BETTER SELL BAGASSE THAN SURPLUS ELECTRICITY?

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ABSTRACT

Over the past decade, electricity consumption in Brazil grew faster than generation capacity. This situation obliged an urgent return to investment in the sector, and revitalization of the restructuring in the national electricity sector. In these circumstances, the use of renewable energy sources, such the biomass, became an option for decentralized electricity generation. Sugar cane bagasse is one of the most important biomasss residues for electricity generation. The present publication analyses an investment made in the expansion of the energy cogeneration system in an industry that produces sugar and alcohol, from sugar cane, considering the seasonal bagasse price, energy generation costs and a 10 year period. With the new cogeneration system the factory became self-sufficient in energy, with a saleable surplus of 21,240 MWh, at an average power of 4,000 kW. However, an economic analysis indicated that the best option would have been to maintain the original system and sell surplus bagasse at R$ 26.00/t.

Keywords: Biomass residue, Cogeneration, Investment economics, Sugar cane factory, Cane sugar alcohol.

NOMENCLATURE

B	bagasse, t
C	cost, R$
D	expenditure, R$
E	energy, kJ ou kWh
I	irreversibility, kJ
m	mass, kg
N	period, h
P	principal or present worth, R$
Q	volume flow rate, m^3/h
R	income, R$
W	total work, kJ
Y	sale price, R$

Subscripts

ag	water
b	bagasse
cd	condensing
cp	backpressure
ef	off season
en	energy
est	reserve
ex	extraction
exc	surplus
F	plant
liq	net value
sf	season
T	total
1	backpressure turbine (2.800 kW generator)
2	backpressure turbine (1.800 kW generator)
3	condensing turbine (12.000 kW generator)

Superscripts

.	rate

INTRODUCTION

Hydro electricity accounts for about 42%, of Brazilian energy consumption, or around 90% of total electricity production (ANEEL, 2002). During several years, the abundant electricity supply, from the large hydro power potential of the country, provided cheap and abundant energy for economic growth. However, over the past decade, generating capacity could no longer match the average growth in electricity consumption of 4.2 % per annum (MME, 2002). A system collapse in 2001, after the series of droughts, led the Federal Government to decree rationing, with a reduction of 20% in national electricity consumption, in relation to the level in 2000. This was equivalent to consumption around 1990.

To stimulate an urgent return to investments in generating capacity, the country began restructuring the national electricity sector. In this context, in view of then long delays and high investments required for new (large) hydroelectric power plants, the non conventional, and particularly renewable, sources such as biomass, offer technically and economically competitive options for decentralized electricity generation, able to complement, energy demand in the short term. Besides being environmentally friendly, because of its local availability, the use of biomass permits decentralized energy generation and provides local employment, reducing external energy dependence and rural exodus.

A very important renewable energy source is sugar cane bagasse. The high productivity, added to successive increases in the processing of biomass in sugar factories and fuel alcohol distilleries, provides considerable bagasse surpluses, to not only energize the plants, but also cogenerate large electricity surpluses. Cogeneration is defined as the simultaneous generation of process heat and work (e.g. electricity) from fuel (natural gas, woody residues, cane bagasse, etc). The attractiveness of cogeneration in the sugar cane industry stems from the relatively high energy content of bagasse, allowing generation of surplus electricity. Injected into national electricity grid, these surpluses can meet the demand of large centers of consumption. Another advantage of this scheme is that the sugar cane harvest in the principal plantations coincides with the dry season in the main hydrographical basins of the Brazilian hydroelectric system.

However, simply installing cogeneration systems will not ensure financial gain, or even capital recovery. For this reason, cogeneration programs should only be adopted following careful techno-economic evaluations. Furthermore, it must be noted that there is no generalized method for determining a cogeneration program. In a sugar cane distillery, the cogeneration project starts out with several questions, directly, or indirectly connected to bagasse use. The success of enterprise will depend on knowing the quantity of bagasse available during the (harvesting) season and the necessary steps to increase distillery efficiency and thus bagasse surplus. As a preliminary step, the bagasse required to meet all plant energy requirements for process heat and work (including electricity) must be. For selecting the surplus to be sold, the prices of electricity and bagasse, as fuel or input for paper, animal fodder or fertilizer production must be estimated or given.

This publication analyses an increase in the cogeneration system in Japungu Agroindustrial S.A.[1], to take advantage of the substantial increase in electricity prices, to more than R$ 680.00/MWh in September 2001 (Gazeta, 2002) and government proposals to define electricity sector regulatory

landmarks. In its project the enterprise incorporated an existing deactivated 15 MVA turbogenerator thermoelectric power plant. Economic and financial analyses incorporating operating costs and bagasse and electricity prices permit comparisons between the previous and the new system.

THE PLANT BEFORE MODIFICATION

Figure 1 is a sketch of the previous electricity cogeneration system. The main equipment are: a 3.24 MPa (33 kgf/cm² - absolute) and 340 °C boiler by Zanini, with a 60 t/h steam generation capacity, a plate deaerator with cylindrical metallic shell, a pressure reducer, backpressure turbo-generators with 3.04 MPa (31 kgf/cm²) and 340 °C inlet and 0.245 MPa (2.5 kgf/cm²) and 134 °C exit, and a boiler feed water softener. Two backpressure turbo-generators with capacities of 3,500 and 2,500 kVA supply a total power of 4,800 kW. The average plant electricity was about 5,300 kW, the deficit of 500 kW being supplied by the local utility.

Plant activity occurs in two distinct periods: "season" and "off season". In season, cane is cut, usually between July and March. During the off season, (hydrous) alcohol is produced from stored molasses and anhydrous alcohol produced from hydrous. Off season plant energy demand drops to about 1,800 kW, because there is no cane extraction, and only turbine 1 operates. The plant is the shut down for complete maintenance.

A extraction capacity of the four cane milling tandems is 4.000 t/day, corresponding to an average of 166 t/h.

TECHNICAL FACTORS DECIDING THE INCREASE IN ELECTRICITY GENERATION CAPACITY

A prerequisite to raising cogeneration capacity is increasing steam production, by modifying or substituting in Japungu. Investigations[2] indicated that the existing boiler's capacity could be raised to 80 t/h, at the present 3.24 MPa (33 kgf/cm²) and 340 °C. Under these conditions the maximum electricity surplus could not be achieved, leaving a bagasse surplus in all cases. To maximize electricity surplus, burning all available bagasse, the management opted for a new boiler with higher operating temperature and pressure. In order to minimize cogeneration system investment, it was decided to use a second hand 15 MVA condensing/extraction turbine generator set lying in the yard.

THE NEW ELECTRICITY COGENERATION SYSTEM

The plant management with their consultants, designed the new electricity (co)generation system, now in operation, sketched in Fig. 2. The equipment analysed, shown in this

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1   Japungu Agroindustrial S. A., is located in Santa Rita, to 40 km of João Pessoa, in Paraíba, has always sought technological leadership, having cogenerated 1 MWe surplus electricity in 1986 for sale to the utility.

2   The cost of this enlargement was estimated in R$ 300,000.00

flowchart, are: an Equipálcool boiler, rated at 100 t/h steam capacity, at 4.22 MPa (43 kgf/cm²) and 420 ºC, a metallic cylindrical shell plate deaerator, two pressure and one temperature reducers, two backpressure and one of condensing turbo-generators, water demineralising and softening (inactive in this plant) equipment.
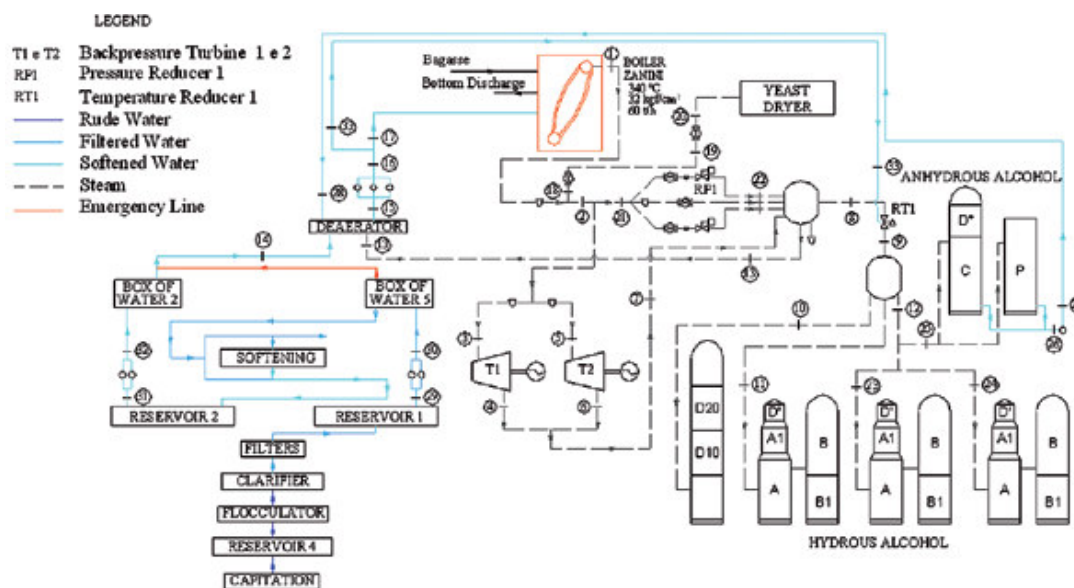

Figure 1. Scheme of the cogeneration system of the Japungu Agroindustrial S/A, before the modification.
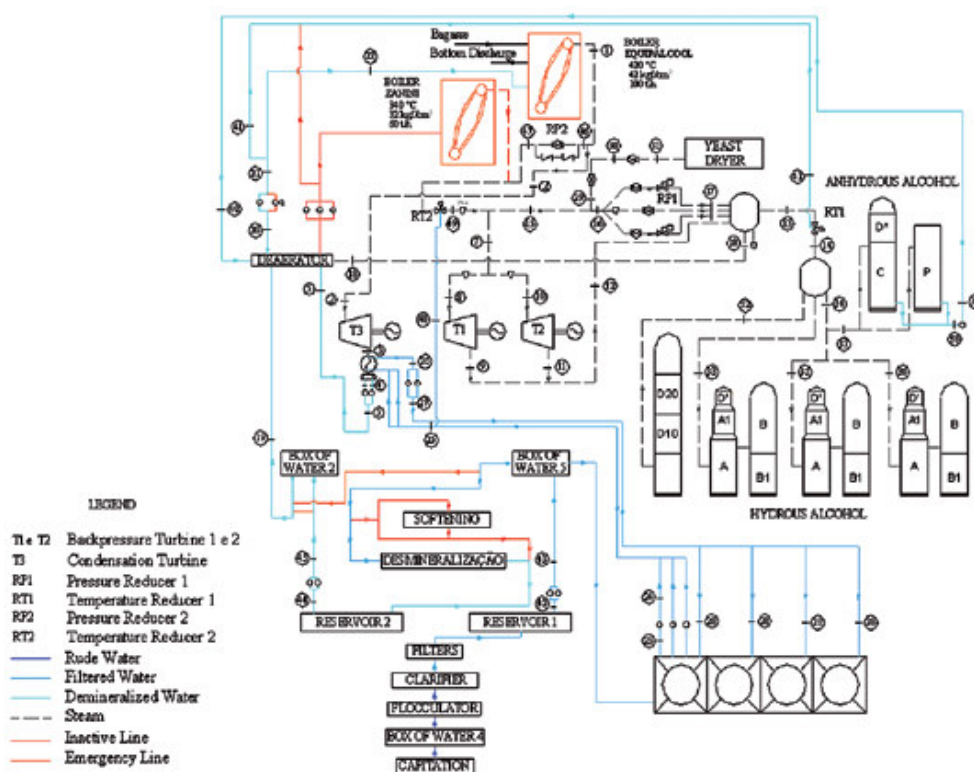

Figure 2. General scheme of the cogeneration plant adopted by Japungu Agroindustrial S/A.

Two scenarios are considered in the present analysis:

a) System operation to meet plant energy require-ments with sale of surplus bagasse (this is the present case, due to the high price for bagasse and present uncertainty on the electricity sector regulatory landmarks). The data in this mode is identified by the index "a";

b) The plant consumes all available bagasse to generate surplus electricity for sale. Data in this mode is identified by the index "b";

The Equipálcool water tube boiler operates (in mode "a", or "b") at 4.22 MPa (43 kgf/cm²) and 440 °C. Because of design limitations, the backpressure turbines inlet is 3.04 MPa (31 kgf/cm2) and 350 °C; outlet is 0.2452 MPa (2.5 kgf/cm2) in both modes and 184.5 °C in mode "a", 142.4 °C in mode "b". The condensing turbine inlet conditions are assumed equal to boiler outlet (in practice they will be somewhat lower) and outlet conditions are assumed 0.1961 MPa (2 kgf/cm2) and 44 °C. Table 1 shows generator powers for the new system, where numbers 1, 2 and 3 represent the 3500 kVA, 2500 kVA and 15000 kVA generators respectively. Off season, the condensing turbine is inoperative for lack of bagasse, and the plant operates with the old boiler, because of the high cost of water demineralising (1.20 R$/m3), as against water softening (0.08 R$/m3). Hence off season, in mode "a" the system operates as formerly, and in mode "b" the two backpressure turbines generate a total of 4,800 kW.

Table 1, with steam turbine performance data, was obtained from turbogenerator bulletins (Japungu, 2003), and equations found in related literature (Bejan, 1988; Camargo et al., 1990; Hugot, 1969; Jones, 1986; Kotas, 1995; Moran, 2002 and Sonntag, 1998).

In Table 1, it is important to note that in mode "a" backpressure turbine load was reduced by 1800 kWe. This because the plant management required operation of the condensing turbine to achieve energy self-sufficiency. The configuration includes pressure and temperature reducers (see devices RP2 and RT2 in Fig. 1), to be able to connect the backpressure turbine inlets to the new boiler outlet de 4.12 MPa (42 kgf/cm2) and 420 °C. Analysing Table 1, it is seen that the two backpressure turbines operate to generate 1800 kW and 1000 kW. The reason is to avoid a considerable drop in condensing turbine efficiency and stability if it were to generate only 1400 kW (with the backpressure turbines generating the former 4800 kW).

In mode "b", due to the pressure reducers, backpressure turbine powers were similar to those in the former system (see Table 1).

INVESTMENT FOR THE NEW COGENERATION SYSTEM

The total cost of the alterations in Japungu was over R$ 8,000,000.00. The investment covered the following main components: a natural circulation vertical water tube boiler model 100-V-2-S, with a fire box to burn cane bagasse pneumatic fuel feed and forced draught; four cooling towers by Alpina; water demineralising equipment; a 69 kV substation.

PRINCIPAL EQUATIONS IN THIS ANALYSIS

Bagasse Consumption

The bagasse consumption, B, in t, for plant operation in season, Bsf, or off-season, Bef, is obtained as the product of bagasse mass flow rate, , in t/h, during of the period, N, in h (Jaguaribe, et al., 2002; Lobo, et al., 2002 and Souza, 2004):

$$B = \dot{m}_b \cdot N \qquad (1)$$

Bagasse Surplus

Table 1. Steam turbine performance data. Turbines

Parameters	Units	Season						Off-season	
		1a	1b	2a	2b	3a	3b	1a[3] & 1b	2b
Power generated	kW	1,800	2,800	1,000	2,000	3,400	5,400[1]	2,800[2]	2,000
Steam flow rate	t/h	23.13	27.41	12.85	19.58	16.95	26.92	27.85	19.89
Specific steam consump.	kg/kWh	12.85	9.79	12.85	9.79	4.98	4.98	9.95	9.95
Efficiency	%	53.0	69.58	53.0	69.58	53.0	53.0	69.58	69.58
Effectiveness	%	60.97	75.49	60.97	75.49	51.81	51.81	75.43	75.43
Irreversibility	kW	1,152.1	908.97	640.06	649.33	3,163.55	5,024.46	911.96	651.4

[1] Maximum power burning all bagasse
[2] Increment of 1,000 kW to power irrigation
[3] Turbine 2a inactive

Table 2. Consumption and evaluated performance comparison of the cogeneration options.

Parameters	Units	In Season Old	In Season a	In Season b	Off-season Old	Off-season a	Off-season b
Harvested cane	t	700,000	800,000		0	0	
Milled cane	t	672,000	768,000		0	0	
Total bagasse produced	t	215,575	246,372		0	0	
Bagasse surplus – Eq. (2)	t	51,266	29,406	0	0	0	
Power generated – Eqs. (3) and (5)	kW	4,800	6,200	10,200	1,800	2,800	4,800
Power generated – Eqs. (4) and (6)	MWh	24,000	32,922	54,162	2,160	3,360	5,760
Plant electricity demand	kW	5,300	6,200		0	2,800	
Required import	kW	500	0		0	0	
Electricity consumption – Eq. (8)	MWh	26,500	32,922		2,160	3,360	
Average electric power import	MWh	2,500	0		0	0	
Power surplus – Eqs. (10) and (11)	kW	0	0	4,000	0	0	2,000
Electricity surplus – Eq. (9)	MWh	0	0	21,240	0	0	2,400
Cost water softening – Eq. (12)	R$	17,368.35	0		3,167.22	4,139.42	
Cost water deminerilzation – Eq. (12)	R$	0	274,760.94		0	0	
Cost electricity purchased – Eq. (13)	R$	224,650.00	0		0	0	

The bagasse surplus, B_{exc}, in t, is calculated by subtracted the bagasse consumptions in season, B_{sf}, off-season, B_{ef} and reserve stock, B_{est}, in t, from the total bagasse production, B_T (Jaguaribe, et al., 2002; Lobo, et al., 2002 and Souza, 2004):

$$B_{exc} = B_T - B_{ef} - B_{sf} - B_{est} \qquad (2)$$

AVERAGE POWER FROM THE BACKPRESSURE TURBOGENERATORS

The average power from the backpressure machines, $\dot{W}_{cp}$, in kW, is the sum of the average powers from turbo-generators 1, $\dot{W}_1$, and 2, $\dot{W}_2$, both in kW:

$$\dot{W}_{cp} = \dot{W}_1 + \dot{W}_2 \qquad (3)$$

ELECTRICITY FROM THE BACKPRESSURE TURBOGENERATORS

The electricity produced by the backpressure turbogenerators, E_{cp}, in MWh ($E_{cp,sf}$ in season and $E_{cp,ef}$ off-season), is the product of the average power in season, $\dot{W}_{cp,sf}$, or off-season, $\dot{W}_{cp,ef}$ and the period of operation, N, in h (Jaguaribe, et al., 2002; Lobo, et al., 2002 and Souza, 2004):

$$E_{cp} = \dot{W}_{cp} \cdot N \qquad (4)$$

AVERAGE POWER FROM THE CONDENSING TURBOGENERATOR

The average power, $\dot{W}_{cp}$, in kW, of the condensing turbo generator is the sum of the average powers from the extraction, $\dot{W}_{3,ex}$, and condensing, $\dot{W}_{3,cd}$, modules, both in kW:

$$\dot{W}_{cd} = \dot{W}_{3,ex} + \dot{W}_{3,cd} \qquad (5)$$

In the present case the extraction module, is inoperative, so $\dot{W}_{3,ex} = 0$.

ELECTRICITY FROM THE CONDENSING TURBO GENERATOR

The electricity produced by the condensing turbo generator, E_{cd}, in MWh ($E_{cd,sf}$ for the season and $E_{cd,ef}$ for the off-season), is the product of the average power, $\dot{W}_{cd,sf}$ in season and $\dot{W}_{cd,ef}$ off-season, and the period, N (Jaguaribe, et al., 2002; Lobo, et al., 2002 and Souza, 2004):

$$E_{cd} = \dot{W}_{cd} \cdot N \qquad (6)$$

TOTAL ELECTRICITY GENERATED

The total electricity generated, E_T, in MWh, is the sum of the electricity from the backpressure, E_{cp}, and the condensing, E_{cd}, turbo generators:

$$E_T = E_{cp} + E_{cd} \qquad (7)$$

TOTAL PLANT ELECTRICITY CONSUMPTION

The total plant electricity consumption, E_F, in MWh, is the product of the average plant electricity demand, $\dot{W}_F$, in kW, and the period, N, in h (Jaguaribe, et al., 2004; Lobo, et al., 2002 and Souza, 2004):

$$E_F = \dot{W}_F \cdot N \qquad (8)$$

ELECTRICITY AVAILABLE FOR SALE

The electricity available for the sale, E_{exc}, in MWh, is obtained by subtracting the plant electricity consumption, E_F, from the total electricity generated, E_T:

$$E_{exc} = E_T - E_F \qquad (9)$$

AVERAGE SALEABLE POWER IN SEASON

The average saleable power in season, $\dot{W}_{exc,sf}$, in kW, is the sum of the powers supplied by the backpressure, $\dot{W}_{cp,sf}$, and the condensing, $\dot{W}_{cd,sf}$, turbo generators, less the average plant electric power demand, $\dot{W}_{F,sf}$:

$$\dot{W}_{exc,sf} = \dot{W}_{cp,sf} + \dot{W}_{cd,sf} - \dot{W}_{F,sf} \qquad (10)$$

AVERAGE SALEABLE POWER OFF-SEASON

The average saleable power off-season, $\dot{W}_{exc,ef}$, in kW, is the power supplied by the backpressure turbo generators, $\dot{W}_{cp,ef}$, less the average electric power demand of the factory, $\dot{W}_{F,ef}$:

$$\dot{W}_{exc,ef} = \dot{W}_{cp,ef} - \dot{W}_{F,ef} \qquad (11)$$

COST OF BOILER FEED WATER TREATMENT

The cost of boiler feed water treatment, D_{ag}, in R\$, is the product of the replenishment water flow rate, Q_{ag}, in m³/h, the cost of water treatment per unit volume, C_{ag}, in R\$/m³, and the period, N, in h:

$$D_{ag} = Q_{ag} \cdot C_{ag} \cdot N \qquad (12)$$

COST OF ELECTRICITY PURCHASED

The cost of electricity, D_{en}, in R\$, purchased from the utility is the product of the energy acquired, E_{exc}, in MWh, and the unit electric power cost, C_{en}, in R\$/MWh (Jaguaribe, et al., 2004 and Souza, 2004):

$$D_{en} = E_{exc} \cdot C_{en} \qquad (13)$$

TOTAL WATER AND (PURCHASED) ELECTRICITY OPERATING COST

The total operating cost, D_T, in R\$, is the sum of costs with feeding water, D_{ag}, and electric power, D_{en}:

$$D_T = D_{ag} + D_{en} \qquad (14)$$

REVENUE FROM BAGASSE

The revenue, R_b, in R\$, from surplus bagasse sales is the product of the bagasse surplus, B_{exc}, and the unit bagasse sale price, Y_b, in R\$/t (Jaguaribe, et al., 2004; Lobo, et al., 2002 and Souza, 2004):

$$R_b = B_{exc} \cdot Y_b \qquad (15)$$

REVENUE FROM SURPLUS ELECTRICITY

The revenue, R_{en}, in R\$, from the sale of surplus electricity is the product of the surplus electricity available, E_{exc}, and the unit electricity sale price, Y_{en}, in R\$/MWh (Jaguaribe, et al., 2004; Lobo, et al., 2002 and Souza, 2004):

$$R_{en} = E_{exc} \cdot Y_{en} \qquad (16)$$

NET REVENUE

The net revenue, R_{liq}, in R\$, is the gross revenue, R, in R\$ (R_b for the sale of the bagasse and/or R_{en} for the sale of electricity), less the total operating cost, D_T:
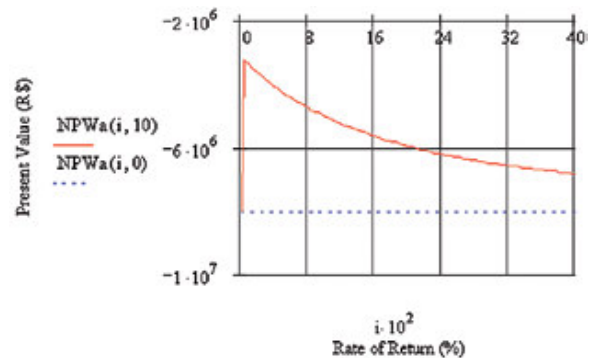
$$R_{liq} = R - D_T \qquad (17)$$

Figure 3. Rate of return for the system operating in the mode " a ".

INTERNAL RATE OF RETURN

The internal rate of return (IRR), i, of an investment, defined as the interest rate that reduces the present worth of a series of receipts minus disbursements, during a determined period, to zero. That is, the rate of return is the value of the interest rate "i" for which the present worth, P, of a uniform series of payments, R_{liq}, that satisfies the equation

$$P = R_{liq} \frac{(1+i)^n - 1}{i(1+i)^n} \qquad (18)$$

$(P/R_{liq}; i; n) = \dfrac{(1+i)^n - 1}{i(1+i)^n}$, is called the present worth factor for the uniform series of "n" payments, R_{liq}, during the period.

The IRR may then be defined as the value of "i" that satisfies the equation (Casarotto, et al., 1998 and Marim, 1980):

$$- P + R_{liq}(P/R_{liq}; i; n) = 0 \qquad (19)$$

NET PRESENT WORTH

The net present worth (NPW) is the sum of present worth values for cash flows representing each alternative.

The calculation of the Present Liquid Worth is obtained directly by Eq. (20) (Casarotto, et al., 1998 and Marim, 1980):

$$NPW = - P + R_{liq}(P/ R_{liq;}\, i; n) \qquad (20)$$

RESULTS

Table 2, obtained from Eqs. (1) to (13) and the harvest report (Japungu, 2003), presents data on cane milled, electricity (co)generation and operational costs before and after system alteration, for operational modes "a", and "b", defined earlier.

It is seen in Table 2, that more cane, 800.000 t, processed in season with the present system than with the previous system. It is planned to increase the quantity processed in future harvests.

Figures 3 and 4 plot present worth of bagasse or electricity revenues versus rate of return for a 10 year period, using Eqs. (19) and (20), and the minimum attractive rate of return, MARR, equal to the annual interest rate of 8%. Fig. 3 refers to plant operation in mode "a" with bagasse sold at R$ 26 per ton for a net income of R$ 479,479.35. In Fig. 4 the plant operates in mode "b" with electricity sold at R$ 89.89 per

MWh (ANEEL, 2002) for a net income of R$ 1,848,699.54. For both modes, the initial investment in plant modifications is R$ 8,000,000.00.

ANALYSIS OF THE INVESTMENT

In mode "a", the system produces surplus bagasse and revenues will be determined by unit bagasse price. For the price considered, Fig. 3 shows that NPW (net present worth) is always negative. In mode "b" the system produces surplus electricity. With the unit electricity price considered, Fig. 4 indicates an IRR of 19%, above the MARR assumed.

It should be observed that the financial analyses correspond to a ten year amortization period for the investment. There was not concern of imposing limits for the profits, settling down the viability criterion, the option where the Internal Rate of Return (IRR), be larger than the Minimum Rate of Attractiveness, MARR, assumed 8% a year. The simplified model adopted assumed equal inflation for costs and prices, and neglected maintenance costs as well as the effect of the income tax on revenues. However, these limitations do not invalidate comparisons between the options obtained from the model.

Fig. 5 compares the net present worth for the cases "a", NPWa, "b", NPWb, and for the previous system, NPW. It
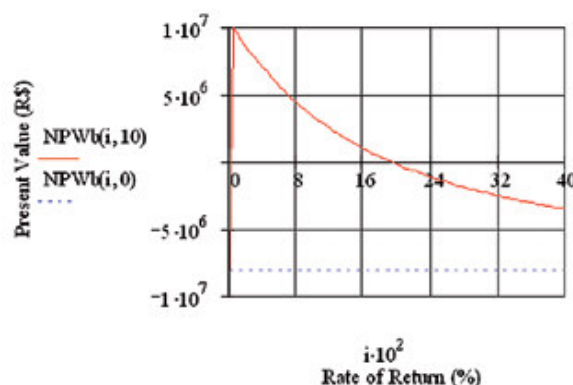

Figure 4. Rate of return for the system operating in the mode "b".

indicates over the amortization period considered, net present worth values, for the modified system, are always below that for the previous system. For a longer amortization period, the net present worth curve for mode "b" may cross that for the previous system. Also electricity prices may rise above inflation, which would increase the present worth for mode "b". However, much more reliable information would be required to justify the investment made.
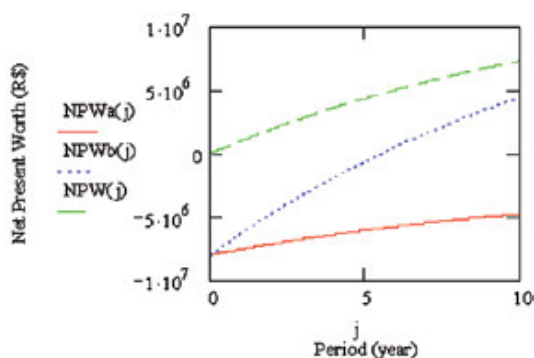
Figure 5. Comparative graph for NPW's.

CONCLUSIONS

The Japungu distillery has always attempted to utilise the revenue potential of sugar cane bagasse, be it "as is", for fodder, fertilizer or paper manufacture or for generating surplus electricity for sale. This range of options allowed the sugar and alcohol industry to survive several situation of market price devaluation. With the recent electricity supply crisis in Brazil, the sector which already used bagasse to cogenerate process work (including electricity) used surplus bagasse to generate electricity surpluses for sale to the utilities. However, as this analysis has demonstrated, (co)generating surplus electricity is not necessarily the best financial option, given the possibilities of selling surplus bagasse "as is". Furthermore, even increasing bagasse surplus may not be sufficent to assure net financial gain, before any substantial investment is realised. Ideally, the economics of any new investment must be thoroughly analysed before implementation. The analysis performed indicates that Japungu did not carry out a satisfactory economic analysis before the installation. This post-analysis indicates that:

1. Plans for the new system, involving the installa-tion of a new 4.12 MPa (42 kgf/cm^2) boiler and an existing extracting/condensing turbine, did not take into account the necessary enlargement of cane crushing capacity.

2. In the present operating mode, Japungu can never recover the investment in the scenario assumed, given that the net present worth is always negative. In mode "b", capital recovery is impossible within ten years, for an internal rate of return below 19 %, for an unit electricity price of R$ 90/MWh. For a substantially larger amortization period, capital recovery may be possible, especially if electricity prices rise substantially. In the circumstances, the safest option, would have been to maintain the previous system and sell surplus bagasse at R$ 26.00/t.

REFERENCES

ANEEL, Agência Nacional de Electricity, 2002, Resolution nº 488, of August 29, 2002, Brasília (in Portuguese).

Bejan, A., 1998, *Advanced Engineering Thermodynamics*, A Wiley-Interscience Publication, New York.

Camargo, C. A., 1990, *Energy Conservation in the Sugar and Alcohol Industry (Conservação de Energy na Industry do Açúcar e Álcool: manual de recomendações – in Portuguese)*, Instituto de Pesquisas Tecnológicas – IPT, São Paulo.

Casarotto Filho, N.., and Kopittke, B. H., 1998, *Analysis of Investments: Financial Mathematics, Economical Engineering, Taking of Decision, Business Strategy (Análise de Investimentos: Matemática Financeira, Engenharia Econômica, Tomada de Decisão, Estratégia Empresarial – in Portuguese)*, 8ª ed., Atlas, São Paulo.

Hugot, E., 1969, *Sugar Engineering Manual (Manual da Engenharia Açucareira – in Portuguese)*, Ed. Mestre Jou, São Paulo, Vol. I and II.

Jaguaribe, E. F., Lobo, P. C., Lima Neto, J. R., Souza, W. L., Rocha, F. A. A., 2002, Expansion of a cogeneration plant in a sugar cane alcohol distillery to achieve energy self-sufficiency (*Ampliação de uma Plant de Cogeneration de uma Distillery de Cana de Açúcar Visando a Auto-Suficiência Energética – Estudo de um Caso* - in Portuguese). In: Proceedings of the II National Mechanical Engineering Congress, CONEM 2002, paper CPB0130, João Pessoa-PB.

Jaguaribe, E. F., Lobo, P. C., Lima Neto, J. R., Souza, W. L., Rocha, F. A. A., 2002, Thermoeconomic analysis of the expansion of a cogeneration plant in a sugar cane alcohol distillery (*Estudo Termoeconomico da Ampliação de um System de Cogeneration de Energy em uma Distillery de Cana de Açúcar* - in Portuguese). In: Proceedings of the IX Brasilian Engineering and Thermal Science Congress, ENCIT 2002, paper CIT02-0240, Caxambu.

Jaguaribe, E. F., Lobo, P. C., Souza, W. L., Rocha, R. M., Nascimento, E. T., 2004, Is it better to sell bagasse or cogenerated electricity? - *Vender Bagasse ou Comercializar Energy Gerada pela Cogeneration?* - in Portuguese). In: Proceedings of the X Brasilian Engineering and Thermal Science Congress, ENCIT 2004, paper CIT04-0400, Rio de Janeiro.

Japungu Agroindustrial S/A, 2003, General Harvest Report and Harvest Comparisons (in Portuguese): 02/03, Santa Rita-PB.

Japungu Agroindustrial S.A., 2003, Operation Bulletins: Turbo Alternators (in Portuguese). Seasons 01/02 and 02/03, Santa Rita-PB.

Jones, J. B., Hawkins, G. A., 1986, *Engineering Thermodynamics – an introductory textbook*, John Wiley & Sons, Inc, New York.

Jornal Gazeta Mercantil, 22/02/2002, Caderno Agronegócios, www.gazeta.com.br, São Paulo (in Portuguese).

Kotas, T. J., 1995, *The Exergy Method of Thermal Plant Analysis*, Krieger Publishing Company, Reprint edition, Florida, USA.

Lobo, P. C., Jaguaribe, and F., Lima Neto, J. R., Rocha, F. A. A., Souza, W. L., 2002, Comparison Between Two Cogeneration Schemes in Sucro-Alcohol Plants. In: Proceedings of the 15th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2002, v. III, pp 1448-1454. Edited by G. Tsatsaronis, M. J. Moran, F. Cziesla and T. Bruckner. ISBN 3-00-009533-0. Berlin, Germany.

Lobo, P. C., Jaguaribe, and. F., Lima Neto, J. R., Rocha, F. A. A., Souza, W. L., 2002, Comparative analysis between cogeneration Systems in two sucro-alcohol plants (*Análise Comparativa de Sistemas de Cogeneration Usadas em duas Diferentes Plants Sucro-Alcooleiras* - in Portuguese). In: Proceedings of the II National Mechanical Engineering Congress, CONEM 2002, paper CPB0131, João Pessoa-PB.

Marim, W. C., 1980, *Analysis of Investment Alternatives: a Financial Approach (Analysis de Alternatives de Investment: uma Abordagem Financeira – in Portuguese)*, 2ª ed., Atlas, São Paulo.

Moran, M. J., and Shapiro, H. N., 2002, *Fundamentals of Engineering Thermodynamics (Princípios de Termodinâmica para Engenharia – in Portuguese)*, 4ª ed, LTC, Rio de Janeiro.

van Wylen, G. J., Sonntag, R., and, Borgnakke, Claus, 1998, *Fundamentals of Thermodynamics (Fundamentos da Termodinâmica - in Portuguese)*, Edgard Blücher, 5ª ed., São Paulo.

Souza, W. L., 2004, Comparações Termo-Energéticas e Econômicas de Opções de Cogeneration de uma Destilaria, Master's thesis, UFPB - João Pessoa-PB.