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USE OF FLAT SOLAR COLLECTORS, IN REPLACEMENT OF LPG GAS FOR WATER PRE-HEATING, TO BE USED IN ENGINES OF ELECTRIC POWER THERMAL GENERATION PLANTS

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Abstract

Energy consumption in the world has been growing every year. The industrial sector represents 27.32% of the world energy demand. Implementation of flat solar collectors (temperature > 100°C) replacing the LPG gas to preheat the water used in the electricity industry, for the three engines of the Thermal Power Plant of Electricity Energy Generation – TermoCabo with power 45 MW. Given the importance of the matter, this research project aims a technical analysis and economic evaluation of the use of flat solar collectors, including an analysis in the control system of the plant, besides an adaptation of the collectors to the charge demand and to the thermal energy storage system in order to maintain autonomy of 24 hours. The system consists of a battery of collectors associated to a complex grid of flow control and maintenance of stagnated temperature of 65°C, besides the system working independently, having the heat exchanger as a point of intersection between the primary and the secondary system. The project was planned as three closed and independent systems, because due to load operating complexity (engines) required the collectors independent worked the other parties, and the need to use glycol to increase the boiling water point, plus there a water storage system to maintain the autonomy and the third stage is the engine heating system, which is composed of thermal additive.

Keywords: *Flat Solar Collector, Solar Energy, Energy Efficiency, Heating System.*

1. Introduction

Energy consumption in the world has been growing every year. The industrial sector represents 27.32% of the world energy demand. The search for greater energy efficiency, along with policies of clean development mechanism, has encouraged the study of new techniques for power generation using renewable energy sources with lower generation of pollutants (DINIZ & BERMANN, 2012). Among the alternative energy sources, solar energy is becoming more popular, especially for residential water heating, being a cost-effective alternative to the use of electricity and natural gas (Goldemberg & Lucon, 2007; Luna et al., 2008; Oliveira et al., 2008; Altoé et al., 2012). Heating systems that use solar energy may contribute with a percentage of the total energy required by industries. Heat is often underappreciated in public policy discussions on energy, frequently overshadowed by transportation energy and electric power. However, heat accounts for 37 percent of energy consumed within most developed countries, and 47 percent of the world's energy consumption (IEA 2013). While many people associate solar energy with electricity-producing photovoltaic (PV) panels, solar can also be used for heating purposes. Solar thermal energy is most commonly used to heat outdoor swimming pools and residential water in the United States, but it can also be used for many types of industrial processes (IEA 2014). This issue brief will examine the role that solar thermal technology currently plays in industrial heating processes and outline opportunities for increased application in the world industrial sector.

The industrial sector is the leading source of energy consumption in the United States. At nearly one third of total energy use, it exceeds both the transportation and residential sectors. Within the industrial sector, nearly two thirds of energy used is consumed as heat. Some industries have even higher rates, such as the glass industry, which consumes about 80 percent of its energy for heating purposes. The remaining third can be

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attributed to electricity generation or energy lost in transmission within the grid, or by inefficient conversion within the power plant itself.

Depending on how industrial thermal energy is defined, nearly 90 percent of the energy comes from burning fossil fuels, but biomass can count for up to 11 percent.6 The remaining 10 percent of thermal industrial energy comes from electricity, which is often generated by power plants that burn fossil fuels. When including the environmental degradation from extracting fossil fuels, like mountaintop removal mining, water pollution from hydraulic fracturing of shale for natural gas, the air pollution emitted after their combustion, and large emissions of greenhouse gases, there is Environmental and Energy Study Institute a clear social incentive to find alternative sources of energy. Industry's role as the largest consumer of energy in the nation, its large heat requirements, and its heavy reliance on fossil fuels, present tremendous opportunity for application of solar thermal technology.

In Brazil, usually the use of sun energy for the generation of thermal power for industrial use is small. This issue involves the understanding of the relationship between sustainable development, modernity, freedom, market, citizenship, and especially the relationship between the lack of access to energy and technological knowledge. Given the broadness of these aspects, the attention is directed the regulatory framework of the Brazilian energy industry and the use of water heating with solar energy by national industries. Brazil receives high levels of solar radiation incidence during almost every month of the year, including in June, which corresponds to the winter solstice for the Southern Hemisphere.

The average daily distribution of global radiation per region of the country is: North 5,462 Wh/m^2; Northeast 5,688 Wh/m^2; Midwest 5,630 Wh/m^2; Southeast 5,478 Wh/m^2; South 5,015 Wh/m^2. These high solar radiation levels may provide a wide use of solar collectors for water heating, mainly in the industrial sector and can be applied in the reduction of fossil fuels, reducing also the emission of CO_2 into the atmosphere.

Given the importance of the matter, this research study aims for a technical analysis and economic evaluation of the use of solar collectors, replacing the LPG gas for water pre-heating to be used in the engines of the Termocabo plant.

1.1 Characteristics of industrial thermal demand

Industrial heating needs can be categorized into three main temperature ranges. All of them can be achieved with solar. The lowest temperature range consists of everything below 80ºC. Solar collectors are capable of meeting these temperatures and are commercially available today. The medium temperature category is between 80ºC and 250ºC. While the collectors servicing this level of heat demand are relatively limited, they do exist and are on the verge of emerging into competitive commercial production. The highest range includes everything over 250ºC and requires concentrated solar power (CSP) (see appendix) to achieve such temperatures. While CSP furnaces are rare - a few have been installed in the World for electricity production. They can achieve temperatures as high as 800ºC.

The challenge of mitigating imminent risks arising from climate change embraces not only governments, but the civil society and companies; therefore, it is necessary to develop and establish techniques that reduce the concentration of gases causing the greenhouse effect in the atmosphere. In the industry, the use of solar energy has been little explored since the energy obtained via solar collectors may be used for fluid pre-heating, what greatly reduces the amount of fuel material burnt in boilers (KALOGIROU, 2004; ABRAMOVAY, 2010).

Many industries already can take advantage of the commercially available low and mid-range temperature solar thermal collectors. They are particularly suited to meet the heating needs of the food, beverage, textiles, paper and pulp industries. Processes like sterilizing, pasteurizing, drying, hydrolyzing, distillation and evaporation, washing and cleaning, and polymerization do not require high temperatures and can easily benefit from flat plate and evacuated tube collectors (see appendix, table below). According to a study of industrial heating in European countries, 30 percent of industrial processing requires heat below 100ºC and 27 percent of industrial heating needs can be met with heat between 100-400ºC, and 43 percent requires heat over 400^{0}C.18 In the food, wine and beverage, transport equipment, textile, machinery, and pulp and paper industries, roughly 60 percent of the heating requirements can be met by temperatures below 250ºC. Despite tremendous opportunity, solar thermal heating for industrial processes has been insignificant compared to the residential sector, and the few industrial applications that do exist have been experimental in nature, show in Table 1 different temperatures of process industry.

Tab. 1: Heating process in the different industry (Mekhilef *et al*., 2011).

INDUSTRY	PROCESS	TEMPERATURE(ºC)
Dairy	Pressurization	60-80
	Sterilization	100-120
	Drying	120-180
	Concentrates	60-80
	Boiler feed water	60-90
Tinned food	Sterilization	110-120
	Pasteurization	60-80
	Cooking	70-90
	Bleaching	70-90
Textile	Bleaching, dyeing	60-90
	Drying, degreasing	100-130
	Dyeing	70-90
	Fixing	160-180
	Pressing	80-100
Paper	Cooking, drying	60-80
	Boiler feed water	60-90
	Bleaching	130-150
Chemical	Soaps	200-260
	Synthetic rubber	150-200
	Processing heat	120-180
	Pre-heating water	60-90
Meat	Washing, sterilization	60-90
	Cooking	90-100
Beverages	Washing, sterilization	60-80
	Pasteurization	60-70
Flours and by-products	Sterilization	60-80
Timber by-products	Thermal diffusion beams	80-100
	Drying	60-100
	Pre-heating water	60-90
	Preparation pulp	120-170
Bricks and blocks	Curing	60-140
Plastics	Preparation	120-140
	Distillation	140-150
	Separation	200-220
	Extension	140-160
	Drying	180-200
	Blending	120-140
Energy Generation	Thermic	150-800

1.2 Barriers

The main barriers to the implementation of a solar heating system of high performance are the lack of data on collectors when high temperatures are employed, and its actual efficiency under different temperature conditions. In this sense, this study aimed to identify relevant parameters of fluid heating for solar power systems as well as the main process responses. In addition to tests of heat transfer, economic viability studies were performed by calculating the return time and rate on the investment.

Despite the large potential for solar energy to meet industrial thermal demand, there are several barriers to large scale implementation. The most noteworthy barriers are cost, variability of output, energy storage and process integration.

1.2.1 Cost

The economic viability of solar thermal energy depends largely on two factors: the initial cost of the installation and the price of alternatives. High upfront costs often prevent companies from investing in new technology, like solar thermal, even if the overall lifetime cost would be lower. However, while the cost of solar technologies is decreasing, the financial investment in solar remains more stable than many of the markets for fossil fuels. Thus, 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. The more expensive fossil fuels become, the easier it is to justify an investment in solar thermal energy. Nevertheless, if the price of solar thermal were to drop, it would certainly enhance its economic viability. With the volatility of fuel prices, some manufacturers opt for the fixed upfront cost (see case studies) with a predictable payback period. In addition to the potential for a lower overall cost, there exists a benefit from having a predictable cost structure which is insulated from fuel market volatility. Approximately 40 percent of industrial primary energy comes from natural gas, and approximately 41 percent comes from petroleum (Kalogirou, Soteris. 2012).

Furthermore, solar thermal collectors can be made even more cost effective when tailored to the specific process heating needs of the plant (see Process Integration below). On the factory level, large-scale applications can benefit from economies of scale and lowered investment costs, increasing its economic viability. On the national level, the IEA estimates that costs can be reduced by as much as 20 percent when a country's total installed capacity doubles.

1.2.2 Variability

Solar energy, like wind energy, can be predicted to a high degree of confidence. Its availability, however, presents challenges for industries that require "24/7" demand. The reliability of the heating supply is of paramount concern to many manufacturers for whom an unanticipated disruption in production can be economically devastating. Solar thermal energy is reliable but not always available. Therefore, industries which either do not require constant production, or for whom the sunlight availability can be aligned with heating requirements, may be more confident about integrating solar thermal energy into their production. The variability of sunlight can also be mitigated by conducting statistical analyses of heating requirements vis-à-vis the regional insolation—the irradiance per square meter over a given period of time. This can be conducted as part of a procedure known as process integration (see below). Another possible solution is to store heat for later use to smooth the gaps in sunlight availability (see below).

1.2.3 Process Integration

Process integration, also known as "pinch analysis," is a field of engineering which seeks to optimize operational energy efficiency, or in other words, to reliably produce a product with the minimum energy inputs necessary. The variability of energy supply must be quantified based on daily solar radiation, ambient temperature profiles, and available storage opportunities, so that the solar collectors can be optimized to reduce economic inefficiencies. Variable energy, like solar and wind, presents a particular challenge for process integration because the supply of energy is non-continuous. Therefore, the nature of solar thermal energy supply must be addressed or it can become unaffordable in some cases.

If solar collectors supply all of the energy, the manufacturer must either align production with the energy supplied, or store the energy for later use. However, even if sunlight is not available to meet all of a factory's thermal energy needs, solar thermal can still play a role by supplying a portion of the total energy required. Under such hybrid systems, solar collectors can provide a baseline energy supply whenever it is available and the remainder can be fulfilled by a complementary fuel source. The commercially available low temperature collectors are especially effective in this strategy and are often used for pre-heating purposes.

1.2.4 Energy Storage Options

Large scale thermal energy storage is a nascent market but it can compensate for the inherent variability of sunlight. For low and medium temperatures, this can usually be performed by storing the heat in a transfer fluid like hot water or oil. Sometimes pressurized steam is used. For higher temperatures, this becomes more difficult, and costly, and requires an alternative heat transfer fluid and storage material.

The most common heat transfer fluid for CSP is molten nitrate salt, which is thermally stable within a temperature range of 220° C to 565°C, below which the salt freezes.32 The molten-salt system is currently the only practical thermal energy system with hours-long storage potential, and has proven reliable at commercial scales.33 The National Renewable Energy Laboratory (NREL) has called on researchers to develop a heat transfer fluid that can sustain temperatures up to 1300°C and operate as low as 0°C.34 This temperature, according to NREL, is a necessary component in reaching the full potential of solar thermal applications.

1.3 Market Tends

The solar thermal industry has seen steady growth over the last few years. The global solar thermal market grew by 17 percent in 2012 and again by an estimated 42 percent in 2013, largely due to a 45-50 percent surge in the U.S. residential sector. By the end of 2014, the United States and Canada combined for 8.7 percent of the world-wide installed capacity. China led the global market with 58.9 percent of installed capacity, followed by Europe with 18.9 percent.

Excluding solar that is used mainly to heat outdoor swimming pools, the United States ranked 10th in the world in 2009 for overall installed capacity and 36th in the world for per capita capacity. Firms have begun using solar thermal for industrial process heating with a few large-scale projects in Europe and China.

1.3.1 Energy efficiency

According to the DOE's Office of Energy Efficiency and Renewable Energy, best practices in process heating, such as opportunities for heat recovery, can reduce the cost and consumption of energy by as much as 30 percent. Even plants and factories with energy management systems can improve energy efficiency from 10 percent to 15 percent by implementing best practices, thereby reducing energy costs for process heating from 5 percent to 15 percent.

2. Methodology

2.1 Analysis of types of solar thermal technology

There are two main types of solar thermal technology: stationary and concentrating (typically non-stationary). Stationary collectors do not move and can be further subdivided into flat-plate collectors and evacuated tube collectors. Stationary collectors are cheaper and require little maintenance but they can only achieve low to medium temperatures. Alternatively, concentrated solar power (CSP) collectors usually rotate to track the sun's rays and can therefore achieve much higher temperatures. However, they are also more expensive and require more maintenance.

2.1.1 Flat plate collectors

Flat plate collectors are simple, inexpensive and require little maintenance. Most commonly used to heat outdoor swimming pools and home water heating, they consist of an insulated metal box with a glass covering and an absorber plate inside. The absorber plate utilizes the sun's radiation to warm an internal heat transfer fluid (HTF), usually water, oil or air.

Flat plate collectors can be either glazed or unglazed. Unglazed collectors have no insulation over the glass which augments both heat gain and heat loss. These collectors typically reach temperatures of only 30ºC are almost exclusively used to heat outdoor swimming pools. Glazed collectors have an insulated glass covering and can typically achieve temperatures of up to 80ºC and are thus applicable to a number of the industrial heating processes in the chart above. Flat plate collectors can penetrate the medium range and achieve temperatures between 90ºC and 150ºC, but they are not yet economically efficient beyond 80ºC.

2.1.2 Evacuated tube collectors

Evacuated tube collectors are the other stationary collector and they typically consist of a row of parallel tubes which use the sun's rays to heat an absorber plate at the center of a vacuum. These collectors can achieve higher temperatures because the vacuum reduces conductive heat loss and eliminates convective heat loss. However, they are also more expensive to manufacture. Vacuum collectors have reached economically efficient temperatures between 90 oC and 150 oC, making them a useful complement to the flat plate collectors.55 By adding reflector plates to concentrate the sunlight, these collectors have efficiently reached temperatures up to 200 oC.56

2.1.3 Concentrating Solar Power (CSP) collectors

CSP collectors can achieve the highest temperatures but they are also the most expensive to manufacture and maintain. They are extremely rare for industrial process heating and virtually nonexistent the United States, outside of utility-scale solar power plants. CSP collectors can reach extremely high temperature by rotating to follow the sun and by using arrays of reflectors to focus large amounts of sunlight onto the absorber.

2.2 Step by Step

The first step was to determine the total steam demand of the main equipments from the Termocabo plant, consisting of three generating engines, totaling installed power capacity of 48MW.

By analyzing the thermal charge on one or more items of the plant with heat transfer equations, it may be possible to obtain an estimate for the steam consumption. The mathematical model for each device uses the equations of mass balance and energy balance in control volumes, which were transcribed in an appropriate programming language for the development of applications of technical nature. The thermal charges considered in this study were: 1 Storage (1,495.0m^3), 1 Buffer (85.8m^3), 1 Day (176.0m^3), 3 Lub Oil Separators (5.0m^3), 3 Fuel Oil Separators (5.9m^3) and 3 Preheater Engines (5.5m^3). Vapor pressure is of 7 bar g at any point of the system and the boiler is capable to continuously maintain this pressure. The evaporation heat for 1 kg of steam at 7 bar is of 0.566 kW. It is known that the total heat at 7 bar of steam is 0.700kW (660.8 kcal or 2,764 kJ found in steam tables). However, the condensate still contains some heat that is not released, being completely safe ty o use the indicated value. The main equations used are:

Energy transfer equation (eq. 1).

$$Q = mC_p(T_f - T_i) \qquad \text{(eq. 1)}$$

where,

C - specific heat for water evaluated at the mean temperature, J/kg K;

m - mass flow, kg/s, and

T_f and T_i - inlet and outlet temperatures of each collector.

(Eq. 2) describes the efficiency of collectors according to local radiation:

$$\eta = \frac{Q_{absorbed}}{Q_{solar\ energy} x A_c} 100 \qquad \text{(eq. 2)}$$

The heat transfer function in the solar collectors is obtained using the Hottel--Whillier Bliss equation (Smith and Weiss, 1977) (eq. 3).

$$Q_{SC}(t) = A_{SC} f_r \left[I_r(t)(\tau\alpha) - U_{SCi}\left(T_{SCi}(t) - T_{amb}(t)\right)\right] \qquad \text{(eq. 3)}$$

The dynamics of the boiler is described by eq. (4) (Duffie and Beckman, 1980):

$$c_p \rho V_{bo} \frac{\partial T_{bo}}{\partial t} = Q_{bo}(t) + Q_{SC}(t) + Q_{cons}(t) + Q_{loss}(t) \qquad \text{(eq. 4)}$$

In Figure 1, the "cold water" of the thermal reservoirs, which due to the physical characteristics is found at the bottom part, is then pumped through the collectors, returning to the reservoir. This process is controlled by ARISTON controller as follows: When temperature T1 of the collector is higher than temperature T2 of the reservoir by a pre-adjusted constant, is actioned by a water circulation pump. The "hot water" that comes out from the thermal reservoir goes to the heat exchangers, pulled by a second pump, located after the heat exchanger, where heat is lost and returns to the thermal reservoir.

On the secondary of the heat exchanger, the mixing valve allows to adjust the temperature of the water supplied to the engine block, when the temperature of the water resulting from solar heating is sufficient to meet the needs of the engine block. In this configuration, the deviating valve controlled by a BUDERUS controller, causes the "cold water" of the engine block, pumped by a third pump, to go past the right side of the heat exchanger, receiving heat from solar heating system and returning to the engine block. If the temperature achieved with this is not sufficient, the deviating valve causes the engine block to receive water from the simulating reservoir of the boiler, where, in this case, water is heated by using electric resistance.

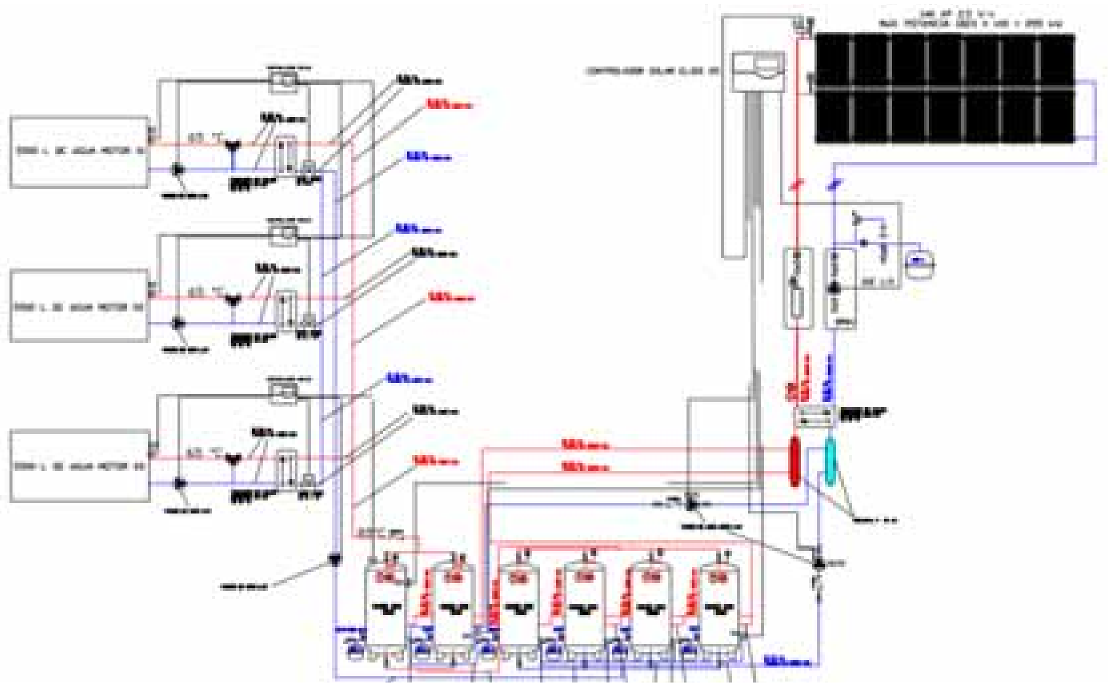

Figure 1 – Executive project

Legend: 5500L DE ÁGUA MOTOR – 5500L OF ENGINE WATER; CONTROLADOR SOLAR ELIOS – ELIOS SOLAR CONTROLLER; MÁX. POTÊNCIA – MAX. POWER.

3. Conclusion

While solar thermal use in home water heating is still extremely small, solar thermal use in other sectors of the economy is even smaller, especially in the United States. These technologies are capable of cost-effective integration into many commercial and industrial processess. However, they remain too risky for many businesses and major manufacturers due to the large upfront costs, concerns over availability of heat, and to a lack of understanding of the opportunities it provides. Despite the industrial sector consuming the largest amount of energy in the United States, and the tremendous opportunity which solar thermal technology presents, it has been largely overlooked by both manufacturers and policymakers.

Solar thermal technology is commercially available to meet demand in lower temperature ranges and already can be integrated into the food, beverage, textiles, paper, and pulp industries on a large-scale. Many of the technological barriers can be eliminated through prudent analysis of energy requirements and appropriate mechanisms for energy storage. Solar thermal's opportunity should be viewed as a way to substantially offset fossil-fueled thermal energy. A total replacement of thermal capacity could be appropriate in certain circumstances, for processes that do not require round-the-clock supply, for example, or when integration of energy storage technology to meet longer periods of demand is possible. Solar thermal integration strategies would be even more effective when coupled with energy efficiency strategies.

Incentives should do more to target the industrial heating sector specifically, and expand commercialization of medium temperature collectors and higher temperature storage technology. The economic opportunities are abundant and the environmental payoff will be much larger if policymakers focus more attention on the opportunities to reduce fossil fuel consumption in industry.

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