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TECHNICO-ECONOMICAL ASPECTS RELATED TO HEAT-RECOVERY IN HETEROGENEOUS CATALYTIC PROCESSES[1]

by

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1. INTRODUCTION

Due to the fact that the reaction products resulting from heterogeneous catalytic processes are later processed at temperatures lower than those at which the reaction occurs, the reactor effluent must be cooled.

This necessity is even more evident in the catalytic processes which occur under hydrogen pressure, recirculation of which requires its separation from the reaction product, in liquid phase, at the process pressure and at the lowest possible temperature. Due to this fact and considering that the effluent contains a large quantity of heat and it is at a high thermal level, partial recovery of this heat is possible.

The typical diagram of such a process (figure 1) shows that the charge stock blended with hydrogen is preheated by heat exchange with the reactor effluent, and heated up to the reactor operating temperature while passing through the heater. The reactor effluent, following heat transfer in the charge stock preheater, is cooled to the temperature at which the liquid-vapor blend can be separated, obtaining hydrogen rich gas which is recycled and the liquid phase which is processed later.

The heat exchanging equipment may be so sized as to obtain a more or less advanced recovery of the heat contained in the effluent which in turn determines the requirement of heat related to the heater.

The economical implications of heat recovery are discussed in this article, and the effect of effluent outlet temperature from the charge stock preheater is analysed as an independent variable, upon the operating cost (cost of heat introduced in the heater, cost of effluent cooling, following heat exchange with charge stock) and investment charges (cost of effluent-charge stock heat exchanger, heater, effluent cooler).

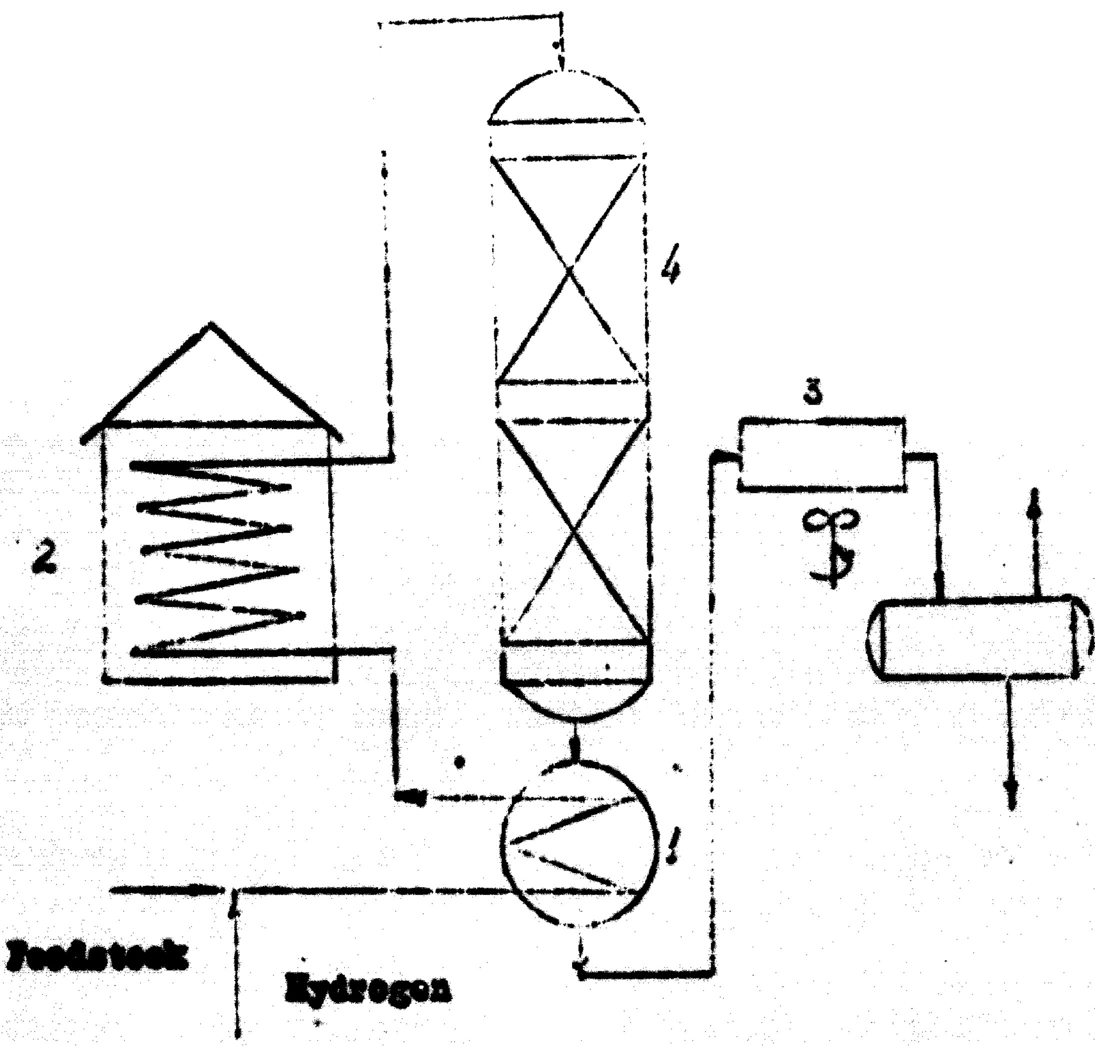

Fig.1. Schematic diagram of hydrogen treating unit.

1. Heat exchanger
2. Heater
3. Cooler
4. Reactor

II. THERMAL DUTY OF EQUIPMENT

A hydrogen treating process is considered, as an example, of 100,000 t/year capacity, the charge stock being a heavy oil fraction.

It is assumed that the charge stock with 40°C temperature, blended with the hydrogen, is preheated by heat exchange with the reactor effluent, being further heated in the heater up to the reactor operating temperature.

The reactor effluent, following the transfer of a part of the charge stock heat, is air cooled up to the high pressure separator temperature (60°C) where 150 at. pressure was considered.

The calculations were carried out by choosing as an independent variable the effluent outlet temperature from the charge stock preheater for which four values were considered each time and namely : 319°C, 274°C, 218°C and 156°C.

The thermal duty variation of the preheater, heater and cooler is plotted in figure 2 function of the above-mentioned parameter.

In order to carry out the respective calculations, the charge stock and effluent PRF curve was taken into account (respectively, the distribution of reaction products) and quantity of hydrogen recycled in the heater.

The percentage of vaporized product from the streams concerned was calculated each time, assuming and then checking the partial pressure of vapors and liquid on basis of equilibrium vaporization curves plotted in accordance with the Edmister/1/ method. The enthalpies for liquid and vapor products were taken from /3/, while for gas from /4/, heat calculation being carried out by multiplying the quantity of product by the difference of enthalpy corresponding to the two temperature levels in order to exclude the calculation basis of the enthalpies.

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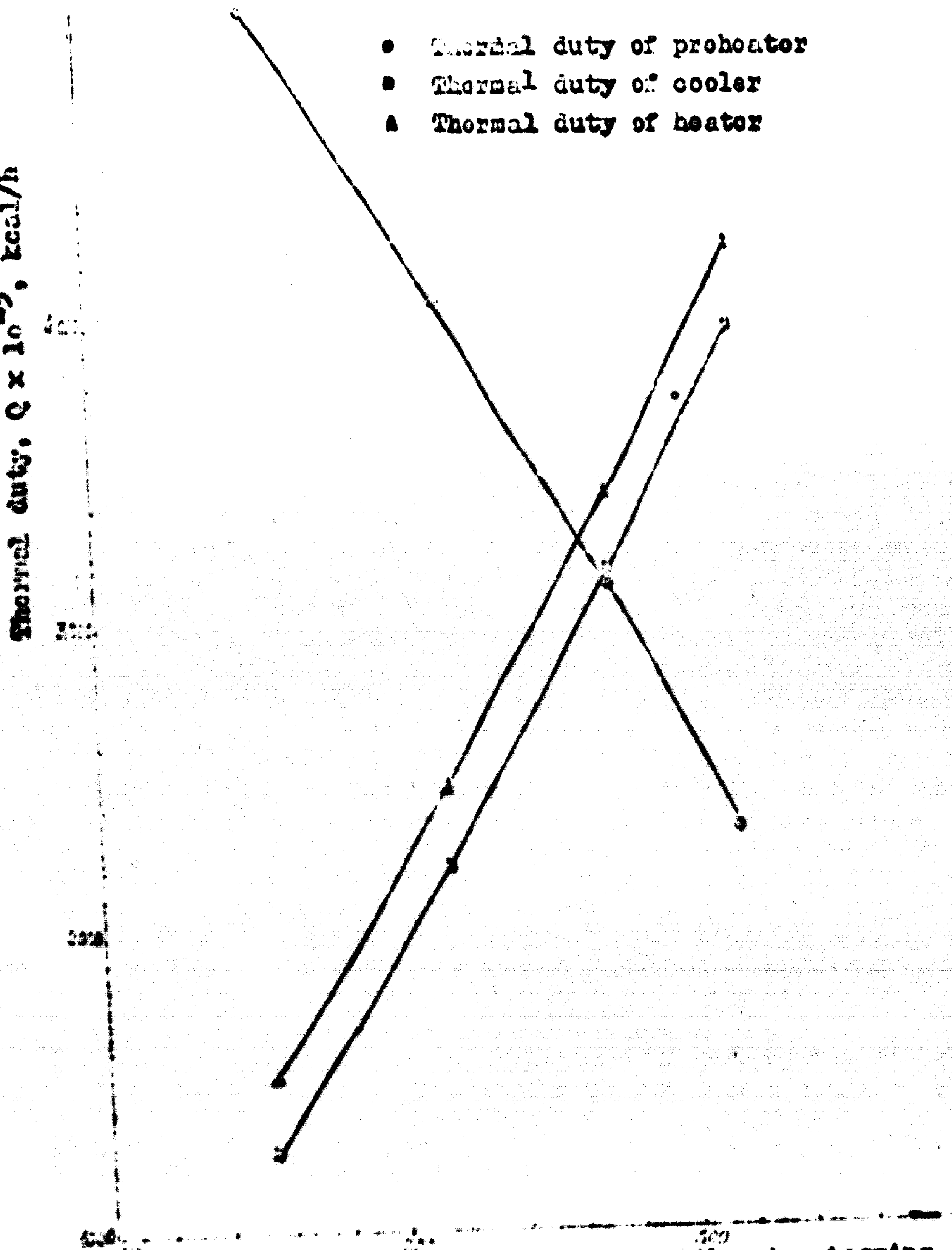

Fig.2. Variation of equipment thermal duty in relation to temperature of effluent outcoming from feedstock preheater.

III. INVESTMENT CHARGES

Investment charges were estimated according to data given in literature /4/ for which it was required to know the heat exchange surfaces and thermal duty of the heater.

The prices obtained from the data specified above were corrected according to the procedure function of the quality of materials used and operating pressure.

In the following paragraphs shall be presented only the result of these calculations with all sizes required to determine the cost price.

A 10% redemption quota per year was established, considering that the unit would be paid off within 10 years.

Ultimately, the cost price variation of the equipment as well as redemption quota variation were plotted function of the effluent outlet temperature from the exchanger.

In order to emphasize the effect of the material although in the example considered the equipment shall be fabricated of alloy steel, the cost prices were calculated for cases where the exchanger and cooler would be either carbon steel or alloy steel, the heater being of alloy steel in all cases.

a. Cost of charge stock preheater

In order to establish the cost of the charge stock preheater the heat exchange surfaces were calculated, considering, according to practical operating data of similar equipment, an overall heat-transfer coefficient of K = 400 $kcal/m^2h^oC$.

The costs of the heat exchanger in the four calculating alternatives are given in table 1, while the variation of the cost price with the effluent outlet temperature from the preheater is plotted in fig. 3.

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TABEL I

Cost of charge stock preheater

Crt. Nr.	T_0 effluent, °C	T_1 charge stock °C	$Q \times 10^{-3}$ kcal/h	S, m^2	Cost of exchanger $ Carbon steel	Alloy steel	Annual redemption, 10% Carbon steel	Alloy steel
1.	319	200	2500	24	11400	24400	1140	2440
2.	274	250	3100	42	16100	34700	1610	3470
3.	218	300	4050	74	29400	63000	2940	6300
4.	156	350	5000	140	58800	126000	5880	12600

TABEL II

Cost of heater

Crt. Nr.	T_0 effluent, °C	T_1 charge stock, °C	$Q \times 10^{-3}$ kcal/h	Heater cost $	Annual redemption 10%
1.	319	200	4200	117000	11700
2.	274	250	3400	98000	9800
3.	218	300	2450	73600	7360
4.	156	350	1500	47200	4720

TABEL III

Cost of cooler

Crt. Nr.	T_0 effluent, °C	$Q \times 10^{-3}$ kcal/h	S, m^2	Cost of cooler, $ Carbon steel	Alloy steel	Annual redemption, 10% Carbon steel	Alloy steel
1.	319	3950	135	6700	12800	670	1280
2.	274	3150	122	5800	11200	580	1120
3.	218	2200	105	5200	10000	520	1000
4.	156	1250	77	4100	7800	410	780

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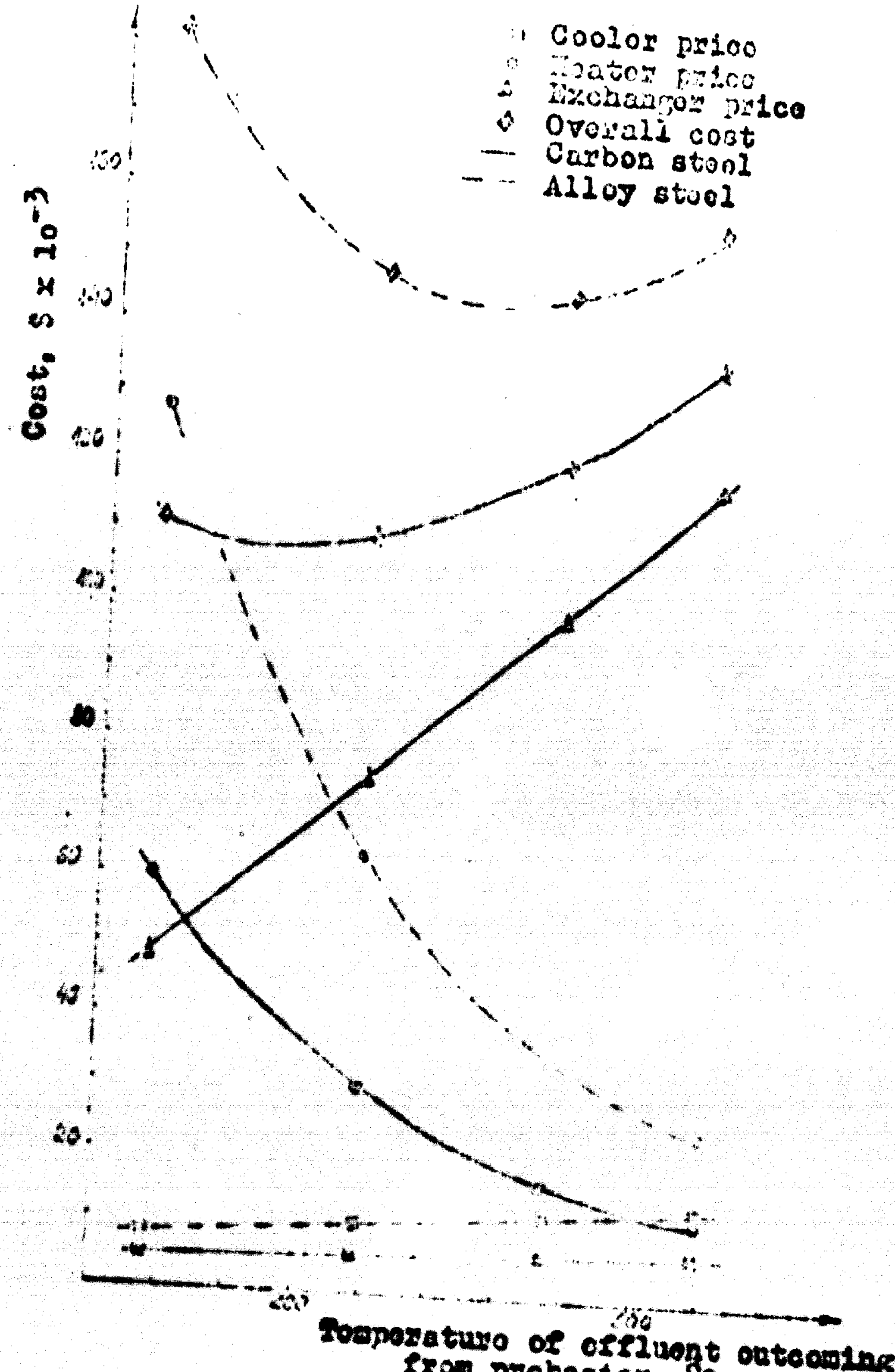

Fig.3. Variation of equipment cost in relation to temperature of effluent outcoming from preheater.

b. Cost of heater

According to data given in literature /2/, function of the thermal duty of the heater, the cost of the heater was established, the results being given in tabel II. Graphic representation of heater cost price variation function of effluent outlet temperature from the exchanger, is also given in figure 3.

c. Cost of effluent cooler

Air coolers were suggested to be used for effluent cooling considering the advantages of these as compared to water coolers (deposit of scale in certain points, shortage of water, easier to maintain, etc.).

Heat exchange surfaces were calculated according to the procedure proposed by Hudson Engineering Corporation, allowing an overall heat-transfer coefficient against finless tube surface of 317 $Kcal/m^2h^oC$. The air used in calculations, is dry with 21.1^oC temperature at 760 mm Hg pressure. Results obtained are given in table III, and graphic representation in figure 3 (variation of air cooler cost function of exchanger outlet temperature of effluent).

d. Total investment charges

Variation of investment charges for the 4 calculation alternatives is obtained by totalling the cost of the 3 units (carbon steel or alloy steel fabrication).

As can been seen from figure 3, when the units are of carbon steel fabrication, investments are minimum at 180^oC effluent outlet temperature from the exchanger, while for alloy steel fabrication the investments are minimum at 260^oC temperature.

The influence of operating costs over the position of this minimum of investments shall be further studied.

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IV. OPERATING CHARGES

In order to establish operating charges, only cost variation of heat transfer in the heater was considered below as well as power consumed by the fan.

Cost of power consumed by the pump and compressors was not taken into account as these are practically constant (pressure drop variation is small as compared to reactor operating pressure, and the total surface of heat exchanger and effluent cooler, respectively, exchanger and charge stock heater, varies within small limits.

Operating charges were established for one year of operation, taking from literature data regarding cost of heat the value of 0.11 /1000 Kcal /5/ and for cost of power the value of 1 / Kwh /6/.

a. Cost of heat transfer within the heater

Knowing the absorbed heat for the four calculating alternatives and assuming a value of 0.75 for overall heater efficiency, consumption of heat per year was determined. The results of the calculation are given in Tabel IV, and cost variation of heat, function of exchanger outlet temperature of the effluent, is plotted in figure 4.

b. Cost of fan power consumption

According to the procedure specified for the design of coolers, power consumption for the fan was estimated. In tabel V are given the results of these calculations, and in figure 4 are plotted cost variations of electric power in the four alternatives.

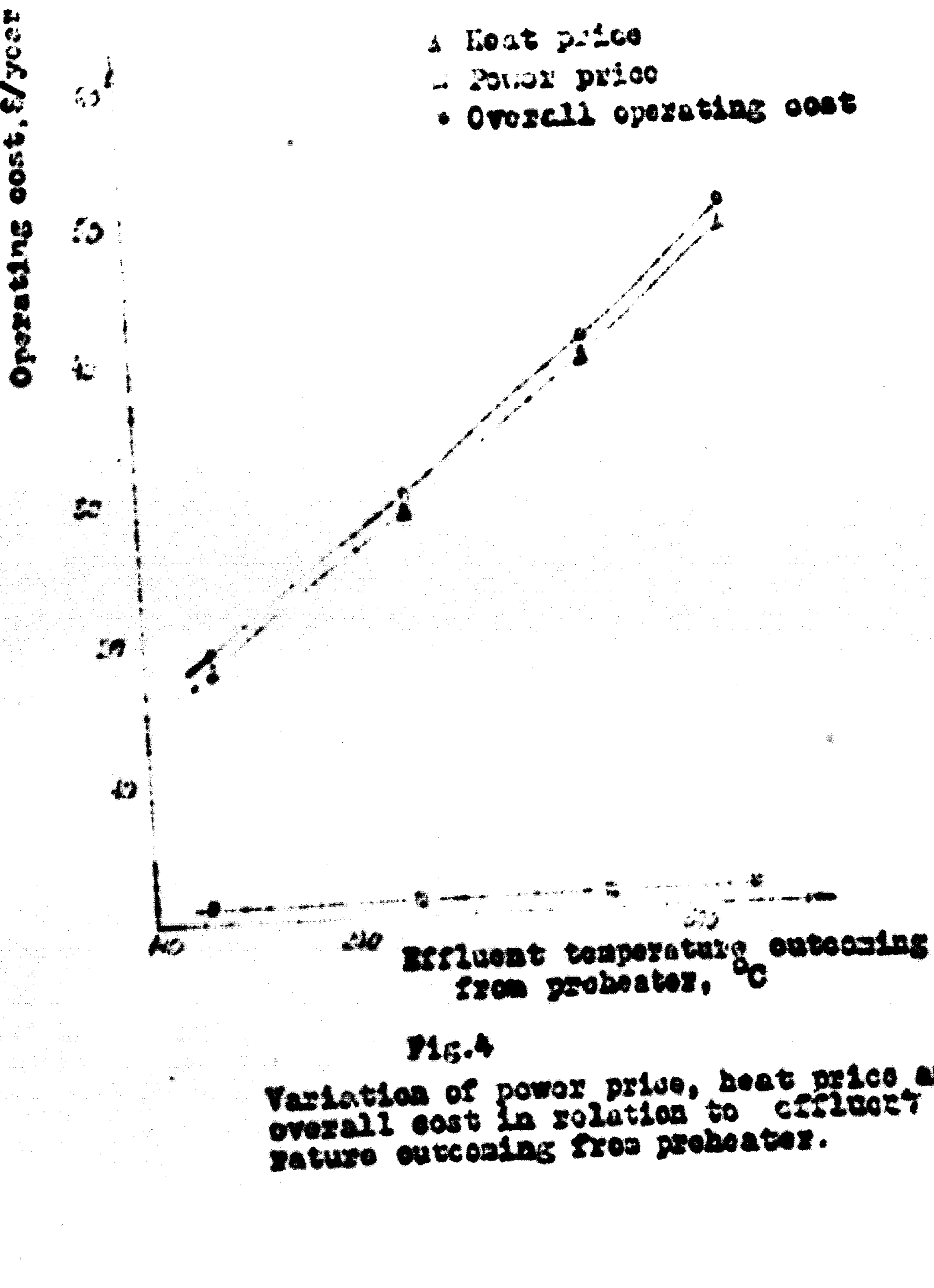

Fig.4

Variation of power price, heat price and overall cost in relation to effluent temperature outcoming from preheater.

c. Total operating cost

Total cost variation with exchanger outlet temperature of the effluent was obtained by totalling the operating costs in the four calculation alternatives.

As can be seen in figure 5, the cost of power for the fan represents only 5% of the total operating costs. Operating costs increase rapidly concurrently with the increase of effluent temperature at the exchanger outlet.

V. CONCLUSIONS

In order to establish the effect of heat recovery upon the total cost (annual redemption plus annual operating charges), the total cost variation, function of effluent temperature at exchanger outlet, was plotted in figure 5.

As may be observed, operating costs have a great influence upon the minimum position of investments established earlier, in order to give the total cost curve an aspect of continuous increase from the high pressure separator operating temperature to a practically complet recovery of the effluent heat.

As an advanced recovery of heat leads to more expensive equipment, while the annual cost (as compared to redemption + operating costs) does not emphasize this aspect, the initial cost must be taken into account.

Only the general aspect is given in this article. For each actual case, function of the specific conditions of the country, company, industrial complex within which the unit is located, different decisions may be taken. In any case, for each unit, more so for countries under development, a careful study must be made of the economical aspects regarding the technical solution and the choice of the optimum alternative prescribed by the operating conditions.

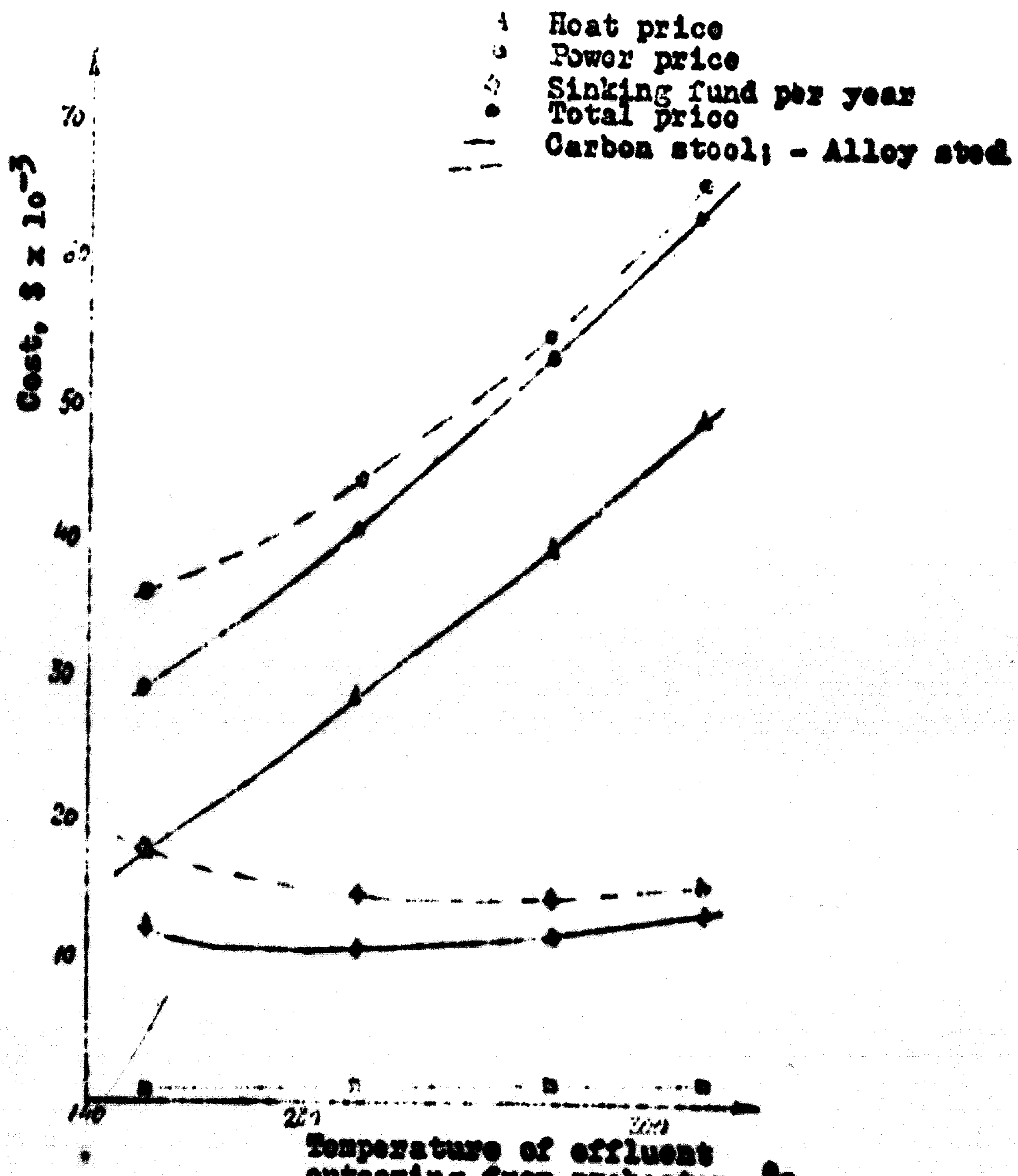

Fig.5

Variation of overall operating cost in relation to effluent temperature outcoming from preheater.

TABLE IV.

Cost of heat

Crt. Nr.	T effluent oC	Qx10⁻²Kcal/h heater	Cost of heat $/year
1.	319	4200	49,200
2.	274	3400	39,900
3.	218	2450	28,800
4.	156	1500	17,600

TABEL V.

Cost of power

Crt. Nr.	T effluent oC	S, m2	Kwh/year	Cost of power $/year
1.	319	135	136,000	1,360
2.	274	122	120,000	1,200
3.	218	105	104,000	1,040
4.	156	77	80,000	800

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