benefit analysis provision and availability of land area.

Keyword: Concentrating solar technology, Incentive, oil treatment, crude oil storage, DNI, GHI.

1. INTRODUCTION

A huge amount of fossil fuel is being consumed for thermal applications, such as water/air heating, community cooking, process heat, and space cooling in various establishments. About 15 million tonnes of fuel oil is estimated to be consumed in industries alone for process heat applications requiring temperature below 250°C.Over 5,000 trillion units of electricity is also being used for heating water and air applications. This electricity needs to be conserved for other useful applications in a country like ours where 35 per cent of the population has no access to power and 80 per cent of the fuel oil is being imported. India is full of sun energy and the use of Concentrating Solar Thermal (CST) technologies at places of direct utility for such applications can help save significant amounts of fossil fuels.

India is highly dependent on crude oil to meets in energy demands. The crude oil production for the year 2016-17 is at 36.01 Million Metric Tonnes (MMT). Indian refinery industry has done well in establishing itself as a major player globally. India, which is second largest refiner in Asia after China. The production of petroleum products is at 243.55 MMT in year 2016-17. (Source: Ministry of Petroleum and Natural Gas, Government of India, 2017-2018).

India is endowed with a vast solar energy potential and receiving an average 5-7 kWh/m^2/day. The abundant solar radiation, clean character of solar energy, high cost of fossil fuels and negative emission consequences of fossil fuel consumption along with large requirements for process heat below 250°C are the key drivers of the strong focus on the development of solar thermal applications in India. The solar water heating industry in India is fairly well developed and is already on an accelerated growth path. The use of solar concentrators to meet the process heat requirement of community, industrial and commercial establishments is an emerging and exciting market opportunity in India.

CST is the most capable technologies is considered an alternative source of renewable energy that can be used for pre-heating oil prior to it entering a dehydration process at Lubricants oil re-refining plant.

The objective of the paper for automotive lubricant & grease manufacturer and blender in India and to explore renewable energy technology in order to reduce their costs and environmental footprint. In the paper explores to solutions using

Compound Parabolic Collector (CPC) solar thermal technology and shows the economics of the project and the cost savings possible by the implementation of these technologies.

2.0 PROCESS OF WASTE OIL TREATMENT

In lubricant and grease manufacture industries determined that the heat is currently supplied to the process via a thermal fluid system. In this closed loop system, the fluid is heated to around 300°C, after which it is used to provide heat to three distinct processes. At the end of these three processes the thermal fluid is approx.100°C cooler than at the start and is then reheated to 300°C before being re-circulated.

One of the lubricant plants in India uses coal fired boiler system to heat 21,000 litres of waste oil per day in batches of 7000 litres. The processes used to remove contaminants and the temperatures at which they take place are shown below.

i. Dehydration – 140 -150° C
ii. Distillation Moderate – 250 °C
iii. Distillation high vacuum – 310 °C @ .01 torr
iv. Bleaching

The boiler is running 24 hours per day for assumed 300 days per year with no seasonal variation. Currently the plant is using coal which has a consumption of 1200 ton of coal per annum.

To overcome economical and environment problems, solar energy is introduced in this paper for heating applications in oil industry. For the applications of solar energy in oil industry, most of the lubricant plant uses coal fired boiler system to heat waste oil to meet heating requirement with the flow rate is 96 m3/tones with running in the closed loop in the following process for removal of oil contaminates with the required temperature.

A fractional distillation process in a refinery is used to split crude oil into several streams with different properties. The hot liquids collect at the bottom of the column as residual oil (RO) (Carbon Brain Project, July 2011).

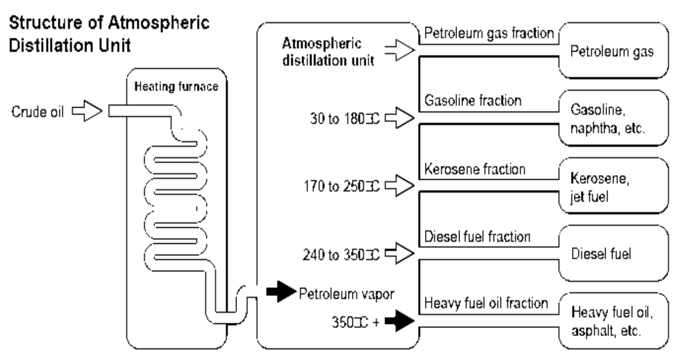


Figure 1: Schematic of an oil refinery from crude oil storage to distillation columns. (Cosmo Energy Holdings)

As per the importance of a cost-effective solution with energy and economy analysis it would be provide a solution of appropriate solar thermal technology.

3.0 SOLAR THERMAL TECHNOLOGY

Concentrating Solar thermal technologies harness solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors. CST essentially comprise of reflectors/collectors for reflecting incoming solar radiation onto a receiver, thus concentrating a large area of sunlight onto a single receiver. This principle is similar to how a small lens generates enough heat to burn a piece of paper, except that here the small lens is much bigger to the tune of 100 square meters or more depending on the type of technology. This heat energy received is then used to heat a heat transmitting fluid depending on the end requirements of the process.

Under the concentrating type – there are imaging and non – imaging technologies. Imaging technologies have a smaller range of acceptance angle compared to that of non – imaging technologies. The below table indicate that the technology wise operating temperature for pre-heating of waste oil prior to the following process in order to obtain dry oil for further processing.

Sl. No	Tracking Type	Type of Technology	Operating Parameter (°C)	Application
1	Non-Tracking	Non-imagine CPC /NIC	80 - 140	Dehydration
2	Single axis	Scheffler, Parabolic, CLFR	100-300	Distillation Moderate
3	Double axis	Paraboloid, Fresnel Reflector (Arun)	120-400	Distillation high vacuum

Table 1: CST collectors with corresponding operating temperatures

3.1 SOLAR RESOURCE IN STATE/REGION

The success of any solar project is very much linked to the level of solar radiation in the project location. The solar resource levels measured in terms of Global Horizontal Irradiance (GHI) in India vary significantly by region, from 3 kWh/m²/day in Arunachal Pradesh to 6.5 kWh/m²/day in Eastern Himachal Pradesh. As per the National Renewable Energy Laboratory (NREL) / MNRE satellite data, one of the states in East region can expect to receive solar insolation between 5.0 – 5.5 kWh/m²/day, which is very suitable for Concentrated Solar Thermal (CST) technologies for industrial heat application. The specified site of an average annual GHI of 5.28 kWh/m²/day.

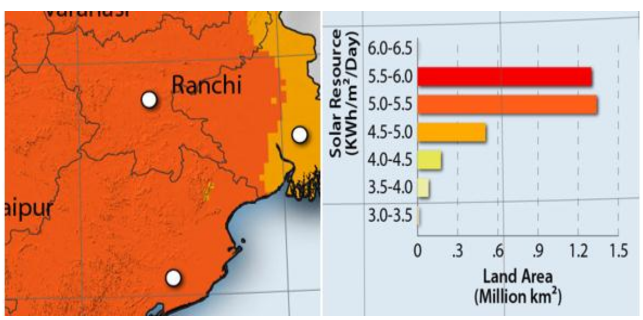


Figure 2: Solar resource data for Ranchi in the state of Jharkhand. (Source: NREL)

In order to produce a viable annual yield determination, reliable weather data has to be considered. Several suppliers and sources of weather data can be found worldwide and by comparing the solar radiation predictions from these suppliers it is possible to get a good idea of the likely accuracy of the results. The results from the three main suppliers of weather data are given below:

Organisation	Global Horizontal Irradiance (GHI) / kWh/m²/year	Diffuse Irradiance kWh/m²/year
NREL/MNRE	1929	825
World bank / Solar GIS	1861	883
Meteonorm	1856	769
Average Irradiance	1882	826

The NREL/MNRE will be used for the calculations in this report however it should be noted the solar radiation levels given by NREL /MNRE is slightly higher than the data provided by Meteonorm and the World Bank/solar GIS.

3.2 SELECTION OF APPROPRIATE TECHNOLOGY

The selection of an appropriate solar collector basically depends on five factors as have been described alongside. For low temperatures, below 60-80°C, generally evacuated tube and flat plate technologies are used.

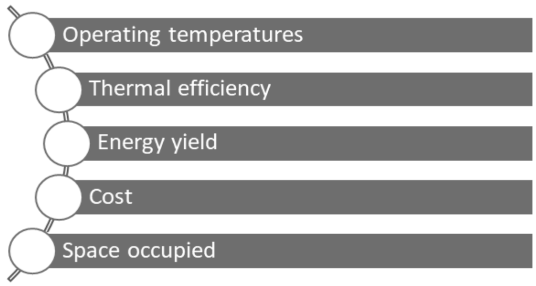


Figure 3: Five factors for selection of CSTs

For medium temperatures, in the range of around 100-250°C, generally parabolic troughs and linear Fresnel technologies were used, but lately solar dish technologies have started gaining prominence. In the case of higher temperatures, only point focus technologies can be used. A brief representation of the suitability of the type of technology based on the temperatures to be achieved has been provided below for representation purposes.

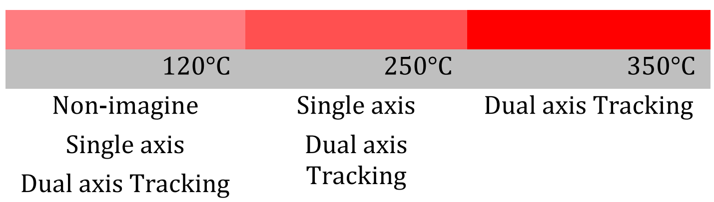


Figure 4: Temperature wise appropriate Technologies

4.0 SOLAR PROCESS HEAT STRATEGY

The paper aims to conduct sizing of suitable CST technologies for application in the waste heat recovery in oil industry. The suitable technologies would be selected based on the profile matching of the quality of heating required and the quality of heat that can be provided from various CST technologies. To do a basic analysis, the systems being chose are at two ends of the spectrum of CST technologies in terms of efficiency and cost.

The process selected for intervention is the dehydrating process which requires temperatures up to 150˚C. Sizing of the system would be done based on the heat requirement for the dehydration process. Since the dehydration process is the least heat consuming process, the study aims to deduce the size of the CST system to meeting the energy needs for pre-heating purposes along with its combination with the waste heat recovery system.

As the site is situated in the East of India and it has high GHI (Global Horizontal Irradiation) and low DNI (Direct Normal Irradiation), the Compound Parabolic Collectors (CPC) is the most suitable technology that can be deployed to provide solar process heat. The next step is to determine how to optimize the installation in order to keep costs to a minimum and ensure that the maximum possible benefit is obtained.

As the efficiency of the CPC collectors that will be used for this installation reduces with increased operating temperatures, 110°C can be seen as being the practical upper temperature limit. For this reason, the heat energy collected should be used in the low temperature phases of the process. In this case to preheat the used oil prior to it entering the dehydration process, thus reducing the amount of conventional energy required.

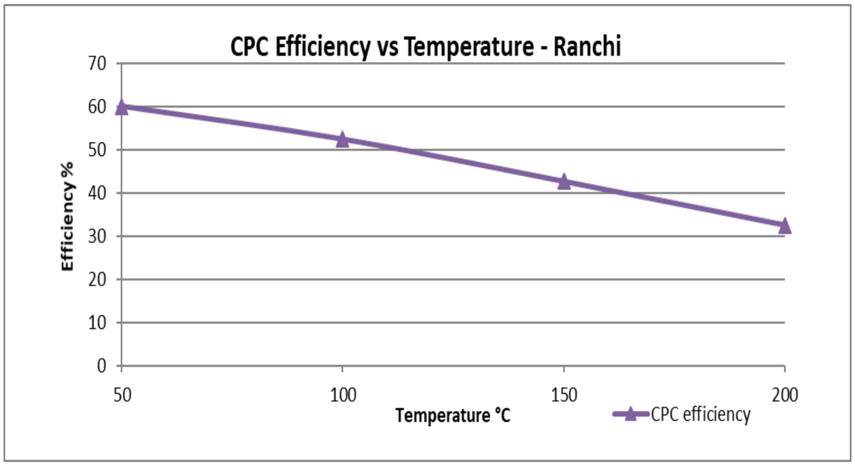


Figure 5: CPC Efficiency vs Temperature

The following initial calculation is carried out to determine how much used oil can be heated and to what temperature.

Description	Unit	Value
Oil inlet temperature	°C	35
Oil heated	°C	150
Temperature increase	°C	115
Daily heat requirement	kCal	1,000,000
Average solar radiation (GHI)	kWh/m^2 day	5.3
	kCal/m^2/day	4,553
Assuming a typical average annual efficiency of CPC collector	%	52
Heat delivery (per m^2 of collector area)	kCal/m^2/day	2,368
Total heat delivered by system	kCal/day	473,600

- Assuming that the heat capacity of the used oil remains constant over the temperature range.
- Then temperature increase = 115°C x 473,600kCal/1,000,000kCal = 54°C
- This results in the temperature of the used oil being able to be increased to 89°C
- We can see that the results are very similar to those of the initial calculation with the annual output rising from 473,600 x 365 = 172,864,000 kCal → 172,9 MMkCal to 174,3 MM kCal.

Below the table, we can see the effect on heat output of a system due to solar radiation.

Month	Solar radiation		Temperature	Heat output		Savings	
	Global (GHI) kWh/m²	Diffuse kWh/m²	T amb °C	Q field MWh	Q field MMkCal	Fuel kg coal	Financial INR
January	139,2	55,8	17	17,1	14,7	4.593	₹27.558
February	148,1	43,4	21	18,1	15,6	4.867	₹29.200
March	192,8	63,6	27	22,3	19,1	5.976	₹35.854
April	203,2	69,6	32	21,4	18,3	5.735	₹34.409
May	206,5	90,9	34	19,8	17,0	5.312	₹31.870
June	167,7	83,9	29	14,2	12,2	3.826	₹22.957
July	151,3	92,3	27	12,4	10,6	3.318	₹19.909
August	147,4	86,3	26	12,8	11,0	3.425	₹20.550
September	143,9	72,2	25	14,1	12,1	3.796	₹22.775
October	154,3	68,5	24	17,1	14,7	4.586	₹27.518
November	140,3	50,0	20	16,9	14,5	4.534	₹27.204
December	135,1	48,7	17	16,8	14,4	4.515	₹27.093
Average	160,82	68,76	25	16,9	14,5	4.538,0	27.228,1
Total	1.929,83	825,13		202,9	174,290	54.482,7	326.896,4

Table 2: Heat output based on solar radiation data

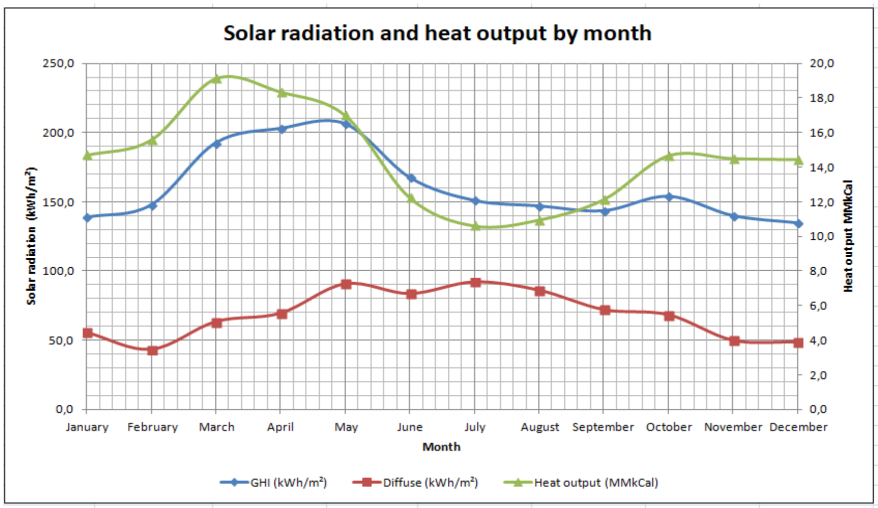


Figure 6: Comparative analysis between solar radiation and heat output.

We can also see is that the lowest solar yield occurs in June, July, August and September which are the monsoon months. However, this is also due in part to the angle of the solar collector which is inclined 22.5° to the south in order to achieve the highest annual yield. By changing the angle, the performance in these months could be improved albeit at the expense of the overall annual performance. The heat energy from the solar collector would either be used to heat the oil being pumped into the dehydration tank via a heat exchanger; in which case surplus energy collected in the daytime would be stored in a hot water tank for use at night. Or alternative all the energy collected in the daytime would be used to heat an intermediate oil storage tank, with the used oil being pumped from this tank into the dehydration tank as required. The solar plant's control would be programmed to operate automatically. With the only regular maintenance being the periodic cleaning of the collectors and checking and cleaning of used oil filters.

4.1 COMPOUND PARABOLIC CONCENTRATOR

Compound parabolic concentrators are fitted with a row of evacuated receiver tubes, which convert sunlight into heat through the use of a high-performance absorption coating. As each tube functions like a thermos flask, the heat is stored in the tubes for a long time and is not lost to the environment.

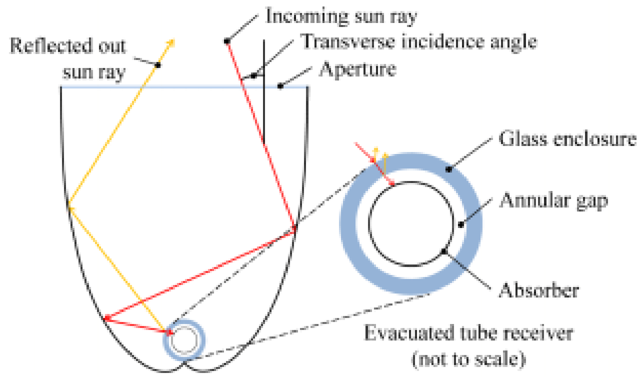


Figure 7: Schematic of CPC Collectors

When constructed using high quality materials, this tried and tested type of collector has a long operational lifetime, with almost no components subject to wear. The selective absorber layer, which is highly efficient at converting sunlight into heat, is situated on the inner glass tube inside the evacuated tube, which means that it is protected from all forms of weathering and physical damage and therefore has an almost infinite life.

Figure 8: Cross-section view of a CPC's collector tube

The main properties of a CPC are:

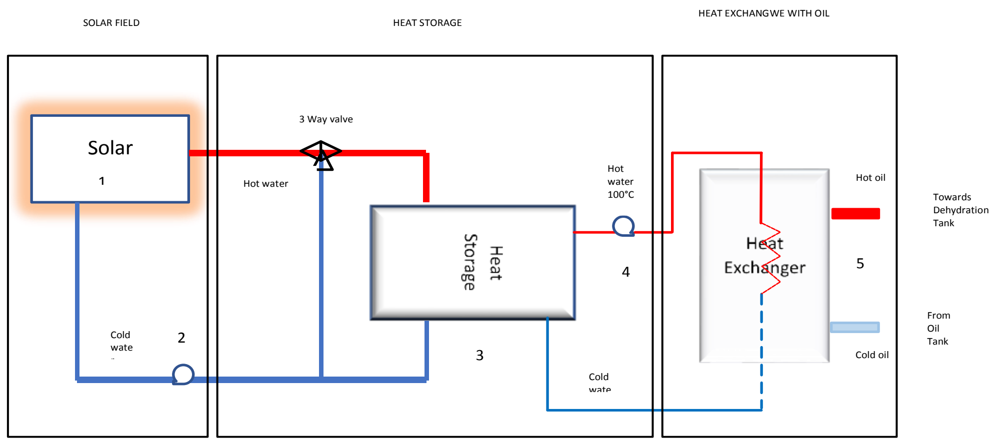
- Highly Efficient Evacuated Tubes based on the Thermos Flask Principle (Dewar Tubes)
- Antireflective Coating
- Weather-Proof CPC
- Designed for very large systems and industrial applications

4.2 TREATMENT OF WASTE OIL USING CPC BASED CST TECHNOLOGY

Two possible schematic layouts are shown below. The layout of the complete system, comprising of: Compound parabolic collectors using water as a Heat Transfer Fluid (HTF), a heat storage system and a heat exchanger or a combined heat exchanger and storage system.

4.2.1 SOLAR SYSTEM WITH SEPARATE WATER TANK HEAT STORAGE

The vacuum tube collector (1) is fed with the heat transfer fluid (HTF), in this case water, by the pump (2) which pumps cold water from the storage tank into the collector. The water is then heated by solar radiation to about 100°C. After heating, the water passes through a 3-way valve that allows the water to enter the heat storage tank (3) or return directly to the pump.



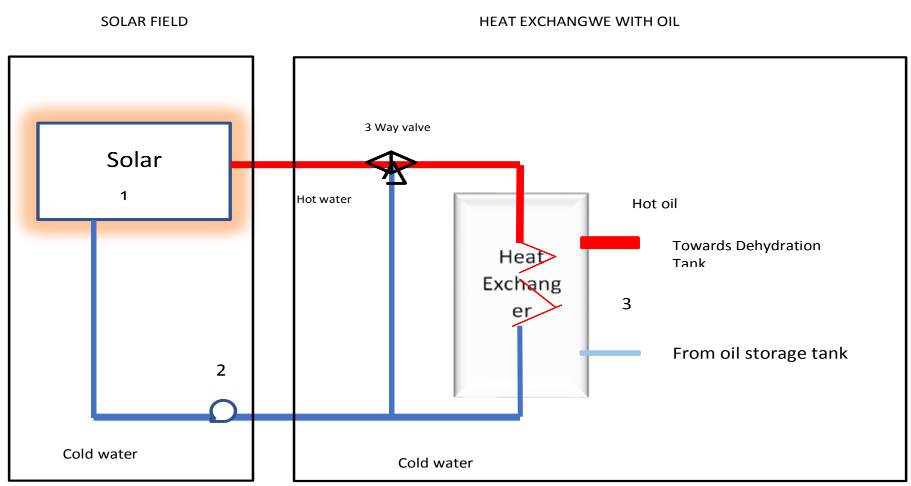
(1) CPC collector (2), (4) Pump
(3) Heat Storage Tank (5) Heat Exchanger

Figure 9: Option 1 for CST system with separate storage tank

A second pump (4) is employed to pump hot water from the storage tank into the heat exchanger unit (5) where it transfers its thermal energy to the cold oil before being returned to the bottom of the storage tank. The heat exchanger is used to heat the oil to a temperature of up to 95°C, before it enters the dehydration tank.

4.2.2. DIRECT HEAT EXCHANGER AND INTERMEDIATE OIL STORAGE UNIT INCLUDING INTEGRATED HEAT EXCHANGER

The vacuum tube collector (1) is fed with the heat transfer fluid (HTF), in this case water, by the pump (2) which pumps cold water into the collector. The water is then heated by solar radiation to about 100°C. After heating, the water passes through a 3-way valve that allows the water to enter the heat exchanger incorporated in the intermediate oil storage tank (3) or return directly to the pump.



(1) CPC collector (2) Pump (3) Oil Storage Tank

Figure 11: Option2 for CST system integrate with heat exchanger

All the solar energy captured during the daytime is transferred to the oil within the intermediate oil tank, which is large enough to feed the dehydration process with hot oil for up to 24 hours.

5.0 ENERGY AND COST-ECONOMIC

In order to calculate the energy and cost saving made through the use of solar, the amount of energy available from the fuel used has to be known, for this study it has been assumed that coal with similar properties to the Indian Ministry of coal, non-coking coal, grade D (net calorific value between 4200 and 4940 kCal/kg) is being used.

Coal – Net calorific value	: 4570 kCal/kg
Boiler efficiency	: 70%
Annual energy saved by the use of solar collector	: 174.29 MMkCal
Equating to an annual fuel saving	: 54.5 tons
Annual cost saving – 365 days running	: 54.5 tons x 6 Rs/Kg : Rs 3,27,000

However, the plant only operates for 300 days in the year so assuming that these days are evenly distributed throughout the year then.

Annual fuel saving - 300 days running	: 54.5 tons x 300/365 : 44.8 tons
Annual cost saving – 300 days running	: 44.8 tons x 6 Rs/Kg : Rs 2,68,800

If it is to some extent possible to schedule downtime or periods of low production to match periods of low radiation (monsoon), or alternatively to spread production over more days, then the saving can be increased: For the financial calculations it is assumed that this is possible to some extent, in which case.

Annual fuel saving - realistic scenario	: 50.0 tons
Annual cost saving	: Rs 3,00,000

6.0 Conclusion

CST system is the alternative source of energy to save fossil fuels for process of waste oil in lubricant & grease manufacturer and blender in India and to explore concentrating solar thermal technology in order to reduce their costs and CO_2 abatement. It does not require kerosene, coal, LPG/PNG gas or firewood because it works with the heat energy received directly from the Sun (Source of Energy). So, no matchsticks, no lighters, no fuel bills. In addition, there is huge potential of Concentrating Solar Thermal (CST) technology in various sectors where heat generated at high temperatures from such technologies could be utilized for the purpose of heating applications in various industries; thereby, reducing the use of conventional fuels and GHG emissions in the atmosphere.

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He had dealt with issues related to solar thermal energy at both operation and policy levels.
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He has received, among others, an award for his work for the work and contribution for the promotion of solar energy from Dr Shirin Gadhia Sustainability from Eco Centre ICNEER (International Centre for Networking, Ecology, Education and Re-integration) this year.
He has published articles and research papers in various publications and has attended as a speaker in various National & International conferences and workshops on renewable energy and energy-efficiency.