201404843

Analysis of the viability of using solar thermal energy for Maluti Mountain Brewery

Msc Research draft report

Malillane
Lillane
12-31-2020

Contents

1 INTRODUCTION
1.1 Background
The world is facing a number of challenges which are results of increasing energy demand, lack of energy security and unsustainability; caused by a great dependence on fossil fuels. Efforts are being made to resolve the issues relating to increasing energy cost and security of supply, this is done through implementation of various energy efficiency techniques [1]. The global frequency of environmental problems induced by emissions suggests that minimization of energy related emissions should take priority in energy systems.
Industrial processes are mainly dependent on either electricity or fossil fuels to supply industrial process heat[2]. The use of clean and renewable energy resources is crucial in achieving improved environmental quality, sustainability and a long term solution to global warming [2]. These forms of renewable energy resources are solar energy, bioenergy, hydropower and wind energy to name a few [1].
As an abundant source of energy, solar energy technologies have proven potential to substitute conventional energy. Solar heating is a promising method when it comes to reduction of the energy consumption of buildings as it also curbs the rapidly increasing energy crisis as well as global warming [3].
Solar energy has two different forms through which it can be explored, one being solar thermal energy and the other solar photovoltaic(PV) systems. Solar PV directly converts sunlight into electricity through a solar cells while solar thermal energy uses the sun’s heat energy for a variety of applications[4].
The use of solar energy for industrial processes, especially low- and medium-temperature industrial processes is very feasible due to the natural availability of solar [1]. Solar thermal technology has successfully been explored for domestic purpose applications but not enough exploration has been done for the industrial sector [5]. “The industrial sector is important, since it consumes nearly 30 % of the total final energy consumption according to European Union 27 [6], of which 67 % is thermal energy. Industrial sector activities of a country have a great impact on the country’s economic growth. This sector possesses a significant share of the overall energy demand globally but the percentage varies from country to country [7].
Solar thermal energy and solar photovoltaic (PV) systems are different solar energy techniques but are both technically feasible, environmentally friendly and cost effective [8]. Solar thermal energy is the best suited type of solar energy because it converts solar radiation directly into heat at an efficiency of 3-4 times higher than those which are achieved by solar PV. Again the storage technology for solar thermal energy are cheaper than those of solar PV[9]. Solar thermal energy is a type of renewable energy produced by conversion of sun rays directly into usable heat through solar thermal collectors [10]. Solar thermal technology and its application is very suited to the industrial and manufacturing sectors [3].

In industries, there are three groups of solar thermal technologies that are useful for process heat namely solar concentrators, solar air collectors and solar water systems [11]. They can be built locally. The costs of these systems is dependent upon local building materials and labor. There are conventional solar water systems such as flat-plate collectors (FPC) and evacuated tube collectors (ETC) which are commonly used in residential areas, but they can readily be installed on industrial rooftops to service heat demand of up to 125°C [2]. The efficiency of these solar thermal collectors is dependent on their inlet temperature, ambient temperature, irradiance and the efficiency parameters of a certain collector [12].

The challenges faced by use of solar thermal energy is its intermittent and fluctuating nature. The available solar radiation varies by hour and day and is dependent on the clearness of the sky. Again the solar collectors experience some thermal losses which are dependent on the ambient temperature and causes some sort of uncertainty in predicting the available energy from the sun. These challenges can be solved by use of solar thermal energy storage or use of hybrid systems [12]. The collectors used for solar water heating can be classified into flat plate and evacuated tube collectors. A flat plate collector has an absorber plate to absorb solar energy and also has a glazing above for reduction of convective heat loss. An evacuated tube collector is made up of tubes which have vacuum maintained between the tubes and are glazed for better protection against convective heat losses [13]. One other disadvantage of solar thermal technology is the high upfront costs albeit with less recurrent costs.

Studies have clearly indicated that there are challenges faced by implementation of solar thermal energy in industries such as breweries. There needs to be proper sensitization on the benefits of switching to solar energy from conventional energy, such reduction of CO_2 emissions, opportunity of getting carbon credits and subsidies like the ones provided by SOLTRAIN when companies switch to solar thermal energy and opportunities of new investments from savings made from switching to solar energy[10].

The economic viability of solar thermal energy is greatly dependent on two factors being the initial cost of the installation and the price of alternatives. The high upfront costs may unjustifiably discourage companies from investing in solar thermal technology, despite that their overall lifetime costs would be lower [10].

The energy consumption in industries is mainly comprised of electrical or thermal energy forms [6]. The most convenient processes of integration of solar heat are those that have lower temperature range and load profile that matches with the available solar resource as much as possible [12]. Amongst a number of processes that require energy in industrial, residential and manufacturing sectors, water heating is the most essential one [4]. It is the key demand of various industrial and domestic heating system [14].

Sixty percent of thermal energy in industries such as solar cooling, thermal desalination and food processing are said to be in medium temperature ranges (80-250 °C) [9]. Solar thermal energy systems can potentially provide process heat for industrial processes suited for low pinch temperature such as those in the beverage (e.g breweries), food and textile industry [5].

Breweries are huge consumers of energy within the industrial and manufacturing sector. The heat demand for breweries is largely within relatively low temperature levels but again there is a large potential for heat recovery [13]. This shows that integration of solar thermal energy in breweries has a great potential. Figure 1 shows the beer brewing process and their temperature requirements. It is noted that all the required temperatures can be met by non-concentrating solar collectors such as ETC and FPC.

Figure 1: The beer brewing process [15]

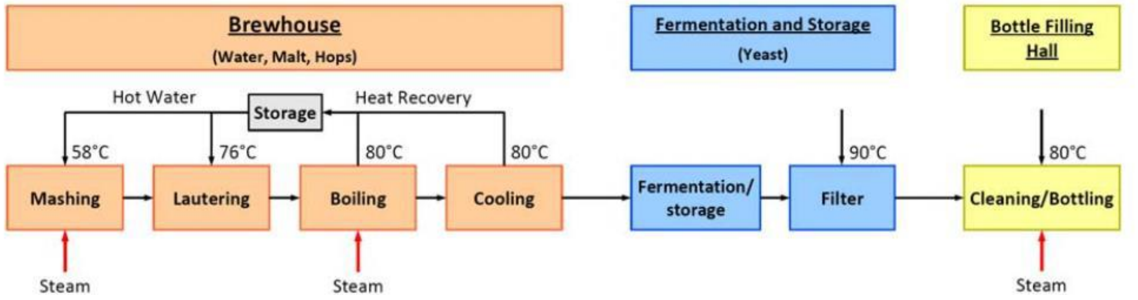

Figure 1 shows the beer brewing process as a whole together with the temperature ranges at which they occur. These are low and medium temperature ranges and can easily be met by common collectors such as FPC and ETC. Conventional flat-plate collectors (FPC) and evacuated tube collectors (ETC) both provide temperature levels up to 120°C [2].

A solar water heater is made up of two major elements being, the collector and the storage tank. These elements have their respective functions. The collector absorbs solar radiation and transfers it to the water and the storage tank serves the purpose of storing the water for usage[13]. In designing of a solar thermal system, these elements have to be correctly sized for the load that they will serve with regards to the temperature requirements.

Cape Brewing Company (South Africa) installed solar thermal system in their plant in 2015. The solar fraction is 29.6% of total paraffin demand with the annual saving of 19 386 liters of paraffin. The gross collector area is 120 m^2 and R 1.4 million was invested into this system including installation. Heating of process water is between 70°C and 90 °C. SOLTRAIN provided a subsidy of 30 000 Euro to this company. The subsidy encourages shifting from conventional energy resources to renewable energy resources [13].

Utilization of renewable energy resources in breweries has been studied through what is called “Green Brewery Concept tool”. This was developed based on three case studies. It is an Excel based tool that provides breweries with guidance towards a GHG emission free production whereby renewables cover the thermal energy demand. It is important to develop a tool instead of a basic guideline because of the small technological differences of brewing and packaging capacity which influence the energy management of breweries to a very large extent [7].

Integration of solar thermal energy in breweries can be done through preheating to increase the boiler efficiency.

Lesotho has a beer brewing company called Maluti Mountain Brewery(MMB), situated in Maseru. This company uses both electricity and coal to perform the beer brewing processes which costs the company large sums of money. For instance, MMB used a total of 313063 kWh of electricity in their main boiler house to produce thermal energy and 1693196 kg for the process of mashing; a process whereby soluble substances are dissolved directly into hot water and then undergo enzymatic hydrolysis which is followed by separation of the dissolved substances [16] to produce 440 000 hectoliters of beer in 2019. Figure 2 shows this information. There are many processes within brewery which use electricity but only some use electricity to serve the thermal energy demand. The company has goal that by 2025, a certain percentage of their processes be done using renewables.

The processes that go into beer brewing at MMB are namely malt loading which is followed by malt transfer, malt milling, mashing, lautering, boiling, wort cooling, fermentation, maturation, filtering, washing of kegs and halls, filling, packaging, pasteurization, labelling and lastly packing into crates. Figure 1 and 2 show the temperatures at which this processes take place.

In 2019, the rate at which MMB purchased electricity from LEC at an industrial tariff while coal the price of buying coal at that year was $65.50/ ton of coal. About $200418 is spent on coal for thermal demand. The operations of this company are expensive and environmentally unfriendly. This place receives solar radiation which can be used to displace a certain portion of electricity and coal if not all.

Table 1: Electricity and coal usage at MMB together with the overall beer production for 2019

Production Volume of beer	HL(hectoliters)	440 285.40
Electricity supplied-Main Boiler House	kwh	313 063.0
Coal Supplied-Boiler 1	kg	916 568.0
Boiler 2	kg	860 908.0
Total coal	kg	1777 476.0

Selection of a collector is central in the designing of a solar thermal system. There are different methods of solar collector appraisal, one is energy per dollar (epd) criteria which is based on cost effectiveness of using a certain solar collector at the climatic conditions in question as rated by Solar Ratings & Certification Corporation (SRCC) [17]. Collectors are ranked with respect to their epd and then the collector with the highest epd is preferred amongst those that it is being compared with. According to the energy-per-dollar (epd) comparison metric the most cost effective collector area is at the knee of the solar fraction curve [17]. After selecting the most cost effective solar collector, the most cost effective collector area determined. The value to be maximized when designing the most cost effective solar collector area is the Net Present Value of Solar Saving which varies with the marginal specific yield[17] .

It is expected that for the MMB case study, the optimal collector area will be found using this framework for each temperature and load of the processes in the beer brewing.

Figure 2: Site Plant layout of MMB

Space availability for collection of solar resource at the site where a solar thermal system is to be built has to be analyzed. Figure 5 shows the MMB roof tops which present potential space for placement of solar collectors.
It is of great importance that solar energy which is quite abundant in Lesotho and environmentally friendly be used to uplift the socio-economic situation in the country [18]. Lesotho's daily sunshine hours range between 10.2 and 13.8 hours while the daily solar radiation in Lesotho ranges between 5 kWh/m^2 and 7 kWh/m^2. [18]. The solar resource data can be collected from ground or satellite records [17]. The solar resource of MMB as collected at the weather station at Lerotholi Polytechnic is shown in Table 2.

Table 2: Average monthly horizontal irradiation at MMB for years 2005-2016 from satellite records [kWh/m^2] [27]

Time and day	T2m	G(h)	Gb(n)	Gd/h)
1/1/13 0:00	21.58	0	0	0
1/1/2013 1:00	21.71	0	0	0
1/1/13 2:00	21.84	0	0	0
1/1/2013 3:00	21.97	0	0	0
1/1/13 4:00	22.1	0	0	0
1/1/2013 5:00	22.23	0	0	0
1/1/13 6:00	22.36	11	0	11
1/1/2013 7:00	22.49	343	692.05	92
1/1/13 8:00	28.17	576	827.06	113
1/1/2013 9:00	28.85	734	710.55	214
1/1/13 10:00	29.54	923	843.14	192
1/1/2013 11:00	30.22	1078	1009.29	113

1.2 Knowledge gaps and challenges

Industries such as breweries rely on fossil fuels for their thermal energy needs. These fossil fuels are not environmentally friendly and also expensive [3].
As a contribution to science, study presents an analysis of how solar thermal energy can cost effectively implemented at breweries using MMB as the case study. This will in turn reduce the electrical load of LEC (which relies on imported electricity from South Africa and Mozambique) [19]. South Africa uses the environmentally unfriendly coal for electricity production. This use of solar thermal energy will reduce the national electricity demand by a certain portion. Moreover, it will reduce the greenhouse gas emissions as coal is used at MMB for production.
Maluti Mountain Brewery uses a lot of electricity and fossil fuels to produce beer. Most of this electricity or fossil fuels can potentially be displaced by use of abundant, renewable and environmentally friendly solar thermal energy. Breweries which have integrated solar thermal energy in their production have come out as an interesting solution for CO_2 emissions from breweries. Also there are long term economic benefits of using solar thermal energy even though the initial capital costs are high.
There is no tool that can be used by breweries that is specifically designed to simulate the most economical solar thermal system for breweries. Green Brewery Concept tool was designed to assist breweries by incorporating solar thermal energy in order to reduce greenhouse gas emissions disregarding the most cost effective design[7]. There are different processes in beer

brewing and it is not all that can be serviced by solar thermal energy if the aim of the system is to be cost effective so the study will provide brewery industry with a tool that will simulate the most cost effective solar thermal system.

1.3 Purpose of the study

The study is aimed at establishing the opportunities of using solar thermal energy in the beer brewing at MMB and to do a techno-economic design of solar thermal systems at the brewery. Also to evaluate all the necessary parameters for integration of solar thermal energy in breweries. The study will evaluate space availability at MMB whereby solar thermal collectors will be placed. The space will likely be the roof tops, taking into consideration any forms of shading, day lengths and the available solar resource.

Another purpose of this study is to determine the thermal energy demand of MMB and the all the processes that go in to brewing so as to know which processes can produce the most economic benefit when serviced with solar thermal energy. Determination of the most cost effective solar thermal system will be simulated by an Excel based model. The model will also determine the most economical solar collector to use at MMB based on the energy per dollar criteria. The model will establish the economic and environmental benefits of integrating solar thermal energy at MMB by determining the highest Net Present Value of Solar Savings [17].

The largest driver of a collector’s cost effectiveness is often the price of alternatives, like coal, oil and natural gas, not the cost of the collector itself. Hence it is important to build a model that will align the cost effectiveness of solar collectors in comparison with alternatives of energy. It is easier to justify the use of solar thermal energy when fossil fuels become expensive [10]. The most cost effective solar collector field size will be determined in relation to the available solar resource, the cost of solar thermal technology, the price of electricity in Lesotho, price of coal and other economic parameters such as interest rate and collector price on the energy market.

This study seeks to sensitize stakeholders within the beer brewing industry of the importance of switching from conventional energy resources to the use of renewables, specifically solar thermal energy. It is apparent that the use of solar thermal energy in the beer brewing industry will reduce greenhouse gas emissions while providing them with long term economic benefits such as potential new investments from the solar savings.

1.4 Hypothesis and Research Questions

It is hypothesized that solar thermal energy can be used to service the beer brewing energy demand.

The main research questions are as follows: What are the opportunities of using solar energy in the MMB brewing processes? Is it technically and economically viable to use solar thermal energy at MMB?

The questions are addressed by answering the following sub-questions:

a. What is the thermal energy demand of MMB?

b. Which type of solar thermal collector(s) is suitable for the processes at the brewery.

c. Is the use of solar thermal energy economically beneficial to MMB?

d. What size of solar collector field produces maximum benefit to the processes, given the available solar resource, the cost of solar thermal technology, the price of electricity in Lesotho and other economic parameters such as interest rate?

1.5 Objectives

The main objective of this study is a result of the main purpose of the study which is determination of the technical and economic viability of using solar thermal energy at MMB. This viability will be determined by use of an Excel based model that can carry out thermal and economic analysis of producing thermal energy for MMB.

a. To determine the entire thermal energy demand of the beer brewing process which will assist in knowing how solar thermal energy can be integrated in the process.

b. To study the usable solar resources at MMB, taking into consideration shading which could come from objects such as trees or building. Also to determine sunshine hours at MMB. These issues will help in knowing the exact amount of solar radiation can be collected by solar thermal collectors to produce usable heat.

c. To select the type of solar thermal collector to employ for beer brewing at MMB, based on the energy per dollar criteria as it selects a collector based on the highest energy per dollar and collector area with the highest Net Present Value of Solar Savings which is what this study is mainly focused on.

d. To establish the most economical size of solar thermal collector field and its storage size to employ at MMB. This will also be done through determination of which processes can be serviced by solar thermal energy and produce the most economic solar thermal system design and size.

1.6 Justification

The heat requirements of processes in the beer production range between temperatures 25°C-105°C [3] which can be achievable by common solar collectors. Solar thermal energy, depending on the system size and solar fraction employed can be more economical than using electricity from the power grid [20]. The use of solar thermal energy in the beer brewing processes can be economical in the long run regardless of the high capital cost compared to the use of electricity and fossil fuels and therefore it would make sense to displace some electricity use by employing solar thermal energy. The use of solar thermal energy will reduce the rate of greenhouse gas emissions from the industry when compared to using fossil fuels.

The Lesotho energy sector is faced with challenges such as low access to modern and clean forms of energy. It relies on imported electricity and fossil fuels and declining forest reserves (which poses an energy security problem) [19].The use of solar energy in large industries such as the beer brewing industry in Lesotho may reduce the country's electricity imports and fossil fuel imports, this means that the costs incurred by the country may be reduced. The use of solar thermal energy will help in reducing the electricity demand and coal demand of MMB, which will be economically beneficial for the company.

1.7 Thesis structure outline

The outline of this paper is as follows: introduction in Chapter 1, literature review in Chapter 2, methodology in Chapter 3, results and discussions in Chapter 4. conclusions and recommendations in Chapter 5.