Energy Vol. 16, No. 8, pp. 1147–1151, 1991
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0360-5442/91 $3.00 + 0.00

COGENERATION AT ALCOHOL PRODUCTION PLANTS IN BRAZIL

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(Received 24 January 1990; received for publication 5 March 1991)

Abstract—Two cogeneration systems for use at alcohol production plants in Brazil are suggested and analysed. These can be implemented with currently available technology and, in economic terms, are relatively inexpensive to install. Each system is analysed based on available knowledge relating to the efficiency of alcohol production and the specific energy contents of the waste fibres and waste distillation products. Significant advantages ensue from the incorporation of cogeneration which, in terms of overall efficiency, can amount to as much as 15%. Which system is implemented in any given region in Brazil depends on the relative importance of whether additional electricity generation (from cogeneration) is a main requirement of the region or whether some contribution (from biogas) for fuel usage in road transport engines is desirable.

INTRODUCTION

In Brazil, there are numerous alcohol-production plants capable of processing 3000 tons of sugar cane daily. 210,000 l. of alcohol are correspondingly produced from this for gasoline blending purposes so as to provide ultimately suitable fuels for vehicular transportation. However, other products also ensue from the production plants (e.g., waste fibres, waste distillation products), which can then be used in a cogeneration context at the plants themselves. Two systems used to achieve this goal are described and analysed in this paper.

Sugar cane is a very good source of potential energy in this respect. With the current installations in Brazil, it is possible to extract the following from each ton: (i) 70 l. of alcohol for vehicular usage ($\approx 39 \times 10^4$ kcal), (ii) 250 kg of waste fibres ($\approx 45 \times 10^4$ kcal), and (iii) 200 l. of waste distillation products that can be used to produce 11,830 l. of biogas containing 65% methane ($\approx 6.7 \times 10^4$ kcal).

To improve the overall efficiency of an alcohol production plant in the cogeneration context, it is desirable to utilize the available energy in the waste fibres and waste distillation products in productive ways rather than simply letting them go unused as waste. In this paper, we suggest two ways in which this aim may be accomplished. Both relate to currently available technology and benefit from the economics implicit in the minimal alteration to present system installations. Energy Utilization Coefficients (EUC) are evaluated for both schemes so that direct comparisons can be made. It should be noted, however, that more advanced systems (e.g., MHD plants) are under investigation than those proposed here for the efficient energy utilization of such waste by-products.[1] Figures 1 and 2 portray the two suggested schemes.

OVERALL EFFICIENCY

The overall efficiency η_T of a generalized plant that incorporates a single additional cogeneration system (as shown in block diagram form in Fig. 3) is given by

$$\eta_T = (E_1 + E_2)/Q_1 \tag{1}$$

under conditions of no heat loss. In terms of the individual efficiencies η_1 and η_2, this relation becomes

$$\eta_T = \eta_1 + \eta_2 - \eta_1\eta_2. \tag{2}$$

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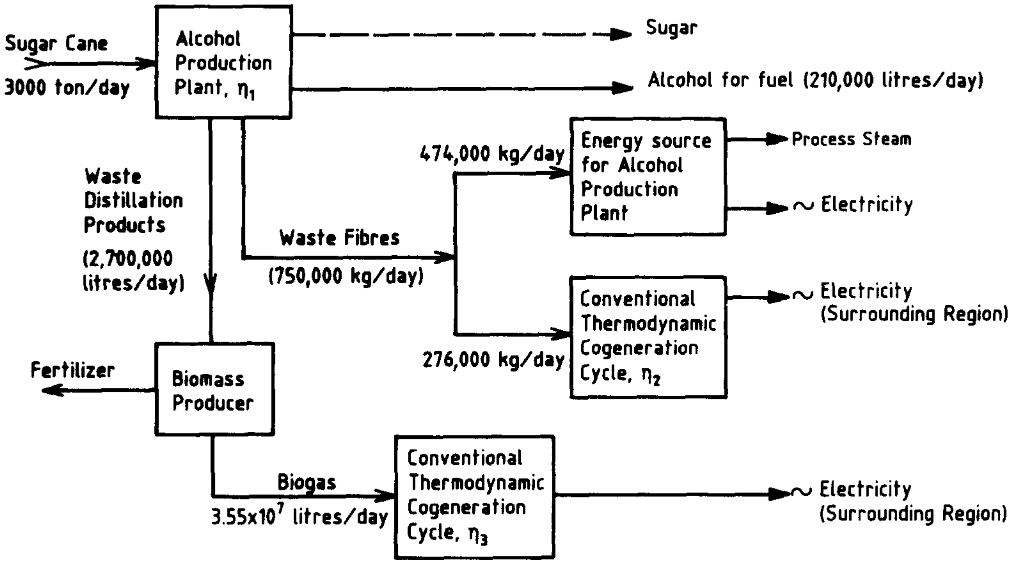

Fig. 1. Cogeneration at an alcohol-production plant (System 1).

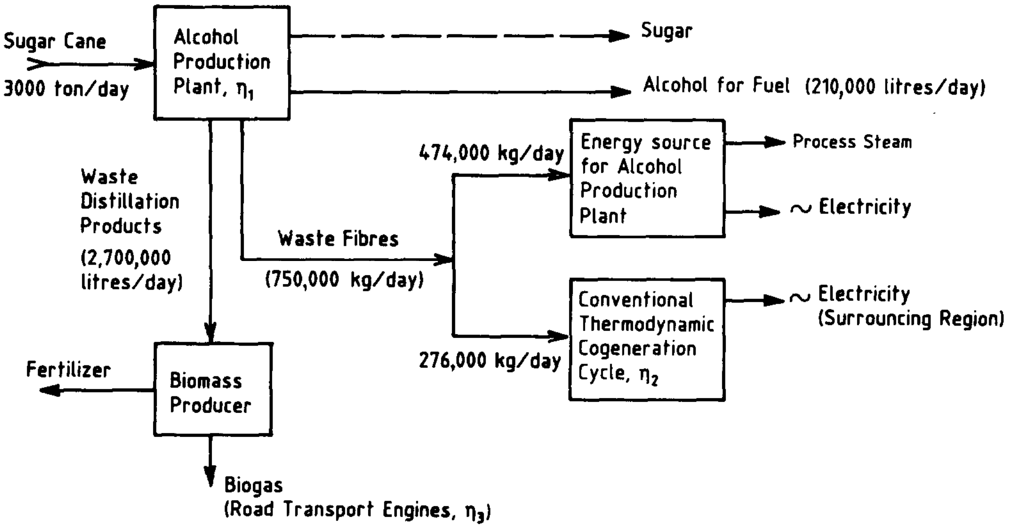

Fig. 2. Cogeneration at an alcohol-production plant (System 2).

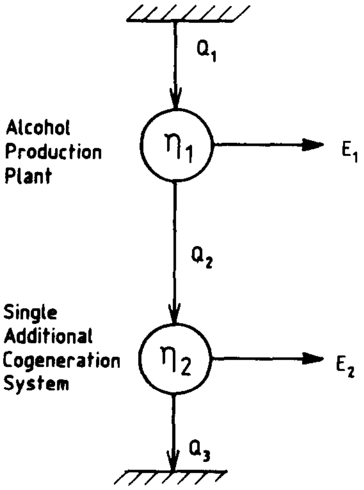

Fig. 3. A single cogeneration system applied to an alcohol-production plant.

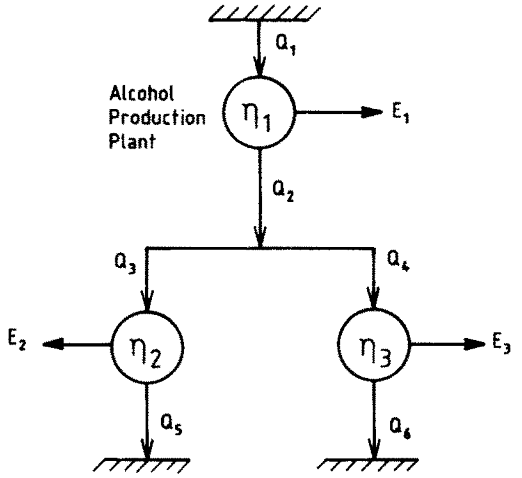

Fig. 4. Two cogeneration units applied to an alcohol-production plant.

The corresponding block diagram for the alcohol production plants shown in Figs. 1 and 2 (incorporating two cogeneration systems) is portrayed in Fig. 4. Here, if f is a proportionality factor that quantifies the subdivision of the total waste output Q_2 of the alcohol production unit alone into waste fibres Q_4 and waste-distillation products Q_3 according to

$$Q_3 = f \cdot Q_2 \quad \text{and} \quad Q_4 = (1-f) \cdot Q_2,$$

then the total useful energy output E_T is given by

$$\begin{aligned} E_T &= E_1 + E_2 + E_3 \\ &= \eta_1 Q_1 + \eta_2 f(1-\eta_1)Q_1 + \eta_3(1-f)(1-\eta_1)Q_1. \end{aligned} \tag{3}$$

The overall efficiency is

$$\eta_T = E_T/Q_1 = \eta_1 + \eta_2(1-\eta_1)f + \eta_3(1-\eta_1)(1-f). \tag{4}$$

ENERGY UTILIZATION COEFFICIENT (EUC)

Since the specific energy levels of the waste fibre, waste-distillation products and the produced alcohol are known, it is possible to calculate an energy utilization coefficient EUC for cogeneration systems of the type described.[2] Thus,

$$(\text{EUC})_{CG} = \eta_{CG}(\lambda_{CG} + 1), \tag{5}$$

where

$$\eta_{CG} = \eta_2 - \eta_1\eta_2$$

for the reference cogeneration system (Fig. 3) and

$$\eta_{CG} = f(1-\eta_1)\eta_2 + (1-f)(1-\eta_1)\eta_3$$

for the two cogeneration system plant shown in Fig. 4. In this context, η_{CG} represents the increase in efficiency resulting from cogeneration and

$$\lambda_{CG} = \frac{\text{total energy of the by-products}}{\text{net useful energy produced from cogeneration}}.$$

CALCULATIONS OF η_T AND EUC

For the plant referenced earlier in which 3000 tons of cane are processed daily, the efficiency of alcohol production η_1 is between 50 and 70%. It is now possible to estimate the increase in overall efficiency η_T when this plant is associated with one or more cogeneration units. For the system displayed in Fig. 1, the total energy supplied per day to the cogeneration units is 6.52×10^8 kcal. Based on the given values, we find that this comprises

$$276{,}000 \times \frac{(45 \times 10^4)}{250} = 4.77 \times 10^8 \text{ kcal}$$

for the waste fibres and

$$3.55 \times 10^7 \times \frac{(6.7 \times 10^4)}{11830} = 1.55 \times 10^8 \text{ kcal}$$

for the waste-distillation products.

Assuming (i) an average efficiency for alcohol production $\eta_1 = 60\%$, (ii) cogeneration thermodynamic cycle efficiencies[3] (η_2 and η_3) of 37%, and (iii) an f value of 0.76 (typical for Brazilian alcohol production plants), then η_T is 75% from Eq. (3). This result represents a 15% increase in overall efficiency due to cogeneration. Corresponding values of λ_{CG} and $(EUC)_{CG}$ for the configuration in Fig. 1 are 1.72 and 0.41, respectively.

Similar calculations can also be applied to the plant shown in Fig. 2. Using the same efficiency values as before but incorporating a more typical and realistic efficiency for biogas usage in road transport engines (viz. 30% from Ref. 3), an overall efficiency η_T of 74% now ensues. This is slightly lower than for Fig. 1 because it reflects the reduced conversion efficiency of biogas when used in road transport engines as opposed to thermodynamic cogeneration cycles. The relevant values of $(EUC)_{CG}$ and λ_{CG} are 0.38 and 1.72.

The above analysis refers to relatively idealized alcohol production plants. The inclusion of heat losses in the calculations (due, for example, to heat transfer from uninsulated pipework etc.) adds greater realism. A block diagram of such a plant incorporating two cogeneration systems is shown in Fig. 5.

The total energy output is

$$E_T = E_1 + E_2 + E_3 - Q_{u2} - Q_{u3}. \tag{6}$$

For a unit energy output, this result translates into

$$E_T = 1 = \eta_1 Q_1 + \eta_2[fQ_1(1 - \eta_1) - Q_{u2}] + \eta_3[(1 - f)(1 - \eta_3)Q_1 - Q_{u3}] \tag{7}$$

or

$$Q_1 = \frac{1 + \eta_2 Q_{u2} + \eta_3 Q_{u3}}{\eta_1 + f\eta_2(1 - \eta_1) + \eta_3(1 - f)(1 - \eta_1)} \tag{8}$$

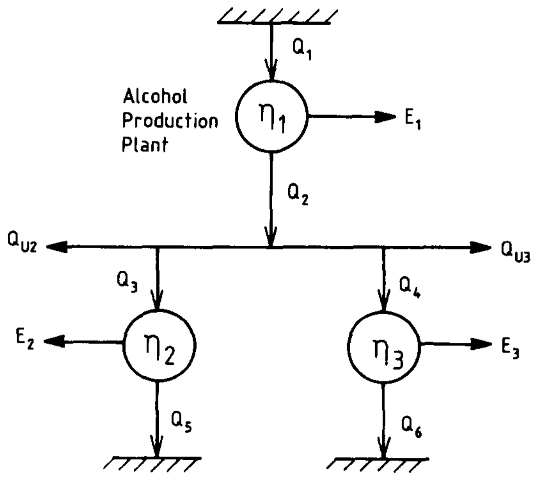

Fig. 5. Cogeneration at an alcohol-production plant together with heat transfer.

and

$$\eta_T = \frac{\eta_1 + f\eta_2(1-\eta_1) + (1-f)\eta_3(1-\eta_1)}{1 + \eta_2 Q_{u2} + \eta_3 Q_{u3}}. \tag{9}$$

Compared with Eq. (3), the presence of heat losses clearly detracts from the overall plant efficiency as would be expected.

DISCUSSION AND CONCLUSIONS

Our results indicate the benefits to be achieved from the application of cogeneration to alcohol production plants in Brazil. Further, these benefits can be gained with currently available technology. In the two systems investigated (Figs. 1 and 2), the overall efficiency values η_T are not greatly different but the EUCs do display a more apparent divergence, reflecting the reduced efficiency of biogas usage in road-transport engines.

It should be noted that alcohol production plants have been proliferating all over Brazil. In this respect, there are real advantages to be gained from the two thermodynamic cogeneration cycles (in Fig. 1) being used to generate electricity for the surrounding local areas. The system in Fig. 2 can also contribute to electricity production in this way but with the additional biogas used to fuel road transport engines. This is still most desirable in terms of the Brazilian economy (even though the EUC is now lower) since the biogas can be and is used immediately at the alcohol production site to fuel trucks that carry the sugar cane from the surrounding local agricultural areas to the alcohol production plants themselves. Thus, convenience and local population factors, as well as energy utilization and efficiency, play a part in deciding which system is best for a given locality in Brazil. Furthermore, regional legislation has to be complied with whilst local fuel difficulties may dictate that the system depicted in Fig. 2 may be more beneficial for such regions.

The following are our primary conclusions: (1) two cogeneration systems for use at alcohol production plants in Brazil have been investigated. These can be implemented with currently available technology and, in economic terms, are relatively inexpensive to install. (2) Each system has been analysed, based on available knowledge relating to the efficiency of alcohol production, the daily intake of sugar cane and the specific energy contents of the waste fibres and waste distillation products. (3) Significant advantages ensue from the incorporation of cogeneration in the alcohol production plants. In terms of overall efficiency, the increase can amount to as much as 15%. (4) Which system is implemented in any given region in Brazil depends on the relative importance of whether additional electricity generation is a main requirement of the region or whether some contribution via biogas (to fuel the trucks that carry the sugar cane) is desirable. (5) The overall efficiency of each plant investigated is very similar but there is a slightly improved energy utilization coefficient when cogeneration leads to electricity production only.

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