SOME ECONOMIC APPROACHES TO TURBO-GENERATED POWER IN SUGAR FACTORIES

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Abstract

As a result of various developments in the sugar industry, principally the increased application of irrigation, and the processing of bagasse, new uses arise for turbo-generated power.

Economic investigations become considerably more important. After having defined some basic terms, the DCF-method is explained in principle. Thereupon some of the essential influences on the economy of turbo-generated power are discussed. In order to demonstrate their interdependence with reference to the plant and the economy, and to give a practical example of the application of the DCF procedure, one economic comparison is carried out in which different parameters are varied, whereafter certain conclusions are drawn.

1. Introduction

New useful economic conclusions can only be drawn if recent technical alternatives result or if the economic circumstances change. Both of these take place in the sugar industry. In many cases, steam drives are displaced by electric motors, diffuser plants become relevant, irrigation extends seasonal production and requires additional electric power without simultaneous heat consumption in the process, the possibility of processing bagasse leads to relatively high fuel costs, and in certain places, e.g. Mauritius, the percentage of power supplied to municipalities increases. For the above-mentioned reasons it appears worthwhile to investigate what conclusions can be drawn regarding the economy of turbo-generated power. We will consider which is the most suitable procedure for such an investigation, how it is to be carried out and how the economy of the plant can be influenced.

In no other technological process are the circumstances as favourable as in the sugar industry, where the heat consumption requirements of the process suffice to generate the electric power required. This is actually the reason why power is generated instead of producing saturated process steam and purchasing electricity from the public network. Besides higher availability and reliability — two terms which are almost impossible to consider in a calculation of profitability — the process of sugar production yields the fuel automatically. But even if the fuel has to be purchased, turbo-generated power in a sugar factory is more economical, provided certain aspects are taken into account.

Basically, the power of the public network is generated in condensing plants. Here, the heat capacity of the exhaust steam, which consists of the heat of evaporation and the ambient temperature difference, is transferred to the cooling water and is completely lost. In a backpressure turboset, which is still mostly applied in sugar factories, the heat content of the exhaust steam is conveyed entirely to the process. Although the efficiencies of an industrial turboset cannot reach those of a, say, 500 MW-condensing plant, the heat consumption of a backpressure turbine is approximately a fourth of that of a condensing turbine.

In this paper we will assume that bagasse is not sufficiently available for all power requirements and therefore additional coal or oil has to be purchased. Accordingly, the terms 'steam' and 'heat consumption' will be of great importance.

Here follow some simple equations; these will be given as dimensionalised equations to facilitate practical use.

The symbols used are:

C	Annual operation expenditures	R/year
c	Specific costs	R/kWh
E	Annual expenditures	R/year
h	Specific enthalpy	kJ/kg
i	Rate of interest	%
J	Capital expenditures	R
k	Ratio of cooling water and steam flow	unity
$\dot{m}$	Steam flow	t/h
n	Expected life of the plant	year
ncv	Nett calorific value	kJ/kg
p	Absolute pressure	bar
P	Power, output	kW
q	Heat consumption	kJ/kWh
$\dot{Q}$	Heat flow	kJ/h
r	Interest factor	unity
R	Annual receipts	R/year
s	Steam consumption	kg/kWh
t	Years hence	year
to	Reference point of time	unity
V	Residual value	R
Δ	Terminal temperature difference	grd
Δh	Enthalpy difference	kJ/kg
ϑ	Temperature	°C
η_{Ge}	Generator efficiency	unity
η_{Gb}	Speed reduction gear efficiency	unity
η_{Ht}	Boiler and heat transfer efficiency	unity
η_{i}	Internal efficiency	unity
$(\eta_{th})_{max}$	Maximum thermodynamic efficiency	unity
η_{total}	Overall efficiency	unity
η_{Tu}	Turbine efficiency	unity

Indices as follows:

$_{A,B}$	Alternatives A or B
$_{c}$	Condensate
$_{e}$	Extraction steam condition
$_{in,\,out}$	Inlet or outlet condition
$_{s}$	Isentropic
$_{w}$	Referring to water

$_1$ Inlet steam condition
$_2$ Backpressure respectively condensing steam condition

2. Some fundamental definitions

In the following we frequently use two terms which are very simply defined, but appear complicated when they are practically applied. In order to retain the continuity of the following considerations, we discuss them in this paragraph. These two terms are 'steam consumption' and 'heat consumption', and we apply them in particular to the extraction-condensing turbine, since this basic type plays an important role in our consideration.

2.1 STEAM CONSUMPTION

The steam consumption s of a turboset is defined as the amount of steam necessary to generate 1 kWh at the generator terminals, thus

$$s[\mathrm{kg/kWh}] = \frac{m[\mathrm{kg}/\mathrm{h}]}{P[\mathrm{kW}]} \tag{2.1}$$

We re-arrange this equation to obtain more information from it, since

$$s[\mathrm{kg}/\mathrm{kWh}] = \frac{3600}{(h_1 - h_{2_s})\,[\mathrm{kJ}/\mathrm{kg}]\,\eta_i\,\eta_{Tu}\,\eta_{Gb}\,\eta_{Ge}} \tag{2.2}$$

We can easily see, that the steam consumption depends on the theoretically available enthalpy difference, the internal efficiency of the turbine, and last of all, on the mechanical and the electrical efficiencies of the turboset. For an extraction turbine we find, if we split the total enthalpy difference into the two actual expansions, applying same units:

$$s = \frac{3600}{(h_1 - h_{e_s})\,\eta_{i_1} + (h_e - h_{2_s})\,\eta_{i_2}\,(1 - m_e/m)} \tag{2.3}$$

This equation implies that the internal efficiencies of the two expansion sections are different. For instance, if the turbine is running in such a way that the process requires a maximum amount of extraction steam, and the irrigation system is not in operation, so that little condensing electricity is needed, these efficiencies can differ by 10 points, or even more. In Chapter 5 we shall prove how important this is.

2.2 HEAT CONSUMPTION

The heat consumption has the same importance in any economic study as the steam consumption has for the design of the steam process. It is defined by the amount of heat energy, which is required for the generation of 1 kWh:

$$q[\mathrm{kJ}/\mathrm{kWh}] = \frac{3600}{\eta_{total}} \tag{2.4}$$

The overall efficiency η_{total} consists of

$$\eta_{total} = (\eta_{th})_{max}\,\eta_i\,\eta_{Tu}\,\eta_{Gb}\,\eta_{Ge}\,\eta_{Ht} \tag{2.5}$$

The maximum thermodynamic efficiency gives us the ratio of the theoretic isentropic expansion, which ends at the enthalpy, where the steam becomes condensed:

$$(\eta_{th})_{max} = \frac{h_1 - h_{2_s}'}{h_1 - h_c} \tag{2.6}$$

Therefore, with the units applied above:

$$q = \frac{3600(h_1 - h_c)}{\eta_i\,\eta_{Tu}\,\eta_{Gb}\,\eta_{Ge}\,\eta_{Ht}\,(h_1 - h_2{}'_s)} \tag{2.7}$$

Since the theoretical terminal enthalpy of a back pressure turbine is identical to the isentropic expansion terminal point, the maximum thermodynamic efficiency is equal to 1, and the terms in brackets are deleted in equation (2.7).

The heat consumption of an extraction condensing turbine consists of a portion, which leaves the turbine as backpressure steam and a portion which is condensed; if we rearrange equation (2.4) we obtain:

$$q[\mathrm{kJ}/\mathrm{kWh}] = \frac{m_e(h_1 - h_e) + m_2(h_1 - h_c)}{P} \tag{2.8}$$

We can draw the conclusion that the heat consumption, besides the ratio of backpressure steam and condensing steam, only depends on the efficiencies of the plant. One can therefore write down average values for the heat consumption which is not possible for the steam consumption, since it depends on the inlet and outlet conditions. The heat consumption of a backpressure turbine is approximately 4 600 kJ/kWh, and for a condensing turbine around 17 000 to 19 000 kJ/kWh. This is discussed in Chapter 4.

3. Some methods of assessing investment

If a company intends to invest in plant, different technical alternatives in technological process can be chosen. Which solution is the most advantageous is not a question of the technical yield, like performance, steam consumption and so forth, but of the economy. The most important auxiliary means for investment planning therefore is the economic investigation.

Many different methods of profitability calculations have been developed, some of which will now be mentioned. In the main we distinguish between static and dynamic methods.

3.1 TRADITIONAL STATIC METHODS

Under the term 'static' we will summarise all methods where no allowance is made for the fact that R1,00 tomorrow is worth less than R1,00 today: The value of money is assumed to remain constant. Most firms still assess investment projects by considering 'return on capital' and 'payback period'.

Return on capital — this principle is usually defined as expected profit after allowing for depreciation, but before tax, as a percentage of the investment involved. In some cases, the initial investment is taken; in other cases, the average investment over the life of the project. Depending on different ambiguities, we obtain peak profits or average profits over the expected life.

The 'payback period' — a method calculating the number of years to recover the cost of the project, ignoring depreciation. Sometimes it is calculated before tax, sometimes after tax.

These methods are subject to a number of criticisms, which we do not list here. We will restrict ourselves to stating that these methods, which are cost systems only, do not be applied in the case with which we are concerned. Static calculations are permissible up to capital expenditures, of, say ten to twenty thousand Rand, and, at the same time, for an economic life of a few years. Since we are considering investment of some hundred thousand Rand, over at least ten years, we must apply a dynamic method which considers the time factor.

3.2 The DCF method

What does a company look for in its investment policy? Above all, we assume the maximum nett cash flow, i.e. after deducting taxation. This cash flow must be sufficient to repay the initial outlay and to pay an adequate rate of interest on the balance outstanding at any time. The worthwhileness of the investment will, therefore, be expressed by the magnitude of the average effective rate of interest on the outstanding balances over the life of investment. This is what is measured by the DCF method.

When an investment is made, it typically results in an estimated cash flow in the future. By means of taking different intervals into account, different valuations can be considered. The principle of the DCF method consists of discounting all these present and future expenditures and receipts to an appointed date, which we assume will be the year in which the turboset becomes operational, as is usually done in the power industry.

Put another way, the difference in receipts and expenditures, calculated annually for the end of every year, yields a certain return on the investment expenditures. If the receipts are altered, for instance by a decrease of the sugar price, or if the expenditure increases through an increase in fuel costs or an extension of the annual operational hours, the return is affected.

From these considerations, written down in the form of a comprehensive equation, we obtain:

$$J(t_o) = \sum_{t=1}^{n}(R_t - E_t)r^{-t} + V_n r^{-n} \tag{3.1}$$

We can easily see, that the solution rate r, which is given by

$$r = 1 + \frac{i}{100}, \tag{3.2}$$

where i is the interest on the capital invested, depends on the cash flow, the amount of the investment, the expected life and the residual values, i.e. the scrap values. All payments are discounted on the date of commissioning.

To simplify matters we make the following convenient assumptions:

1. Scrap values are not considered.
2. The investigations done in Chapter 5 do not consider taxation. Although the consideration of taxes is essential for the absolute cash flow and the solution rate, it is not worthwhile to take it into account, since it complicates our calculations considerably without materially assisting our theme.
3. We restrict ourselves to economy comparisons, where the yields of two alternatives, say A and B, are the same. Thus we ask, how the additional initial expenditures yield interest by savings in general operating expenses. Therefore, we have to put the difference between the two initial expenditures, $\Delta J(t_o)$ as expenditures, and the savings on current expenditures, ΔR as annual receipts:

$$-\Delta J(t_o) = \sum_{t=1}^{n}(\Delta R_t r^{-t}) \tag{3.3}$$

This is the final equation which enables us to perform the following necessary considerations as simply as possible.

4. Essential influences on economy

As we learnt from the above, the economy of capital investment depends on its capital expenditures and its operation expenditures. Usually when decisions are to be made between alternative possibilities, different operating costs are involved with different capital costs. Thus we cannot split the investment cost of each of two alternatives from its operating costs. Therefore, in this chapter, we shall discuss only some items which essentially influence the economy of turbo-generated power; these items however, are to be considered from the investment as well as from the operational point of view.

4.1 Live steam conditions

We may state that, above all, economic operation of a turboset is determined by its live steam conditions. We, therefore, have to examine how capital and operational costs alter if the live steam figures are changed.

The output of a turboset is directly proportionate to the steam mass flow as well as the enthalpy difference between inlet and outlet. If we consider the conversion factors concerned, we obtain:

$$P[\mathrm{kW}] = 0{,}278m[\mathrm{t/h}]\ \Delta h[\mathrm{kJ/kg}] \tag{4.1}$$

Since the outlet-enthalpy is more or less prescribed by the requirements of the process, only the inlet conditions can be chosen.

Industrial turbines have to be of high reliability, must be easy to operate and have a good efficiency to reduce purchase of power and the portion of output which is obtained by condensing. Priority, however, has to be given to the availability, as a stoppage can decrease the economy considerably.

Ferritic steels permit live steam conditions of approximately 540°C and 140 bar. Turbines with horizontally split casings and without blade ring carrier can be operated up to 80 bar/490°C economically.

Figure 1 demonstrates the increase of relative prices for turbosets and boilers of standard types as a function of the live steam conditions. It is essential that the technical resources of the boiler increase

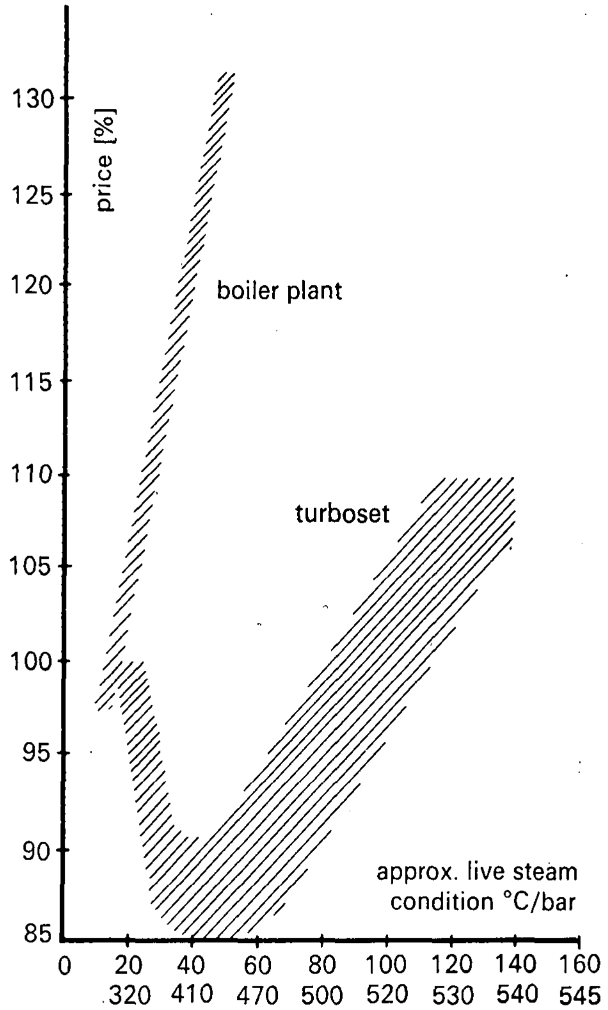


FIGURE 1: Price of boiler plant and turboset as a function of the live steam conditions, based on 16 bar/300°C = 100%

linearly up to approximately 450°C, which is around 50 to 60 bar. From this point on other construction principles and materials become necessary, and the technical resources increase over-proportionately. In this range the turboset price reaches a minimum, since the specific volume of the steam is the smallest where simple construction features are still applicable. Within the limits of our theme it is sufficient to state that, for the above-mentioned reasons, live steam conditions for an economically laid-out turboset should be chosen within the range of 40 to 55 bar, according to 400 to 450°C, where the higher figures should be preferred.

The above equation, which gave us the relation between output, mass flow and enthalpy, still contains an important figure, which we will now discuss. The actual enthalpy difference Δh between inlet and outlet is obtained by

$$\Delta h = (h_1 - h_2)\ \eta_i\ \eta_{Tu}\ \eta_{Gb}\ \eta_{Ge} \qquad (4.2)$$

The mechanical and electrical efficiencies only differ within very narrow ranges, whereas the internal efficiency of the turbine depends on the construction principle, the accuracy of manufacture, the operational conditions, the load factor and some others.

The efficiencies of modern backpressure turbines at most economical rating are between 70% and 80%, and highly sophisticated multi-stage reaction turbines now even exceed 85%.

Since sugar technologists successfully increase the yields of their plantations by artificial irrigation and drainage, considerably more electric power is required without simultaneous increase of process steam, and the production periods are extended. Moreover, the availability of bagasse as fuel does not increase proportionately to the requirements of electric power. Therefore, during recent years, the efficiency of the plant has become more and more important for the economy of a sugar factory, and this development leads to new considerations regarding the construction features of a turbine. We will not discuss the various possible technical solutions which were developed for expanding steam in a turbine. But we may state that taking the above into account, the development of the application of turbo-alternator sets in the sugar industry tends towards more sophisticated, highly efficient multi-stage turbines. In Paragraph 5 we shall demonstrate, by means of a distinct example, what the influence of the turbine efficiency is.

4.2 CONDENSER LAYOUT

At the beginning of this chapter we stated that the steam conditions of the outlet are prescribed by the requirements of the process. However, let us briefly consider the circumstances as they refer to an extraction condensing turbine. We will investigate which parameters of the condenser influence the output of the turbine.

We will assume that neither conduction nor radiation transfers heat from the condenser to the surroundings and that the condensate does not become sub-cooled.

From the heat balance we obtain

$$mh_2 - m\vartheta_c = km\vartheta_{in} - km\vartheta_{out} \qquad (4.3)$$

and from this equation in the form of a straight line, and with $\Delta = \vartheta_2 - \vartheta_{out}$ for the terminal temperature difference we obtain

$$\vartheta_c = \frac{k}{k+1}\,\vartheta_{in} + \frac{k\,\Delta + h_2}{k+1} \qquad (4.4)$$

In Figure 2 this function is shown, where the parameters k, h_2 and Δ are varied.

If we, for instance, drop the condensing pressure from 0,059 bar to 0,049 bar, we find that this is in accordance with an advantage of 20 kJ/kg, which means almost 15% additional output, referred to the above recommended live steam range. On the other side, if we increase the cooling water ratio k from, say 40 to 80, the condensing pressure decreases from 0,08 bar to 0,059 bar at the same cooling water temperature, according to almost 40 kJ/kg. In this case, if we install 35 kW additional power for the circulating water pumps, we obtain 350 kW additional output of the generator.

These few examples may be sufficient to demonstrate the very important influence of the suitable layout of the condenser for the economy of the generated power.

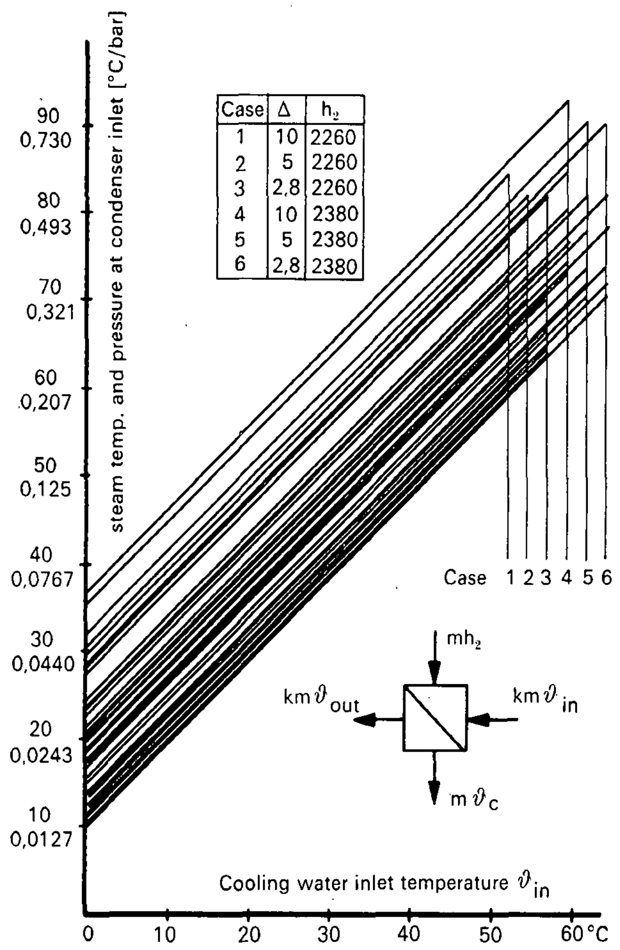


FIGURE 2: Condensing pressure as a function of the cooling water inlet temperature.

Of course, the condensing pressure cannot be dropped without restriction. Primarily it is limited by the cooling water temperature, as the above figure showed us. Secondly, it is limited by the construction of the turbine. The steam velocity increases and consequently the pressure drop increases. When these outlet losses reach the amount of the advantage of the enthalpy, the limit of the condensing pressure is exceeded.

Referring to the capital cost it should be mentioned that the condenser price increases approximately logarithmically with the cooling water ratio.

4.3 Efficiencies of components

As we learnt in the second chapter, steam as well as heat consumptions are inversely proportional to the over-all efficiency. Since the thermodynamic efficiency is mainly a matter of the prescribed steam conditions, it is not subject to this consideration. Thus the gross efficiency of a turboset is given by

$$\eta_{total} = \eta_i \, \eta_{Tu} \, \eta_{Gb} \, \eta_{Ge}. \qquad (4.5)$$

This efficiency considers all losses which are generated between the turbine inlet at the emergency stop valve, and the terminals of the alternator.

All these efficiencies basically depend on two principally different factors: excellence of construction and execution on one side and the load factor on the other. Although the efficiencies of all constructions are not equal, in order not to be submerged in technical details we shall base our reflections on one single efficiency of the design point.

Figure 3 shows the approximated steam consumption line of a backpressure turbine. The curve of the internal efficiency demonstrates the significant dependance on the load factor. Opposite to the internal, the generator efficiency has its maximum at maximum load. The turbine and gear efficiencies we can assume as constant within the range concerned. Thus we obtain the overall efficiency of a turboset as shown.

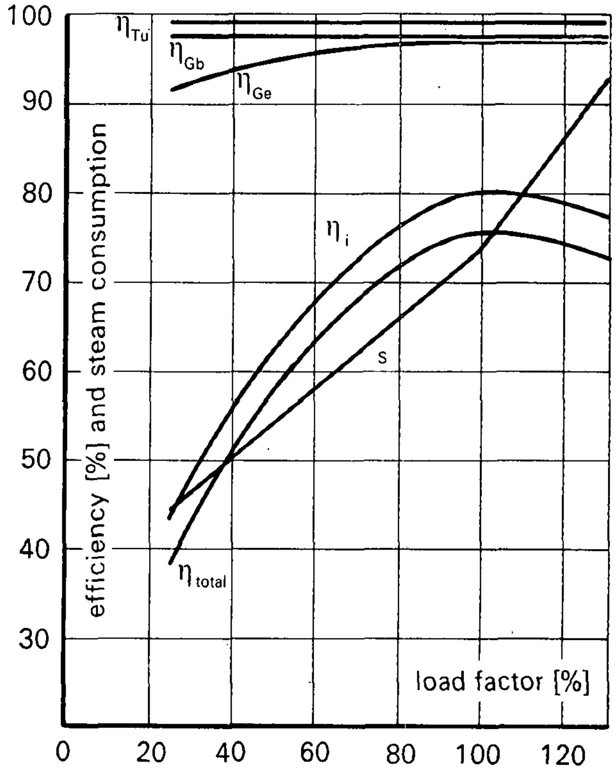


FIGURE 3: Overall efficiency of a backpressure turbine as a function of the load.

The following conclusions are of importance for our economical considerations:

Primarily: the overall efficiency of a turboset which is proportional to the fuel expenditures and proportional to the steam consumption, depends on the load factor to a great extent. Therefore, an economic feasibility study must be done, not only for the design point, but also considering the circumstances referred to at partial load.

Secondly: before the design of the turboset, it has to be carefully investigated at which load the turboset will preferably be operated, since it is possible to adjust the design point within certain limits. If this is done correctly, the economy of the plant can be increased considerably.

5. A basic economic comparison on turbo-generated power

In Chapters 3 and 4 we learnt the principles of the DCF method as well as the essential influences on the economy of turbo-generated power in relation to the costs involved. We now would like to know to which extent the economy — or expressed in a more accurate term, the rate of interest of an investment — is influenced by the parameters mentioned. For the sake of illustration we shall select a characteristic case, calculate the solution rate according to the DCF approach and finally we shall vary several parameters and investigate their influence.

5.1 DESCRIPTION OF THE ALTERNATIVES A AND B

The extension of a sugar factory is planned where the additional sugar cane plantations are to be irrigated. To supply the electric pumping stations, the purchase of power from the public system is possible. Thus we get two alternative power stations.

Alternative A: Backpressure turbosets and purchase of electric power for irrigation.

Alternative B: Extraction condensing turbosets, generating the electric power for irrigation.

For the design of both extensions A and B, we shall distinguish three cases, as 'production only', 'production and irrigation' and 'irrigation only'. The distribution of these periods over the year is shown in Figure 4.

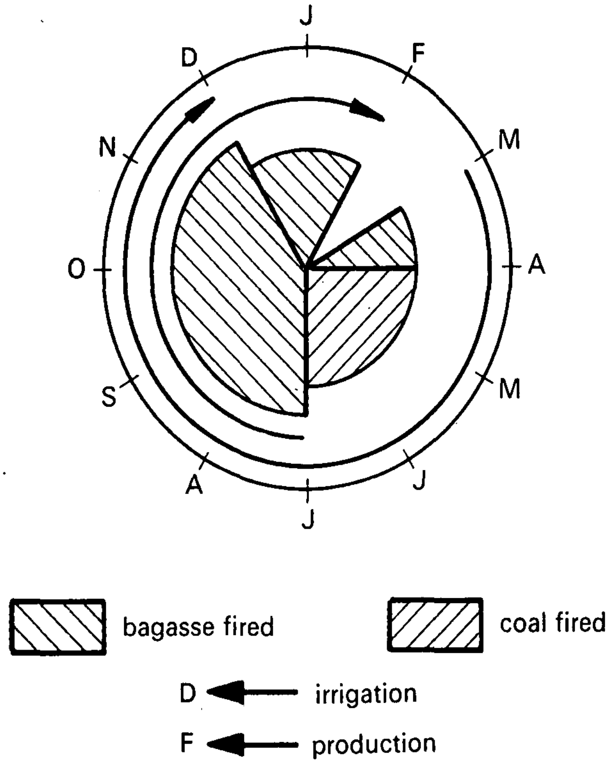


FIGURE 4: Assumed mode of operation.

The existing steam net is assumed to be

Live steam	43 bar / 438°C
Backpressure	3,0 bar

and the extension should be based on these conditions.

With these assumptions we make the following more or less arbitrary design for the above-mentioned extension:

	Production only	*Production and Irrigation*	*Irrigation only*
Requirements			
Total power required / MW	8,6	23,6	15
Process steam required / t/h	60	60	—
Length of period / months	2	5	4
Alternative A:			
Backpressure steam / t/h	2×30	2×30	—
Turbo-generated power / MW	2×4,3	2×4,3	—
Purchased power / MW	—	15	15
Number of turbines running	2	2	—
Alternative B:			
Extraction steam / t/h	1×60	2×30	—
Condensing steam / t/h	—	2×29	2×32
Turbo-generated power / MW	8,6	2×11,8	2×7,5
Number of turbines running	1	2	2

5.2 CALCULATION OF EXPENDITURES

As described under 3.2, Paragraph 3, for an economic comparison it is sufficient to consider the differences of the expenditures involved, and the 'receipts' are assumed to be same for both alternatives, namely the total power and the process steam quantity required.

5.2.1 INITIAL EXPENDITURES

As agreed above, we assume the following differences in capital expenditures:

Alternatives	A	B
Two turbosets	—	600 000
Two condensers	—	150 000
Boiler auxiliaries	—	200 000
Transformers, switchgear	50 000	—
Pipes and pumps	—	50 000
Difference of total initial costs		R(−950 000)

Manufacturing, erection and commissioning time is estimated at 2 years from date of order. If we assume terms of payment of $\frac{1}{3}$ with order, $\frac{1}{3}$ when half the delivery time has elapsed and $\frac{1}{3}$ with commissioning, we obtain under consideration of the time factor, referred to the date of commissioning:

$$-\Delta J(t_o) = (317\,000 \times 1{,}156) + (317\,000 \times 1{,}075) + 316\,000 = R1\,022\,000$$

5.2.2 OPERATIONAL EXPENDITURES FOR ALTERNATIVE A

In order to simplify matters, we base our calculation on one price for one kWh of electric power, purchased from the public system only, which is supposed to be $c_A = 5 \times 10^{-3}$ R/kWh. As assumed in Figure 4, a total power of 15 MW has to be purchased over a period of nine months, thus

$$C_A = t_A \times c_A \times P$$
$$= 23h \times 26 \times 9 \times 15 \times 10^3 \text{ kW} \times 5 \times 10^{-3} \text{ R/kWh}$$
$$= R404\,000$$

The annual expenditures for purchased power are R404 000, if we assume 23 hours per day and 26 days per month.

5.2.3 OPERATIONAL EXPENDITURES FOR ALTERNATIVE B

In accordance with our above assumptions, there are still 3 months remaining where the irrigation system requires power and where coal has to be fired. Let us base the following calculations on

$t_B = 23h \times 26 \times 3 = 1\,795$ h
ncv $= 25\,000$ kJ / kg
p $= 6{,}0$ R/t

In this simple condensing operation, the heat consumption, in accordance to equations (2.4), (2.5) and (2.6), is

$$q[\text{kJ/kWh}] = \frac{3600}{\eta_{\text{total}}}$$

Figure 5 demonstrates the expansion of the live steam of our extraction condensing turbine, alternative B. If we assume an average condensate temperature of 50°C, we are able to calculate the maximum thermodynamic efficiency:

$$(\eta_{th})_{\max} = \frac{h_1 - h_{2s}^{\prime}}{h_1 - h_c} = \frac{3300 - 2160}{3300 - 210} = 0{,}369,$$

and thus

$$\eta_{\text{total}} = 0{,}369 \times 0{,}84 \times 0{,}93 \times 0{,}77 = 0{,}231,$$

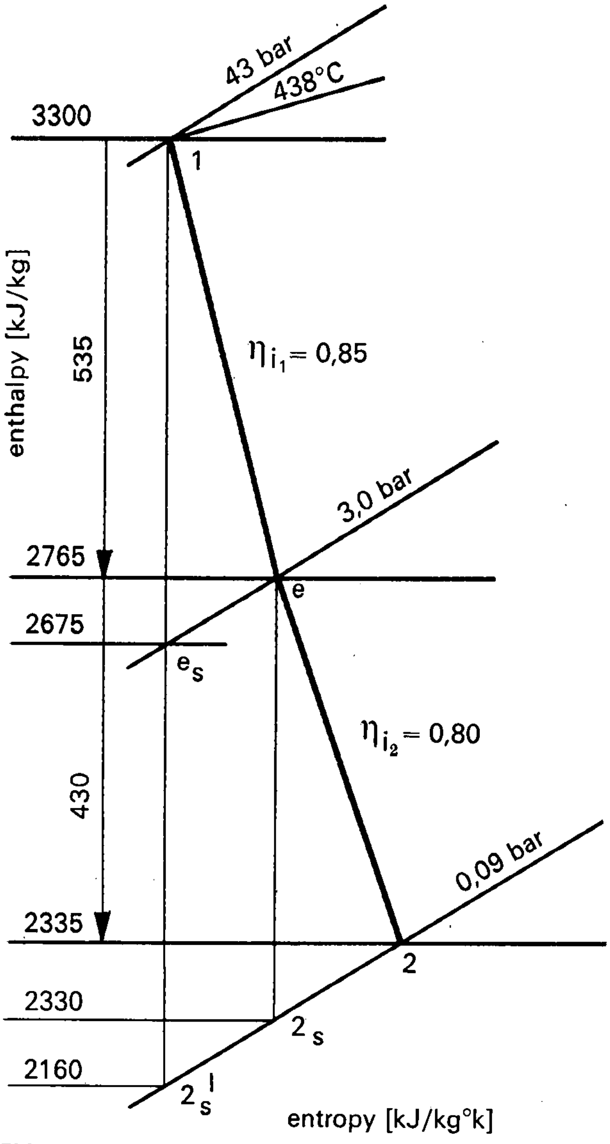


FIGURE 5: Expansion of an extraction condensing turbine, referring to section 5.

where the efficiencies of turbine (mechanical), gearbox, alternator and boiler and heat transfer are assumed. So we obtain the heat consumption

$$q = \frac{3\,600}{0{,}231} = 15\,600 \text{ kJ/kWh}.$$

With

$$c_B = \frac{p \times q}{ncv} = \frac{6{,}0 \text{ R/t} \times 15{,}6 \times 10^3 \text{ kJ/kWh}}{10^3 \times 25 \times 10^3 \text{ kJ/kg}} = 3{,}74 \times 10^{-3} \text{ R/kWh}$$

we obtain the annual fuel costs for alternative B:

$$C_B = t_B \times c_B \times P$$
$$= 1\,795 \text{ h} \times 3{,}74 \times 10^{-3} \text{ R/kWh} \times 15 \times 10^3 \text{ kW}$$
$$C_B = \text{R}100\,500$$

As maintenance and administrative expenses for alternatives A and B are approximately the same, we can neglect them for this comparison.

We consider the price increase as follows:—

Electric power from public system	4% p.a.
Coal free on site	5,5% p.a.

5.3 THE DCF PROCEDURE

We assume the expected life to be ten years and thus obtain as annual expenditures E_A and E_B and its difference $E_A - E_B$:

Year	E_A	E_B	$E_A - E_B$
1	420 000	106 000	314 000
2	436 000	112 000	324 000
3	454 000	118 000	336 000
4	472 500	124 500	348 000
5	491 500	131 000	360 500
6	510 500	138 500	372 000
7	531 000	146 000	385 000
8	553 000	154 000	399 000
9	575 000	162 500	412 500
10	598 000	171 500	426 500

We are now applying equation (3.3); the discount factors referred to are scheduled in the literature concerned, for instance (1). Thus we get

$$\begin{aligned} 1\,022\,000 = {} & +314\,000r^{-1} + 324\,000r^{-2} + 336\,000r^{-3} \\ & +348\,000r^{-4} + 360\,500r^{-5} + 372\,000r^{-6} \\ & +385\,000r^{-7} + 399\,000r^{-8} + 412\,500r^{-9} \\ & +426\,500r^{-10} \end{aligned}$$

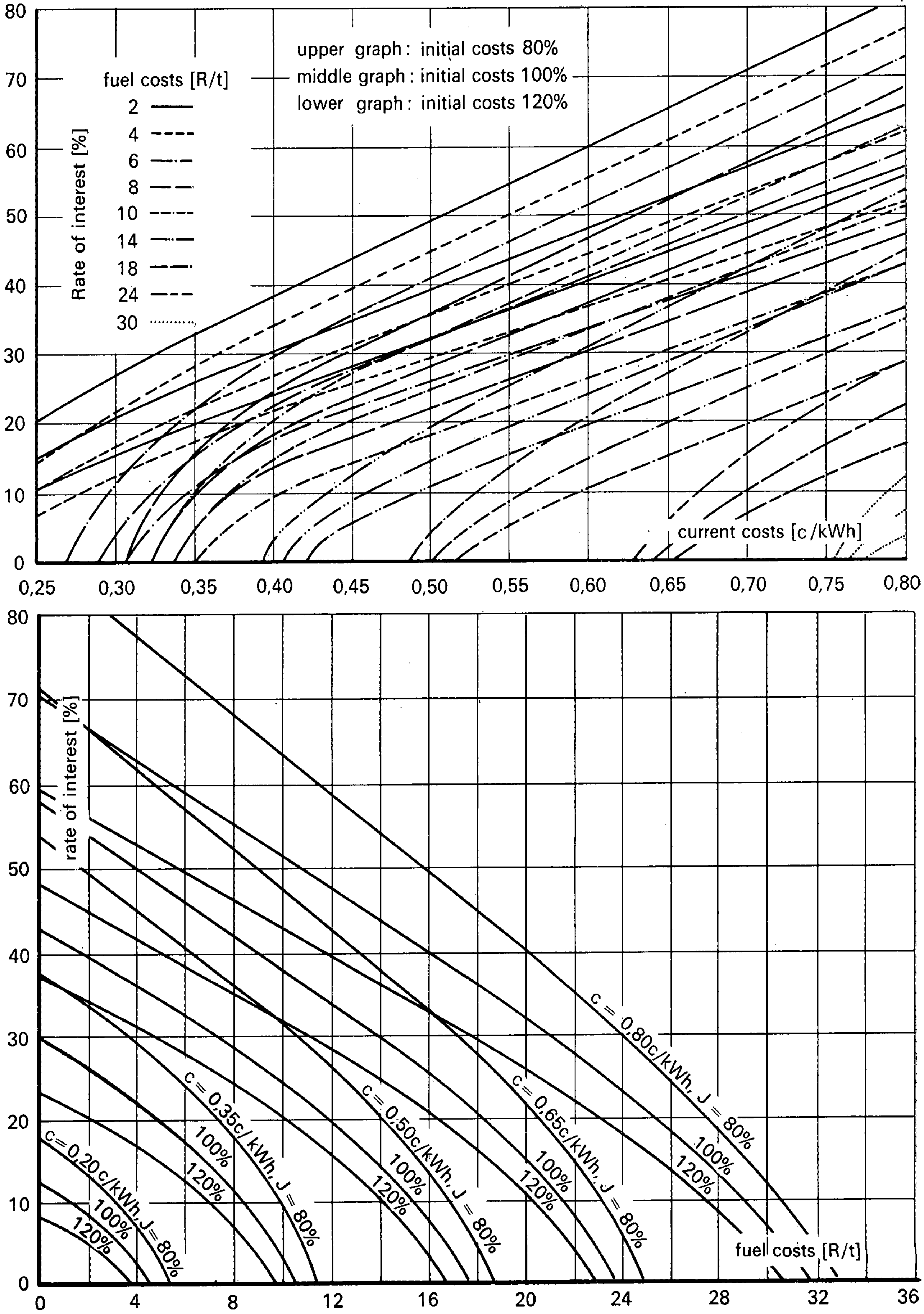
By trial and error we find the solution rate $\underline{\underline{r = 31{,}5\,\%}}$

This means that the additional initial expenditures of alternative B effect a yield of interest in the savings of the operation expenditures of 31,5%. Or in other words: The excess investment of alternative B yields a rate of return of 31,5%.

5.4 VARIATION OF THE PARAMETERS

One of the most important considerations of our above DCF approach is still missing; this calculation should never be done unless two additional cases are taken into account; the calculation must still be performed with a less advantageous and a more advantageous assumption — most likely, better, worse, as it is usually called. In this case we will do this during the following variation of parameters.

Having outlined the procedure, the result is not particularly interesting. We are, therefore, interested



FIGURES 6 AND 7: DCF—procedure solutions.

in what would happen if a certain number of the assumed parameters are altered.

For this purpose we programmed the DCF procedure and thus we were able to obtain the solution rates for the variation of the following parameters:

$-\Delta J(t_o) = 822\,000 \quad 1\,022\,000 \quad 1\,222\,000$ R
$c_A = 2{,}0 \quad 3{,}5 \quad 5{,}0 \quad 6{,}5 \quad 8{,}0$ R/kWh
$c_B = 2{,}0 \quad 4{,}0 \quad 6{,}0 \quad 8{,}0 \quad 10{,}0$
14,0 18,0* 24,0* 30,0 40,0* R/t

*These figures consider the higher ncv of oil, they are actually based on 30 40 50 67 R / t.

Figure 6 demonstrates the dependence of the rate of interest of the savings on the operation expenditures of alternative A, where capital investments and operation expenditures of alternative B are varied.

Figure 7 shows the solution rate of the savings as a function of the operation expenditure of alternative B, where those of alternative A and the initial expenditures are varied.

In Figure 8, the rate of interest is eliminated; the interdependence of the two operation expenditures A and B is demonstrated, while the yield of interest as well as the capital investment are parameters.

Figure 9 is the three dimensional representation of the results obtained by variation of all parameters, except the capital expenses which we have omitted for the sake of illustration.

5.5 Discussion of the results

In Figure 6 we are impressed by the sensitivity of the rate of return from the current costs. For instance, if the current costs increase by 18% (from 0,30 to 0,355 c/kWh), the fuel price can increase by more than 50%, and we still get the same profitability. This relation, however, is not linear, as the graphs demonstrate. Where higher current costs are assumed, if they should increase by the same amount of about 18% (from 0,65 to 0,77 c/kWh), we can only increase the fuel costs around 34% to obtain the same rate of return.

On the other hand, if we consider low investment expenditures, the increase in the equivalent percentage fuel costs, provided the rate of return and a certain increase of current costs is the same, is smaller than for high initial expenditures. The reason is to be found in the fact that, for low capital expenditures the portion of the operation costs is higher anyway.

Consequently, this figure demonstrates that we cannot draw conclusions for cases where different capital expenditures are applied or the whole cost level is altered, if a permissible increase of the current costs based on a correspondingly calculated fuel cost increase is assumed.

A further interesting fact can be seen from these graphs. If the current price is supposed to be, say 0,35 c/kWh, then the rate of return of the savings is, based on the medium capital expenditures, about 10%. If, however, it is possible to purchase power

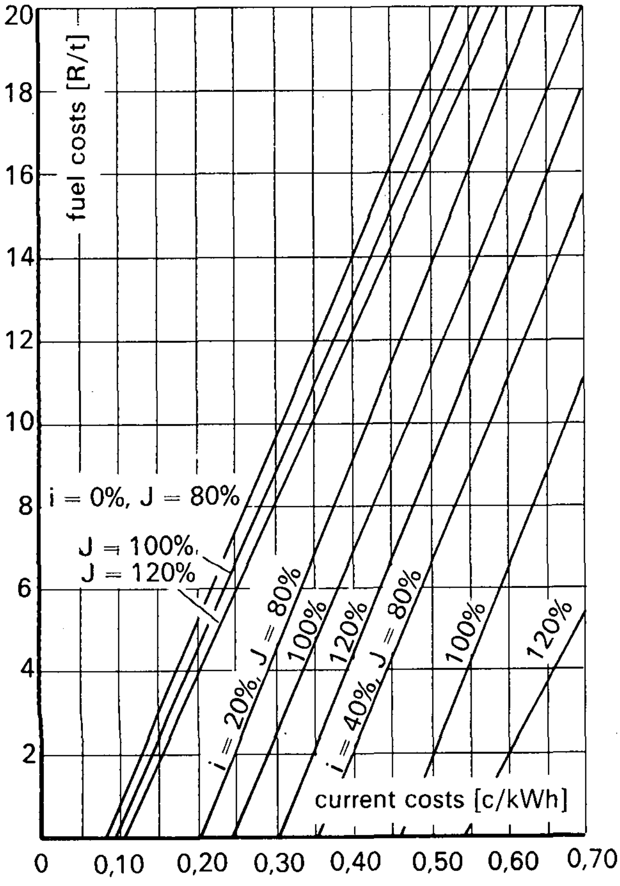


FIGURE 8: DCF – procedure solutions.

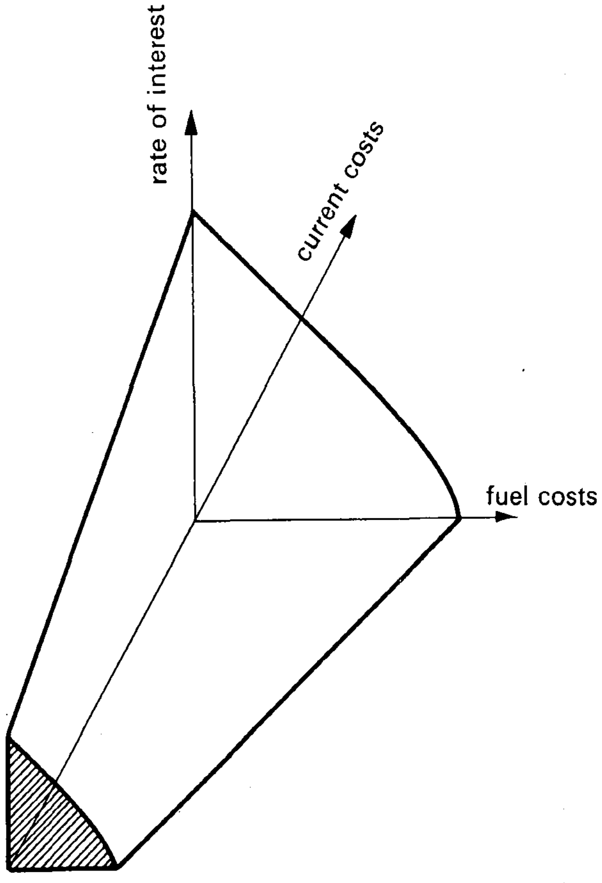


FIGURE 9: Three dimensional diagram of the DCF – procedure.

for 0,32 c/kWh, then the advantage of the turbogenerated power disappears, as no profit will be available in the savings. This comparison is particularly sensitive for low current costs, and therefore calculations have to be done very carefully.

The diagram also demonstrates the highest fuel costs at which profitability disappears, provided current costs are the same.

Figure 7 does not show anything basically different from the above figure. However, it facilitates investigations should current costs, for instance, be negotiated and it is to be found how far investment expenditures influence the rate of return. On the other hand, we see that for high current costs and low fuel costs, initial expenditures influence the rate of return far more than high fuel costs and low current costs. This is explained by the fact that this constellation yields the mentioned high rate preferably by low capital costs.

Furthermore, we can see that the graphs sometimes cross each other, which is easy to explain. For the same fuel costs the profitability can be equal, if low capital costs and high current costs or high capital costs and low current costs apply. This is an important fact, as we can learn whether it is worthwhile to increase the efficiency of the plant if a certain amount of additional capital expenditure is involved.

Finally we can see that it is easier to increase the profitability from, say 10 to 20% by, for instance, improving the heat consumption, than from 30 to 40%. The efficiency of such efforts is, therefore, limited.

Figure 8, where the yield of interest is eliminated, gives the answer to all questions based on same rates of interest. At low rates, for instance, we find that the efficiency of the plant — boiler included — must be improved by 13% to justify an increase in the initial costs by R200 000. In the case of our extraction condensing turbine calculation, the thermodynamic efficiency of the turbine can easily be improved by 8% merely by increasing the cooling water ratio from 30 to 100, the remaining 5% being obtained by a more sophisticated turbine.

This measure could be performed without exceeding a total expenditure of R200 000 thus increasing the rate of return.

An integrated graph is shown in Figure 9, demonstrating what happens if one or several of the values are altered.

5. Summary

After having introduced the fundamental terms and the principle of the DCF method, we discussed some essential influences on the economy of a plant and finally, we followed up the extent to which these fundamental figures evaluate the economy of turbogenerated power. Of course, we could only take into consideration a certain selection of the comprehensive aspects involved. For instance, the economy of a turboset in case of divergence from the projected load or mode of operation results is a separate study. Moreover, we only discussed a single economy comparison. We could also have, for instance, compared the economies if the turboset remains unchanged, but coal is burnt instead of bagasse. Or a turboset, together with the boiler, is replaced by a plant with higher steam conditions. Our performance therefore demonstrates which figures have to be taken into account, how to treat them and which results can be obtained.

Finally, we must of course mention that no economic calculation, even the most comprehensive one, can foretell the future. All that it does is enable the correct conclusions to be drawn from the assumptions. We explained in detail what would happen if the parameters were altered. The range of returns shown, indicate the sensitivity of the return to changes in the assumptions, and this can give an idea of the project's degree of risk. We may, therefore, state that one of the most important conclusions from the above is the necessity to study this degree of risk by careful investigation of the possible ranges of the assumptions made.

REFERENCE

1. A. M. Alfred and J. B. Evans. Appraisal of Investment Projects by Discounted Cash Flow, Chapman & Hall, London, 1971.