USE OF SOLAR CONCENTRATORS FOR STEAM GENERATION IN INDUSTRIAL PROCESSES

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ABSTRACT

Steam plays a substantial role in several industrial processes and is usually required in significant amounts to enable continuous production in beverages, dairies, flower farms, and many other agro-processing industries. Currently, the predominant method for steam generation in such industries is by using furnace oil to fire boilers that generate the required steam. This technique has negative environmental and economical consequences, whose impact is felt especially in developing countries like Uganda.

In order to become competitive both locally and internationally, there is need to develop a sustainable technology, which is economically viable, environmentally friendly and provides the steam requirements appropriate for the various industrial applications mentioned above. The solar technology will utilize the considerably high insolation of Uganda which is approximated at 157kWh/m^{2}per month. This insolation is ten times more than that in London and seven times more than that in Vienna or Berlin.

This paper reports on the development of a solar water heater concentrator for use in industries in Uganda. The issues tackled in this work are: different reflective materials, heating fluids, the combination of hybrid flat collector-cum-concentrator, solar tracking possibilities versus static ones, heat power measurement and parabolic design, and economical viability study

It is expected that this study, done in cooperation with Solar Construct (U), will create capacity to have this type of solar-powered water heater produced and utilized in Uganda to partially replace furnace oil boilers as a more economical alternative.

1.0 INTRODUCTION

In Uganda, industries are basically of small or medium scale with a handful of large scale industries. The soft drink and breweries industries use steam to clean up tanks (Cleaning in Plant), heat water in various sections and in pasteurization.

The steam used in these industries is currently being produced at a high cost using furnace oil. This type of fuel is very expensive in Uganda, since this is not an oil producing country and besides is landlocked. The partial use of flat collectors or solar concentrators or both seems to be a viable solution to reduce costs in industrial processes.

Some institutions have developed prototypes using parabolic concentrators to produce steam in Africa. University of Cape Town, South Africa (for academic purposes) for instance has developed a 2000Watts one with works quite well and can reach temperatures close to 150 Celsius degree.

Figure 1 and 2 show a commercial solar plant in Egypt. The solar field comprises of 144 solar parabolic trough collectors arranged in eight rows with 18 collectors in each row, thereby constituting a total net reflective surface area of approximately 1,900 m^2. The collectors are arranged to form four identical hydraulic loops of 36 collectors each, through which the condensate passes to gain solar heat and transfer it to the flash drum. In this plant, the flash drum, instead of the heat exchanger, has been used to produce steam. The parabolic trough solar collectors were locally manufactured in aluminum. The heat absorber tube lies in the focus of the collector where the direct beam solar radiation concentrates, and is manufactured from carbon steel pipes coated with a black nickel surface with highly effective absorption and surrounded by a glass envelope to minimize the heat losses.

The solar collectors are monitored and tracked automatically to follow the sun with a simple mechanism using electric motors and worm gear actuators and a group of ropes and pulleys.

Figure 1: A section of the solar plant in Egypt

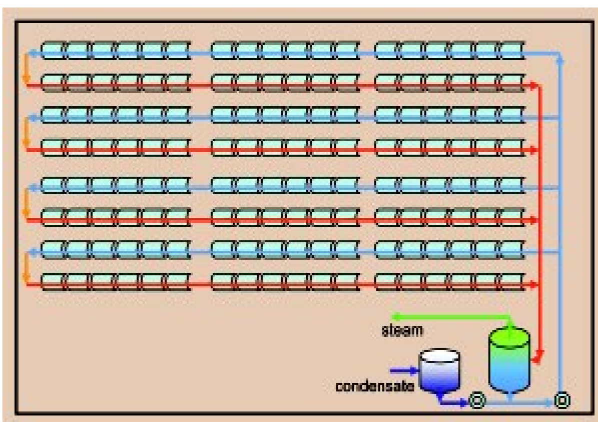

Figure 2: *Pilot solar plant layout*

2.0 APPLICATION OF STEAM IN INDUSTRY

Cost of production, technology utilized, and more so satisfied markets are key to the success of any business that directly involves industrial processes. An effective technology aims at producing a quality product at an optimum cost and ensures that minimum time is spent on the production line. This largely depends on the energy cost at which the plant is run.

Many industries such as dairy plants, abattoirs, pharmaceuticals, breweries, confectionaries, at some stage along the production line require steam to achieve the desirable production needs and hygienic standards say through sterilizatiBy adopting solar thermal technology, particularly parabolic concentrator water heating which is already commercially in use in certain African countries, considerable financial benefits and high quality standards can be realized in industrial processes.

The industries that use steam in Uganda are mentioned in the sections hereafter.

1. Soft drink industries: Crown Beverages Limited and Century Bottling Company are the main industries in Uganda. In the soft drinks industries steam is used in the Sugar Dissolver to heat the water-sugar solvent, Cleaning In Plant (CIP), to heat the water for washing, Bottle Washer and Case Washer. The section that takes the biggest amount of steam is the Rinse Section; that also takes the greatest amount of water.

2. Breweries: Uganda Breweries and Nile Breweries are the tow industries in this category.
The breweries take a huge amount of steam in the various processes that require heating and use of heated water.

3. Sugar factories: Kinyara Sugar Works Limited, Kakira Sugar Works Limited and Lugazi Sugar Works Limited are the three in this category. Steam is needed in very large quantities in sugar industries. To start off steam production, firewood is used. As soon as enough steam is produced, the firewood supply is cut off and steam is used to heat water and produce more steam. This steam is used in drying sugar and cleaning tanks in the factory.

4. Tea factories; that use steam for withering and drying the tea. They include Mpanga Growers Tea Factory, Ankole Tea Factory and Madhvani Tea factory. In tea industries, steam is produced using firewood. The steam is then used to wither the tea leaves and drying the tea at a later production stage.

5. Diary Corporation Uganda

Steam here is used to pasteurise the milk and also for cleaning purposes.

6. Other industries

Flower industries, Cement Factories, Fish curing industries, Timber processing, post harvest processing, etc. also use steam for heating, drying and cleaning purposes and therefore qualify for using solar water heater concentrators.

3.0 PROTOTYPE DESIGN AND CONSTRUCTION

To achieve temperatures above $120^{o}C$ using the solar technology, parabolic concentrators should be used. As opposed to other types of solar collectors such as flat plate and vacuum tube, the parabolic concentrators have the potential of achieving very high temperatures, even beyond $1000^{o}C$. As there are no commercially available solar concentrators, a study has been done with the support of ICEP – Austria to find out whether this type of technology is viable. For that matter, a prototype was built at Solar Construct (U), a solar thermal company in Uganda which builds flat collector solar water heaters for residential, commercial and industrial purposes. The prototype was designed to have an integration of flat plate collectors (to raise the amount of heat energy) and parabolic concentrators to boil up and vaporize the water into steam. The parabolic concentrator was tested to ascertain the most appropriate design that can achieve the desired objective- steam production.

In designing a parabolic concentrator, a trade off is usually made between temperature achieved and heat generated. The heat quantity depends on the efficiency of the concentrator. However, the efficiency is lower for a system designed to produce very high temperatures.

The prototype design parameters were obtained as follows:

- Length of aluminum (L) = 200cm
- Aperture width (W): This was determined considering efficiency limitations. Efficiency depends on concentration ratio (Cg).
- Cg = Aperture Area (Ae)/Absorber Surface Area
- $=(LXW)/(2\Pi rL)$
- Radius of copper pipe (r) = 0.5inch =0.0125m
- $Cg = W/(2\Pi X0.0125)$
- The value of Cg was calculated form various values of W, from which the optimum width of 0.7m was chosen.
- To obtain the curvature of the sheet and the focal length (f), the general equation of the parabola was used i.e. $y^2 = 4fx$

The focus was found to be 16 cm from the bottom with the sheet 19cm deep as illustrated in Figure 3.

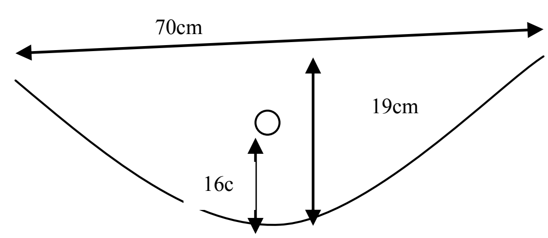

Figure 3: Cross-sectional sketch of the prototype

The parabolic concentrator was constructed out of easily available materials that are relatively cheap. These include: aluminum, copper pipe, steel flat pieces and hollow sections.

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The structure of the prototype is shown in Figure 4

Figure 4: First Prototype initially tested

The aluminum sheet used was 2m long and was curved into a parabolic shape so that the aperture width is 70cm, the focal length is 16cm and the depth of the curved parabolic shape is 19cm. The copper pipe used was 0.5inch diameter. Painting it black made increased heat absorption by about 20%.

There was a provision for tracking the sun so that at all times of the day for which tests can be done, the sunlight can be made to hit the reflecting surface normally. The tracking was made by a simple movable hinge.

The copper pipe, through suitable connectors, would get cold water via a horse pipe from one tank and deliver the heated water/steam to another tank.

The whole setup stood on stands made out of hollow section of steel and some flat pieces meant to support the aluminum sheet.

4.0 PROTOTYPE TESTS

A number of tests were performed on the prototype. The main parameter of concern was the temperature attained under different conditions namely:

1. Blackened and un-blackened copper pipe.
2. Time of the day, early morning, noon, afternoon, etc.
3. Position: East-West, North-South, etc
4. Tracking angle
5. Material of the pipe
6. Material of the sheet
7. Polished and unpolished sheet
8. Rate of flow of water
9. Quantity of water heated.

The results on the tests carried out so far reveal that a black coated pipe can raise the temperature by 20%, that the performance is quite good between 8 am and 5 pm, that in a cloudy day the concentrator does not raise the water temperature not even to 70 ^{o}C, that the longitudinal axis of the concentrator should be aligned with the East-West axis, that a simple manual tracking is enough to get a reasonable performance, that a more reflective aluminum surface is required to attain economically viable results.
At the present moment Solar Construct has ordered a highly reflective ceramic coated aluminum sheet from Alcan (Germany). It is expected that with this new surface higher temperatures shall be attained and we will be able to attach the prototype to a real industry to proceed with the tests.

5.0 ECONOMIC ANALYSIS OF PARTIAL USE

An economic analysis was performed to assess the viability of utilizing the collector to partially replace furnace oil.

5.1 Cost of the Prototype

The material costs were as illustrated in Table 1. From the table, it can be seen that the parabolic concentrator is relatively cheaper to build compared to the flat plate collector.

Table 1: Material costs for the parabolic collector

Item	Cost (USD)	Cost (UGX)
Aluminum sheet	50	90,000
Copper pipe	17	30,000
Joints	17	30,000
Tanks (200litres)	56	100,000
Steel plates for support/shoes	28	50,000
Labour	112	200,000
Others	56	100,000
Total	**336**	**600,000**

Energy from furnace oil

To vaporize 1 litre of water at 100^{o}C, we need 0.627kWh = 627Wh of energy.

To raise the temperature of 1 litre of water by 1^{o}C, we use 1.16Wh of energy.

Therefore to produce steam from 1 litre of water;

Heat the water from 20^{o}C (tap temperature) to 120^{o}C

Energy = 1X1.16X(120-20) = 116Wh

It was assumed that because of effects of pressure, water boils at 120^{o}C.

Therefore to produce steam from 1litre of water we use 116 + 627 = 743Wh
= 0.743kWh

1 litre of furnace oil contains 10 kWh of energy. The boiler of Dairy Corporation Uganda Limited (case study industry) was assumed to have an efficiency of **55%**.
Therefore 1 litre of furnace oil will provide:

0.55 X 10 = 5.5 kWh

Dairy Corporation uses on average 1000litres of furnace oil per day; therefore, the energy used per day by Dairy Corporation is:

5.5 X 1000 = 5,500kWh

As Kampala receives an average of 157kWh/m^2 of solar radiation per month, we can count on 5.233kWh/m^2 per day.

At a concentrator collector efficiency of 50%, 1m^2 of parabolic concentrator will generate 50% of 5.233 = 2.6kWh of power per day.

Given our parabolic collectors of aperture area:

LXW = 2X0.8= 1.6m^2

Energy generated by 1 collector is:

1.6X2.6 = 4.16kWh per day.

Number of 1.6m^2 collectors:

(5,500/4.16)= 1,322 collectors

Considering 40% replacement on the partial replacement of the oil boilers, the number of collectors used will be 529 collectors.

1 litre of furnace oil costs UGSHS 850 or US$ 0.47. This makes that the saving per day considering 40% replacement (400 liters of furnace oil) is US$188. Considering 312 working days in a year, the saving in furnace oil for that period is US$ (312 X 188) = US$58,650.

A unit of parabolic collector costs UGSHS 600,000 = US$336 and therefore total cost of collectors is US$177,744. These figures makes that the pay back period will be 3 years.

Considering a 20 years life span of the system, the savings for the remaining 17 years is close to one million dollar:

(17 X 58,650)=**US$997,050**

The economic analysis of the partial replacement of furnace oil burners with solar concentrators shows that the project is economically viable. We are quite hopeful that with the use of the new polished aluminum from Germany higher temperatures are going to be achieved and therefore we could eventually cut in the number of concentrators.

6.0 POLICY ASPECTS

The main policy goal for the energy sector is to meet the energy needs of the Ugandan population for social and economic development in an environmentally sustainable manner (Energy policy, 2002). This is consistent with global and regional energy policies. Uganda being a signatory to the United Nation's Framework Convection on Climate Change (UNFCCC) may participate in the Clean Development Mechanism (CDM). This mechanism can help Ugandan industries to tap resources for projects such as replacing furnace oil with solar energy and make the payback period even shorter.

The Clean Development Mechanism strongly favours renewable (solar, biomass, hydro) energy projects whose proper implementation will create sustainable development in the host country

(Uganda) and at the same time earn carbon credits to the developed Nation providing subsidies (Investor).

The introduction of solar water heating in industry therefore can be viewed as an opportunity to enable Uganda fulfill her commitment to participation in the global Climate Change challenge while becoming internationally more competitive. Development and use of renewable energy resources for both small and large-scale applications is therefore an important strategy of the Ugandan Energy Policy.

One of the main obstacles for the success of this project is the lack of awareness on the benefits of such systems. The solution will be to install the prototype in a given industry and use it for some months to go by so that the management can realize the savings in furnace oil.

7.0 CONCLUSION

This study has demonstrated the effectiveness of the solar concentrator. Work relating to the implementation of a full system is yet to be done. Yet to be tested is the hybrid concentrator cum flat collector. This hybrid has the theoretical possibility to generate greater quantities of steam as the flat collector can bring the temperature of the water to 60 ^{o}C or 70 ^{o}C before entering into the concentration section.

It is estimated that some two more years of research are necessary before Solar Construct can begin a commercially viable production of such systems. It is also hoped that the prototype will be successful and the industry using it can become a "show-case" for those interested in investing in renewable energy.

The fact that the construction is quite simple and the material is already available can make it simple for other companies to begin manufacturing similar systems.

8.0 REFERENCES

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