USE OF SOLAR WATER HEATERS IN INDUSTRIAL PROCESSES TO REDUCE FURNACE OIL CONSUMPTION

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ABSTRACT

The high costs and environment problems that arise from the non-renewable sources of energy call for the conversion to more sustainable and less hazardous energy supplies such as solar thermal energy. This paper discusses the use of solar water heaters in industries to reduce furnace oil consumption. Solar thermal is not always viable. Technical design and financial analysis are presented.

1. INTRODUCTION

During the oil crisis in 1973-74, the public became aware of the scarcity of the resources of the present energy sources, mainly oil and natural gas. Later on attention was driven to the fact that the combustion of fossil fuels has harmful effects on the environment.

The emissions from burning fossil fuels cause the green house effect and acid rains which threatens the very existence of human life on earth.

Among others, a solution for the above problems is the increased utilization of solar energy in the form of passive (solar architecture) and active solar systems (thermal and photovoltaic).

Today, the world's energy supply is based on the non-renewable sources of energy: oil, coal, natural gas and uranium, which together cover about 82% of the global primary energy requirements. In Uganda, most of the energy used in industries for heat purpose comes from furnace oil. Nevertheless, Uganda being located in the tropics is endowed with enormous solar radiation.

The average solar radiation on a horizontal surface in Kampala is 157kWh/m^2 per month, which is about two times more than that in London and in Vienna. In Uganda the sun is a very stable and free source of energy that the country hardly uses. Countries such as Germany with solar radiation averages of less than half of that of Uganda have thousands of square meters of installed thermal panels, while in Uganda the number of Solar Water Heaters sold are limited to a few hotels and households. Many other countries have passed regulations to foster this technology. In Israel, for example, it is forbidden by law to use electricity to heat water. In USA the Department of Energy has a project to install a million SWHs on household rooftops by 2010.

Crown Beverages limited (Uganda) holds the franchise for Pepsi-Cola and produces about 25 thousand bottles of soda daily. They use solely oil furnaces for heating water and this study tries to find out whether it is financially viable to introduce solar thermal technology to reduce oil consumption and the consequent CO_2 emission.

Table 1: Average monthly global solar radiation on a horizontal surface in kWh/m^2

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
EUROPE													
London,	17	31	64.2	91.1	128.0	150	136	112	81.3	48.3	24	15	74,8
Vienna	25.2	43	81.4	118.9	149.8	160.7	164.9	139.7	100.6	59.8	26.3	19.9	90,8
AFRICA													
Kampala	**174**	**163.9**	**170.4**	**153.4**	**151.0**	**142.6**	**141.4**	**151.0**	**154.8**	**163.7**	**154.0**	**164.4**	**157,0**
Moshi,Tz	179.8	169.4	179.8	162.0	148.8	148.8	147.2	187.6	169.5	182.9	165.0	178.2	168,2
Harare	175.1	147.8	163.2	152.0	147.7	135.1	145.8	165.3	178.2	140.3	172.2	172.3	157,9

2. SOLAR RADIATION

The Sun is the central energy producer of our solar system. A small fraction of its energy hits the earth and makes life possible on our planet. The duration of the sunshine as well as its intensity depend on the time of the year, weather conditions and on geographical location.

The monthly amount of solar radiation for some places is shown in Table 1.

In Uganda, due to lack of awareness, almost none of the enormous solar energy is utilized in industrial processes or households.

2.1 Active Solar Thermal Systems for Solar Water Heaters (SWH)

Solar thermal systems convert sunlight into heat. "Flat-plate" solar thermal collectors produce heat at relatively low temperatures (27°C to 60°C), and are generally used to heat air or a liquid for space and water heating or drying agricultural products.

In locations with average available solar energy, flat plate collectors are sized at approximately 3.75m^2 to 7.5m^2 per thousand litres of daily hot water use.

A solar water heater uses the sun's energy rather than electricity, gas or furnace oil to heat water, thus reducing monthly utility bill, gas or oil expenditure. When installed properly, solar water heaters are by far the cheapest way of heating water. It is cheaper than heat pumps, heat recover units or LPG.

The three most common types of solar systems in use today are:

- Pumped Circulation System
- Integral Collector Storage (ICS),
- Thermo-siphon.

The **Pumped Circulation System** *(Figure 1)* circulates potable water from the water storage tank through one or more collectors and back into the tank. The solar collector is the main component of the solar system. It is usually a metal box with insulation and a black absorber plate that collects solar radiation and heats the water. The circulating pump is regulated by an electronic controller, a common appliance timer, or a photovoltaic (PV) panel.

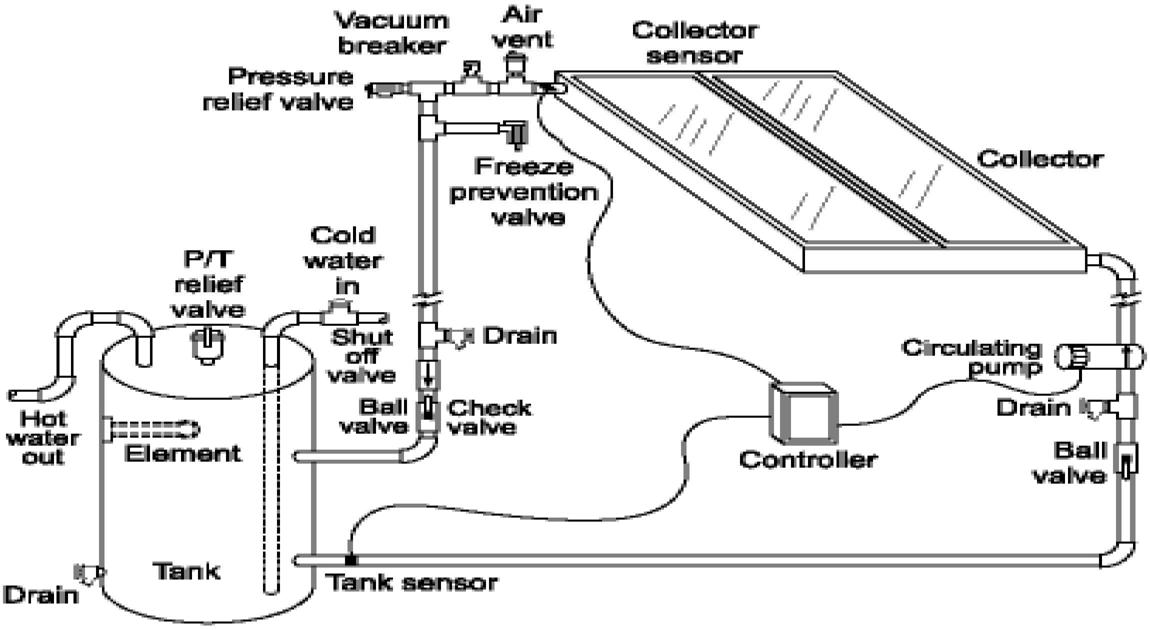

Figure 1: A solar water heating system

In **ICS** systems, the solar water storage system is built into the collector. The potable water in the collector unit is heated by the sun and delivered by city or well water pressure to an auxiliary tank (which contains non-solar back-up heating) or directly to the point of use.

A **Thermo siphon** solar water heating system has a tank mounted above the collector (normally on the roof) to provide a natural gravity flow of water. Hot water rises through piping in the collector, which is mounted below the tank; heavier cold water sinks to the lowest point in the system (the collector), displacing the lighter hot water which rises to the tank.

The ICS and thermo siphon systems are simple since they use no pumps or controllers and water always flows through the collector.

Active solar thermal systems are those in which the incident solar radiation is converted by means of collectors to heat and delivered to a consumer (hot water storage tank, space heating and swimming pool). The main part of the SWH is the collector.

2.2 Installation of SWH system

The solar collector is usually mounted on the roof and is connected to a circuit containing water with propylene glycol anti-freeze added, if necessary. The heated liquid flows around the circuit, either under the action of a pump to warm the main hot water tank, or by a thermo-syphoning action to warm a solar water storage tank that then feeds the hot water tank.

2.3 Efficiency of Solar Thermal Systems

Solar thermal systems are more efficient at low temperatures. When SWH temperature rises or when SWHs are used to achieve very high temperatures, their efficiencies drop linearly. The efficiency of a solar panel decreases with the increasing of the working temperature.

Working temperature = $T_m - T_a$
Where:
T_m is the middle temperature of the panel.
T_a is the outside temperature.
In Uganda for a solar thermal system, 1m^2 of collector can on average produce 3.25kWh/m^2 per day.

3. SWHs IN INDUSTRIAL PROCESSES

The research project being carried out in Crown Beverages Limited (Uganda) (CBL) is geared at the use of Solar Water Heaters (SWHs) to pre-heat water from tap temperature of 20^{o}C to temperatures of 60^{o}C.

3.1 The manufacturing Process

At the start of the process, there is *defertilzation*[Ψ], that is to say putting the cases on the conveyor. The conveyor takes the cases to the 'unpacker' that removes the bottles from the cases. Bottles and cases then go to separate washers. The washers use steam and caustic soda to wash the bottles. But there is no direct contact of steam and the bottles or cases in the washing process, except that heat is passed through an exchanger. The bottle washer has four chambers and three rinsing sections, whereas the case washer is a small plant that washes and rinses the cases.
Syrup from the sugar dissolver, plus treated water are mixed by the mixer and carbonation is done. This solution now called soda is then bottled by the filler and led away by the conveyors to the packer. The packer loads the bottles into cases, and they are *fertilized.*
There are two production lines in the Factory. One production line produces one of the seven products: Pepsi-Cola, Mirinda Orange, Mirinda Lemon, Mirinda Fruity, 7Up, Tonic or Club Soda, at a go. These products come in 300 milliliters or 500 milliliters bottles. There are provisions for both bottle sizes in the filler.

The manufacturing process can be seen in Figure 2.

The Boiler
There are two boilers that use furnace oil. The furnace oil is stored in two furnace oil tanks. The boilers get water from two feed tanks. The water is maintained at 100-120^{o}C to achieve constant supply of steam that is then fed into the washers, sugar dissolver and routine cleaning avenues.
However some steam/water is lost through leakages and other losses, so the water recycled into the feed tanks after steam has been condensed, is less than the original make up water.
The feed tanks contain water at about 70^{o}C. Adding more cold make up water into the feed tanks leads to bigger consumption of furnace oil needed to heat the water into steam in the boilers. For that matter, one option to reduce oil furnace consumption would be to use Solar Water Heaters (SWHs) to pre-heat the make up water to 70^{o}C, before it is fed into the boilers.

The Sugar Dissolver

The Sugar Dissolver is used for the manufacture of syrup (i.e. a mixture of sugar and warm water). This syrup is later mixed with treated carbonated water and other flavors to form soda. The sugar dissolver has a motor mounted on it that drives the agitator, to ensure uniform distribution of heat. Sugar is poured in the water that has been heated by steam passing through a steam jacket in between the walls of the cylinder. The water is always at a temperature of about 80^{o}C. When the steam loses heat to the water, it condensates and is let out of the steam jacket through a pipe at the lower end of the cylinder.
The total Sugar Dissolver capacity is 5400litres. The condensate from the Sugar Dissolver goes back to the feed water tanks that store the water for boiler use.

Cleaning In Plant (CIP)

The CIP contains two tanks; one for caustic (sodium hydroxide) solution and the other for chlorine. It is a device used for cleaning the pipes and the tanks in the factory. The water used in the CIP is heated to 85^{o}C using steam, and a heat exchanger. It can then be used for Hot Water Protocol cleaning or Five Step Cleaning. The hot water is circulated in the tank for about 20 minutes. When Chlorine is used, the cleaning operation takes a bit longer than the normal cleaning operation.

Rinse Section

It has 4500litre capacity. It uses steam for heating the water. The water coming into the first rinse overflows from the third and second rinse sections, being let into the third rinse section by a pipe from the Water Treatment Plant. From the first rinse, the water just flows out.

[Ψ] The term fertilization and defertilization are used to mean loading and unloading cases onto the conveyors

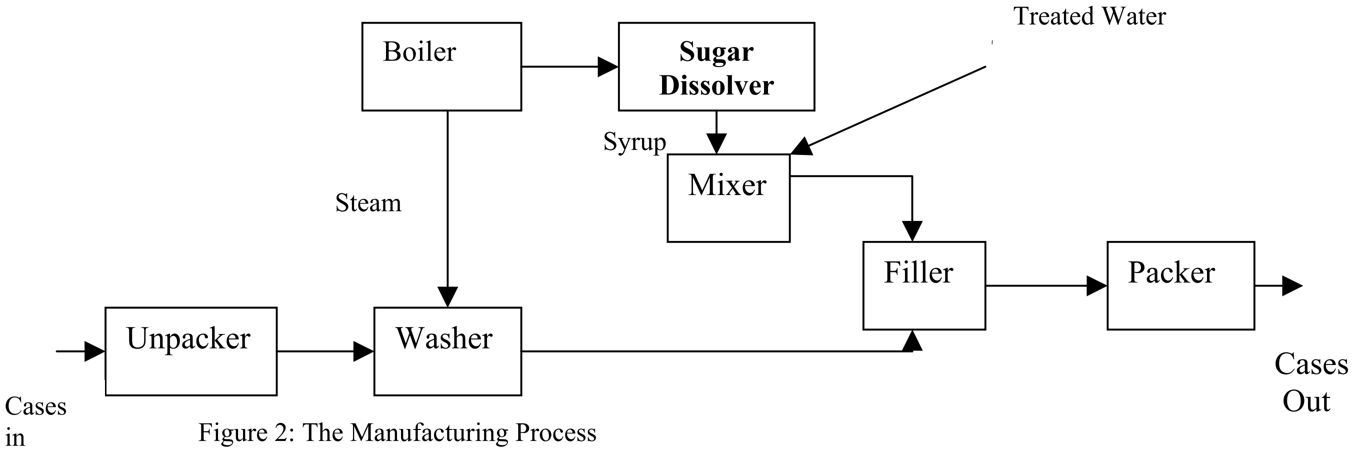

Figure 2: The Manufacturing Process

The industrial processes that could make use of solar water heaters are:

- Heating make up water to the boiler to 70°C
- Heating water to 80°C to be used in the Sugar Dissolver
- Heating water to 85°C to be used in the Cleaning In Plant (CIP)
- Heating water to 40°C to be used in the first rinse section of the bottle washer

The most promising option though is the one of the Rinse section. It is that part of the plant that uses most water. The problem is that it doesn't have a recycling tank and the amount of water is too much for being economically viable to be heated by SWH.

Calculations show that in order to heat the almost 180,000 litres of water daily, a SWH would have to have 2000 m^2 of flat-collector

The oil consumption and oil costs of Crown Beverages Limited are shown in Table 2.

Table 2: Essential data on Crown Beverages' industrial processes

Section	Required Water Temp. [°C]	Furnace Oil Consumption [m^3/annum]	Oil Expenditure [USD/annum]	Oil Expenditure [%]
Rinse	40	176.7	61,484	54.7
Sugar dissolver	85	30.2	10,508	9.3
CIP	80	8.7	3,027	2.7
Make up water tank	70	5.0	1,739	1.5
Bottle washer I	60	9.7	3,375	3.0
Bottle washer II	80	24.2	8,420	7.5
Bottle washer III	65	14.5	5,044	4.5
TOTAL		**323.1**	**112,400**	**100**

3.2 Method of heating water in various sections

This study suggests a recycling system for the rinse section. This system will save 50% minimum of the present water used. Besides, as the temperature of water is just 40°C, a SWH needs only to heat two thirds of the water. This should be the first step. After the payback period the company can consider using the very savings of this section to implant SWH in the other sections.

In the rest of the sections such as sugar dissolver, make up water tank and bottle washer we shall use one tank. The water in this tank shall be heated to a temperature of 60°C. Water from this tank shall then be supplied to the sections where the heating shall be supplemented by furnace oil. That is why solar energy will not totally replace the whole furnace oil energy but cause savings by substituting some of the furnace oil.

3.3 Energy used to heat water

To heat 1 litre of water by 1°C, we use 1.16Wh of energy. 1 litre of furnace oil contains 10 kWh of energy. With a boiler of efficiency 75%, 1 litre of furnace oil will contain: 0.75 x 10 = 7.5 kWh

To vaporize 1 litre of water, we need 0.627kWh = 627Wh of energy.

Therefore to produce steam from 1 litre of water:

- Heat the water from 20 to 120°C and use energy = 1x1.16 x (120-20) = 116Wh

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

So the quantity of furnace oil needed to vaporize 1litre of water = 0.743/7.5 = 0.1litre.
The sections were found to consume the following amounts of furnace oil per day:

- Rinse Section: 564.5 litres
- Bottle Washer: 154.6 litres
- Sugar Dissolver: 96.5 litres
- CIP Section: 27.8 litres
- Make up water: 173 litres

So a total of 1,185.3 litres of furnace oil is used per day.
Each litre of furnace oil costs Ushs. 585 = US$0.3

In one day, furnace oil costs
Ushs.(585x1,185.3) = Ushs.693,401
with 6 working days per week, in 1year, furnace oil costs
Ushs. (52x6x693,401) = Ushs.216,341,112
= US$ 112,400 per year.

4. FINANCIAL ANALYSIS

The savings to be made as well as the pay back period after the installation of the SWHs have been computed for Crown Beverages Limited:

For 1m^2 of collector, we get 3kWh of power per day.
Solar Construct supplies 2.2 square metre panels. Total energy consumed per day is 7,592kWh.. This requires 7,592/3 = 2,530.67m^2 of solar thermal panels.
The total cost of installing the solar system including buying the panels, pipes and other requirements is US$250 per square metre of solar thermal panel installed.
It implies that to install 2,530.67m^2 of the solar thermal panel we use 2,530.67 X 250 = **US$632,668**
Giving a payback period is 632,668/112,385 = **5.6 years.**

In 20 years, we can compute the savings that would be made as follows:
Total cost using furnace oil in 20 years = 20 x 112,385
= **US$2,247,700**
Savings 20 years after installation
2,247,700 – 632,668 = **US$1,615,032**
A savings of 1.5 million dollar is very promising but it is not realist to expect that a company would have 632 thousand dollar to invest in a process that is already working anyhow. This makes us to consider a step-by-step shift from oil furnace to solar energy.
Considering the values in Table 2 one realizes that the most promising first step for this industry is to heat not water but furnace oil.
This beverage industry spends USD 16,441 per annum solely to heat the very furnace oil it utilizes. As we have already seem it uses about 1200 litres of oil per day and it has to be heated to 60 degrees Celsius.

5. CONCLUSIONS

A rough estimate of the savings made is 70% of the current energy expenditure. This means that energy used in CBL will consist of SWHs as the major source, being backed up (supplemented) by furnace oil and electricity. Figure 3 shows the energy used in Crown Beverages Limited (CBL) before and after the installation of SWHs.

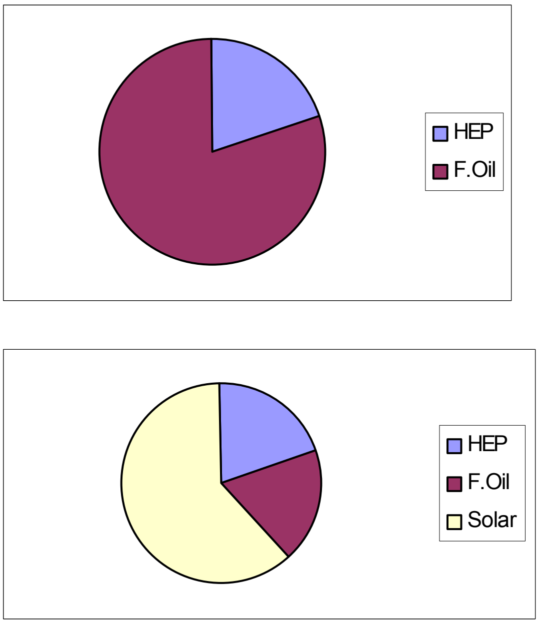

Figure 3: Scenario before and after installation of SWH in CBL

The use of SWHs will not imply a fundamental change on the mechanical structures of the industry because the existing pipes and tanks will not be tempered with to a large extent.
It is imperative that more benefits are realized by using SWHs in industrial processes than costs. It is therefore recommended that a Solar thermal renewable energy source be used especially for developing countries like Uganda, that cannot afford hard currency drainage to buy oil, but are rich in Solar energy (radiation).

6. REFERENCES

[1] Solar Construct Limited: "*Solar Thermal Technologies*", Kampala, Uganda

[2] Howell Bannet: "*Solar Thermal Energy Systems*"

[3] solarenergy.com

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