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Solar Energy as an alternative source in boiler economizers

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1. Introduction

- This study sought to analyze the viability of the use of solar energy, for the operation in boiler economizers, in the replacement of the thermal energy of the exhaust gases.
- The experiment was divided in two steps: analysis of the boiler yield with different feed water temperatures and addition of the solar field to the initial set.
- For the modeling of the economizer-boiler set, the software used was Engineering Equation Solver (Software F-Chart, Wisconsin, USA).
- The technology chosen for the second stage was the high-pressure vacuum solar collector, installed at the inlet of the feed water heater.
- The thermal power of 2014W (per plate) and the solar radiation peak of 1000W.m^{-2} were standardized, considering the calculations for a steady state system at noon.
- From analyzing the data was verified that the efficiency varied by approximately 7.4%, when the feed water temperature was increased by 20° C, close to 48° C. For this variation to occur, it was necessary to use 50 plates.

2. Theoretical Conception

The calculation of this yield corresponds to the product of the mass vapor flow and the enthalpy change between the initial and final stages of the water, divided by the thermal energy that is released through the consumption of the fuel, according to (1):

$$\eta = \frac{mv\,.(hv - ha)}{mc.PC} \qquad (1)$$

Onde: η = thermal efficiency, mv = mass flow of steam (kg.s^{-1}), hv = enthalpy of steam produced by the boiler (kJ.kg^{-1}), ha = enthalpy of feed water to the boiler (kJ.kg^{-1}), mc = mass flow of fuel (kg.s^{-1}), PC = calorific value of fuel (kJ.kg^{-1}).

3. Methodology

The experiment was divided into two stages:

1. Analysis of boiler efficiency, with different temperatures of feed water;
2. Addition of the solar field to the initial set, followed by calculation and modeling of the solar energy system, to reach the heating of the water for a final yield close to 5%, parameter verified for the current gas economizers used in the boilers of greater Yield [9].

The Fig. 1 shows a basic boiler plant without economizer and Fig. 2shows the boiler plant with economizer

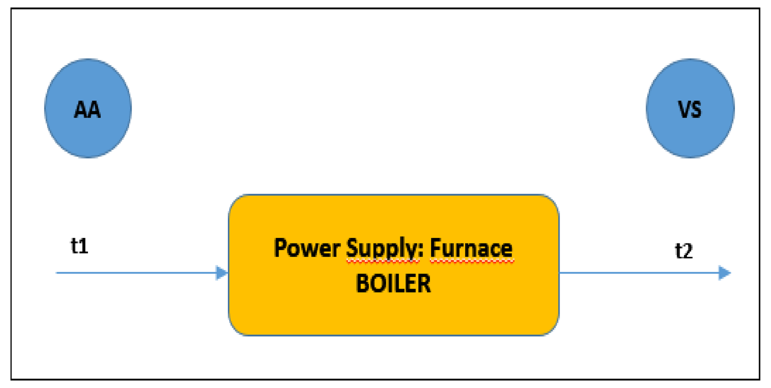

Fig. 1. Simulator plant without economizer

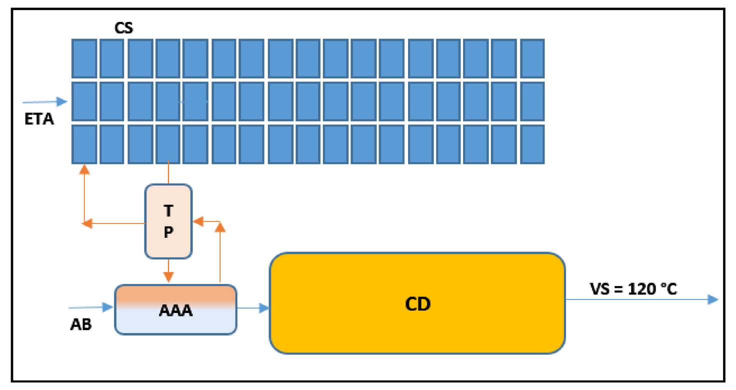

Fig. 2. Simulator plant with economizer

In Fig.1 (VS) is saturated steam; (AA) heating or power water; (t1) heating water temperature (t2) saturated steam temperature. In Fig. 2, (CS) solar field; (ETA) source of cold water; (TP) lung tank with heated water; (AB) raw water supply, (AAA) feed water heater element, which provides a supply fluid with variable temperature; (CD) boiler, (VS) saturated steam.

The Table I shows the average cost of producing a ton of steam from the use of charcoal used in this study and the cost for other energy sources [15].

Table I - The average cost of producing a tonne of steam from charcoal and other sources of energy

Oil LFP	Natural Gas	Electrical resistance	Charcoal	Mineral Coal
USD 36,23	USD 23,49	USD 54,22	USD 11.15	USD 6,75

The process data and solar collector data are described in table II.

Table II – Process data and Solar Collector Data.

Process data	
Intended efficiency in the system	5-7%
Lower calorific value of fuel (charcoal)	7.500kCal/kg
Feed water temperature	28°C
Saturated steam temperature	120°C
Boiler inlet pressure	15.900kPa
Boiler outlet pressure	15.200kPa
Boiler working flow (steam flow)	10 m³/h
Solar Collector Data	
Dimensions (LxWxH)	2005mm x 2196mm x 136mm
Peak output	2014W
Material	borosilicato 3.3
Flow rate	máx. 15L/min
Peak solar radiation on the collector (12:00PM)	1000W/m²
Absorptance	>93% (AM1.5);
Emittance	<8% (80ºC)
Vacuum	P<5x10-³Pa
Startup temperatura	>30ºC
Operating angle	20-80º
Max operating pressure	800kPa / 8bar
Pipe composition	High purity oxygen free copper (ASTM: C10200; DIN: OF-Cu)
Manufacturer	Apricus

For the economizer-boiler set modeling, the software used was the Engineering Equation Solver (F-Chart Software, Wisconsin, USA). The simulator variable was the feedwater temperature. The calculation of the thermal machine's performance was performed with steps of variation of the temperature of the feeding water, varying from 28° C to 58C with an upward step of 10° C. A flow rate of 10 m³.h^{-1} was standardized for the feed water and 120° C the temperature of the steam generated by the boiler. This steam temperature corresponds to that used in sterilization and cooking processes in industries in general.

The fuel used in this simulator was charcoal, whose lower calorific value (LCV) is 7,500kCal.kg^{-1}. For the boiler inlet pressure was adopted the value of 15,900kPa and the outlet pressure as 15,200kPa, considering the system losses. For enthalpy and entropy values the International Association for Water and Steam (IAPWS) standardized values, previously loaded in the EES software, were used through the Steam_IAWPS function, which implements high precision thermodynamic properties for steam and steam calculations. providing accurate results for temperatures between 273.15K and 1273.15K and pressures up to 1000MPa.

After analyzing the technologies available for industrial level heating purposes, it was decided to use in this experiment, due to the low cost, ease of installation, acquisition and satisfactory efficiency, the High Pressure Vacuum Solar Collector, or Pipe Collector. Evacuated (ETC), which provides 2014W thermal power per plate, data provided by the manufacturer for peak solar radiation of 1000W.m^{-2} at noon (12:00 PM).

4. Results

A. Step 1 – Test of the boiler efficiency with the raising of the temperature of the feed water

For the equation (1), the system composed only of the boiler was considered. When the feed water temperature was varied from 28° C to 58 ° C in steps of 10° C, the results shown in Table II were obtained. Standardized data for the calculation: P1 = 15.900 kPa; P2 = 15.200 kPa; mv (kg.sec^{-1}) = 2,77; mc (kg.sec^{-1}) = 0,1; PC = 31.380; s2 = 1,515;

Table III - Result of the yields according to the variation of the boiler feed water temperature.

t1 (°C)	t2 (°C)	h1	h2	s1	s2	EFGV	EFGV (%)	INC η (%)
28	120	131,9	514,4	0,4044	1,515	0,3377	33,77	-
38	120	173,3	514,4	0,5397	1,515	0,3011	30,11	3,66
48	120	214,7	514,4	0,6707	1,515	0,2646	26,46	7,31
58	120	256,2	514,4	0,7979	1,515	0,2279	22,79	10,98

t1) heating water temperature; t2) saturated vapor temperature; mc) fuel mass flow rate (kg / s); mv) mass flow rate of steam (kg. s^{-1}); PC) calorific value of fuel (kJ.kg^{-1}); P1) boiler inlet pressure; P2) boiler outlet pressure; h1) enthalpy 1; h2) enthalpy 2; s1) entropy 1; s2) entropy 2; EFGV) efficiency of the steam generator (boiler); INC.) Yield increase.

B. Step 2 – Efficiency with the elevation of the temperature of the feed water trough the solar field

A set of plates with high pressure (CS) collector tubes was used, with the objective of achieving a yield increase in the system close to 7%, above the 5% achieved with the current water heaters used in boilers to gas, as said earlier in this study.

After the system simulations were carried out, it was verified that in order to achieve an average of 7% increase in the desired thermal efficiency, it would be necessary to use 50 plates of high pressure collector tubes of 30 tubes each of 2014W thermal. The actual increment of this experiment was 7.4% yield (Table III). The composition of the water at the inlet of the feed water heater should be 43% flow from the slab system (CS) and 57% from raw water collection, for mixing in the feed water heater (AAA).

Table IV - Result of the calculation of the modelling with the solar plates for an increase of approximately 7%.

QCS	Nboard	EFGV	EFGV (%)	INCη (%)
99	49,16	0,2637	26,37	7,4

An annual saving of approximately USD 21.081,30 was achieved with the use of the solar-assisted steam generator system.

5. Conclusion

- It is concluded that the efficiency varied by approximately 7.4%, when the temperature of the feed water was increased by 20° C, close to 48° C. For this variation to occur, it was necessary to use 50 plates.
- The technical feasibility of boiler economizer implementation to increase the efficiency and the production of heat in thermal generation systems of this kind is observed in this work. Other issues, for example economic financial viability, need to be adequately studied, considering the calculation for various types of fuels, with different values of calorific value,.

6. References

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