EUR 4524 e

COMMISSION OF THE EUROPEAN COMMUNITIES

TURBINA

A CODE FOR PREDICTING THE PERFORMANCE OF POWER PLANTS OPERATING WITH SUPERHEATED OR SATURATED STEAM CYCLES

by

E. BABORSKY (Politecnico di Milano, Istituto di Fisica Tecnica)
and
A. ENDRIZZI (Euratom)

1970

Joint Nuclear Research Center
Ispra Establishment - Italy

Scientific Data Processing Center - CETIS

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b) saturated with moisture separator
c) saturated with separator and live steam reheater
d) superheated
e) superheated with reheater.

The code has been tested on five existing steam power plants, constructed by different firms; the deviations between the real efficiency and the figure calculated by the code are less than 2°/oo.

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ABSTRACT

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KEYWORDS

STEAM
FLUID FLOW
WATER
TEMPERATURE
CONDENSERS
PRESSURE
TURBINES
GENERATORS
THEMODYNAMICS
NUMERICALS

CONTENTS

INTRODUCTION *)

A code is presented for predicting the performance of steam power plants operating with various steam cycles arrangements, on the basis of the minimum number of given design parameters.

A detailed knowledge of the procedures to design the power plant is not required.
The experience and the high performance level gained by the companies constructing large steam turbine-generators, guarantees that the performances of new power plants can be predicted accurately on the basis of the knowledge of existing designs. This consideration led "GENERAL ELECTRIC Co." to the "Method for predicting the performance of steam turbine generators" (1), (2) which has been followed in this paper.

1. GENERAL REMARKS

1.1 Data

A minimum number of design parameters are required:

a) throttle steam pressure and temperature (or moisture)
b) steam flow
c) reheater (or moisture separator) pressure, if any
d) condenser pressure
e) type of steam cycle

Various types of steam cycles have been considered:

1) saturated or low superheated steam cycle with moisture removal stages
2) saturated or low superheated steam cycle with moisture separator and moisture removal stages
3) saturated or low superheated steam cycle with separator, live steam reheater, and moisture removal stages
4) superheated steam cycle without reheater
5) superheated steam cycle with reheater.

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*) Manuscript received on 15 June 1970

Fig.1 illustrates the possible steam cycle arrangements.

1.2 Preheaters and degasifier

The arrangement of preheaters, degasifier condenser, and feed-water pumps is presented in fig.2 and fig.3 .
The flow diagram shown in fig.2 is used in the case of super-heated and/or reheated steam cycle (type 4 and 5); the diagram described in fig.3 is adopted in the case of saturated or low superheated steam cycle (type 1, 2, 3).

The degasifier's pressure is supposed to be a linear function of the throttle steam pressure.
Fig.4 shows the design parameters of a typical preheater.
Pinch points and pressure drops are standard figures; the feed-water temperature rise is less than 30°C. This condition determines the number of preheaters. As a first approach, the distribution of the extraction pressures is calculated assuming that each preheater raises the feedwater temperatures by the same amount.
If the steam cycle design requires the separator or the reheater, the pressure range $p_1 - p_2$ (fig.5) is not clearly available for steam extraction. Pressure p_1 is assigned; p_2 is calculated by the code taking in account separator and/or reheater pressure drops. It is quite possible that feedwater temperature and re-heater or separator pressure (input data) lead to special arrangements of the preheaters' distribution.

The following rules are always valid:

a) if $p_1 < p < 0.8 \cdot p_2$ where p is the extraction pressure then $p = p_1$

   i.e. the steam extraction is placed at the exit of the high pressure turbine section.

b) if a) is true and p is the highest extraction pressure then $p = p_1$

and ΔT H (fig.4) in the corresponding preheater is modified to obtain the assigned feedwater temperature.
In any case the degasifier extraction point is located in the low pressure turbine section.

1.3 Low pressure preheaters and moisture removal stages

If moisture removal stages are requested (steam cycle type 1, 2, 3), the standard configuration of fig.6 is adopted.

The pressures of the standard moisture removal stages are fixed. The intermediate moisture removal stages coincide with the steam extraction points of the low pressure preheaters. A change in the moisture removal pressures gives a negligible effect on the overall efficiency.

1.4 Separator

The efficiency of the separator is assumed to be 0.8 .
The condensing water is collected by the preheater which operates at the same pressure as the separator. Pressure drops are calculated by standard methods.

1.5 Reheater

Let us consider the steam cycle type 3 : the temperature difference between saturated reheater drains and reheated steam is 13.77°C. The drained water is sent to the preheater operating at the highest pressure.
The reheat temperature of steam cycle type 5 is equal to the throttle steam temperature. Pressure drops are standard.

1.6 Heat balance

Ref. [1] and [2] describe the method for calculating:

- the efficiencies of the turbine sections
- the expansion lines
- the efficiencies of the generator.

Ref. [3] contains the procedure for predicting:

- the extraction flows
- the flows through the turbine sections
- the gross power output
- the pumping power
- the mechanical and electric losses
- the overall efficiency of the plant.

1.7 Efficiency, net power

The efficiency is calculated as follows:

$$\frac{\text{gross power} - \text{pumping power} - (\text{mechanical and electrical losses})}{\text{steam generator flow} \cdot (\text{outlet enthalpy} - \text{inlet enthalpy}) + \left[(\text{reheater flow}) \cdot (\text{outlet enthalpy} - \text{inlet enthalpy})\right]^{*)}}$$

and

$$\text{gross power} = \sum_i \left(\text{flow through the turbine section} \cdot \left[\text{inlet enthalpy} - \text{outlet enthalpy}\right)\right]_i$$

The overall efficiency is therefore defined as:

$$\frac{\text{net electric power output}}{\text{steam generator thermal power input}}$$

*) steam cycle type 5 only

1.8 Assumptions

With the aim of minimizing the number of input data, definite assumptions have been introduced. The procedure supplies a series of design parameters and chooses among many possible design arrangements. The most important assumptions are the following:

- conventionally cooled 3000 rpm generator
- isoentropic efficiency of the pumps : 0.76
- change in enthalpy across the governing stage: 20 kcl/kg

Packing and valve steam leakages are not considered (the effect on the overall efficiency is estimated to be 1%).

2. HOW TO USE THE CODE

The code is written in FORTRAN IV language for IBM 360/65. Total length: 96.000 bytes (2000 FORTRAN cards); 0.5 sec execution time.

The code is intended for iterative calculations such as techniques used to determine an optimum. For this reason a particularly simple data input form was chosen. The user writes his own "Main programme" and the calculation is executed by calling the following subroutines:

```
CALL SAT (P,T,FLOW, PEXHP, TFW, PC, NCYCLE, NCASE, NPRINT,
EFF, POWER, EEXHP, FLOWR)
```

for the steam cycle types 1, 2, 3 (saturated or low superheated steam)

or

```
CALL SUR (P,T, FLOW, PEXHP, TFW, PC, NCYCLE, NCASE, NPRINT,
EFF, POWER, EEXHP, FLOWR)
```

for the steam cycle types 4, 5 (superheated, reheated steam).

2.1 Data

P (kg/cm^2)	- admission steam pressure at the throttle valve, i.e. at the outlet of the steam generator
T (°C)	- steam temperature at the oulet of the steam generator
FLOW (ton/hour)	- steam flow at the outlet of the steam generator
PEXHP	- steam pressure at the outlet of the high pressure section of the turbine = pressure at the separator inlet (cycles 2,3 = pressure at the reheater inlet(cycle 5) PEXHP is meaningless in cycles 1 and 4
TFW (°C)	- feedwater temperature (steam generator inlet)
PC (kg/cm^2)	- condenser pressure
NCYCLE	- integer number : it defines the type of steam cycle
CALL SAT	- = 1 saturated or low superheated steam cycle with moisture removal stages - = 2 saturated or low superheated steam cycle with moisture removal stages + separator - = 3 saturated or low superheated steam cycle with moisture removal stages + separator + live steam reheater
CALL SUR	- = 4 superheated steam cycle - = 5 superheated steam cycle + reheater (reheat temperature = admission temperature)

The following parameters control the output:

NCASE	- integer number if NCASE = 0 no printed output is obtained if NCASE > 0 the results are printed (see output)
NPRINT	- integer number

= 0 normally
if = 1 several intermediate results are printed for controlling the calculation procedure

2.2 Calculated variables

EFF - efficiency of the plant (as defined above)

POWER (MWatt) - net power output

EEXHP (kcal/kg) - steam enthalpy at the output of the HP section of the turbine
= enthalpy at the separator inlet for steam cycle types 3, 2
= enthalpy at the reheater inlet for steam cycle type 5

EEXHP is meaningless in cycles 1 and 4

FLOWR (ton/hour) = steam flow at the reheater inlet (cycle type 5)
= live steam flow required by the reheater (steam cycle type 3)

FLOWR is meaningless in cycles 1, 2, 4.

The number of calculated variables, which appear in the calling sequence of the subroutine SAT or SUR, is small. This is because the user is supposed to be interested in efficiency and net power calculations only. Adopting a steam cycle type 5, the user is also informed about the reheater inlet steam enthalpy and flow, which may be useful for reheater design calculations.

However, by easy modifications it is possible to make any other interesting parameter available.

2.3 Output

If it is required by the user (NCASE > 0), a detailed description of the calculated plant is printed. Two tables contain all the design parameters (see fig.7 and fig.8). The first table gives the thermodynamic properties of steam at the extraction points. The operating conditions of each preheater and moisture removal stage (if any) are also described.
The second table gives a picture of the performance of the other components and of the whole plant.

2.4 Subroutines of the thermodynamic properties of steam and water

Ref. [4] contains the formulation of the thermodynamic properties of steam and water (see also ref. [3]).

The properties appear in the form of FORTRAN functions and they are also available for independent purposes, not connected with the particular code "Turbina".
Below is a list of the functions used by this code.

Saturation region

ELSAT(T)	saturated liquid enthalpy
EVSAT(T)	saturated steam enthalpy
SLSAT(T)	saturated liquid entropy
SVSAT(T)	saturated steam entropy
PSAT(T)	saturation pressure
TLSAT(P)	saturation temperature
EX(P,S,E,X)	enthalpy and quality as functions of pressure and entropy
SX(P,E,S,X)	entropy and quality as functions of pressure and enthalpy

Liquid region

ELIQS(P,T)	liquid enthalpy

SLPT(P,T)	liquid entropy
VSLIQ(P,T)	liquid specific volume
TLIQS(E,P)	liquid temperature as a function of enthalpy and pressure

Superheat region

EVSUR(P,T)	steam enthalpy
SVSUR(P,T)	steam entropy
VSVAP(P,T)	steam specific volume
TVEP(E,P)	steam temperature as a function of enthalpy and pressure
ESURPS(P,S)	steam enthalpy as a function of pressure and entropy

The code carries out the calculations with the following units:

E	P	T	S	V
Kcal/kg	kg/cm^2	°C	kcal/kg°C	m^3/kg

3. SAMPLE CALCULATIONS

The code "Turbina" has been tested on five existing steam turbine plants, constructed by different firms; the deviations between the real efficiency and the figure evaluated by the code are less than 2‰.

Following the good results of these tests, the code has been used for predicting the performance of plants operating with various steam conditions. The results are plotted in figs. 10 to 19.
Certain data used in our designing have been fixed:

- net electric power output 250 MW
- condenser pressure 0,052 kg/cm^2

and

- feedwater enthalpy = K . saturation enthalpy at throttle admission pressure

with K = 0.65 or K = 0.75

The resulting feedwater temperature as a function of the admission pressure appears in fig.9 .
The exit pressure of the HP turbine section (steam cycles 2, 3, 5) has been chosen as:

$$PEXHP = 0.2 \cdot P$$

where P is the throttle admission pressure.

It should be noted that some curves drawn in figs. 10 - 19 are to be interpreted as extrapolations of the calculation procedures; they correspond to merely conceivable, but not technologically achievable designs of steam power plants, because the calculation procedure does not include any feasibility limit.

REFERENCES

[1] SPENCER, COTTON, CANNON :"A Method for Predicting the Performance of Steam Turbine-Generators" General Electric Co., ASME 1963, 85, p.249

[2] BAILY, COTTON, SPENCER:"Predicting the Performance of Large Steam Turbine Generators Operating with Saturated and Low Superheat Steam Condition", Large Steam Turbine Generator Department General Electric Co., Schenectady, N.Y., GER-2454 A

[3] ENDRIZZI:"Un programma numerico per il calcolo delle prestazioni a carico nominale e parziale del gruppo turbina, alternatore, condensatore e preriscaldatori in centrali a ciclo di vapore con risurriscaldamento", EUR 3948.i CETIS, CCR Euratom

[4] "VDI Wasserdampftafeln", Springerverlag 1963

SATURATED - LOW SUPERHEAT

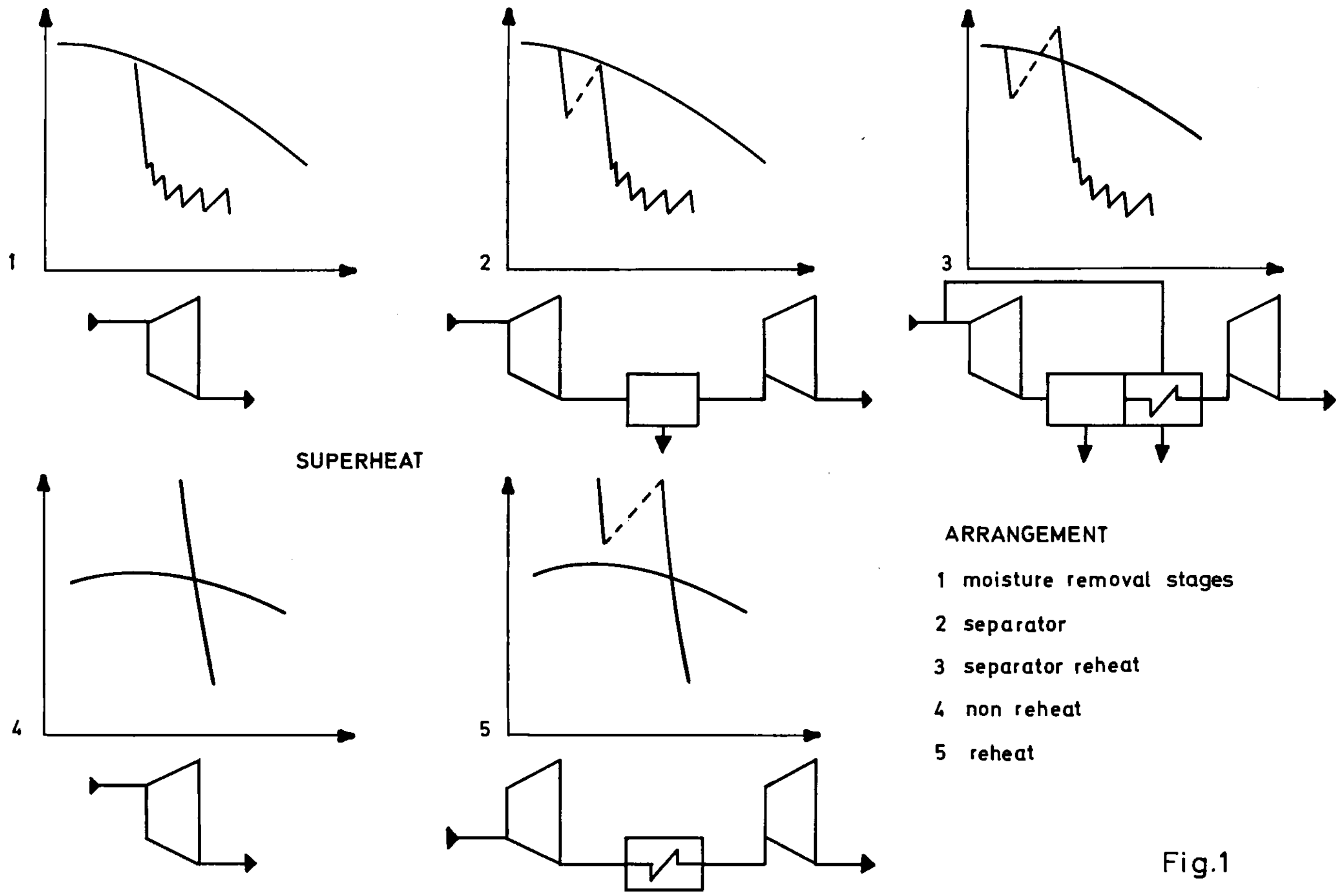


Fig.1

SUPERHEAT - PREHEATERS

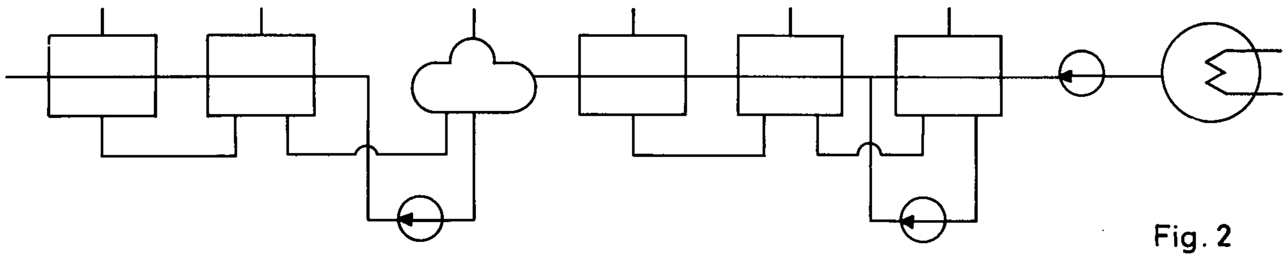


Fig. 2

SATURATED LOW SUPERHEAT-PREHEATERS

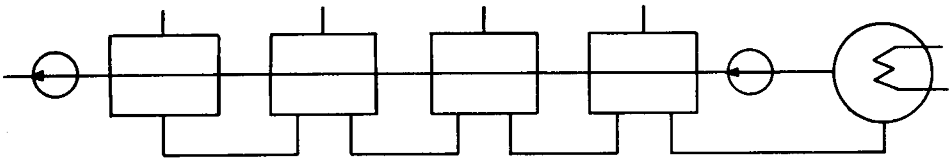


Fig. 3

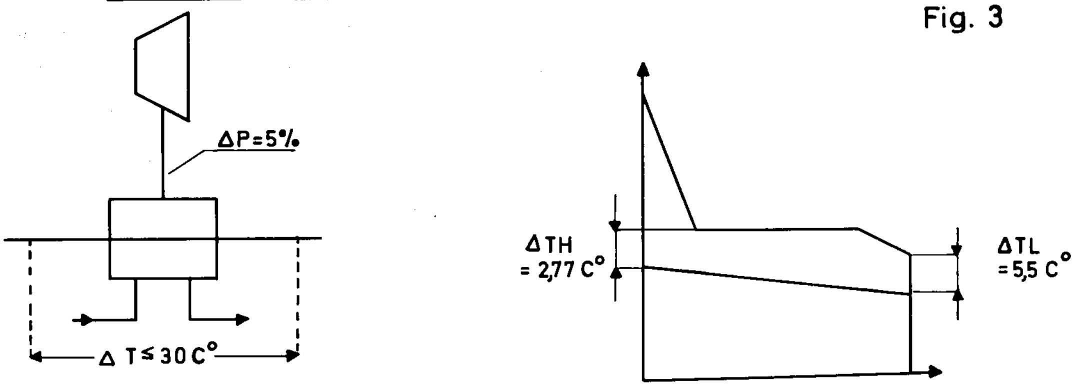


Fig. 4

PREHEATER PRESSURE LOSS-PINCH POINTS

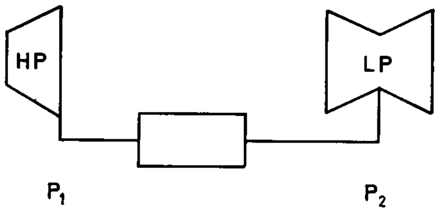
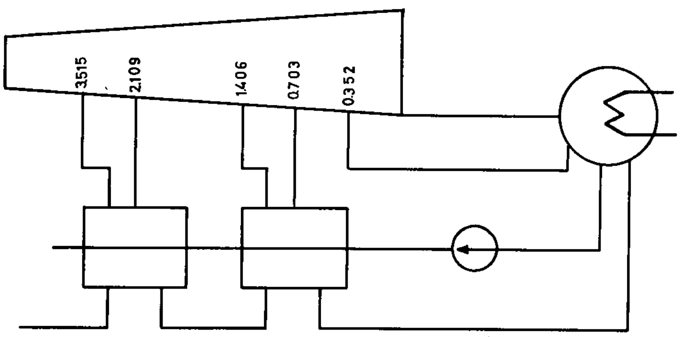


Fig. 5



MOISTURE REMOVAL STAGES LOW PRESSURE PREHEATERS
(pressure Kg/cm²)

Fig. 6

*** PROGETTO N. 1 ***

PRERISC. NUMERO	PRESSIONE DI SPILL.	ENTALPIA DI SPILL.	TEMPERATURA USCITA ACQUA ALIM.	ENTALPIA USCITA ACQUA ALIM.	TEMPERATURA USCITA CONDENSA	PORTATA TON/ORA
1	0.255	593.12	61.20	61.30	63.97	26.905
2	0.81	632.54	89.17	89.29	66.70	28.903
3	2.12	659.23	117.11	117.48	94.67	30.160
4	4.32	706.55	145.06	145.92	122.61	31.502
5	9.14	740.55	177.12	181.68	173.02	30.981
6	19.23	736.50	206.37	212.66	182.62	36.646
7	34.00	694.92	235.37	244.82	212.37	51.430
8	43.20	705.93	250.69	260.16	242.37	26.658

Fig. 7

*** PROGETTO N. 1 ***

CALDAIA	ALTA PRESSIONE	RISURRISCAL.	MEDIA E BASSA PR.	CONDENSATORE	GENERATORE
TIN = 250.59	TIN = 485.00	TIN = 272.13	TIN = 485.00	TIN = 33.26	
PIN = 187.00	PIN = 170.00	PIN = 34.00	PIN = 30.60	PIN = 0.052	
EIN = 250.26	EIN = 775.14	EIN = 694.93	EIN = 817.13	EIN = 553.24	
TOUT = 485.00	TOUT = 272.13	TOUT = 485.00	TOUT = 33.26		
POUT = 170.00	POUT = 34.00	POUT = 30.60	POUT = 0.05		
EOUT = 775.14	EOUT = 694.93	EOUT = 817.13	EOUT = 553.24		
PORTATA		PORTATA		PORTATA	
GG = 792.069		GR = 713.930		GC = 528.883	
CALORE SCAMBIATO		CALORE SCAMBIATO		CALORE SCAMBIATO	POTENZA ALLE PALE
QG = 474.299		QR = 101.454		QC = 319.792	WGROS = 262.270
	RENDIMENTO		RENDIMENTO		RENDIMENTO
	ETAP = 84.0287		ETAC = 91.3433		ETAGE = 0.9834
POTENZA POMPA				POTENZA POMPE REFR.E COND.	PERDITA MECCANICA
WPUMP = 7.004				WR=0.476 WC=0.457	DWM = 1.053
				SUPERFICIE TUBI M2	PERDITA ELETTRICA
POTENZA DISPONIBILE = 249.933			RENDIMENTO = 0.4342	SC = 6318.9	DWE = 3.290

Fig. 7 bis

*** PROGETTO N. 2 ***

SPILLAM NUMERO	PRESS. SPILLAM	ENTALP. A MONTE	ENTALP. A VALLE	DRENAG. TON/ORA	SPILLAM TON/ORA	TEMPER. ACQUA AL	ENTALP. ACQUA AL	TEMPER. CONDENS	ENTALP. CONDENS
1	15.000	615.520	615.620	0.0	50.324	182.053	185.041	154.851	156.043
2	5.903	631.229	631.129	0.0	62.134	149.301	151.189	122.455	122.829
3	3.515	643.739	643.910	0.326	4.791	*********	*********	*********	*********
4	2.109	624.655	625.452	1.147	51.433	116.905	118.314	91.005	91.009
5	1.406	611.419	612.620	2.149	4.502	*********	*********	*********	*********
6	0.705	599.423	594.205	6.687	32.081	85.455	86.723	38.805	39.783
7	0.352	573.776	555.825	13.888	4.025	*********	*********	*********	*********

Fig. 8

*** PROGETTO N 2 ***

	TEMP IN	PRES IN	ENTA IN	UMID IN	PORT IN	POTENZA	
PUMPA	132.053	[illegible]	135.041		1297.033	3.826	
GEN VAP	134.332	75.000	137.577		1297.033	720.505	
TURBINA	274.281	60.000	[illegible]	0.000	1172.863	66.273	
						DRENAG	
SEPARAT	197.365	15.000	[illegible]	0.108	1122.552	102.231	
						POR VAP	POTENZA
RISURR	[illegible]	[illegible]	[illegible]	0.018	1020.271	124.214	54.640
						POTENZA	
TURBINA	[illegible]	13.573	[illegible]	-0.082	1020.271	191.687	
CONDENS	[illegible]	[illegible]	553.639	0.126	782.095	466.369	
	PERD ME	PERD EL	POTENZA DISPONIB.		RENDIMENTO TOTALE		
GENERAT	[illegible]	[illegible]	[illegible]		0.3470		

Fig. 8 bis

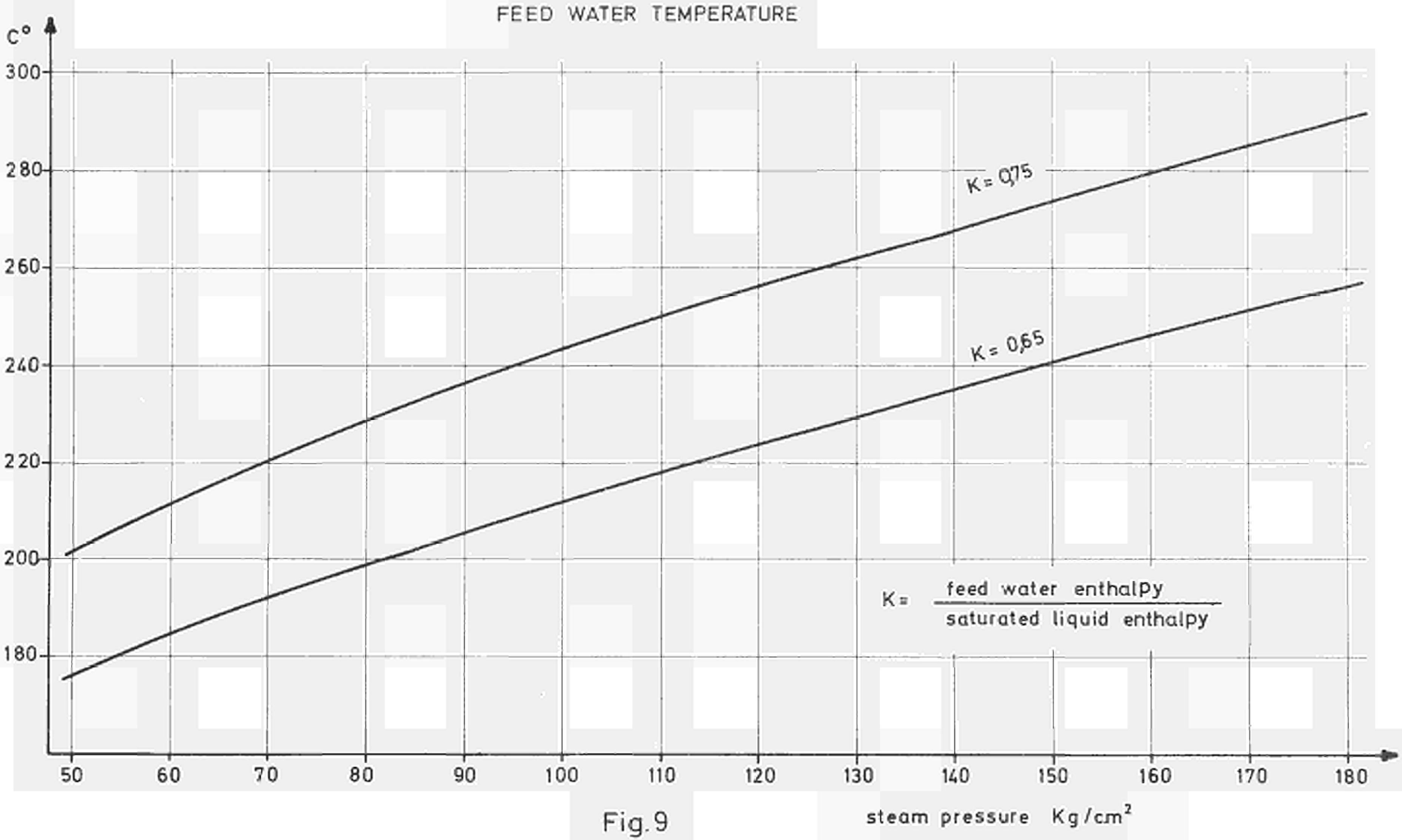

FEED WATER TEMPERATURE
C°
300
280
260
240
220
200
180
K = 0,75
K = 0,65
K = feed water enthalpy / saturated liquid enthalpy
50
60
70
80
90
100
110
120
130
140
150
160
170
180
steam pressure Kg/cm²

Fig. 9

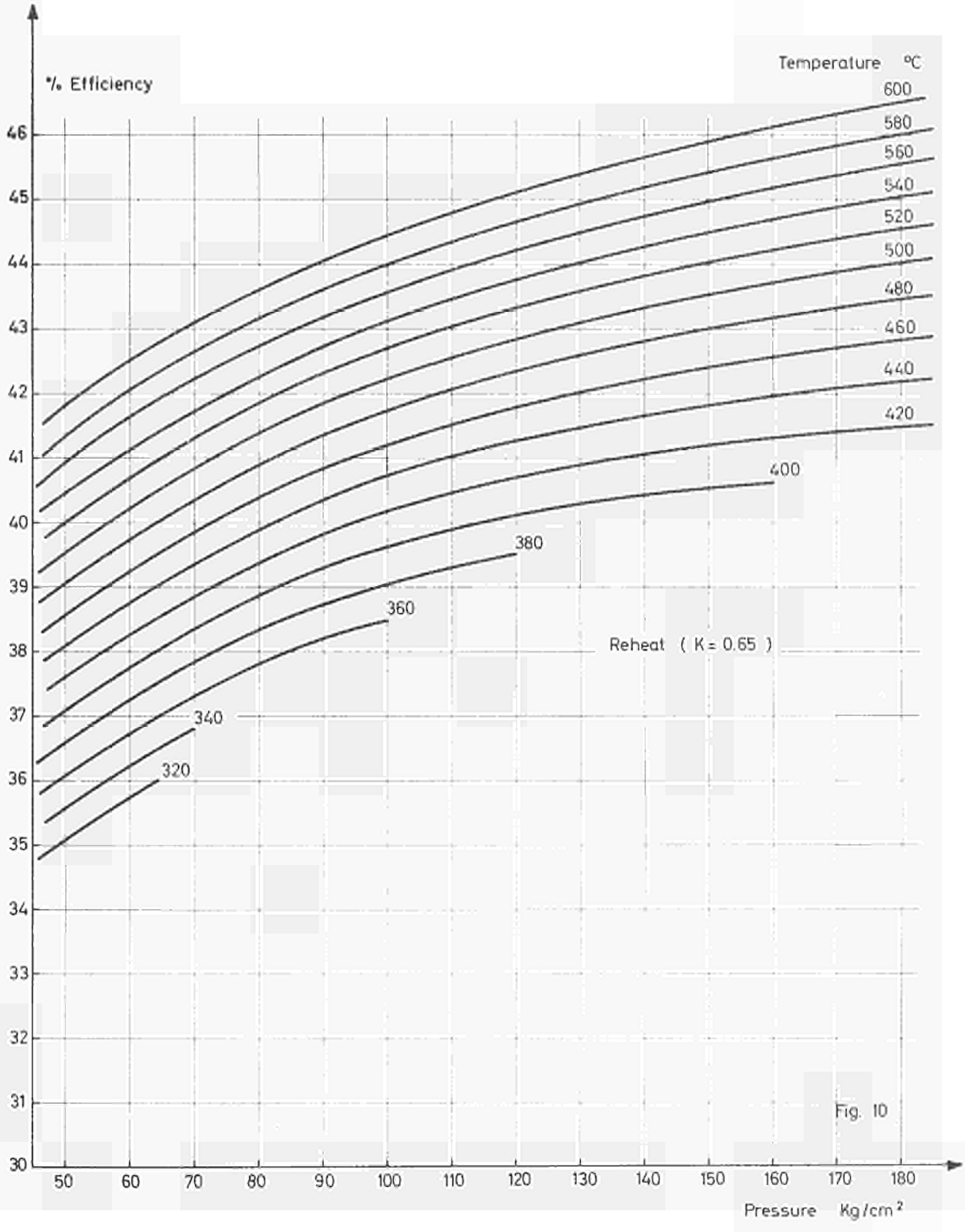

% Efficiency
Temperature °C
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
Reheat (K = 0.65)
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Pressure Kg/cm²

Fig. 10

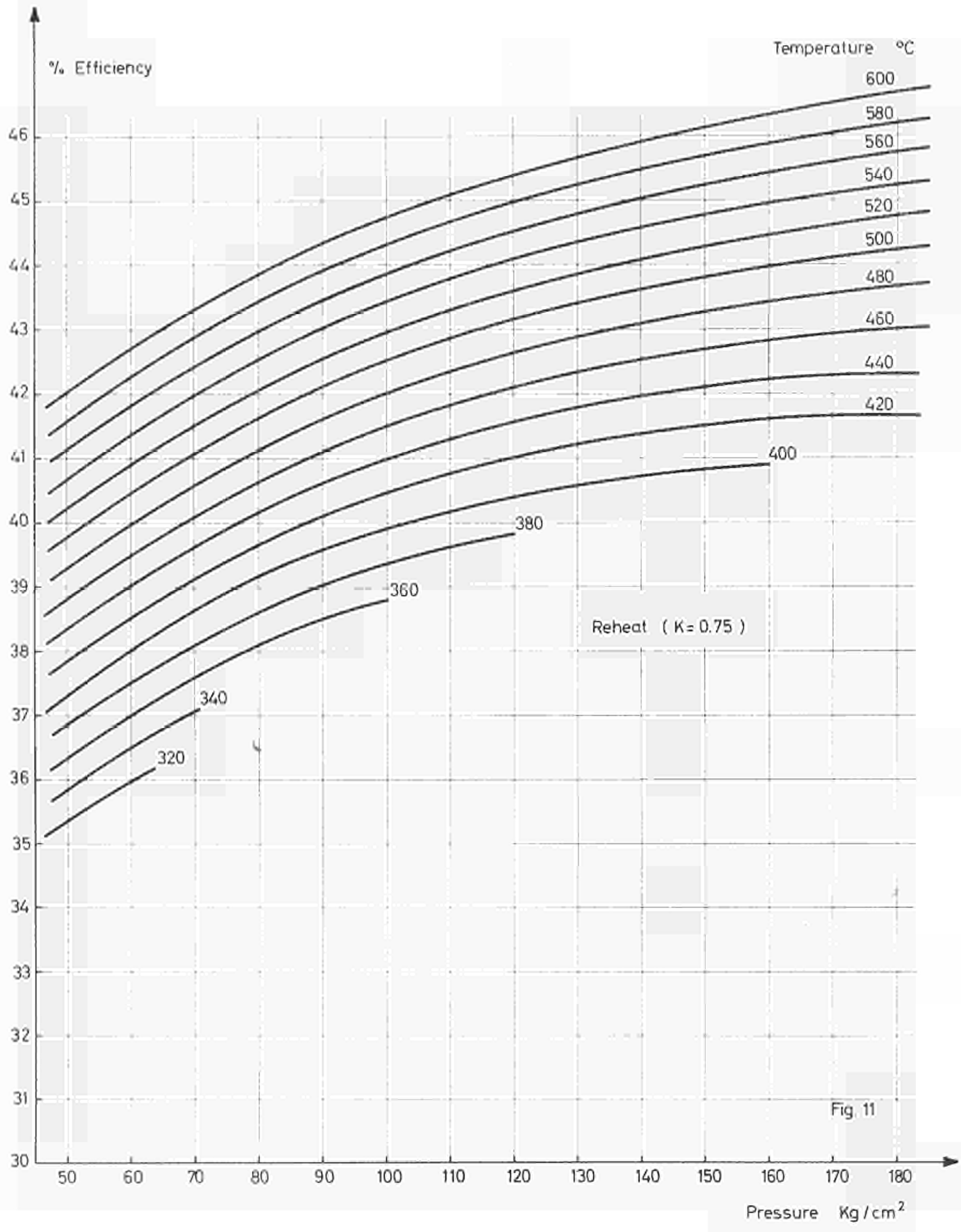
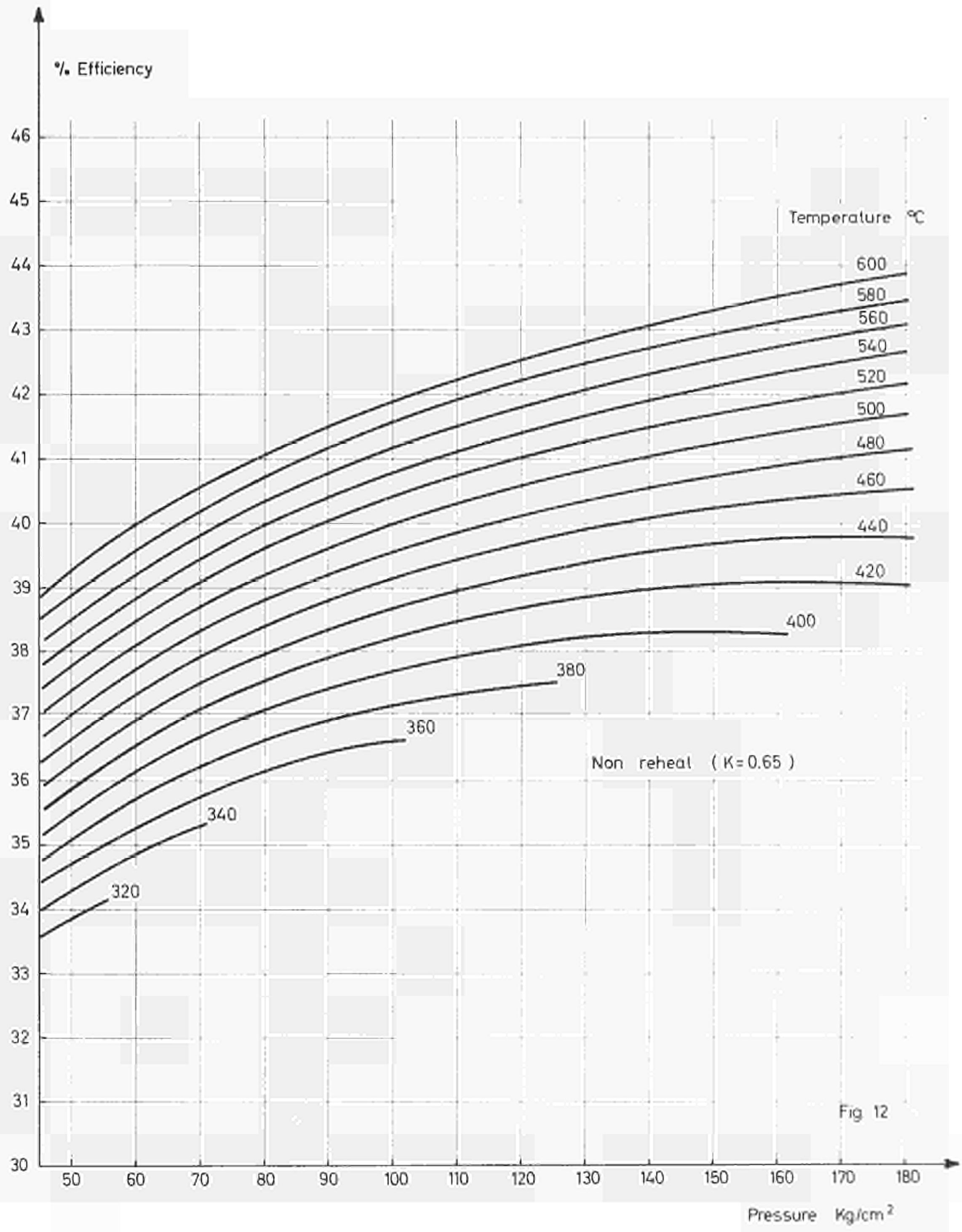
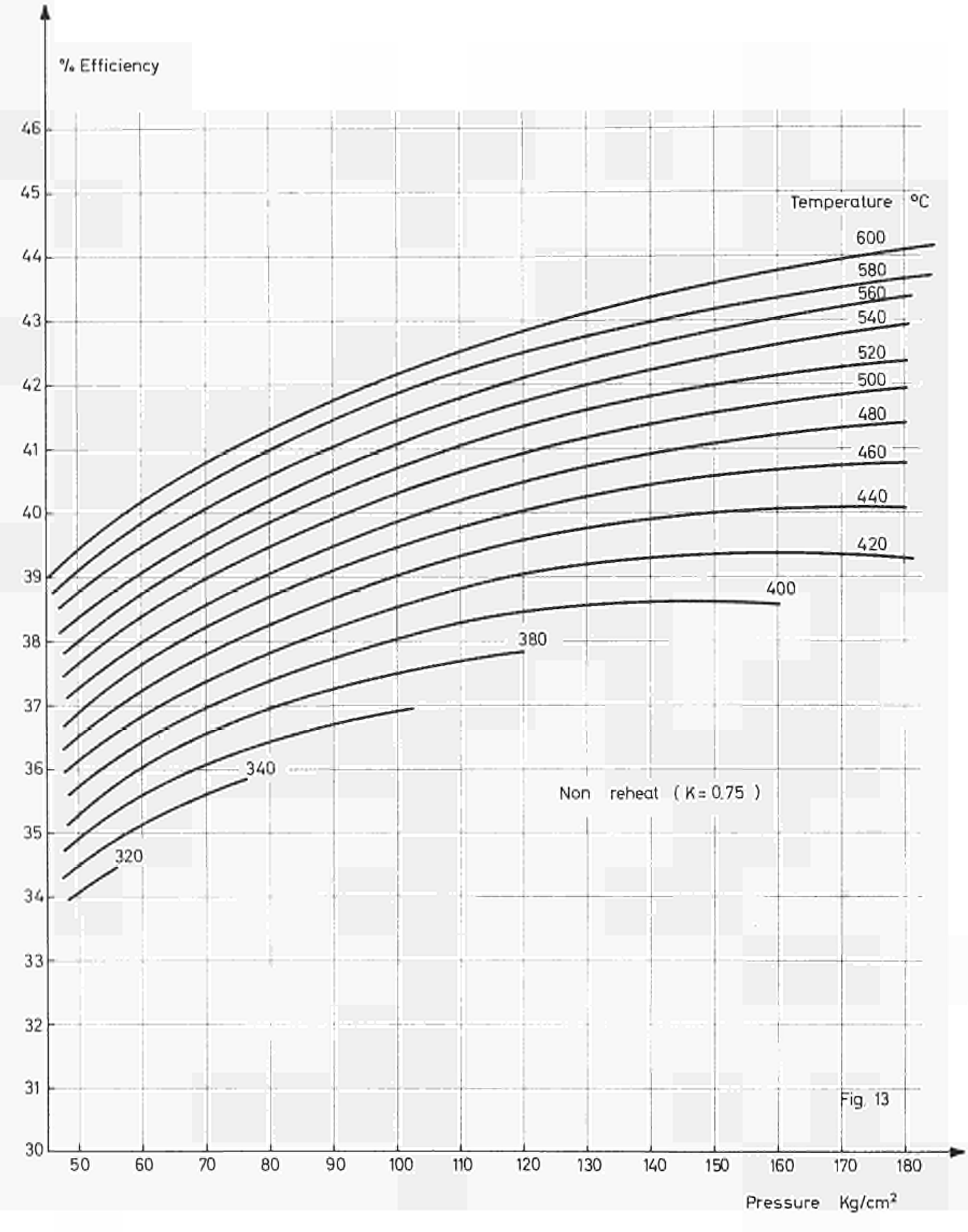

% Efficiency
Temperature °C
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
Reheat (K= 0.75)
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Pressure Kg / cm²

Fig. 11



% Efficiency
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
Temperature °C
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
Non reheat (K = 0.65)
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Pressure Kg/cm²

Fig. 12


% Efficiency
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
Temperature °C
600
580
560
540
520
500
480
460
440
420
400
380
340
320
Non reheat (K= 0.75)
Fig. 13
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Pressure Kg/cm²

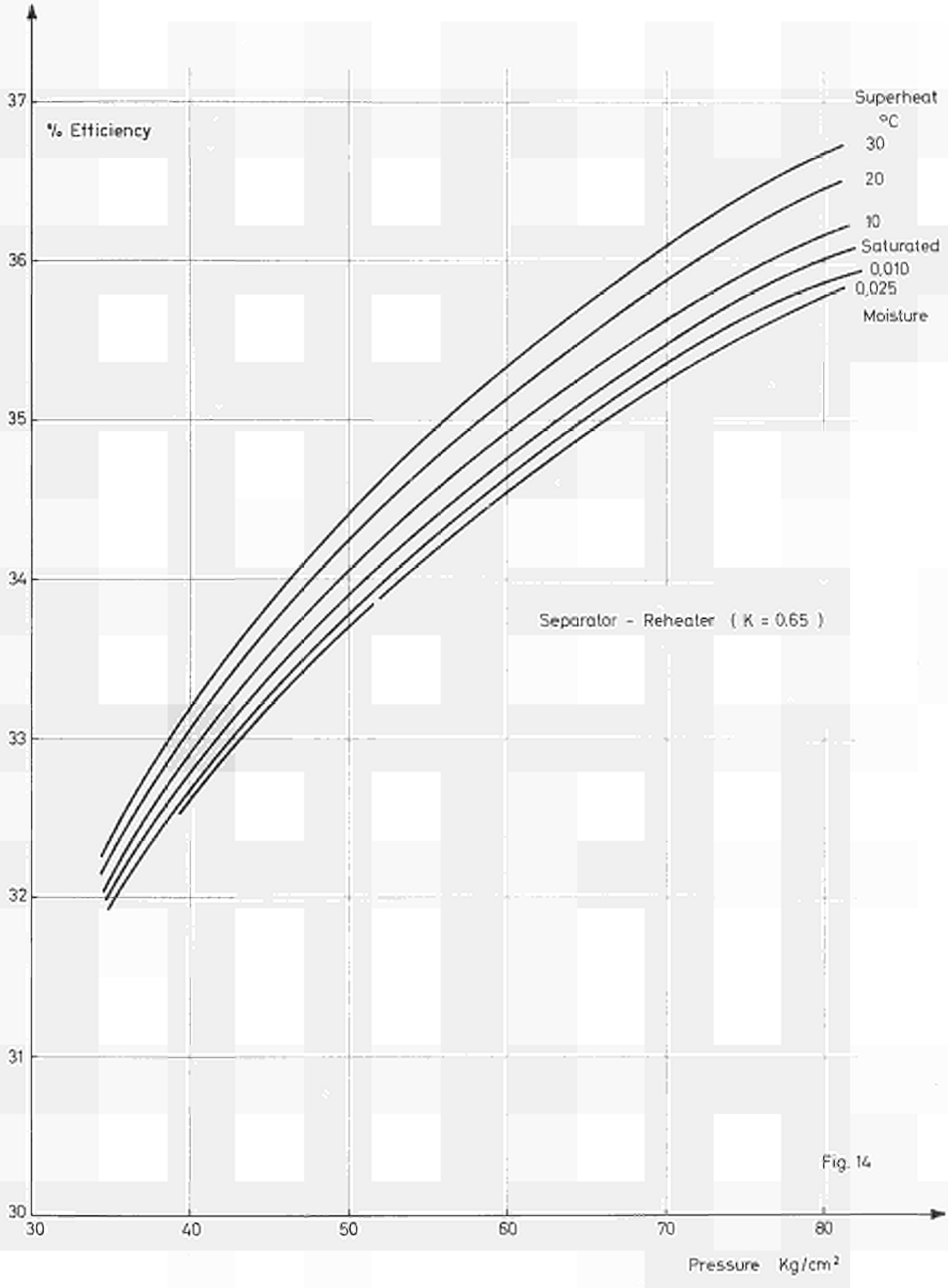
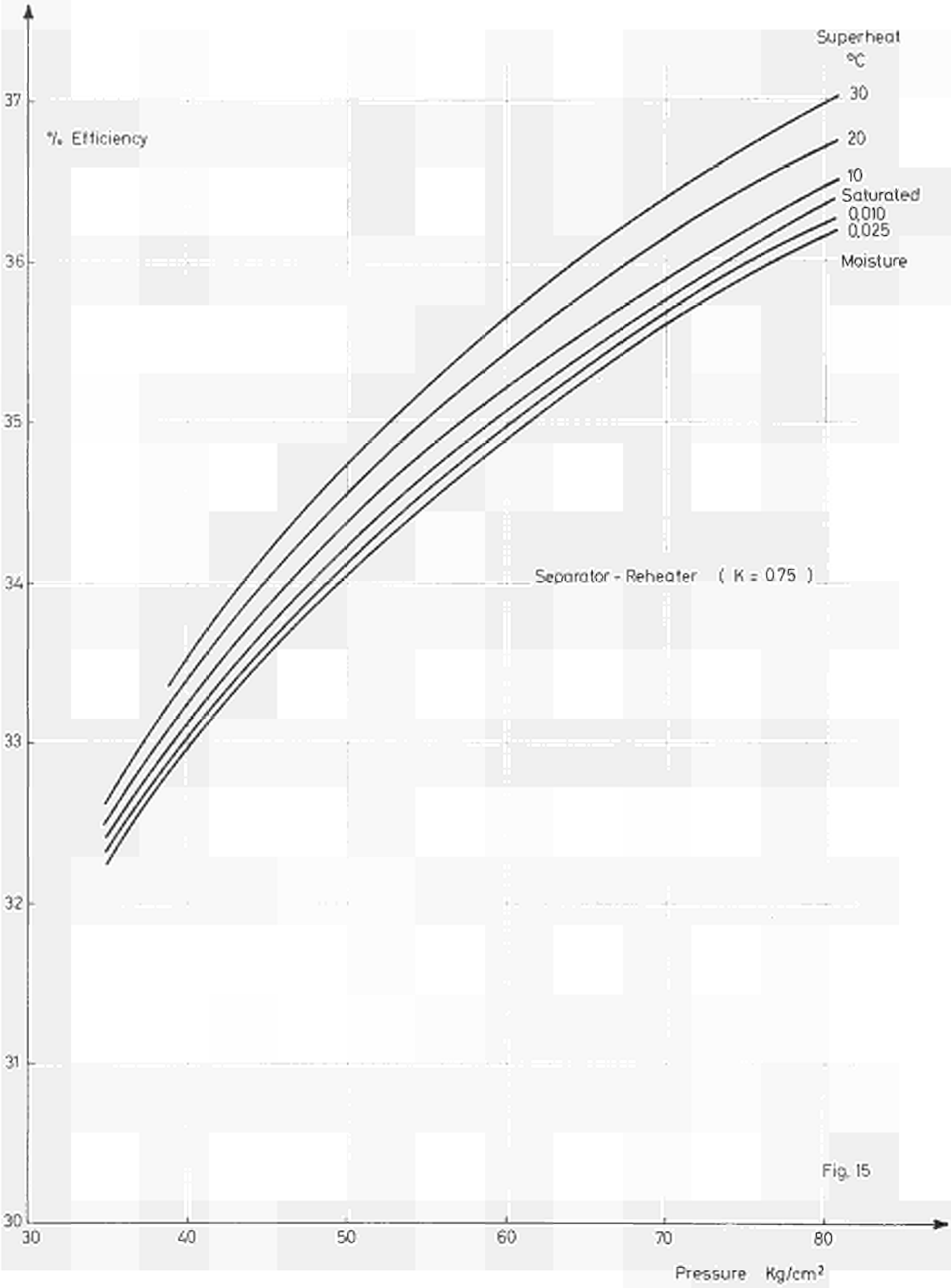
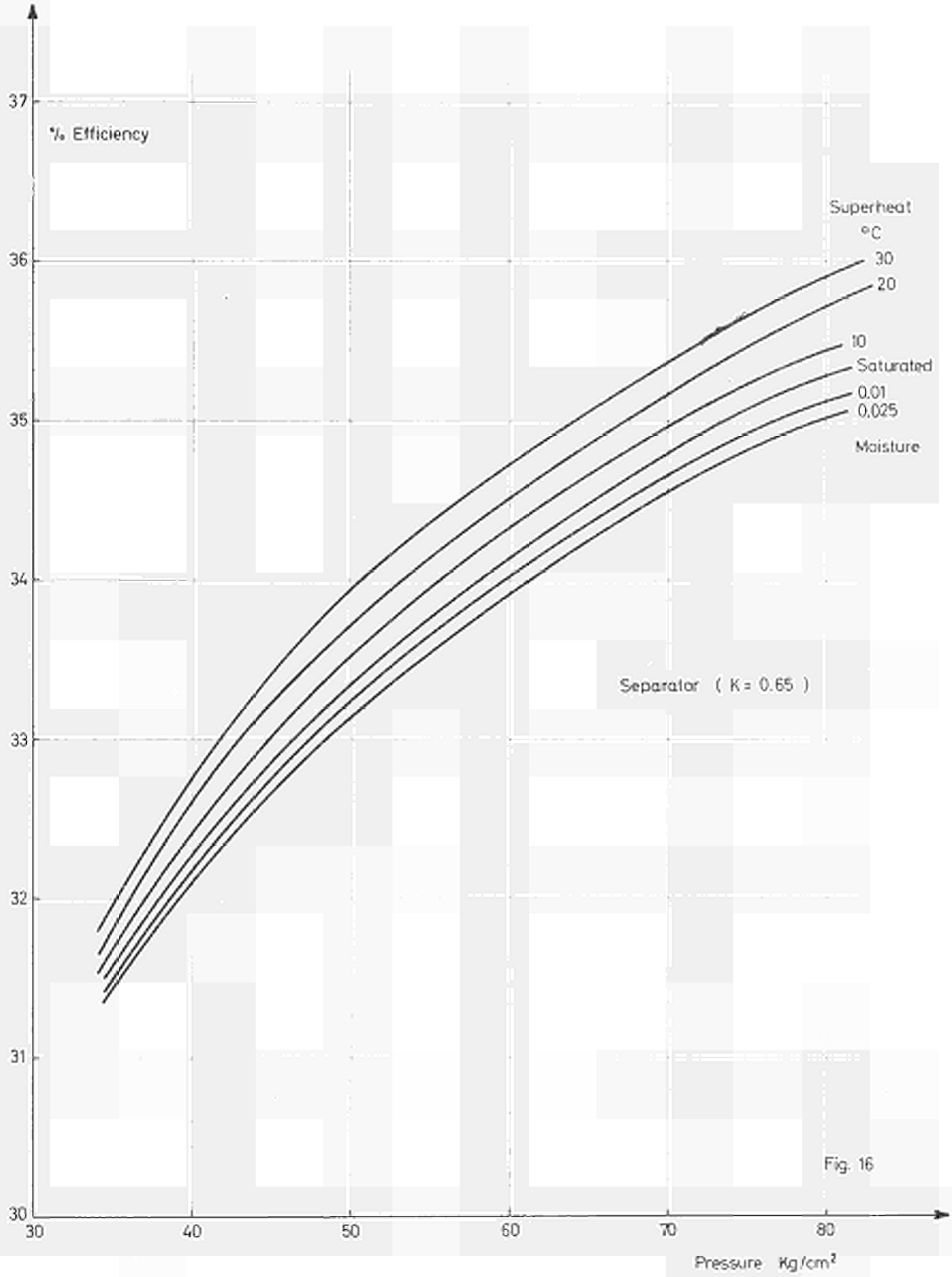

% Efficiency
37
36
35
34
33
32
31
30
30
40
50
60
70
80
Pressure Kg/cm²
Superheat
°C
30
20
10
Saturated
0,010
0,025
Moisture
Separator - Reheater (K = 0.65)

Fig. 14



Superheat
°C
30
20
10
Saturated
0,010
0,025
Moisture
% Efficiency
Separator - Reheater (K = 0.75)
37
36
35
34
33
32
31
30
30
40
50
60
70
80
Pressure Kg/cm²

Fig. 15



% Efficiency
37
36
35
34
33
32
31
30
Superheat
°C
30
20
10
Saturated
0,01
0,025
Moisture
Separator (K = 0.65)
30
40
50
60
70
80
Pressure Kg/cm²

Fig. 16

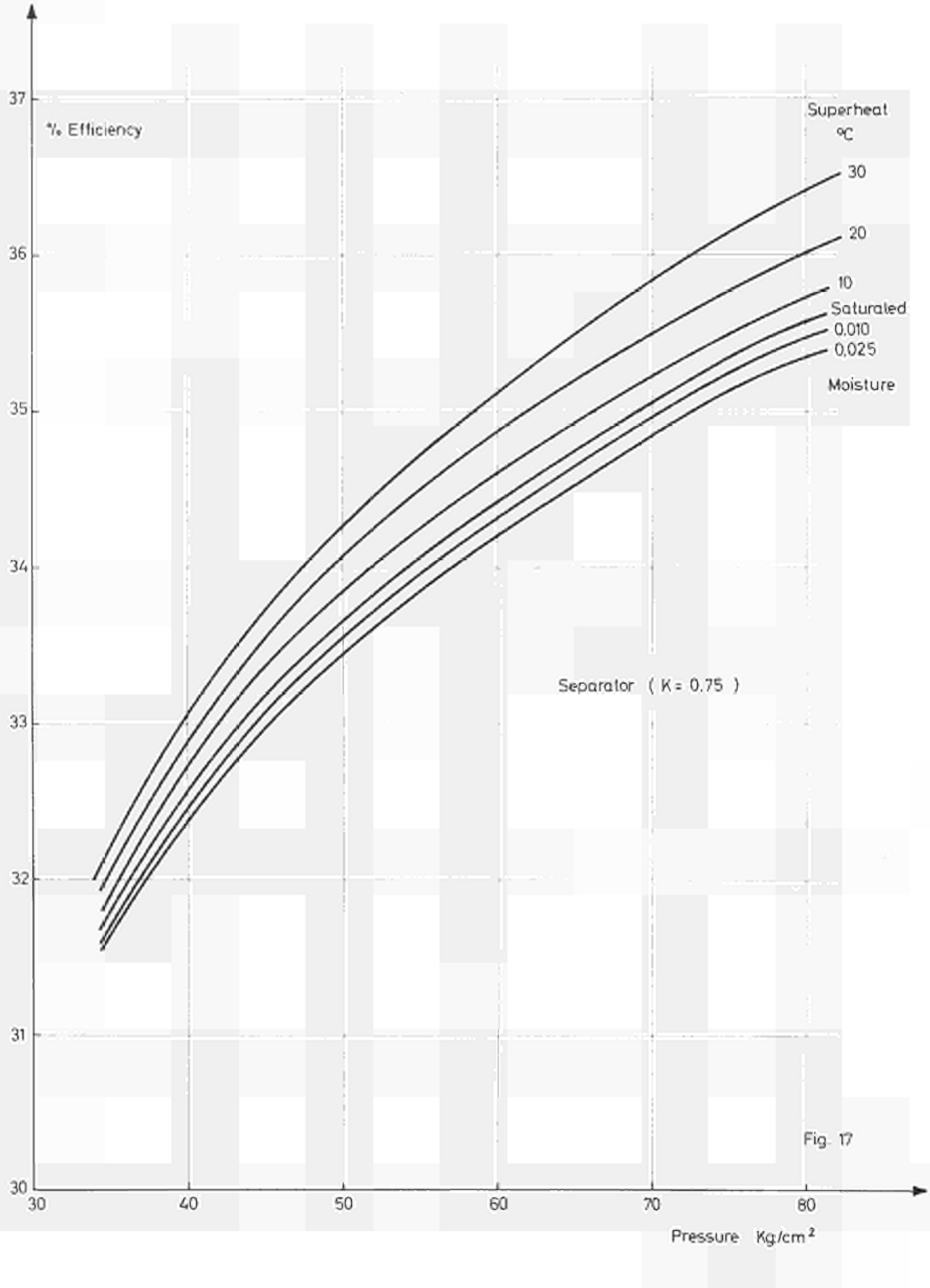
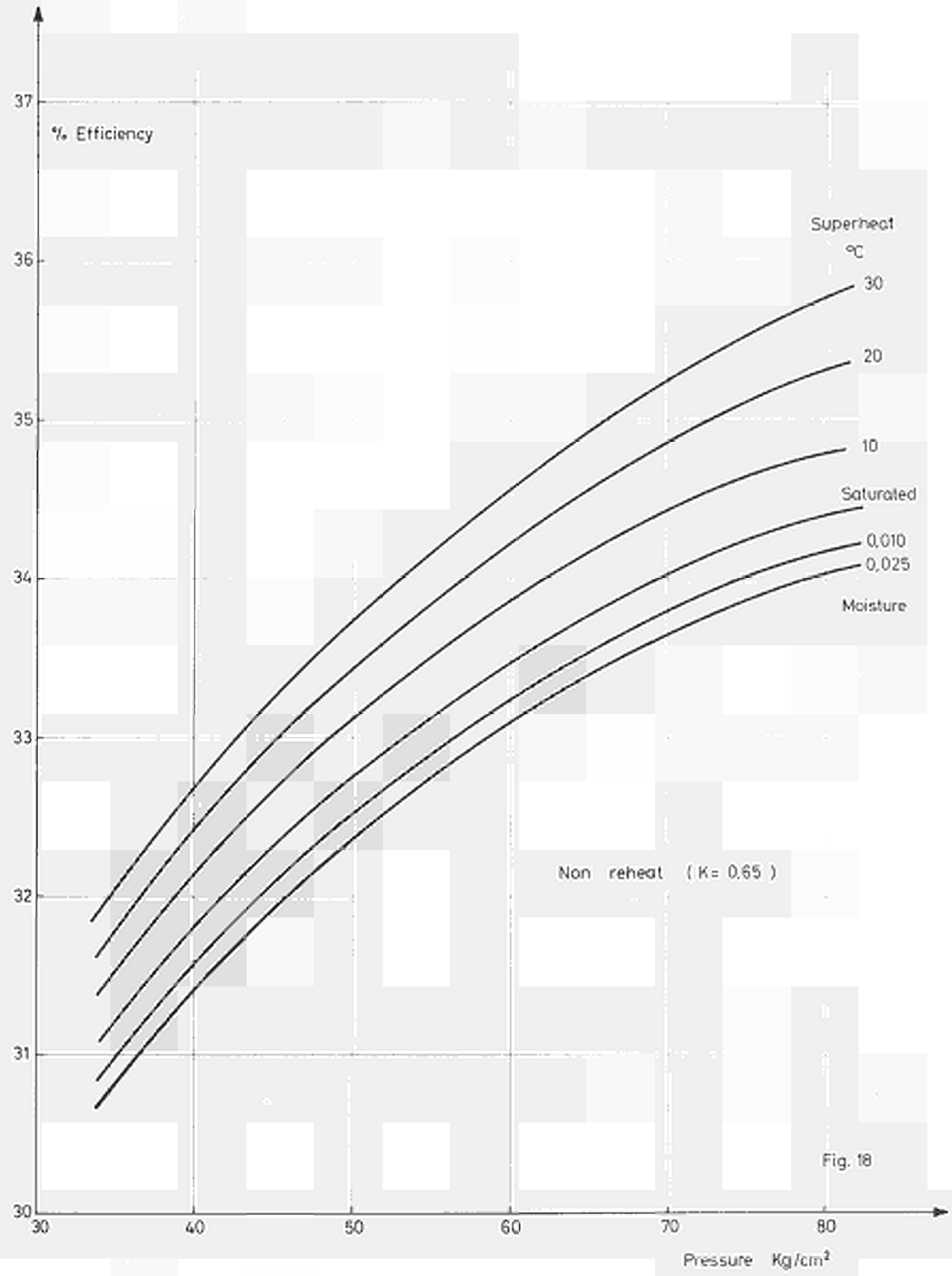

% Efficiency
37
36
35
34
33
32
31
30
Superheat
°C
30
20
10
Saturated
0,010
0,025
Moisture
Separator (K = 0,75)
30
40
50
60
70
80
Pressure Kg/cm²

Fig. 17



% Efficiency
37
36
35
34
33
32
31
30
30
40
50
60
70
80
Pressure Kg/cm²
Superheat
°C
30
20
10
Saturated
0,010
0,025
Moisture
Non reheat (K= 0,65)

Fig. 18

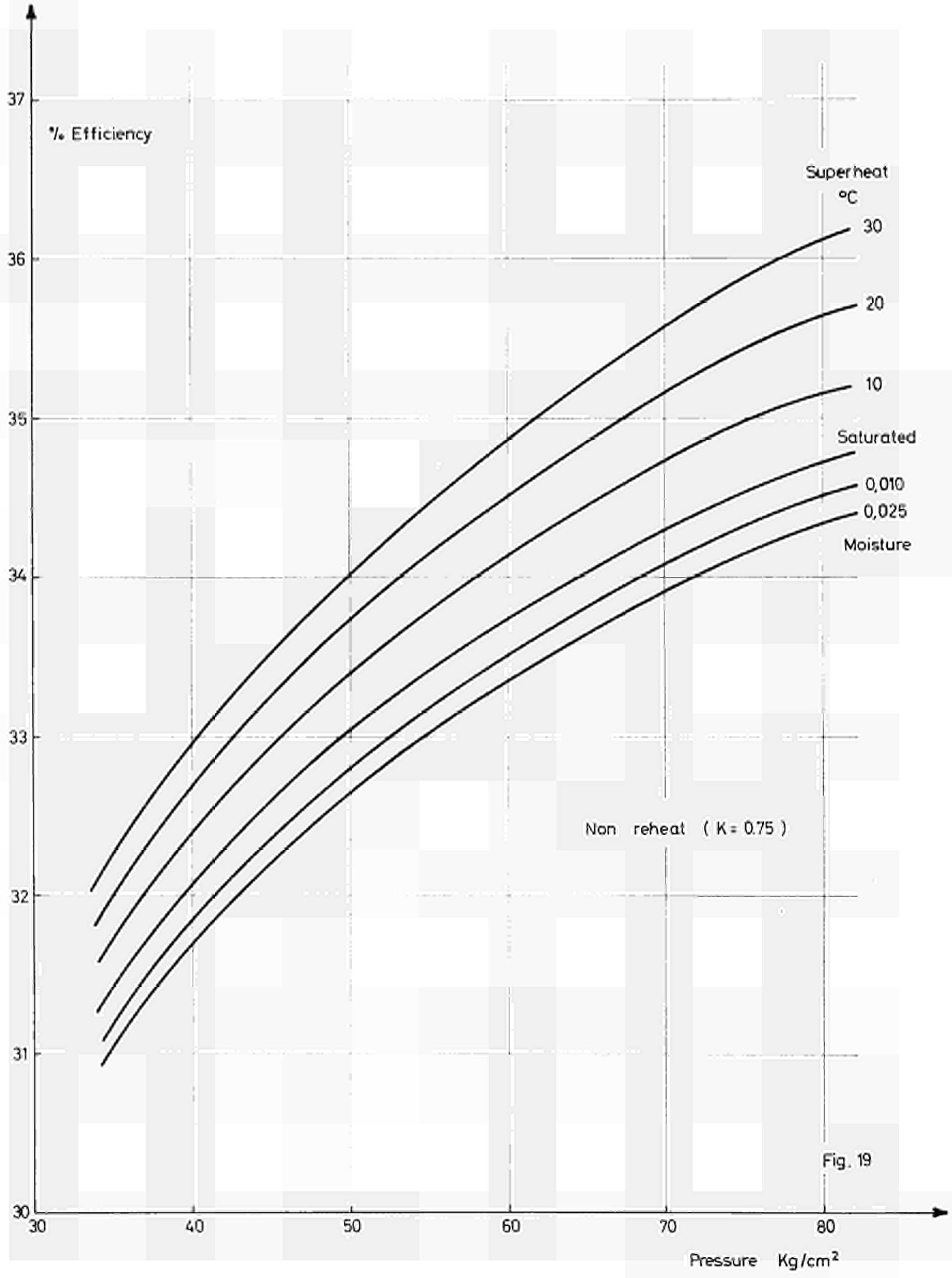

% Efficiency
37
36
35
34
33
32
31
30
30
40
50
60
70
80
Pressure Kg/cm²
Superheat
°C
30
20
10
Saturated
0,010
0,025
Moisture
Non reheat (K = 0.75)

Fig. 19

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Alfred Nobel

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