IFUSP/P-131

A COGENERATION SCHEME FOR THE PRODUCTION OF ALCOHOL AND ELECTRICITY FROM SUGAR CANE

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Novembro/77

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Partial replacement of gasoline by ethylic alcohol is already a reality in some brazilian cities. This is the first practical result of the "National Alcohol Program", a project established in 74 aiming chiefly to reduce the country oil importation. By 79, a alcohol production, mainly from sugar cane, of $3x10^9$ l should be available allowing 20% replacement of the total gasoline consumption.

The "Program" foresees the possibility of full replacement of gasoline plus 50% of Diesel oil by alcohol in the next decade.

In order to achieve these objectives,more than one hundred new distilleries, with a minimum capacity of 60,000 l/day are presently under construction or waiting for governmental financial support.

A total amount of 1.14×10^7 tons* of sugar cane bagasse will become available with the production of 3×10^9 l of alcohol per year.

Alcohol processing is presently carried in Brazil by the following technique (shown in Fig. I): sugar cane bagasse with 50% humidity is used as boiler's combustible, operating at 15 atm (225 psi of pressure). Saturated vapour is used to drive, in parallel, a millstone and a small steam turbine coupled to a generator (0,5 Mw); the vapour of both machines are then used to heat up the bottom of four distillation towers to a temperature around 100°C.

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*This number is obtained from Table I, since 54 tons of sugar cane (or 13.5 tons of bagasse) supplies 3,564 l of alcohol.

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The available technique uses a well known fact: production of process steam is always an opportunity of getting mechanical work interposing a steam turbine between the boiler and the equipment that requires the steam.

Fig. II shows the maximum attainable efficiency η in a thermodynamical system that operates between a maximum temperature T_i and a final temperature T_f imposed by the environment (T_f = 300K). Since the flame temperature obtained by burning bagasse is very high (> 1000°C) we see from Fig. II that we have a potential efficiency around .80, if a high temperature (and so, a high pressure) steam is used to drive a machine. If we also need process steam at 127°C, we still can drive a machine, now with a lower potential efficiency around .55. An illustrative example is given in the Appendix.

In order to simplify calculations we will assume from now on a distillery with an alcohol capacity of 100,000 liters/day.

As can be seen from Table I (1), sugar cane residues have a potential energy of 17,550 Mcal/ha/year, from which 10,814 Mcal/ha/year are used in alcohol industrialization. This means that, with the present technology, there exists an energy surplus of 43% (the largest part as sugarcane bagasse).

Since the residues' energy content is only 1.4* Mcal/kg as compared with oil (10.4 Mcal/l), and because the latter can be easily transported in large tankers and oilducts, the only possibility of utilization for this biomass is in factories very near the place of production.

Taking into account these points we would like to propose a cogeneration scheme for the production of electricity during the preparation of ethylic alcohol. As Fig. III shows we propose the use of a high pressure boiler ($\simeq$ 150 atm), a steam turbine and the utilization of process steam at a very modest pressure ($\simeq$ 50 psi) to heat up the distillation towers.

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*This result is obtained from Table I, since 54 tons of sugar cane (or 13.5 tons of bagasse) supplies 17,750 Mcal.

As can be seen from the same figure, 10^6Btu/hr of process steam at 50 psi can be obtained together with 77 Kw of electrical power with the utilization of 1.38×10^6Btu/hr (2) which means 0.26 tons of bagasse per hour*. Since a 100,000 l/day distillery operating 24 hours a day consumes 1,515 tons of sugar cane**, this means 4,674 Kw of electrical power capacity. Two hundred of these units will be necessary to produce 3×10^9 l of alcohol (assuming 150 days of operation), which means a total potential of 934 Mw.

Part of the energy will be used in the alcohol factory and the surplus can be used for other electrical consumers, if an agreement can be reached between the electrical companies and the alcohol producers.

A typical steam motor used in common distillery has an efficiency of 6.5%*** and large electrical motor an efficiency 10 times higher (70%). So, if we assume an overall efficiency (steam turbine+generator) of 24%, a millstone driven by electricity will operate with an efficiency of 16.8% (24%x70%) which is 2.6 times greater than the conventional system.

This result, together with the 43% excess of bagasse will set the internal plant consumption of electricity at only 22% of the total power generation and the possibility of selling the balance (78%).

Economical considerations

The present cost of a conventional distillery is around US$ 9.3 million dollars. The cost of high pressure boiler is around US$ 20.00/Kw**** and steam turbine+generator, around US$ 200.00/Kw****. This means an extra cost of one million dollars

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* This result is obtained from Table I, since 54 tons of sugar cane (or 13.5 tons of bagasse) supplies 17,750 Mcal.

** This result is obtained from Table I, since 54 tons of sugar cane supplies 3564 l of alcohol.

*** This number is evaluated from the 15 kg of vapour consumption/hour at a pressure of 200 psi in order to drive one horse power motor. 1 kg of vapour at 215 psi has 668,000 cal and 1 HP motor working one hour requires 645,000 cal. (2)

**** These numbers are obtained from ref. (3) and are already corrected to the present day dollar value.

that should be added to the price of the distillation plant. This fraction (11%), can even be reduced if we take into account: 1)that in the cost of conventional distilleries are included low pressure boilers and small turbogenerators; 2) that a large scale standardized production of these units could reduce the unitary cost as is proposed by other authors (4).

Total investment costs in the program will be 205 million dollars; this is a very small fraction of the total investment budget of the state owned company, responsible for electrical generation - Eletrobrás, which only for the current year (1977) is 3.5 billion dollars (5).

Since the demand for electricity is intensive only for 10 to 12 hours during daytime, excess generated during the night period could be used in the plantation area for many purposes, from which artificial irrigation is the most important.

Artificial irrigation would improve productivity which is low in Brazil (54 tons/ha/year) as compared with very similar latitude area of Hawaii (150 tons/ha/year). Also, it is a well established fact that "vinhaça",an alcohol sub-product, presently the largest pollution source related with sugar cane processing, is a very convenient fertilizer agent if proper quantities of N, P_2O_5 and K_2O are added (6). Typical production of "vinhaça" is 14 liters for each liter of alcohol, what means a total production of $1.4x10^3$ m^3/day. Assuming water has to be pumped at 50 m high with an electric motor of 50% efficiency during 12 hours a day (night period), it will require a 33 Kw source , something around 1% of the total installed power.

The above calculation shows that significant amount of energy will be produced at night without any demand unless some modifications in the operational system are made. Bagasse can be stored for several months (7) and be used during the sugar cane growing season, in order to guarantee a continuous supply of electricity for all year round.

From the economic point of view this is a very important task since electric energy will have to be sold to the utility companies in more than one form as is done in Hawaii: fixed base, which means better price and temporary or stand-by base, at a lower price. Technological improvements are important, to achieve the stage of an all year production in the distillation process; addition of thermal insulation in the towers and more application of heat exchanger in the process should be investigated. Present day techniques require 57% of the available bagasse to generate process steam for 150 days of operation. Since 12% improvement in the distillation process is already possible (2) just adding proper thermal insulation, it seems reasonable to reduce fuel consumption for process steam production to something around 50% of the total available bagasse.

Electrical energy can be sold in Brazil at 4 cents/Kwh. Assuming that 80% of the generated capacity will be sold, 37,000 Mwh will result in 1.5 million dollars revenue, or 37.5% of the total profit obtained by selling 15 million liters of alcohol per year*.

Future outlook

Fig. IV shows projections for petroleum consumption up to 86 (8). As we can see, an increase of 64% as compared with 77 will happen. If we assume that at this time all gasoline and 50% of Diesel oil will be replaced by alcohol, a 45 billion liters of the latter has to be produced per year if we just scale up present day consumption of the oil derived combustible shown in Fig. V. This production will require 3,000 distilleries of 100,000 l/day, or the possibility of 14,000 Mw of electrical power generation.

Conclusions

We propose a cogeneration process to generate electricity simultaneously with ethylic alcohol production, using available sugar cane residues. 80% of this electrical power will be used by other consumers and this requires the interest and cooperation of the state owned electric monopoly - Eletrobrás.

The amount of electricity, if some improvements in distillation process are made, will be at user's disponibility for all year around and if totally commercialized will supply 37% more gain than the alcohol alone.

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*Alcohol is quoted at .27 cents/l

As can be seen from Fig. VI and Table II some more complex cogeneration systems are possible to produce as much as 148 Kw, instead of only 77 Kw proposed by us, with roughly the same combustible requirements. Since we are concerned with technological difficulties we believe that the chosen system is the one more easily obtainable under the present development stage of Brazil.

APPENDIX

The available useful work Φ , a quantity that measures the maximum amount of energy that can be obtained in a thermo - dynamical process, is plotted as a function of temperature difference between hot and cold source for a particular hydrocarbon fuel (CH_2) in Fig. VII (3). An inspection of the plot shows that Φ has a very typical behaviour with the temperature difference of the hot source B (combustion flame) and the cold source C (the atmosphere), represented by the solid line. Data are for one pound-mole of CH_2 and we intend to use these results as an example since in the bagasse combustion we have carbonhydrates as reactants.

The maximum available useful work is 291,000 Btu, but unfortunatelly presently we cannot use all this value. The only economical way of hydrocarbon (and carbonhydrates) fuel oxidation requires its burning in a combustion chamber at a temperature of 4,300°F in an irreversible process. This operation is done with a loss in the available useful work, suggested by the broken line AB, which is reduced to 211,000 Btu .

As can be seen from the continuous curve, Φ decreases slowly with the temperature t of the material heated by the combustion when the temperature is above 1,000°F and then decreases significantly for further reducing of t.

From the above consideration we conclude that to achieve high efficiency using a steam turbine we need water vapour at high temperature. There are steam-driven turbogenerators working with efficiency as high as .40; the steam pressure and temperature are respectivelly 3,650 psi and 1,003°F (9).

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TABLE I

Useful data for ethylic alcohol production from sugar cane (1)

Yield	72 tons/ha 54 tons/ha/year
Alcohol Production	66 l/ton 4,752 l/ha 3,564 l/ha/year

Energy (Mcal/ha/year)

Produced		Consumed	
Alcohol	18,747	Agricultural processing	4,226
Residues	17,550	Industrial processing	10,814
Total	36,297	Total	15,040

TABLE II

Process Steam Pressure, psi	Steam-Turbine Power, kw		Gas-Turbine Power, kw		Total Combined Gas and Steam-Turbine System Power. kw
	Alone	Fed From Exhaust of Gas Turbine	Alone	Followed by a Steam Turbine	
50	77		84		
200	49	48	84	100*	148
400	34		84		

*The power of the gas turbine is increased from 84 to 100 kw because some of the available useful work of the fuel necessary for the steam turbine is consumed in the gas turbine.

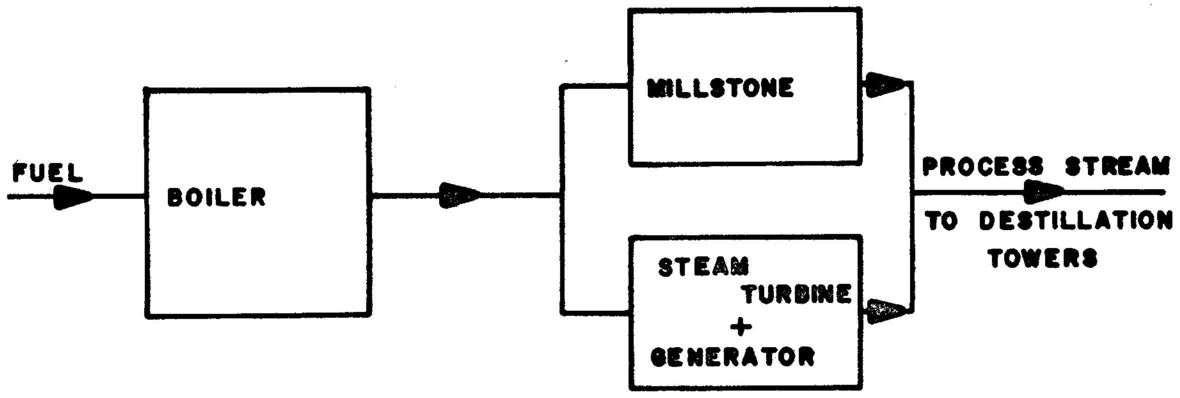
FUEL
BOILER
MILLSTONE
STEAM TURBINE
+
GENERATOR
PROCESS STREAM
TO DESTILLATION
TOWERS

Fig. I

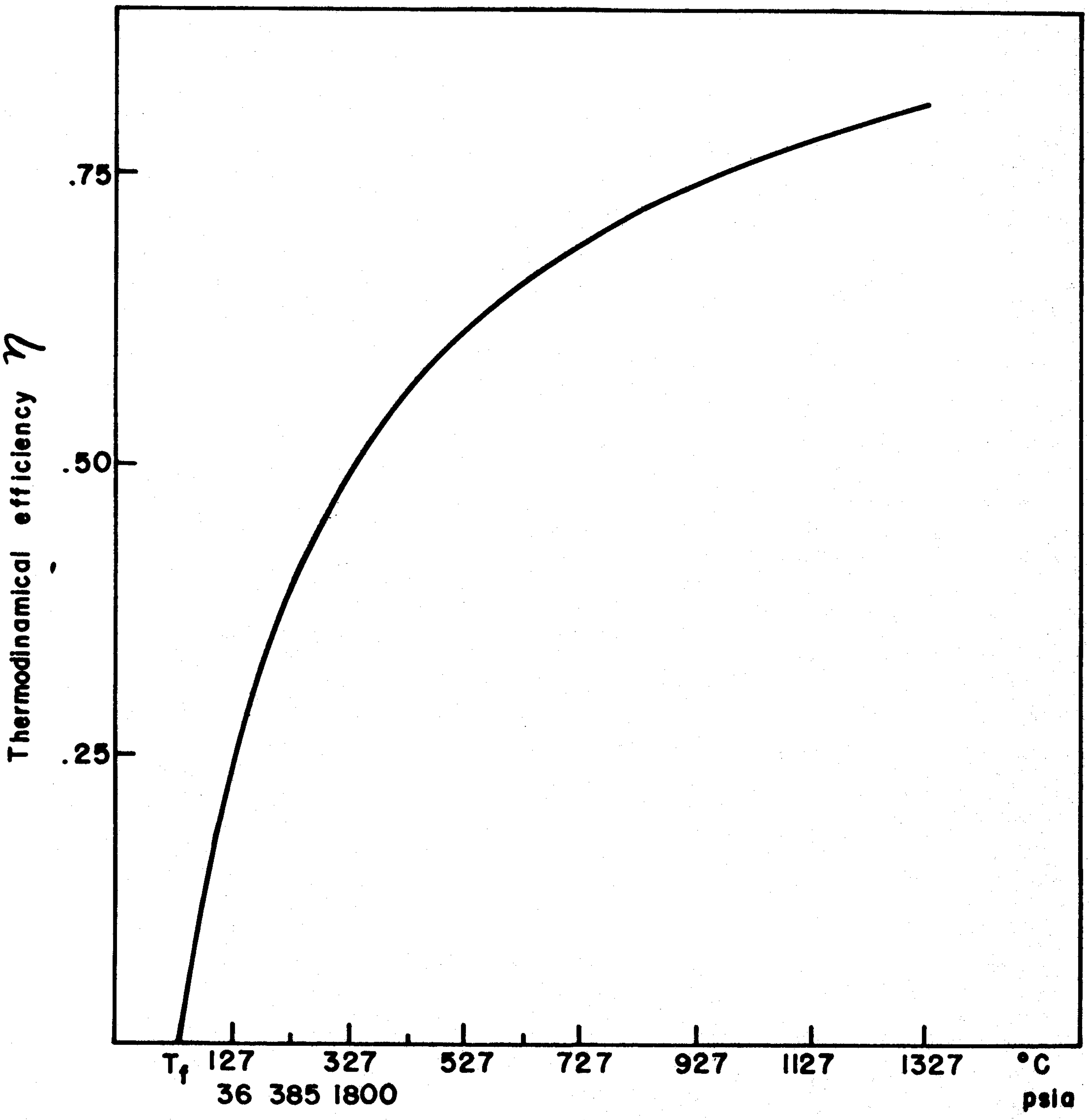
Thermodinamical efficiency η
.75
.50
.25
T_f
127
327
527
727
927
1127
1327
°C
36
385
1800
psia

Fig. II

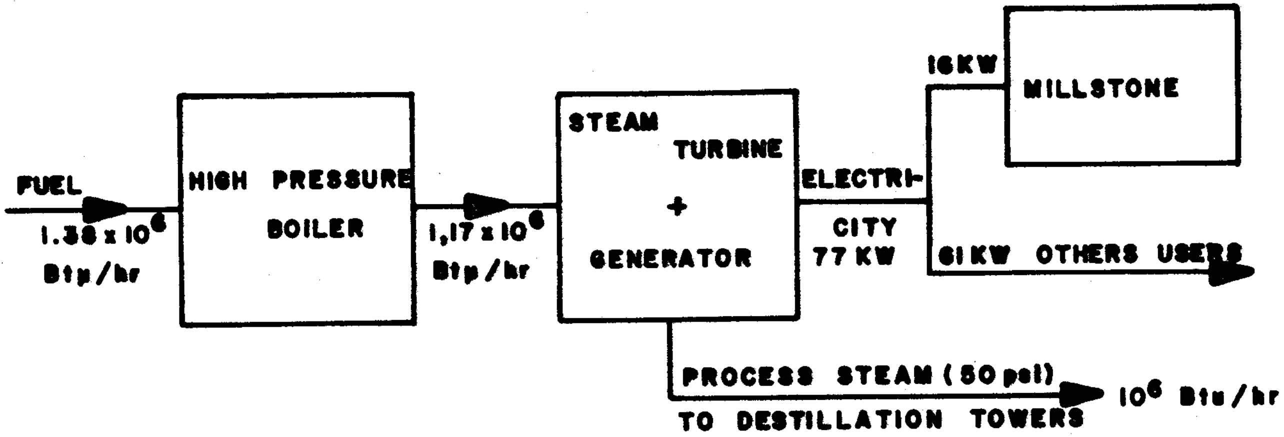
FUEL
1.38 x 10^6
Btu/hr
HIGH PRESSURE
BOILER
1,17 x 10^6
Btu/hr
STEAM
TURBINE
+
GENERATOR
ELECTRI-
CITY
77 KW
16KW
MILLSTONE
61KW OTHERS USERS
PROCESS STEAM (50 psi)
TO DESTILLATION TOWERS
10^6 Btu/hr

Fig. III

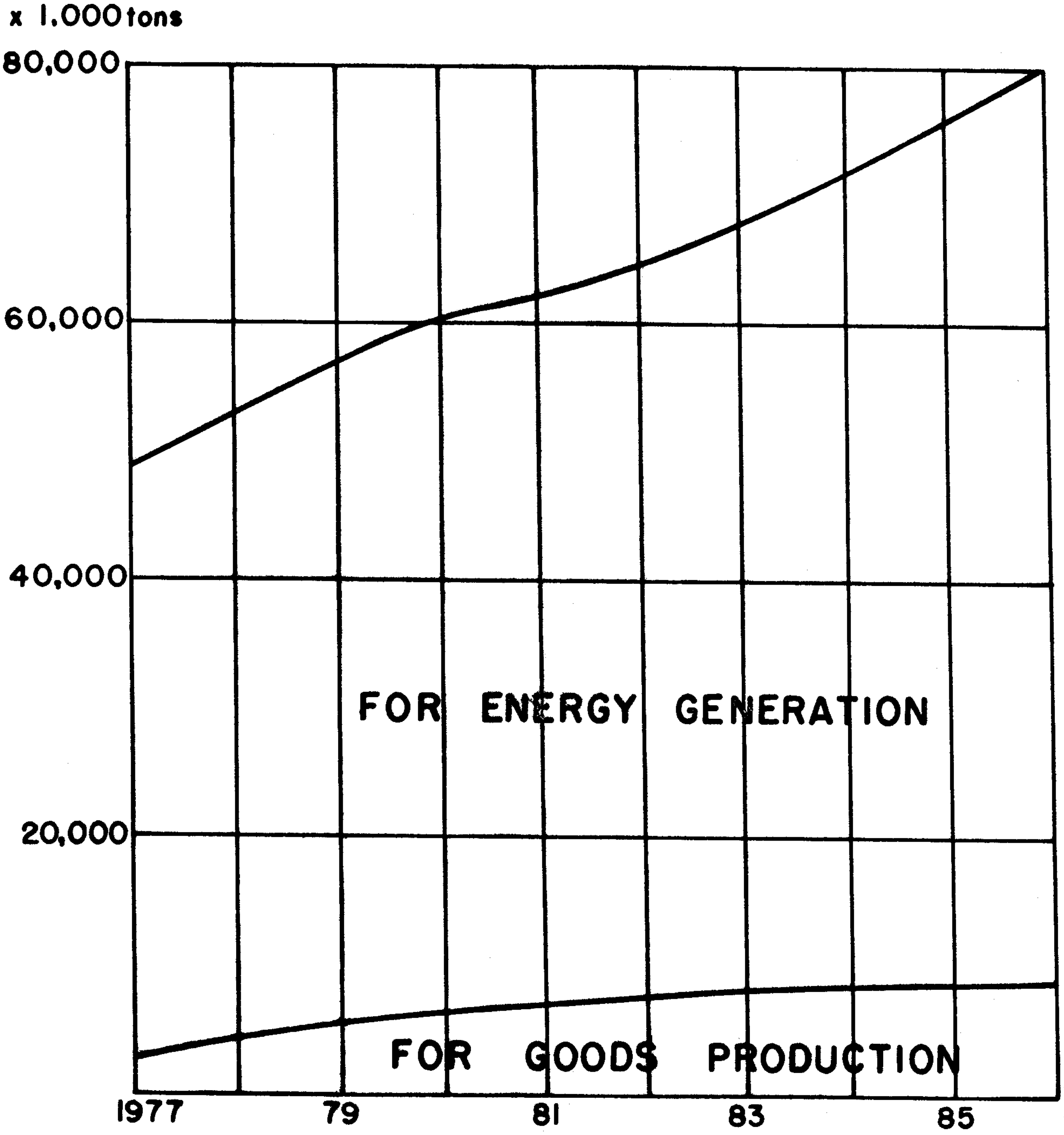
x 1.000 tons
80,000
60,000
40,000
20,000
FOR ENERGY GENERATION
FOR GOODS PRODUCTION
1977
79
81
83
85

Fig. IV

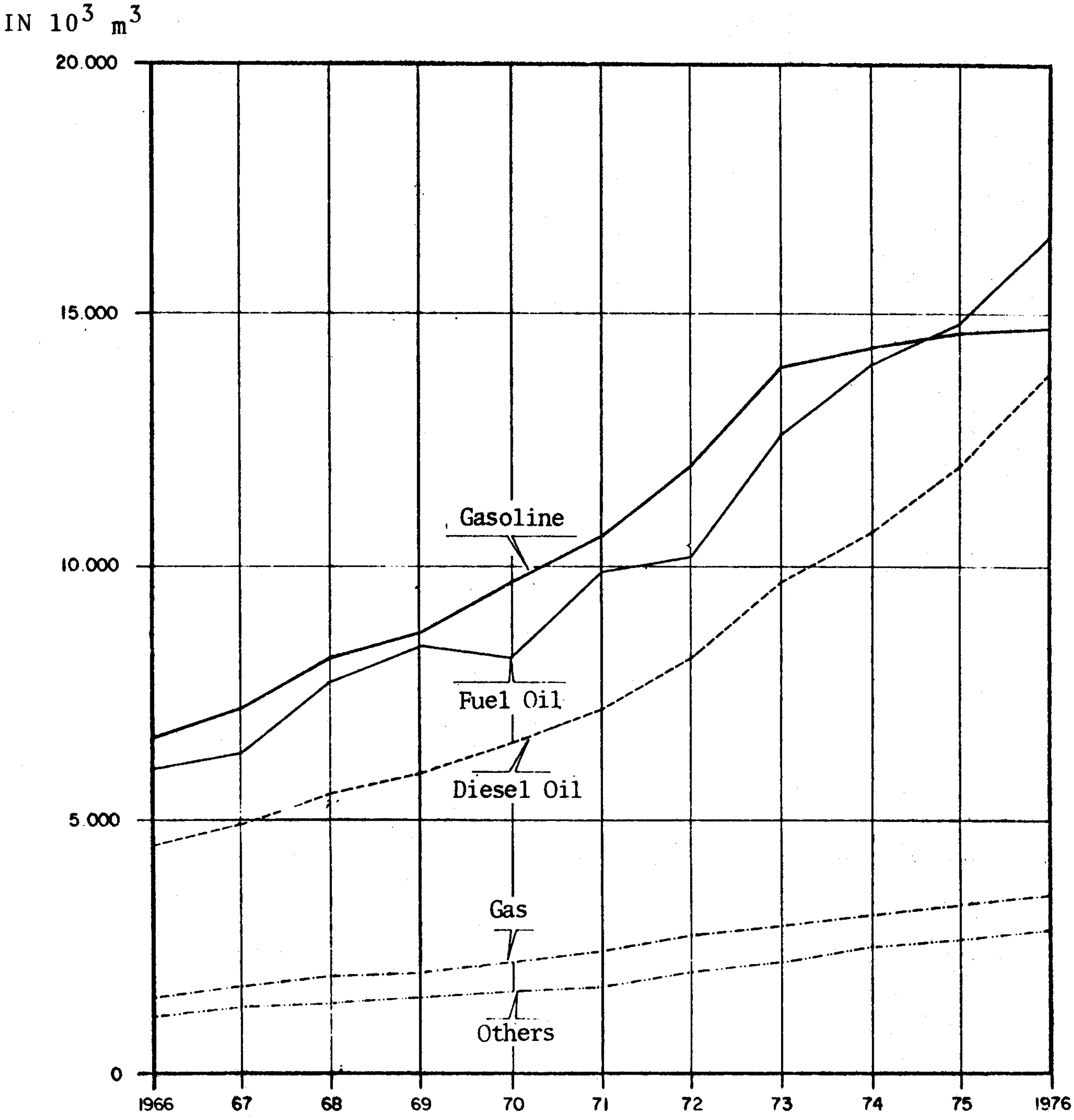
IN 10^3 m^3
20.000
15.000
10.000
5.000
0
1966
67
68
69
70
71
72
73
74
75
1976
Gasoline
Fuel Oil
Diesel Oil
Gas
Others

FIG. V

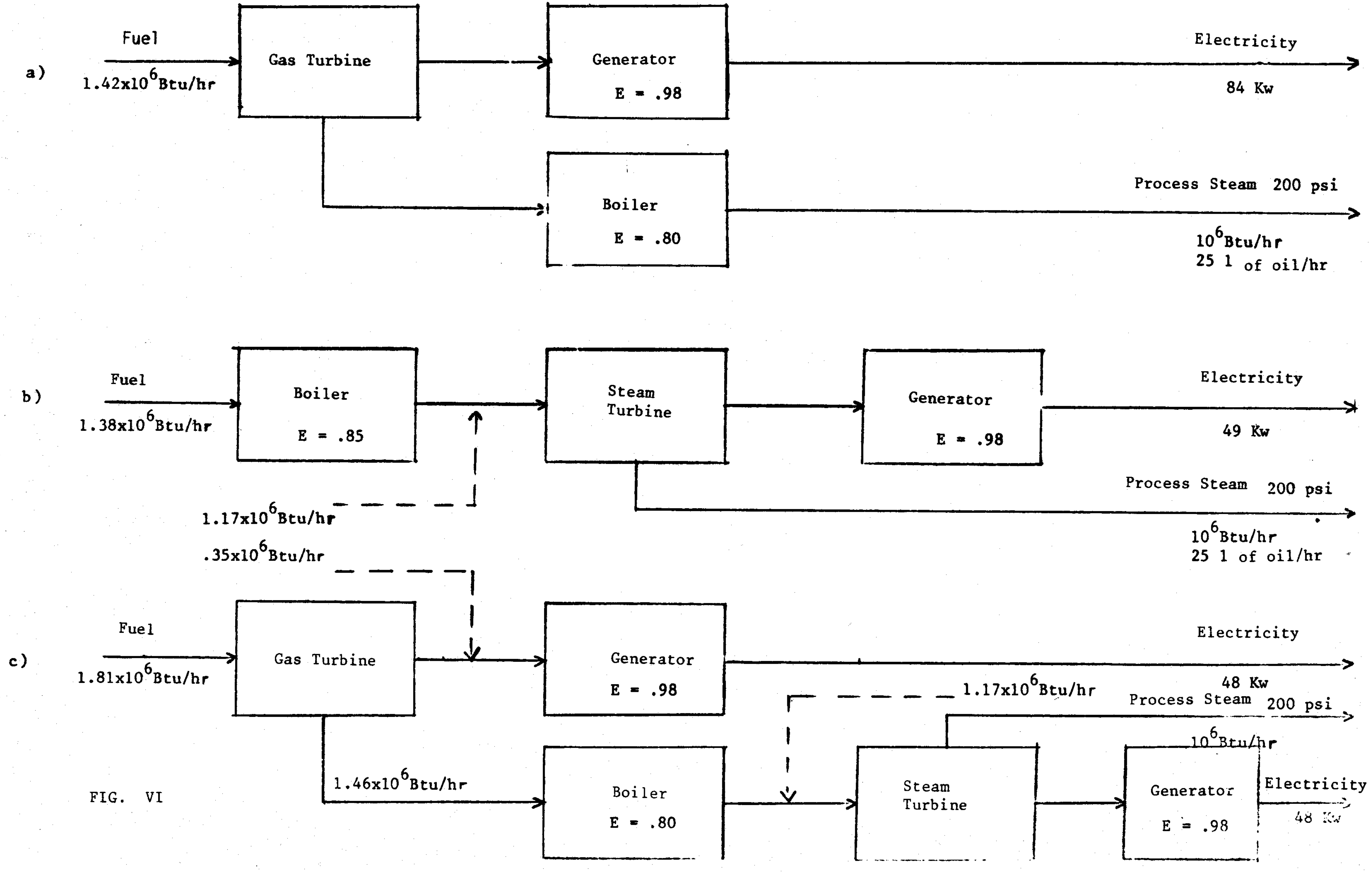
a)
Fuel
1.42x10^{6}Btu/hr
Gas Turbine
Generator
E = .98
Electricity
84 Kw
Boiler
E = .80
Process Steam 200 psi
10^{6}Btu/hr
25 l of oil/hr
b)
Fuel
1.38x10^{6}Btu/hr
Boiler
E = .85
Steam Turbine
Generator
E = .98
Electricity
49 Kw
Process Steam 200 psi
10^{6}Btu/hr
25 l of oil/hr
1.17x10^{6}Btu/hr
.35x10^{6}Btu/hr
c)
Fuel
1.81x10^{6}Btu/hr
Gas Turbine
Generator
E = .98
Electricity
48 Kw
1.17x10^{6}Btu/hr
Process Steam 200 psi
10^{6}Btu/hr
1.46x10^{6}Btu/hr
Boiler
E = .80
Steam Turbine
Generator
E = .98
Electricity
48 Kw

FIG. VI

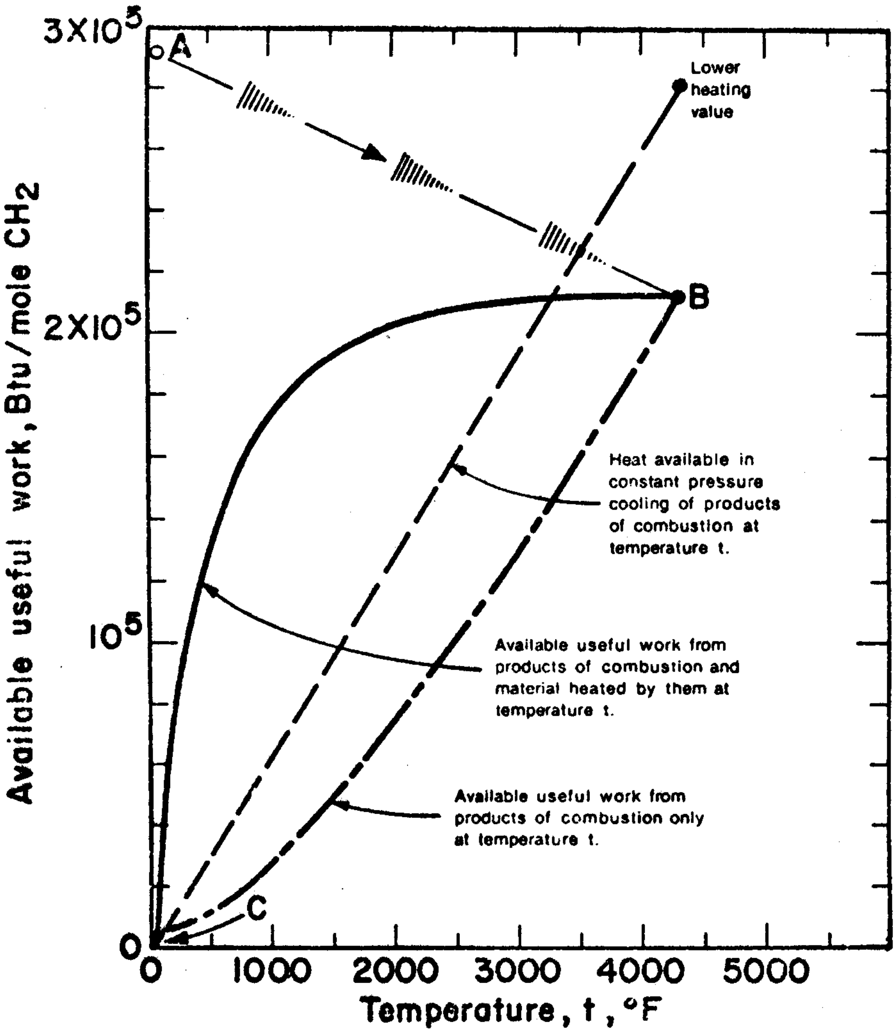3X10^5
2X10^5
10^5
0
A
B
C
Lower heating value
Heat available in constant pressure cooling of products of combustion at temperature t.
Available useful work from products of combustion and material heated by them at temperature t.
Available useful work from products of combustion only at temperature t.
Available useful work, Btu/mole CH2
0
1000
2000
3000
4000
5000
Temperature, t, °F

Fig VII