

Cogenerations of energy from sugar factory bagasse

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Abstract: During sugar production, bagasse (waste) is produced which is used as energy resource in the sugar mill. Cogeneration power plants using bagasse as the feedstock are attached to several sugar factories in Thailand. These produce steam and electricity for use in the sugar mills and also sell the excess power to the grid. Bagasse, being a by-product of sugar production as well as of biomass origin seems to be a suitable candidate for sustainable energy production. However the case is quite different in Shoa Sugar Factory, which suffers from lack of bagasse during stoppage of mill and as a matter of fact it is forced to cut trees of the surrounding to deliver it to its boilers during stoppage of mill. It is a crystal clear fact that cutting trees without replacement causes the desertification, which is currently the case in Shoa Sugar Factory. It is from this fact that the objectives of the research work emanate. The first part of the study deals with bagasse and its properties, this part of the study focuses on determining the quality and quantity of bagasse that has been used by the factory as a fuel for boilers with respect to the conventionally accepted standards. The outcome of the study indicates the bagasse produced by the factory fulfills all the requirements as a boiler fuel both in quality and quantity wise, during milling time and stoppage of mill without the supply of any additional fuel. The second part of the study focuses on the steam generation and utilization unit. The study conducted in the steam generation unit shows the steam generation unit (boilers) has very low efficiency (on average 56%) when compared to the minimum accepted efficiency of boiler that uses bagasse as a fuel (70 %). The low efficiency is manifested by large quantity of heat losses that should be transferred to steam. The investigation on the steam utilization unit shows it operates without problems. In general the outcome of the study proves that the low efficiency of the boiler resulted in shortage of surplus bagasse. The research output indicates existing surplus bagasse shortage can be solved by improving the efficiency of the steam generation unit. The proposed solutions to the problems are optimization of excess air supply in the combustion chambers, application of bagasse drying system, increasing the capacity of evaporators, efficient operations, maintenance of boilers and its accessories.

Keywords: Bagasse, Energy, Fuel, Heat

1. Introduction

The development of sugar industry in Ethiopia has been remarkable since 1954 when the Dutch Company, HVA established Wonji Sugar Factory with a crushing rate of 1400 tons of cane per day (TCD). Wonji Sugar Factory is the pioneer sugar factory in Ethiopia. Eight years after the establishment of Wonji Sugar Factory, in 1962 Shoa Sugar Factory was established with a crushing rate of 1600 TCD. However, the present crushing capacity of the factory is 1700 TCD. The two Factories are located in the rift valley, Orimia region, in East Central Ethiopia, some 107 Km South East of Addis Ababa at an elevation of 1540 above sea level[1,2]. They are under one management and collectively called Wonji Shoa Sugar Factory (WSSF). Since then

the sugar sector has played a vital role in the country's economy and sugar has become one of the major commodities for local consumption and foreign exchange earnings. The production of sugar from sugar cane is a distinctive process in that it involves no element of synthesis [3]. However, sucrose comes in to the factory and subject to some unit operations [4]. The present system of sugar manufacturing process is essentially a combination of juice extraction from sugar cane by milling or diffusion or a combination of both, clarification of juice, concentration of juice by evaporation to syrup, crystallization of sucrose by vacuum pan boiling, centrifugal separation of sugar and molasses from massacutes, drying and cooling of sugar and sugar grading and packing [5, 6]. All the process needs relatively large amount of energy in different forms such as power for prime movers. This power is needed mainly in

the form of electricity for the electric motors and medium to high-pressure steams for the steam engines and steam turbines [7]. The processing of raw cane also requires a large amount of heat provided by low-pressure steam for the processing of juice in to commercial sugar [8, 9]. Sugar cane industry is one of the few industries, which are able to supply its own fuel (in the form of bagasse). The fiber in the cane is generally sufficient to supply all the steam necessary for power production and for manufacture of sugar when utilized as a fuel in the boiler furnaces. With normal fiber content in cane (12-14%) a well balanced factory will be left with a surplus bagasse [10]. Nevertheless, the energy crises of 1974 and 1979 and the uncertainty in the future pricing of fossil fuel has led most sugar producers to think in terms of improved energy balance in their factories. Technological advance in the utilization of by- products of the cane sugar industry have reinforced the policy of maximum efficiency in the use of fuel [11].

The present objective of cane sugar industry is to extract the maximum power from the available fuel by efficiently utilizing the latent heat of steam and reducing the losses to a minimum. The losses are inevitably sustained in the flue gases of steam boiler, gas turbines and in the cooling water of condensers. Significant improvements can be achieved by improving boiling house, and other factory departments leading to maximum process heat economy, bagasse drying to improve its calorific value as fuel, generation of extra electricity from excess bagasse for export to the grid. Shoa sugar factory is the factory that was established to supply its own fuel from the byproduct bagasse and remains with some excess of this bagasse, which will be used during stoppage of mill so that no additional fuel would be used whatever the case may be. At the present condition the reality reveals that the factory is using additional fuel during mill stoppage.

2. Material and Methods

In this research work the detail assessments of the factory has been made by giving due attention on review of existing steam generation plant, present condition and performance of boiler capacity, drum boiler heating surfaces, fittings for boilers attemperator, soot blowers grate, economizer, induced draft (ID) fan, combustion air fan (FD fan), chimney, instrumentation and controls, steam distribution system, steam pressure reducers and de-superheating station, various indicators and recorders installed, lagging and insulation, evaporator station, thermo compressor, juice catcher after last body, condensate extraction system, material and energy balance based on design parameters. The flow diagram of power plant is shown in Fig. 1. The research work, therefore, emanates from current energy imbalance, shortage of excess bagasse, and wastage of steam. To arrive at the solution the number of works was conducted, among which are; Investigating the obscure operating characteristics, which are specific to steam generation from bagasse as a boiler fuel and utilization of steam by the

factory, identifying the root causes of the problem, examining the extent to which the energy system analysis can be used to know the energy impact of the factory, quantifying and evaluating the performance parameters of the factory with respect to steam generation and utilization, studying the effects of the change in the performance parameters which accounts to prevent the existing problems, recommend appropriate solutions [12].

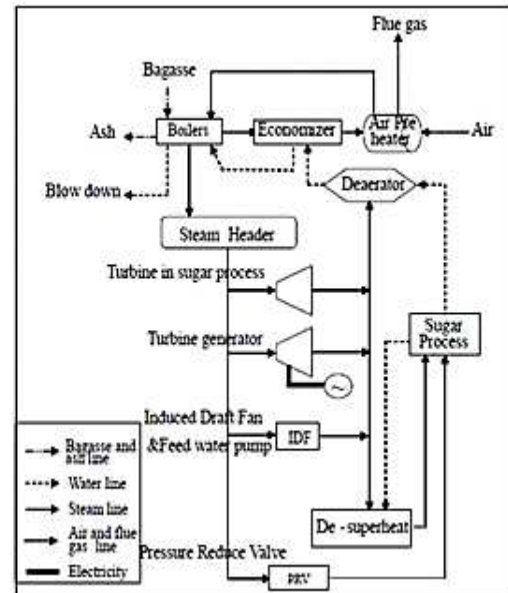


Fig. 1. Power plant of Sugar Industry.

2.1. Physical Testing

Materials used for experiment are, Chopping machine, disintegrator, balances, sodium bicarbonate, and mercuric chloride to determine fiber content of the cane. Perforated tray, balances and Oven were to determine the moisture content of bagasse. Rapi-pol extractor, lead acetate, filter paper and balances: it is used to determine the Pol in bagasse. Bomb Calorimeter, type C210, Make: Junk & Kunkel K.G, IKA WERK Stauten Breisgan, measuring cylinder, balances and ignitions wire were used to determine the high heating Value (HHV) or gross calorific value of Bagasse of different Varieties and different moisture content. Combustion (Flue Gas) Analyzer, KM9104 was used to determine the composition of the flue gas leaving the boiler and its temperature [13].

3. Results and Discussion

3.1. Physical Property of Bagasse

The physical property of bagasse after testing is shown in Table no. 1. In which moisture content in bagasse, fiber content in cane, bagasse content in cane and percentage of pol in bagasse was determine.

Table 1. Physical Properties of Bagasse.

Variety	Moisture content in bagasse [wt/wt%]	Fiber content in cane [wt/wt%]	Bagasse content in cane [wt/wt%]	Pol %in bagasse
N-140	50	14.52	32	3.8
NCO334	50	14.08	30	3.4
B52-298	50	13.67	29	3.2
B41-227	50	14.78	33	3.7
CO-421	50	14.13	31	3.6
Average	50	14.24	31	3.54

3.2. Gross Calorific Value

The heating value of bagasse from cane was shown in Table no.2. In this test determine percentage of moisture, percentage of fiber in cane and gross calorific value was determined from different varieties of cane.

Table 2. Heating Values of Bagasse Obtained from Major Commercial Cane Varieties.

Variety	Moisture %	Fiber % Cane	GCV[KJ/Kg]
N-140	50	14.52	8795
NCO334	50	14.08	8430
B52-298	50	13.67	8396
B41-227	50	14.78	8894
CO-421	50	14.13	8469
Average	50	14.24	8597

*GCV Gross Calorific Value.

3.3. Calorific Value of Bagasse

The calorific value of bagasse before and after drying was presented in Table no. 3. In this calculation both gross calorific value and net calorific value was determine.

Table 3. Calorific Values of Bagasse with Different Moisture Content.

Bagasse	Before drying	After drying
Moisture (%)	50	35
GCV (KJ/Kg)	8597	12544
NCV (KJ/Kg)	7447	10517

*GCV Gross Calorific Value, NCV Net Calorific Value.

3.4. Composition of Gasses

The analysis of flue gasses was presented in Table no. 4. The percentage of different gaseous oxygen, carbon monoxide, carbon dioxide, nitrogen and water at boiler temperature was determined.

Table 4. Results of Flue Gasses Analysis.

Description	% of flue gases compositions		
	B#1	B#2	B#3
Oxygen	9.4	10.5	11.3
CO	0.89	1.23	1.84
CO ₂	10.9	9.8	9.1
N ₂	65	76.97	63
H ₂ O	13.8	12.4	14.3
Temperature	202	218	220

3.5. Bagasse and Steam Balance based on Actual Daily Production

The balances conducted based on the bagasse and steam demand of the factory on daily basis of its present operation condition is intended as one of the factors to address the present fuel problems of the factory. The factory crushes on average 22 hours a day in which this balance is based on. In the determinations of the amount of bagasse and steam produced and consumed, the first step is the determination of losses [14, 15].

- 1) These losses includes bagasse losses due to vacuum filter, stoppage of mill and other undetermined losses.
- 2) Heat losses in the processes of steam generation comprises of losses due to Latent heat of vaporization of the water formed by combustion of the hydrogen contained in the bagasse. This is lost in the flue gases with the water vapor if the latent heat is not condensed.
- 3) Latent heat of vaporization of the water content of bagasse, which in the same way is lost with the flue gases, Losses in ash content and brix of bagasse.
- 4) Sensible heat losses in the flue gases and fly ash.
- 5) Losses by radiation
- 6) Losses by unburned solid,
- 7) Losses by incomplete combustion of carbon giving CO instead of CO₂.

Except losses due to sensible heat in the flue gases and fly ash, radiation, unburned solid, and incomplete combustion of carbon giving CO instead of CO₂, the rest losses are included in the determinations of the N.C.V of bagasse. The rest losses will therefore determined here under, which presented in Table no. 5.

Table 5. Bagasse and steam balance based on actual daily production.

4. Descriptions	Unit	Quantity		
1. Cursing Rate	T/h	77		
	T/d	1700		
2. Fiber in can	%	14.24		
3. Average Bagasse in cane	%	31		
4.1. Bagasse Analysis				
(i) Pol in bagasse	%	3.54		
(ii) Moisture in bagasse	%	50		
(iii) Fiber in bagasse	%	46.46		
4.2. Bagasse loses				
(i) For Vacuum. Filter and other losses in cane	%	2.38		
(ii) For stoppages of cane shortage (8% on production and 85% steam usage)	%	58.59		
4.3. Net Bagasse available % cane	T/n	18.48		
4.4. Calorific value of Bagasse				
(i) G.C.V	KJ/kg	8594		
(ii)N.C.V	KJ/kg	7447		
5.1. Steam Condition				
	Unit	Boiler 1	Boiler 2	Boiler 3
Pressure	Kg/cm ² (g)	21	21	22
Temperature	0C	310	330	320
Temp. of feed water tank	0C	90	90	90
Temp. of feed water after economizer	0C	187	187	190
The gas exit temp	0C	202	218	220
Ambient Temp	0C	30	30	30
CO ₂	%	10.9	9.8	9.1
Air fuel Ratio		1.79	1.89	1.98
Heat-losses in flue gases	kJ/kg	1399	1605	1685
Capacity	T/h	15.002.03	15.00	15.00
Steam/Bagasse Ratio			1.99	1.98
Efficiency				
Factor- Alpha (solid unburned)	%	95	95	95
Factor -Beta (radiat CO ₂ & Conv.)	%	95	95	95
Factor - Neta (In.Comb.)	%	95	95	95
Product : A*B*N	%	85.7	85.7	85.7
Boiler Efficiency				
(i)On G.C.V	%	58	56	55.5
(ii) On. N.C.V	%	69	67	66
Boiler Efficiency				
(i)On G.C.V	%	58	56	55.5
(ii) On. N.C.V	%	69	67	66
5.2 Steam Generation Possible				
Capacity	T/h	15	15	15
Steam pressure	Kg/cm ²	21	21	21
Steam temperature	°C	310	330	3201.98
Steam/Bagasse Ratio		2.03	1.99	
6.Steam Consumptions by prime movers				

6.1. Mill TurbinesCapacity	hp	300	450	450
Live steam condition				
Pressure	Kg/cm ²	21	21	21
Temperature	°C	300	300	300
Exhaust steam pressure	Kg/cm ² t/n	1.25	1.25	1.25
Steam flow at operational load		Total12.32		
6.2. Power turbine		Turbine 1	T turbine 2	
Pressure	Kg/cm ²	21	20	
Temperature	°C	300	300	
Exhaust steam pressure	Kg/cm ²	1.25	1.25	
Operation Av. Load	MW	1.4	1.4	
Specific steam consumption	Kg/MWh T/n	1.68	11.68	
Steam flow at operational load		18	18	
6.3 Steam to process				
Exhaust from Mill turbine	T/n	12		
Exhaust from Power turbine	T/n	18		
Total	T/n	30		
6.4. Steam Generation (Boilers)		Boiler1	Boiler2	Boiler3
Pressure	Kg/cm ²	20	20	20
Temperature.	°C	310	310	310
Installed capacity	T/h	15	15	15
Current Capacity	T/h	12.37	12.37	12.37
Steam/Bagasse Ratio		2.03	1.99	1.98
6.5. Steam Consumption		T/h	% cane	
Inlet steam to mill Turbine		12	15.6	
Inlet steam to power Turbine		18	23.4	
Live steam make up		4.22	5.5	
Sugar Drying, sulfur, remelt		1.5	2.0	
Losses		1.4	1.8	
D. heating water		00	00	
Total steam Demand		37.12		
Exhaust balance		T/h	%cane	
Exhaust produced		37.22	48.2	
Exhaust Required		30	39	
Surplus /deficit		5.22	6.65	
Summary of Bagasse Balance		Boier1	Boiler2	Boiler3
Steam GenerationRequired			1 2.37	12.37
Steam/Bagasse Ratio		12.37	1.99	1.98
Bagasse Requirements		2.03	6.22	6.25
Bagasse Available		6.09	18.48	
Net Surplus Bagasse (Negative)			-0.08	

The bagasse produced from the major commercial sugar cane varieties have on average 50% moisture, 14.5% fiber on cane. For a bagasse with moisture content of 50 % the accepted standard fiber content in cane ranges from 12 to 16%. The experimental result indicates the fiber content in cane of major commercial sugar cane varieties ranges from 13.67 to 14.78 %. The test result also indicates the quantity of bagasse obtainable from a unit weight of cane ranges from 29 to 33 %wt/wt of cane. This gives on average 31 % weight of bagasse per weight of cane. The standard value is 24 to 30 % wt/wt of cane or approximately a quarter. The fiber content % in cane and the quantity of bagasse pro-

duced by the factory is much better to supply the required quantity of bagasse for the boilers both during milling time and stoppage of mill.

6.5.1. Heating or Calorific Value of Bagasse

The results of experiment done on the higher heating value of bagasse at moisture content of 50 % indicate the higher heating value ranging from 8396 to 8894 KJ/kg which is within the standard range. The calorific value of bagasse has also been determined for varying the moisture contents of bagasse. The purpose is to quantify the impact of the moisture content of bagasse on the amount of heat

transferred to steam from bagasse during combustion in the boiler furnaces. The experience so far in the factory reveals moisture content has a significance influence on the performance of a boiler. This effect would be manifested when the moisture content of bagasse increase above 50 %; the boiler needs more bagasse or the boiler losses its pressure stability. The test is, therefore, intended to evaluate the boiler performance under a much wider spectrum of bagasse moisture. The test has been conducted on bagasse moisture content of 30%, 35% and 50%.

The result shows the increase in the calorific value of bagasse with the reduction in its moisture content. It indicates it has necessary to dry bagasse to reduce the moisture content so as to improve its calorific value. This would improve the boiler efficiency. Moreover, the efficiency can be improved further by recovering the sensible heat that has been lost with the flue gas by employing it as the heat source in bagasse drying operation.

6.5.2. Flue Gases Analysis

The flue gas analysis indicates the carbon monoxide compositions of the flue gases on three boilers are 890, 1230 and 1840 ppm, respectively when compared to the maximum allowable 480ppm. The test also indicates the percentage of excess air in the combustions chamber, i.e., 79%, 89.7% and 98.7% and the composition of carbon dioxide in the flue gas is 10.9, 9.8 and 9.1 percent, respectively. However, the percentage of excess air to support complete combustion should lie in the range of 30 - 50%. The analysis can be due to the addition of too excess air into the combustion chamber. This too excess air cools the chamber which in turn needs more energy to heat the air before combustion is started. The excess air due to its high pressure and velocity takes some of the carbon monoxide with it in the flue gases before it is completely converted into carbon dioxide. Moreover, the excess air that leaves with the flue gases takes more sensible heat with it than the conventional losses to the atmosphere. It is, therefore, very essential to optimize the percentage of excess air in the combustion chamber. This can be done by setting the percentage of carbon dioxide that leaves the combustion chamber to 15%, which is the optimum percentage to support complete combustion in the boiler furnace, Hugot ET. Al. (1993). The maximum percentage of CO₂ in the flue gases that can be theoretically achieved is 19.8% Hugot ET. Al. (1993). If it is needed to obtain complete combustion, without appreciable formation of carbon monoxide, it is desirable to work with the minimum amount of excess air, which will yield the optimum carbon dioxide percentage in the flue gases. By carrying out the optimization work on boiler furnaces, the optimum percentage of excess air in the combustion chamber is 32 % as a result the optimum percentage of oxygen in the flue gases is 5.1 %.

The heat losses in the flue gases are determined using the ratio of the optimum excess air to the theoretically required air to support complete combustion. The optimum ratio is 1.32. The heat losses with the flue gases from each boiler

are, therefore, 273kcal/kg (1150Kj/kg), 278kcal/kg (1164 KJ/kg) and 285kcal/kg (1193Kj/kg) respectively. The percentage of heat recovered by optimizing the quantity of excess air in the combustion chamber for each of the three boilers are 18%, 27.4 % and 29.1% respectively. After optimization of the excess air in the combustion chamber, the quantities of heat transferred into the three boilers are 1289 kcal/kg (5395 kJ/kg), 1285 kcal / kg(5384 kJ/kg) and 12798 kcal/kg (5359 kJ/kg), respectively.

6.5.3. Proposed Possible Solutions

To overcome the existing surplus bagasse problems of the factory and thereby to avoid the usage of wood as a boiler fuel during stoppage of mill, the combined improving actions were proposed as:

- Optimization of excess air supply in the combustion chambers.
- Application of bagasse drying system
- Increasing the capacity of the evaporators.
- Efficient operations and maintenance of boilers
- Optimization of Excess Air in the Combustion Chamber

By optimizing excess air in the combustion chamber the boiler efficiency increases 4-6 %. The gain in the above efficiency due to optimization of excess air will lead to save 1.56 tons of bagasse per hour after generation of the same quantity of steam as before.

6.5.4. Bagasse Drying Application

The experimental test results and the operational data have clearly indicated that the energy potential of bagasse has been under utilized. The result of the experiment shows currently, the drying of bagasse has taken much attention, as it is a power full tool to save bagasse energy in sugar industry. In the bagasse draying, the gases, which is the gaseous products of combustion leaving the combustion chamber is employed as a heat source to remove the water from bagasse. In doing so large quantity of sensible heat that has been lost with the flue gases are recovered. By applying the bagasse drying system, the gain in system efficiency is calculated from the change of the stack gas and is found to be 10.4 %. The calculation for the system assumes that there are no losses in the dryer. These are estimated to be about 4% losses in the dryer and are made as a correction on the final efficiency. The actual gain in system efficiency would then be, therefore, 6.4% and this leads to the savings of 2.2 tons / hr bagasse after generating the same quantity of steam.

6.5.5. Increasing the Capacity Evaporator

Increasing the capacity of the evaporator and utilizing the surplus exhaust steam that has been lost through blow down leads to increasing the crushing capacity of the mill to 90 tons /hr. The increment in crushing capacity of the mill leads to the production of 3.57 tons of bagasse per hour. This increment in evaporations and crushing rate of the mill don't affect the quantity of live steam produced and consumed.

6.5.6. Efficient Operations and Maintenance of Boilers

In sugar cane boilers proper operations and maintenance (O & M) procedures must be followed to insure safe and efficient operations. It is often assumed that good O & M provides no energy savings because it simply “what should be done.” In Shoa sugar Factory due to lack of proper O & M energy consumption can increase dramatically as much as 10 to 20 percent. Boilers suffer frequently from failure of the various systems including the pressure parts such as tubes, super heaters, air heaters etc. Thus, by carrying out only proper operation and maintenance the factory saves 10 to 20% of its energy consumption. The maintenance includes keeping physical components in good working order and within design specifications. This includes cleaning heat transfer surfaces, controls tuning, and maintaining insulations. Before boiler tuning system diagnostics should be performed and any deficient equipment brought back to specifications.

- By optimizing the excess air in the combustion chamber, additional 1.56 tons/hr of bagasse would be obtained as a surplus bagasse.
- By employing bagasse dryer the factory will save 2.23 tons/hr of bagasse.
- By increasing the capacity of the evaporators to utilize the existing 5.12 tons/hr of exhaust steam which leads to the increment in crushing capacity of the mill as a result of which surplus 3.57 tons/hr of bagasse is produced.

7. Conclusions

Based on the forgoing outputs of the research, the following inferences are made. All the experimental results, investigation and the analysis made on the physical properties of bagasse reveals that, its heating (calorific) value is quite enough to produce the amount of steam required by the factory both during milling time and stoppage of mill without requirement of any additional fuel such as wood like the current situations in the factory. The flue gases analysis made on three boilers of the factory shows high heat losses with the flue gases due to incomplete combustion of bagasse and excess air in the combustion chamber consequently the reduction in the boiler efficiency in which additional fuel is supplied to produce the required quantity of steam. The balances conducted on daily basis reveals there is even a deficit of bagasse at normal operations. The hourly live steam demand of the factory is 37.12 tons. However, at normal operation condition on average additional 0.08 tons of bagasse is demanded to produce the quantity of live steam required. Based on the balance conducted 35.12 tons/hr of exhaust steam is produced by mill turbines and power turbines, however the exhaust steam demand of the boiler house is on average 30 tons/hr. This illustrates 5.12 tons/hr of exhaust steam is left as waste energy. Since mill has the capacity to crush up to 90 TCH, however, the capacity of the boiler house do not go beyond 77 TCH. On the other hand, the review of the evaporator

shows there is ways of improving its capacity. Increasing the capacity of the evaporator and there by utilizing the surplus exhaust steam that has been lost through blow down leads to increasing the crushing capacity of the mill. The increment in the crushing capacity of mill to 90 TCH yields the production of 3.57 tons of bagasse per hour. This increment in evaporations and crushing rate of the mill don't demand additional live steam requirements.

To overcome the existing shortage of bagasse problems of the factory and thereby to avoid the usage of wood as a boiler fuel during stoppage of mill, the researcher believes and strongly recommends to materialize the proposed solutions as they will improve the fuel economy of the factory there by alleviate the mentioned problems.

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