EFFICIENCY ANALYSIS OF A BOILER FOR SUSPENSION BURNING OF SUGAR CANE BAGASSE.

BRITO, A. L.; BEATON, P.; *BALLESTER J.; *DOPAZO, C.

University of Oriente. Fac de Mecanica
Ave. De Las Americas s/n; Santiago de Cuba, 90900. Cuba

*University of Zaragoza. Dpto de Mecanica de Fluidos / LITEC
Maria de Luna, 3; Zaragoza 50015 Spain

ABSTRACT

The present paper describes the results of the retrofitting of a bagasse-fired boiler (RETO CV 2518) in the sugar mill "Amancio Rodriguez", located in Las Tunas, Cuba. The boiler was modified in order to implement a suspension burning configuration

Among other modifications, the distribution of combustion air along the furnace was redesigned in order to obtain a large-scale swirling movement pattern above the grate. As a result the new aerodynamic organization of the fuel-air mixture within the furnace was significantly improved.

The combustion efficiency of the boiler before and after the retrofitting is analyzed in this paper. The results of the analysis show that the gross efficiency calculated for the modified boiler increased in 2 %. This difference is due mainly to the decrease of the heat losses by mechanical unburnt from about 4 % before the retrofitting to 1.95 % with the new configuration.

Keywords:
Furnace, Efficiency, Combustion, Bagasse, Suspension burning, Heat losses.

THE SUGAR INDUSTRY IN CUBA

The importance of the Sugar Industry for the Cuban energy budget, may be appreciated from the data in Table 1.

Table 1
Energy budget of Cuba in 1997 (compiled by Silva and Barreda 1995)

Energy source	10^3 tef	%
Imported fuel-oil	7200	61.6
National fuel-oil	1287	11.01
Bagasse	2600	22.24
Others	600	5.15
Total	11687	100.0

tef - tons of equivalent fuel-oil.

Near the fourth part of the energy consumed in Cuba in 1997 was generated by the Sugar Industry. That situation has not changed in the last years, and the bagasse constitutes the main energy source after the imported petroleum.

To increase of the efficiency in the steam generation is an objective in the sugar industry, and a programme aimed at the optimization of old plants has been initiated.

AN ENERGY PROGRAM WITHIN THE SUGAR INDUSTRY.

The implementation of an Energy Program within the Cuban Sugar Industry was fostered by the necessity to increase the efficiency and the steam generation capacity of the combustion equipment of the sugar mills. The goals are:

1. To reduce the number of boilers in each mill.
2. To increase the energy yielded per kilogram of bagasse.
3. To obtain a surplus of bagasse that can be supplied as a by-product to other the waste-processing industries (paper and furfural industries, animal food, etc.).
4. To enable the development of cogeneration in the sugar mills.

The following data give an idea of the relevance and possibilities of bagasse in the Cuban energy industry: MINAZ (1995) :

1. The energy potential of bagasse is estimated in 1120-1600 GJ (the fourth part of the energy consumed by in Cuba).
2. 85 % of the Cuban sugar mills are connected to the electricity distribution system.
3. 74 % of the energy demand in the Cuban Sugar Industry is covered by the combustion of bagasse.
4. The energy program is aimed at exploiting as much as possible the energy potential of bagasse.

However, the combustion equipment installed in the sugar mills by the end of the 80's consisted of horseshoe furnaces, not suitable to achieve high capacities or efficiencies. Namely the main disadvantages of these combustion systems are the following (Norton 1980 and Watkins 1993):

- High maintenance cost for furnace brickwork.
- Necessity to maintain a high excess air in the furnace to avoid a high level of heat losses due to incomplete burning from chemical and mechanical causes. This results in low gas temperature inside the furnace and, consequently, in a poor heat exchange by radiation.
- High heat losses in the flue gases due to both the poor heat exchange inside the furnace and to the increased gas flow rate caused by the high excess air. An increased power consumption of forced and induced draught fans is observed
- A great amount of bagasse is piled up on the grate causing a high inertia of the system and consequently a slow response to load changes. It is difficult to introduce reliable combustion regulation systems.
- Poor control of combustion air, with leakages through the bagasse feeding chutes.

The introduction of new combustion technologies can result in more efficient steam generators, allowing an increased capacity of the existing bagasse-fired boilers. As a result, the contribution of the sugar industry to the Cuban energy budget may be increased, reducing the dependence on imported oil for electricity generation. All these benefits can be achieved with a simultaneous reduction of pollutant emissions to the atmosphere.

SUSPENSION BURNING OF BAGASSE.

The retrofitting of the current boilers to suspension burning is one of the alternatives to improve their performance. These firing systems have the following advantages: Beaton (1994), Oliva et al (1991), Brito and Beaton (1997)

- The high turbulence in the combustion chamber guarantees a good mixing between the bagasse particles and the air as well as a more intense convective heat exchange.
- The high level of furnace temperature and residence time of the fuel particles create favorable conditions for an efficient combustion.
- The suspension burning of bagasse results in a fast response to changes in steam demand.

DESCRIPTION OF THE BOILER.

Cuban engineers of the Mechanical Design Company in collaboration with Russian specialists designed a new boiler for bagasse burning on dumping grate, with mechanical feeding of the fuel, with a capacity of 25 ton/hr, pressure of 1.8 MPa and superheated steam temperature of 600 K, denominated RETO CV-25-18. The National Industry began to install this boiler in 1982. Other design parameters summarized in Table 2.

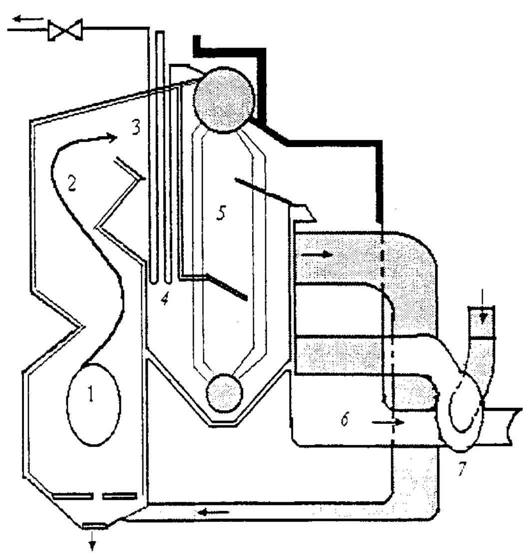
The implementation of suspension burning in a boiler RETO was achieved modifying the injections of bagasse and air: Brito and Beaton (1997). Figure 1 shows an schematic of the furnace after the retrofitting. Bagasse and a fraction of the combustion air are supplied through pneumatic distributors located in the front wall. The rest of the air is injected through overfire air nozzles installed at different heights along the wall. The design is such that the air jets develop a large-scale swirling movement in the lower part of the furnace.

The fuel particles behave differently depending on their size. The bigger particles burn mainly in the lower part of the furnace. The finer fractions, as well as low-density partially-burned particles are entrained into the upwards gas flow, and their combustion takes place in a "vertical flame" over the upper part of the furnace: Oliva et al (1991).

The main modifications carried out in the furnace of the boiler RETO, to introduce the suspension system are the following:

- Lengthening of the rear and front walls.
- Diminish of the surface area of the grate in 50 %.
- Installation of pipe and nozzles for the supply of air.
- Substitution of the mechanical feeder by a pneumatic feeder.
- Change of fans.

Figure 1
Retrofitted boiler for suspension burning of bagasse.



1. Rotational movement in the Lower part 2. Vertical flame in the upper part. 3- Furnace exit. 4- Steam superheater. 5-Convective zone. 6- Boiler exit. 7- Forced draught fan.

Before the retrofitting, most of the combustion took place on the grate where bagasse was deposited forming a pile. After the retrofitting, a much larger fraction of the fuel burns in suspension and the area of the grate was reduced by about 50% to 8.04 m^2. With the new configuration, only the bigger particles are deposited and burn on the grate.

The walls of the retrofitted furnace are covered by tubes of 57x3.5 mm. This represents a transfer surface of 151 m^2. The tubes of the rear and front walls at the height of 3-5 mts and 5.67-6.6 m respectively have been curved forming two "noses" in order to increase the length of the path of the gases inside the combustion chamber and a longer residence time of the bagasse particles.

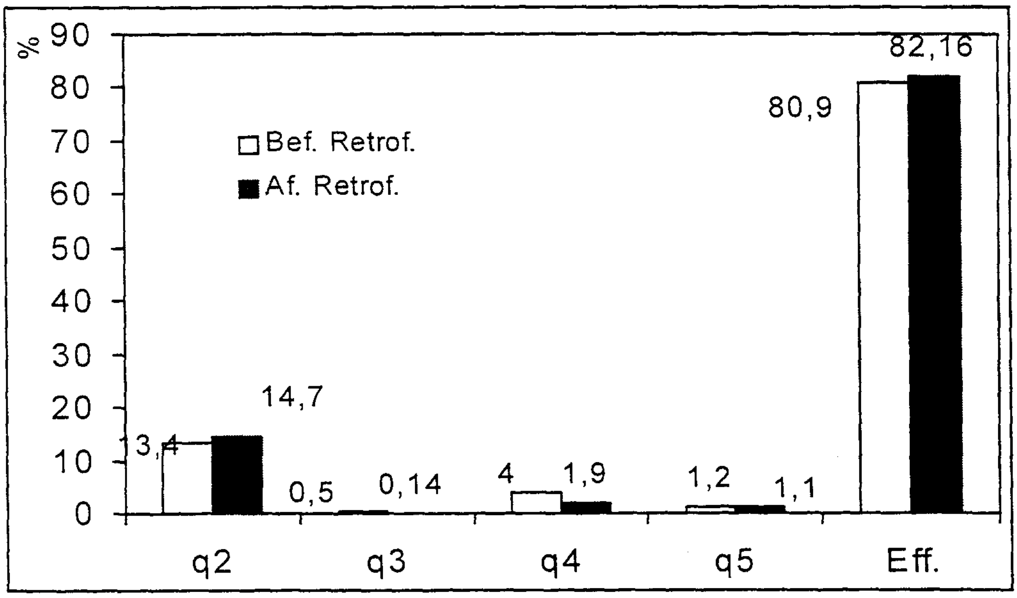
Table 2

Design and operating parameters of the boiler RETO, respectively before (i) and after (ii) the retrofitting.

Parameters	Unit	I	II
1. Steam generation	T/hr	25	35
2. Bagasse moisture	%	50	50
3. Feed water temperature	°C	110	110
4. Bagasse low caloric value	Kj/kg	7954	7954
5. Available heat	Kj/kg	8009	8009
6. Drum pressure	Mpa.	2.1	2.0
7. Superheat steam pressure	MPa	1.9	1.9
8. Superheat steam temperature	°C	320	354
9. Flue gas exit temperature	°C	199	212.51 85*
10. Excess air in outlet gasses	-	1.54	1.62
11. Loss q_2	-	13.4	14.0
12. Loss q_3	-	0.5	0.14
13. Loss q_4	-	4	1.9
14. Loss q_5	-	1.2	1.1
15. Bagasse consumption	Kg/s.	2.89	3.9
16. Gross efficiency	%	80.9	82.86

Figure 2

Heat losses and gross efficiency of the reconstructed boiler (in percentage of load)



Bef. Retrof. -Results oof the energy balance in the boiler before the retrofitting.
Af. Retrof. - Results of the energy balance in the boiler RETO after retrofitting.

EFFICIENCY ANALYSIS .

The efficiency of the steam boilers can be determined by direct and indirect methods. The direct method is rarely used for the study of bagasse-fired due to the difficulty in having a continuos measure of fuel mass-flow rate. The equation for efficiency calculation by the indirect method is as follows:

$$\eta = 100 - \sum_{i=2}^{6} qi \qquad (1)$$

η - Gross efficiency of the boiler, %
q2 - Heat losses with outlet gasses, %.
q3 - Heat losses by incomplete burning from chemical causes, %.
q4 - Heat losses by incomplete burning from mechanical causes, %.
q5 - Heat losses to the surroundings, %.
q6 - Heat losses by the sensible heat of the slag, % (in bagasse boilers this contribution is negligible)

The main results of the tests carried out in the reconstructed boiler are presented in column II of Table 2. Column I in Table 2 includes the value assumed for the design of the boiler RETO before the retrofitting. The comparison of both data series gives an idea of the benefits obtained after the retrofitting. Nevertheless, this is a very conservative estimate, since the operation parameters of the boiler before the modifications were much worse than the quoted design values (eg, the actual efficiency was about 76-78%, instead of the nominal value of 80.9%)

A remarkable result of the reconstruction is that the nominal steam generation-capacity could be increased from 25 to 35 ton/hr (40 %), due to a better use of the furnace volume and to the increase of the heat transfer surface in the furnace.

The suspension burning allows the firing of higher quantity of fuel compared to the combustion of bagasse on the grate in the previous configuration. On the other hand, convective heat transfer to the furnace walls is enhanced in the new geometry due to the higher velocity of the gases.

The gross efficiency of the boiler has increased in about 2% as a result of the retrofitting. The suspension burning produces an improved aerodynamic organization in the combustion chamber that leads to a decrease of the heats losses by incomplete burning from mecnanical (Δq_4=-2.03%) and chemical (Δq_3=-0.357%) causes. This benefits overcome the increase of the heat losses in the exit gases in +1,3 %. The increase of this parameter was caused by the high value of the excess air measured (α''_{eg}=1.6) compared to the value assumed before the retrofitting (α''_{eg}=1.54) together with the increase of the exit gas temperature (199 °C before and 212.5 °C after the retrofitting).

The temperature distribution inside the combustion chamber was measured for a steam generation of 35 ton/hr and is shown in figure 3.

The maximum temperature zone (1250 °C) is located in the central and lower parts of the furnace. No contact between the flame and the tubes of the wall is observed, which guarantees normal conditions of heat transfer: Brito and Beaton (1997).

Figure 3
Temperature field in the reconstructed boiler, (°C)

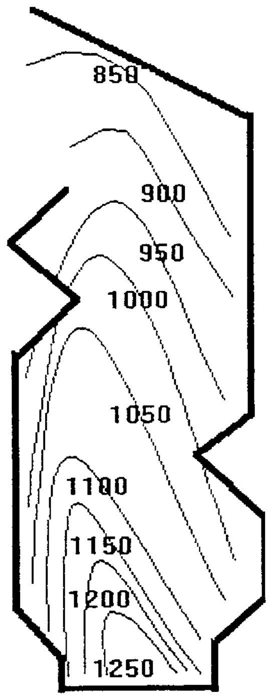
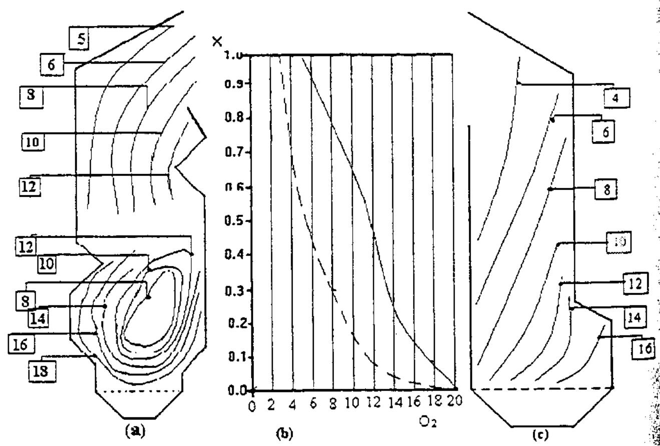


Figure 4
Oxygen concentration field measured in the furnace of the boiler RETO before and after the retrofitting.



(a)- retrofitted boiler RETO
(b) -Average oxygen concentrations in different sections as a function of the adimensional height.
(c) - boiler RETO before retrofitting

The temperature of gases measured at the furnace exit υ'' before retrofitting for the load of 35 tons/hr is 875 °C, similar to the value obtained before reconstruction (850 ^{0}C) for the load of 25 tons/hr. The flame is distributed over the whole furnace volume, which explains the fairly uniform temperature distribution measured in the combustion chamber.

Figure 4 shows the measured oxygen distribution inside the combustion chamber before and after the retrofitting It is apparent from this Figure the different patterns of the oxygen isolines, which are in agreement with the different combustion strategy. In the original boiler, the oxygen concentration decrease gradually as the flow moves downstream from the great, until a final value around 5%. On the contrary, the measurements of oxygen in the retrofitted boiler reproduce the swirling-flow pattern, with a minimum at the center of the lower flame. Downstream, the oxygen concentration is higher near the rear wall, where overfire air is injected, and the values at the exit are in the range 5-10%.

CONCLUSIONS.

1. As a result of the reconstruction of the boiler, the steam generation and combustion efficiency were increased from 25 to 35 ton/hr and from 95.5 to 97.5 % respectively . The high gas velocity in the furnace provokes the increment of the heat and mass transfer and consequently high steam generation.

2. The flow pattern achieved within the retrofitted boiler causes an enhanced air/fuel mixing, leading to a reduction by a factor of 2 of the solid unburnt material leaving the furnace.

3. The high gas velocity in the furnace enhances the convective heat transfer, contributing to the increase of the boiler capacity.

4. The reconstruction includes the reduction of the grate area in 50 %. Most of the fuel being burnt in suspension. However the combustion of a some fraction of bagasse still takes place on the grate which prevents a loss of pressure in the event of an interruption in the supply of bagasse to the furnace.

5. A more homogeneous temperature field in the combustion chamber is observed. In particular, this effect reduces the thermal stresses in the tubes, which cause frequent failures in bagasse-fired boilers.

6. The encouraging results obtained support the convenience of the retrofitting of the old boilers in the Cuban sugar industry. The reconstruction of two other steam boilers for burning bagasse in horizontal swirl are being carried out in the sugar mills "Amancio Rodriguez " and "Los Reynaldos."

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