17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0341
VIABILITY STUDY OF HELIOTHERMIC ENERGY GENERATION WITH PARABOLIC TROUGH CONCENTRATOR TECHNOLOGY AND THERMAL STORAGE SYSTEM FOR THE IFES CAMPUS SÃO MATEUS

Luan Lenke de Paula

Felipe Costa Novo Malheiros
Instituto Federal do Espírito Santo – Campus São Mateus
felipe.malheiros@ifes.edu.br

Igor Chaves Belisario
Instituto Federal do Espírito Santo – Campus São Mateus
igor.belisario@ifes.edu.br

Luisa Colombo Dias
Instituto Federal do Espírito Santo – Campus São Mateus
luisaacolombo@gmail.com

Abstract. *The growing demand for energy coupled with the expressive use of fossil fuels, and energy matrices centered on specific resources, are challenges to be faced by this sector in the world. Linked to these challenges is the prospect that fossil fuels are depleting at an ever-increasing rate. It is estimated that these fuels are scarce in a few decades, since the rate of consumption is higher than the rate of production. Currently, Ifes Campus São Mateus does not have any technology implanted to generate energy through alternative sources, so all its consumption is through the concessionaire. One of the challenges of this study is to evaluate the technical and economic feasibility of a heliothermic energy generation route with parabolic trough concentrators in conjunction with the thermal storage system running for ten hours.*

Keywords: *Solar Energy, Heliothermic Energy Generation, Thermal Energy Storage, Parabolic Trough Solar Concentrators, Ifes Campus São Mateus.*

1. INTRODUCTION

The growing demand for energy coupled with the expressive use of fossil fuels, energy matrices centered on specific resources, are challenges to be faced by this sector in the world. Linked to these challenges is the prospect that fossil fuels are depleting at an ever-increasing rate. It is estimated that these fuels are scarce, since the rate of consumption is higher than the rate of production.

In Brazil, which has a great dependence on water resources for electricity generation, betting on alternative sources of energy is an interesting strategy for the energy industry, since it will not depend only on a resource. In recent years, Brazil has experienced a major water crisis, with a significant reduction of the main national reservoirs and consequently had to mobilize thermoelectric plants, which have a high cost of activation, considerably increasing the energy bills of consumers.

The techniques that propitiate the collection of solar energy are in constant development, making possible its use with success in diverse situations or enterprise. The cost reductions of these technologies for the use of solar energy indicate a trend of their insertion in the world and Brazilian energy matrix.

According to Kalogirou (2014), the use of large-scale solar energy is credited, though not proven, to Archimedes (282 to 212 BC), which would have burned the Roman fleet in Syracuse Bay (now belonging to Italy) concentrating sunbeams in a focus to the point of heating them to catch fire. The Polish mathematician Vitelio referenced by several authors between 100 BCE and 1,100 AD and in the book Optics Vitelio, the fact. The device used by Archimedes was describe as a composite glass with 24 mirrors converging to a single focal point, while some historians believe that Archimedes would have used shields of soldiers instead of mirrors because of the glassmaking technology credited at that time. There are reports that Archimedes would have written a book (On Burning Mirrors), but no copy survived. During the Byzantine period, Proclus repeated the supposed experiment of Archimedes and burned the enemy fleet in Constantinople.

Solar energy is a clean and free source of energy that can replace or support conventional power generation methods. Different technologies are present to collect energy from the sun, one is the technique known as Concentrated Solar Power (CSP) and the other is through photovoltaic panels. In CSP, the sun's rays are concentrated in a specific area to heat a fluid. Among the main methods of solar concentrators that are available, we can highlight parabolic trough solar concentrators (PTSC), solar power tower (SPT), linear reflectors Fresnel (LRF), and collectors parabolic disk solar (PDS). The collected solar energy can be harnessed to heat a fluid and generate mechanical energy and later electric in heliothermic systems.

The United States and Spain pioneered the development of technologies in the industry, with investments in research and development since the 1970s and 1980s. The first solar plants to commercialize their electricity were SEGS in California. SEGS began operations in 1984 (SEGS I) and the last one in the early 1990s (SEGS IX). The SEGS corresponds to about 350MW of installed capacity, almost 80% of the installed capacity in the state. These plants were the direct result of US Federal Public Utility Regulatory Policy Act (PURPA), which was a pricing model that guaranteed a pre-fixed purchase price for renewable energy (TAYLOR, 2008).

The São Mateus campus of the Federal Institute of Espírito Santo (Ifes) is a secondary, technical and higher education institution located in the northern region of the state of Espírito Santo, in the Litorâneo neighborhood of the municipality of São Mateus. Currently, Ifes Campus São Mateus does not have any technology implanted to generate energy through alternative sources, so all its consumption is through the concessionaire. For the year, the campus has an approximate cost of R$ 300,000.00 (three hundred thousand reais) with the consumption of electric energy. One of the challenges of the present work is to evaluate the technical possibility of generating heliothermic energy with parabolic trough concentrators together with the thermal energy storage system for 10 hours.

Specific objectives include:

- To analyze the viability of the implantation of a heliothermic energy generation system with parabolic trough concentrators in conjunction with the thermal storage method at the Ifes Campus São Mateus;
- Check campus energy demand;
- Check the possibility of meeting the campus energy demand and the sale to the concessionaire;
- Analyze what space would be needed and whether the campus has available;
- To ascertain the energy potential of the region;
- Determine the viability of the work regime;

2. HELIOTHERMIC SYSTEMS

Currently there are two technologies to harness energy from the sun and generate electricity. One is through photovoltaic panels and the other is through heliothermic collectors. In photovoltaic panels, plates usually made of silicon absorb the energy of the sun and through the movement of the electrons electricity is generated.

The method of energetic conversion from photovoltaic systems consists of transforming the solar radiation directly into electric current through the photovoltaic effect, direct conversion of light energy (visible spectrum) into electric energy. The photovoltaic cell is the element that accomplishes this conversion (PINHO AND GALDINO, 2014).

The solar collectors absorb incident solar radiation, being converted to heat (TESKE, LEUNG AND ESTELA, 2016). There are the following types of solar collector: parabolic disks, solar tower, parabolic troughs and Fresnel linear reflectors. The main types of collectors are shown in figure 1.

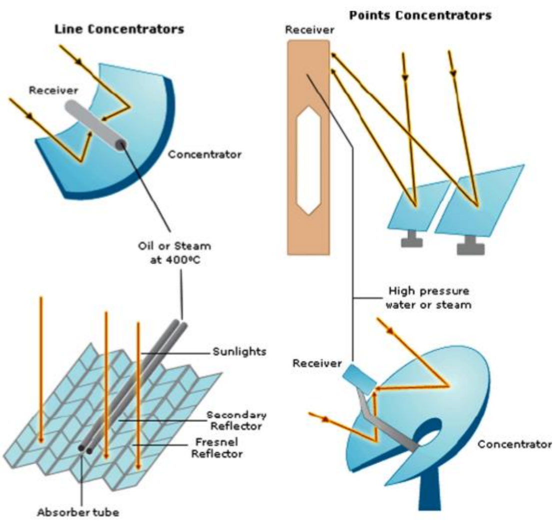

Figure 1 - Main types of Solar Collectors (PUROHIT, PUROHIT AND SHEKHAR, 2012).

In Parabolic Disco type concentrators it is possible to track the Sun through a tracking system with two degrees of freedom. Direct normal radiation is concentrated at the focal point of the disk, through which the working fluid circulates. Thermal energy can be transported through pipelines or there is also the possibility of direct coupling between the receiver and a motor-generator (such as Stirling motors) to convert it into electrical energy (DUFFIE AND BECKMAN, 2013).

Solar Power Towers, also known as Central Tower or Heliostat Field are systems used when high levels of thermal radiation capture are required. They are characterized by a set of scattered movable mirrors that point to a common point located at the top of a tower. The working fluid is heated at this point and circulates in order to carry the absorbed energy (KALOGIROU, 2014).

Fresnel reflectors approach the parabolic form of gutter systems, using long rows of flat or slightly curved mirrors to reflect the radiation and to concentrate it on fixed linear receivers mounted on the mirrors (PUROHIT, PUROHIT AND SHEKHAR, 2012).

The parabolic trough technology consists of rows of parabolic shaped reflector mirrors used to collect solar radiation and concentrate it in a thermally efficient receiver positioned at the focal line of the gutters (TESKE, LEUNG AND ESTELA, 2016).

Typically, this type of system uses thermal oil such as Heat Transfer Fluid (HTF), which limits the operating temperature by approximately 400 °C. The use of fused salts and Direct Steam Generation (DSG) in this type of manifold is still under development. The capacity factor of plants employing parabolic troughs without thermal storage vary between 25 and 28%, depending mainly on the annual amount of direct normal radiation. The storage of thermal oil during the sun's hours, in turn, provides capacity factors of the order of 40% (which represents about 7 hours of turbine operation at rated loads) (BURIN, 2015).

The basic scheme of converting solar energy to mechanical energy is shown in Figure 2. In these systems, solar thermal energy, usually collected by concentrated solar collectors, is used to heat a fluid. Some of these systems also incorporate heat storage, which allows them to operate during cloudy weather and night.

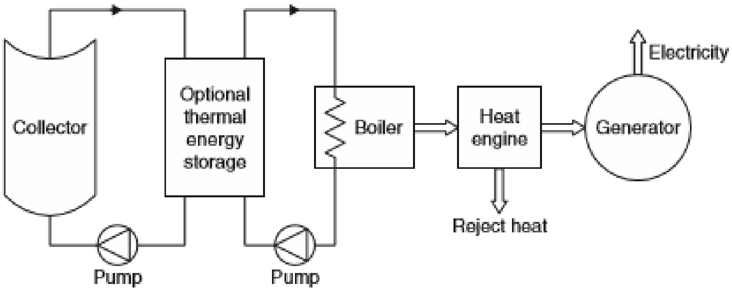

Figure 2 - Schematic diagram of a solar thermal energy conversion system (KALOGIROU, 2014).

Alashkar and Gadalla (2017) carried out a thermo economic analysis in a cycle of parabolic trough concentrators with thermal energy storage system integrated in a Rankine regenerative cycle, and with nanofluid being used in the concentrators. He tested three different modes of operation (without storage and with storage for 7,5 and 10 hours), and after comparing them he found that the use of a thermal storage system leads to a higher power generation.

Reddy, Kaushik and Tyagi (2012) studied the energy and exergetic performances of a solar thermal power plant system in the cities of Delhi and Jodhpur. The solar system consisted of two subsystems. The first is a collector system with a set of parabolic mirrors installed in matrices, and an energy storage system that pumps Therminol VP-1 into the system. The second, a Rankine cycle. The energy performance analysis showed that the heat engine circuit through the condenser has the main energy losses, followed by the collector system. However, the exergetic performance analysis shows the opposite trend, where the main exergy losses occurred in the collector system. In addition, increased operating pressure showed a positive effect on energy and exergetic deficiencies.

Rovira *et all*. (2012) presented a comparison of an integrated solar combined cycle (ISCC) using two solar technologies: parabolic trough solar collector and Fresnel Linear Reflectors. The comparison is made in terms of the annual performances and the cost feasibility of the ISCC. The results show that both technologies provide an improvement in the annual performance of the ISCC, with the gutter providing a better improvement compared to Fresnel.

In Campinas, inaugurated at the end of 2012, Usina Tanquinho was the first solar power plant in the State of São Paulo and is one of the largest in the country. It was installed in an area of 13,3 thousand square meters and could generate 1.6GWh per year with the aid of photovoltaic panels with wind energy. The plant was approved in December 2011 by Aneel and absorbed investments of R$ 13,8 million in research and development by the CPFL Energia group (ASPE, 2013).

The Mineirão stadium, located in the city of Belo Horizonte, was the first Brazilian stadium for the 2014 World Cup to have installed a solar power plant with photovoltaic panels, where only 10% of the energy generated will be consumed by the stadium and the remainder is marketed. The stadium has an installed capacity of 1,42 MW, and the energy generated is distributed and marketed by Cemig's network, which has a substation at the stadium (ASPE, 2013).

In addition to the use of solar energy for electric power generation as in the examples cited above, it can also be used to reduce energy consumption through heaters as can be seen in figure 7. In Espirito Santo, neighborhoods of Serra Dourada I, II and III, in Serra, were the first to use solar energy on a large scale. The project is one of the largest of its kind in the country, with more than 2 thousand residences contemplated by the Good Solar Energy Project. This project is an initiative of the Public Energy Agency of Espírito Santo (to portuguese *Agência de Serviços Públicos de Energia do Espírito Santo* - ASPE) in conjunction with EDP Escelsa. The residences were given the free installation of a water heating system for domestic use. The average economy with these solar thermal panels is approximately 26% (ASPE, 2013).

3. METHODOLOGY

For the development of this research it is necessary to provide information about the climatic conditions of the São Mateus region, such as: solar radiation, local temperature and wind speed. These factors will influence the outlet temperature of the solar collector thermal fluid as well as the thermal losses to the environment.

The data will be obtained on the website of the National Institute of Meteorology (INMET), taking into account the year 2017. These are arranged according to each hour of each day of the year. In this way, an average of the radiation of the coldest day of the year and the hottest day will be made. Given the average value of the solar radiation of the region, it is possible to calculate the thermal energy generated in the collector through the model of Kalogirou (2014).

Alashkar and Gadalla (2017) adopted the chosen cycle, being composed by a solar set integrated to a regenerative Rankine cycle and is composed of three subsystems, as shown in Figure 4, which are: the solar field, a storage cycle of thermal energy (TES), and a steam power cycle. The parabolic trough collectors represent the solar field and the Rankine Cycle represents the generation cycle. The TES is represented in the cycle between the heat exchangers 1 and 3, together with the two storage tanks, the cold and the hot.

In conventional cycles of steam power generation, the water is heated by a boiler. However, when a solar energy source is integrated, the boiler is replaced by a solar field and a heat exchanger to convey the heat from the fluid to the water as can be seen in Figure 3, where the thermal oil after passing through the collectors will exchange heat with pressurized water from the steam power cycle. The steam produced with the elevation of the water temperature will be expanded in the turbine, generating mechanical energy that will be converted into electrical energy. The solar field is composed of multiple solar collectors of parabolic trough (PTSCs) created in matrices in order to maximize the capture of solar radiation.

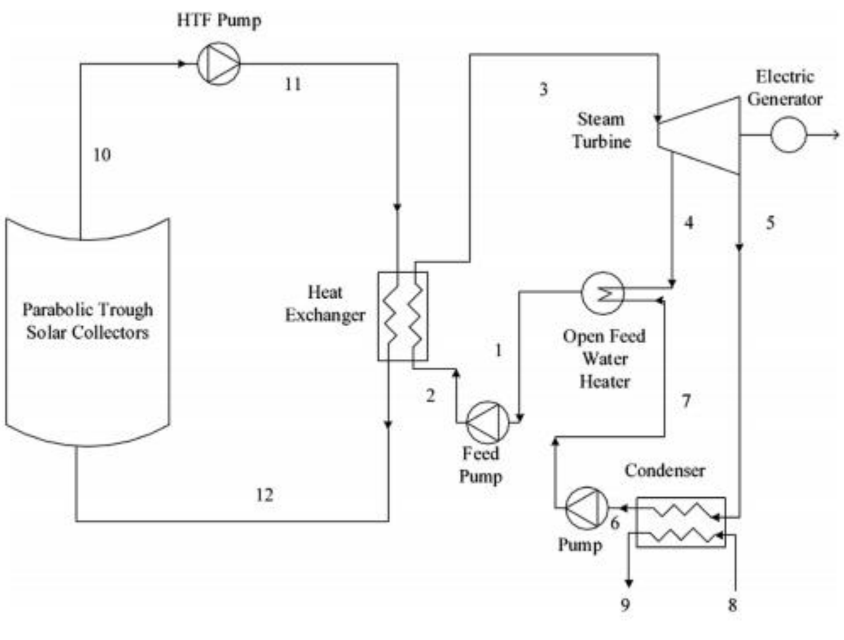

Figure 3 - Heliothermic generation system (ALASHKAR AND GADALLA, 2017).

In the present work, the working regime explored in the PTSCs will be of 10 hours of storage. The addition of the TES system allows flexible working hours and can increase plant production. It should be noted that the longer the storage period, the larger the volume of the salt tanks, thus increasing the cost of the system.

In the system without storage, the plant could only operate as long as it had available radiation, and the cycle is shown in Figure 3. With the storage system, the cycle will operate intermittently, ie it will also generate electricity at night as it stores energy in the form of heat during the day.

The working mode consists of storage for 10 hours a day. In the periods with low radiation, the plant will only operate generating electricity, as shown in Figure 4. The heating of the thermal oil of the collectors ignores the TES system and is directed to the heat exchanger in order to heat the operating water of the Rankine cycle .

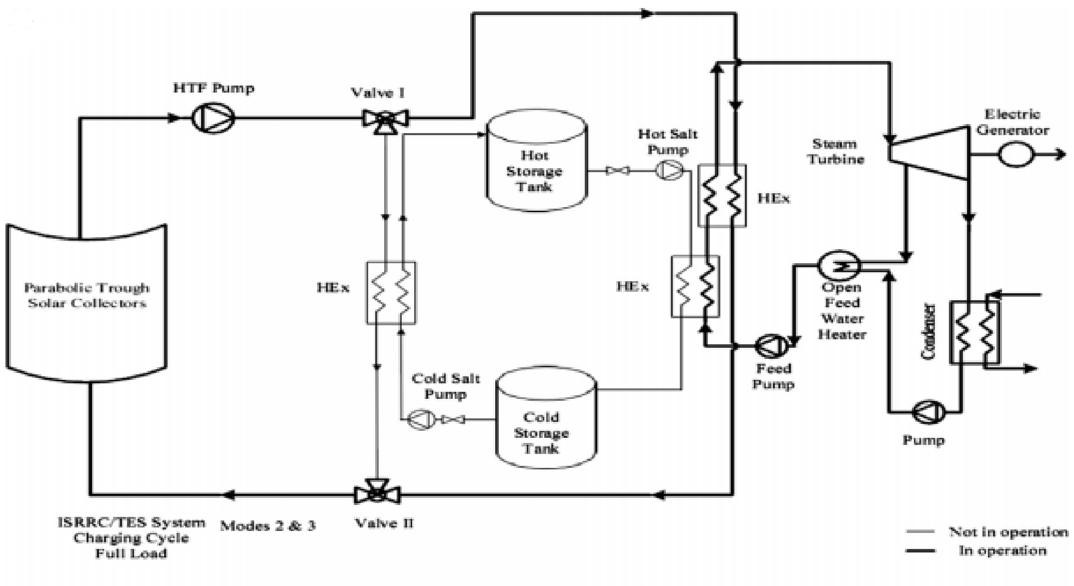

Figure 4 - Solar cycle with storage in the first charging mode (ALASHKAR AND GADALLA, 2017).

During the remaining hours of solar radiation, the plant will be operating in conjunction with the storage, so part of the flow rate will be directed to the heat exchanger to heat the TES and the other part to the steam power cycle as represented in Figure 5. The molten salt leaves the tank cool to the heat exchanger where it is heated and is then stored in the hot storage tank for later use.

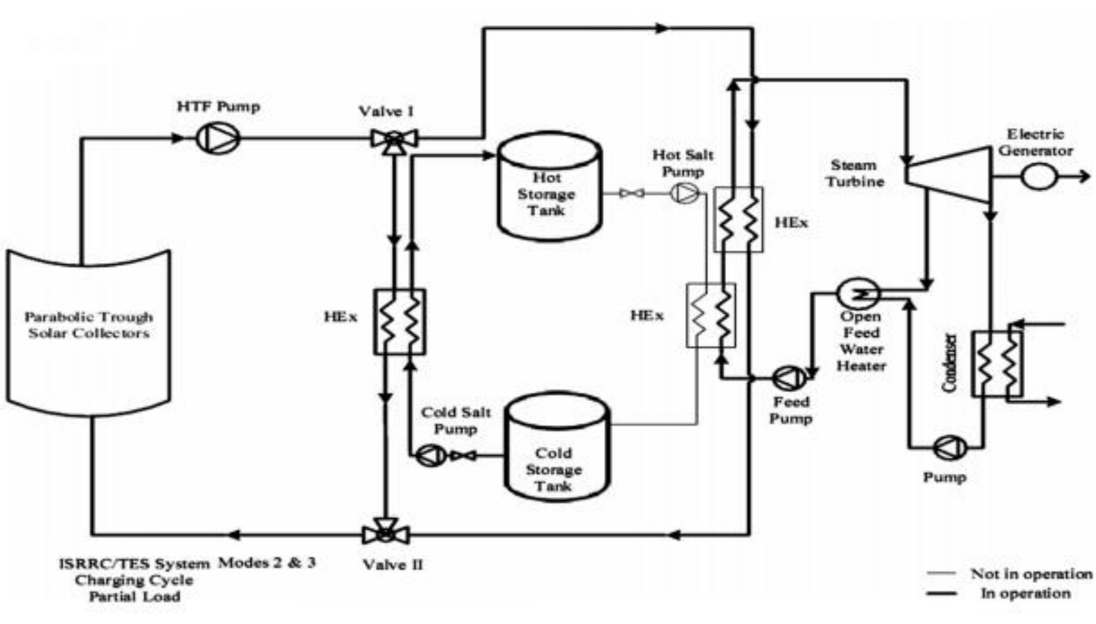

Figure 5 - Solar cycle with storage in the second charging mode (ALASHKAR AND GADALLA, 2017).

Looking at the cycle at night, the plant only operates by generating energy through the heat stored in the TES. Only the thermal load available in the TES will meet the demand for the Rankine cycle, since the collectors will not be in operation as shown in Figure 6. The hot molten salt is directed from the heating tank to the heat exchanger by heating the water of the power cycle. The molten salt then exits the heat exchanger and is stored in the cold storage tank. Because of the long period of storage time, the volume of the storage tank leads to an increase in the cost of the system.

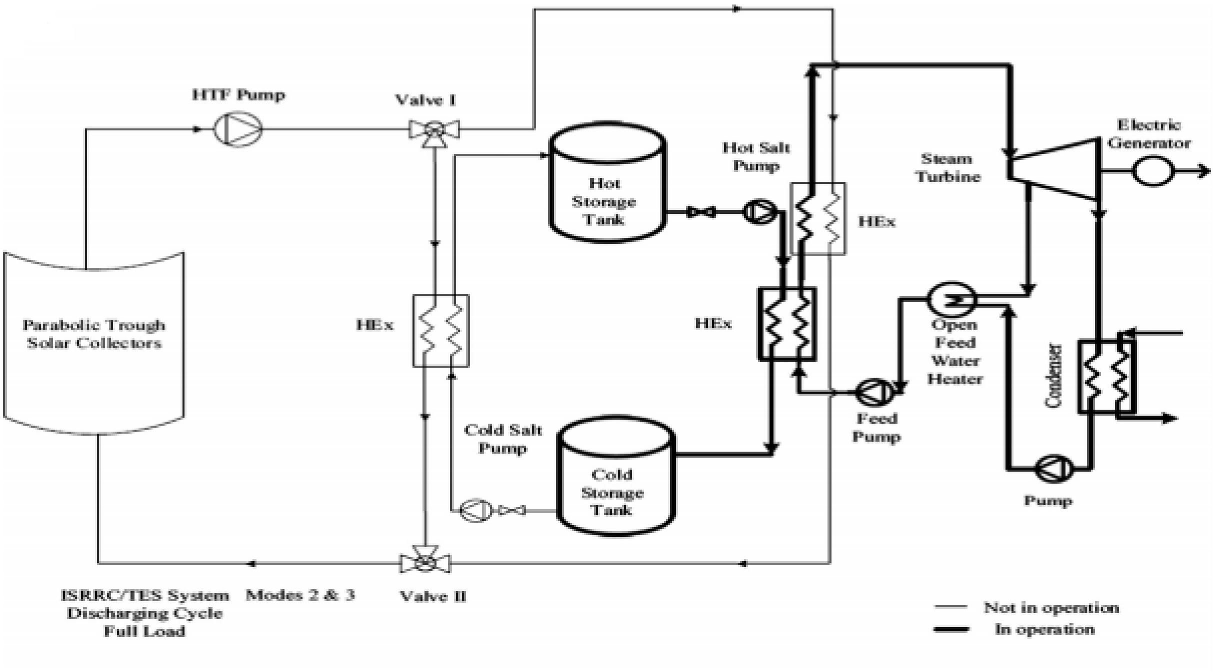

Figure 6 - Solar cycle with storage in the first unloading mode (ALASHKAR AND GADALLA, 2017).

If during the first few hours of the following day the storage system still has available thermal energy, it can be used to assist collectors in energy production, as shown in Figure 7.

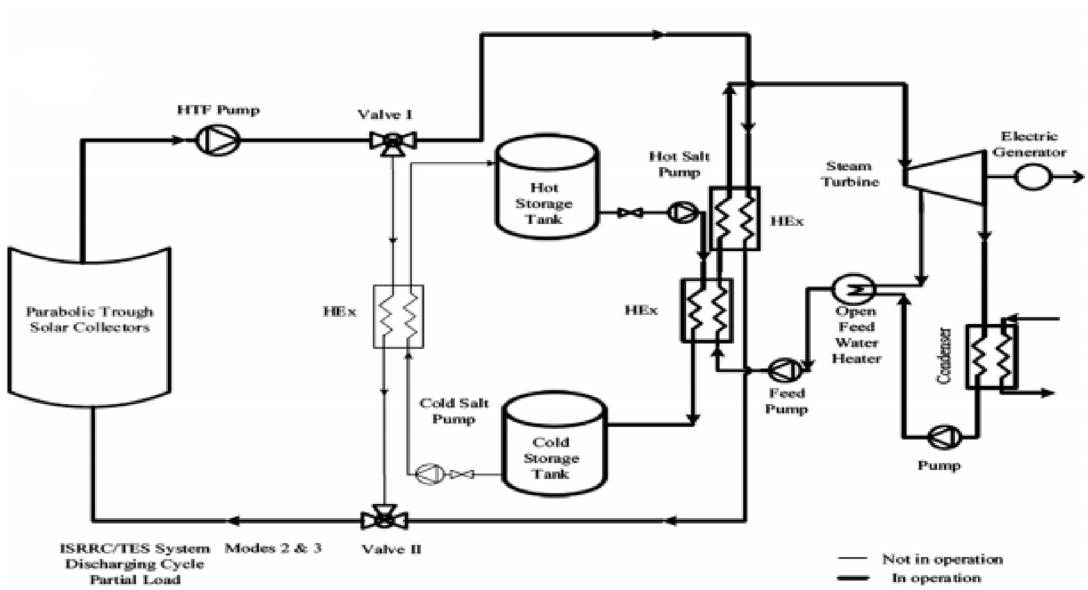

Figure 7 - Solar cycle with storage in the second unloading mode (ALASHKAR AND GADALLA, 2017).

The data of the collectors, receiver and glass cover to be used are shown in figure 8, Alashkar and Gadalla (2017) present these. The Hitec salt is salt will be used in the storage tanks of the TES cycle.

The solar field fluid will be the Therminol-VP1, widely used thermal oil. It should be noted that in the research carried out by Alashkar and Gadalla (2017), it was the oil that presented the best performance in the solar cycle.

Receiver, glass cover and collector specifications.

Parameter	Symbol	Unit	Value
Receiver			
Type	–	–	Schott PTR70 2008
Absorber tube inner diameter	D_{ri}	mm	66
Absorber tube outer diameter	D_{ro}	mm	70
Receiver efficiency	η_r	%	75
Receiver emissivity	ε_r	–	0.92
Receiver absorptance	α_r	–	0.96
Receiver area	A_r	m^2	22
Absorber material type	–	–	Stainless steel 304L
Glass cover			
Glass cover inner diameter	D_{ci}	mm	115
Glass cover outer diameter	D_{co}	mm	120
Glass cover emissivity	ε_C	–	0.86
Glass cover absorptance	α_C	–	0.02
Glass cover transmittance	τ_C	–	0.963
Glass cover area	A_c	m^2	37.7
Collector			
Type	–	–	Solargenix SGX-1
Collector width	w	m	5
Collector length	L_c	m	8.3333
Length of collector assembly	L	m	100
Number of modulus	N_m	–	12
Number of collectors	N_c	–	1
Reflective aperture area	A_a	m^2	470.3
Mirror reflectance	ρ_{cl}	–	0.935
Collector optical efficiency	η_o	%	85.66

Figure 8 - Receiver, glass cover and collector specifications (ALASHKAR AND GADALLA, 2017)

4. RESULTS AND DISCUSSIONS

By evaluating the institution's energy consumption within the stipulated period, it is possible to see that the average maximum power was approximately 53 kW. In this way, the net work must be higher, thus set at 100 kW.

According to Alashkar and Gadalla (2017), the usual working temperature of Therminol VP-1 is between 293ºC to 391ºC, thereby the inlet and outlet temperatures of the collectors are set within that range. For TES, the temperatures of the cold tank and the hot tank have also been fixed, and the only requirement is that they are considerably higher than the freezing temperature of the Hitec salt. In this way, the cycle parameters are exposed in the table 1.

The working pressures, as well as the isentropic efficiencies of both the pump and the turbine, are also those used by Alashkar and Gadalla (2017) and also shown in table 1. It is important to note that for calculation purposes the PTSC and TES are disregarded, since they are only used to overcome the load losses of the cycle and this parameter is not evaluated. Applying the parameters of the table x, in energy balances the results presented in table 2.

However, for a constructive question, the titer leaving the turbine should be greater than 0.9 in order to avoid erosion in the turbine. Thus, by setting the output title of the turbine to 0.9 and realizing the same energy balances, it is possible to obtain the results expressed in table 3. To ensure this, the extraction and condenser pressures increase.

In order to maximize the efficiency of the steam power cycle as a function of the condenser pressure, it is possible to obtain the graph shown in figure 9. This reinforces the literature where the efficiency of the steam power cycle increases as the condenser outlet pressure decreases.

Table 1 – Initial Cycle Parameters

Parameter	**Unit**	**Value**
Input temperature on PTSC	°C	295
Output temperature on PTSC	°C	390
TES hot tank temperature	°C	365
TES cold tank temperature	°C	250
Steam turbine inlet temperature	°C	380
Turbine inlet pressure	kPa	10000
Extraction pressure	kPa	900
Condenser pressure	kPa	10
Isentropic efficiency of pumps	%	78
Isentropic turbine efficiency	%	85
Net Power	kW	100

Table 2 - Main results of the first data interaction

Parameter	**Unit**	**Value**
Heat entering the steam power cycle	kW	268,2
Heat entering the PTSC	kW	536,5
Work spent by bombs	kW	1,642
Work produced by turbines	kW	101,6
Heat lost in the condenser	kW	168,2
Mass flow rate at the turbine inlet	kg/s	0,1178
Mass flow rate extraction	kg/s	0,02668
Condenser mass flow rate	kg/s	0,09112
Title of turbine output	-	0,7719
Extracted mass fraction	%	22,65
Therminol VP-1 mass flow rate	kg/s	2,347
Efficiency of steam power cycle	%	37,28
Efficiency of the whole system	%	18,64

Table 3 - Main results of the second data interaction

Parameter	**Unit**	**Value**
Heat entering the steam power cycle	kW	519,8
Heat entering the PTSC	kW	1040
Work spent by bombs	kW	3,133
Work produced by turbines	kW	103,1
Heat lost in the condenser	kW	419,8
Mass flow rate at the turbine inlet	kg/s	0,2389
Mass flow rate extraction	kg/s	0,008005
Condenser mass flow rate	kg/s	0,2309
Title of turbine output	-	0,9
Extracted mass fraction	%	3,35
Therminol VP-1 mass flow rate	kg/s	4,549
Efficiency of steam power cycle	%	19,24
Efficiency of the whole system	%	9,619
Extraction pressure	kPa	1500
Condenser pressure	kPa	760,2

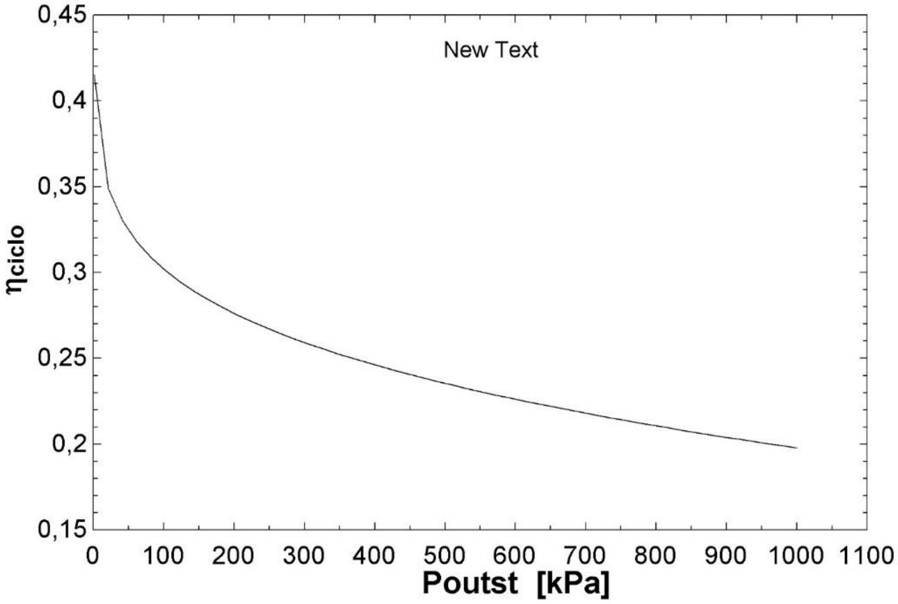

Figure 9 - Variation of cycle efficiency as a function of the condenser pressure.

Table 4 - Main results of the third data interaction

Parameter	Unit	Value
Heat entering the steam power cycle	kW	271,7
Heat entering the PTSC	kW	543,4
Work spent by bombs	kW	3,319
Work produced by turbines	kW	101,7
Heat lost in the condenser	kW	171,7
Mass flow rate at the turbine inlet	kg/s	0,1249
Mass flow rate extraction	kg/s	0,0325
Condenser mass flow rate	kg/s	0,0924
Title of turbine output	-	0,9
Extracted mass fraction	%	26,02
Therminol VP-1 mass flow rate	kg/s	2,377
Efficiency of steam power cycle	%	36,81
Efficiency of the whole system	%	18,40
Extraction pressure	kPa	1504
Condenser pressure	kPa	10

Through the survey of the meteorological station, the data of the climatic conditions of the city of São Mateus are arranged in table 5. From this data and using the model of heat transfer exposed by Kalogirou (2014) from page 203 of his work, it is possible to obtain the main results shown in table 6.

Table 5 - Environmental Data

Parameter	Unit	Value
Average ambient temperature	°C	24
Receiver temperature	°C	500
Glass cover temperature	°C	200
Atmospheric pressure	kPa	101,325
Absorbed solar radiation	W/m²	500
Wind speed	m/s	3

Table 6 - Results of the heat transfer model from the results of the second interaction

Parameter	Unit	Value
Reynolds number of the external flow	-	14800
Nusselt number of the external flow	-	95,34
Reynolds number Therminol VP-1	-	475033
Nusselt number Therminol VP-1	-	1530
Coefficient of fluid convection	W/m^2K	2052
Coefficient of radiation tube - glass cover	W/m^2K	48,81
Coefficient of radiation glass cover - environment	W/m^2K	11,71
Coefficient of glass convection - ambient	W/m^2K	25,25
Number of collectors	-	55,98

Since the number of collectors calculated is 55.98, but each mounted collector has 12 modules, it is necessary the minimum use of 5 collectors mounted 12 modules each, totaling a number of 60 collectors. This matrix will occupy an area of 2500 m^2, disregarding spacing between collectors and other equipment.

Taking into consideration the TES, the minimum volume of the tank for the calculated mass flow for second interaction that was 8,331 kg/s, for the discharge time of 12 hours, which is the period that does not have available radiation, should be of no minimum 175.2 m^3. Thus fixing a diameter of 5 m and a height of 9 m.

5. CONCLUSIONS

Although the institution has the minimum space of 2,500 m^2 for the implementation of the system, it is not possible to assert the feasibility of the project, since more factors should be realized and apply an economic model to analyze the cost and time of return of the plant. The maximum efficiency of the steam power cycle for the set conditions will be 36.81% and the maximum efficiency of the entire cycle will be 18.40%.

As future work, it is recommended to analyze the load losses of the cycle, to analyze the irreversibility's of the heat exchangers to analyze the area of thermal exchange and dimensions of the system, to apply an economic model.

6. REFERENCES

ALASHKAR, Adnan; GADALLA, Mohamed. *Thermo-economic Analysis of an Integrated Solar Power Generation System Using Nanofluids*. Elsevier Ltd, Sharjah, p.469-491, 9 fev. 2017. <https://goo.gl/6qSdja>. 20 Apr. 2018.

ASPE - Agência de Serviços Públicos do Estado do Espírito Santo. *A energia solar no Espírito Santo: Tecnologias, Aplicações e Oportunidades*. Vitória: Aspe, 2013. 120 p. < https://goo.gl/rbTMwi >. 30 May 2018.

BURIN, E. K. et al. *Boosting power output of a sugarcane bagasse cogeneration plant using parabolic trough collectors in a feedwater heating scheme*. Applied Energy, v. 154, p. 232 –241, 2015. < https://goo.gl/FVpgPC >. 10 Jun. 2018.

DUFFIE, J.; BECKMAN, W. *Solar Engineering of Thermal Processes*. John Wiley and Sons, Inc., 2013. < https://goo.gl/qMg9pc >. 10 Jun. 2018.

EPE. *Balanço Energético Nacional 2017*: Ano base 2016. Rio de Janeiro, 2017. < https://goo.gl/7aLNSj >. 20 May 2018.

KALOGIROU, Soteris A. *Solar Energy Engineering: Processes and Systems*. 2. ed. Oxford: Elsevier, 2014. < https://goo.gl/B5mXTt >. 15 Apr. 2018.

PINHO J. T.; GALDINO, M. A. *Manual de Engenharia para Sistemas Fotovoltaicos*. [S.l.], 2014.

PUROHIT, Ishan; PUROHIT, Pallav; SHEKHAR, Shashaank. *Evaluating the potential of concentrating solar power generation in Northwestern India*. Energy Policy. p. 157-175. 11 julho 2012. < https://goo.gl/9qKTUN>. 23 May 2018.

REDDY, V. Siva; KAUSHIK, S.c.; TYAGI, S.k.. *Exergetic analysis and performance evaluation of parabolic trough concentrating solar thermal power plant (PTCSTPP)*. Energy, [s.l.], v. 39, n. 1, p.258-273, 2012. Elsevier BV. <https://goo.gl/djMmmu>. 09 May 2018.

ROVIRA, Antonio et al. *Analysis and comparison of Integrated Solar Combined Cycles using parabolic troughs and linear Fresnel reflectors as concentrating systems*. Applied Energy, [s.l.], v. 162, p.990-1000. 2016. Elsevier BV. <https://goo.gl/V9wSkm>. 08 Apr. 2018.

TAYLOR, Michael et al. *Renewable Power Generation Costs in 2014*. Irena, 2015. < https://goo.gl/kYGHjG>. 23 Apr. 2018.

TESKE, Sven; LEUNG, Janis, ESTELA . S*olar Thermal Electricity Global Outlook*. SolarPACES e Greenpeace International, 2016. <https://goo.gl/HSn73j >. 27 May 2018.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.