An Estimate of Steam Condenser Needs for Less Developed Countries

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ABSTRACT:

This report presents an estimate of the steam condenser needs for sixty-four less developed countries. It is assumed all the new power is generated by steam plants and the condenser market is entirely due to growth in the electric power supply. Since the electrical energy consumption of a country increases with an increase in its GNP and population, the market has been calculated by considering the GNP growth rate and population growth rate.

The total LDC power condenser market is estimated to be $13.000.000/year. Virtually all of this is now imported. It is estimated that if local labor and concrete were used to make the shells for the condensers, and the local labor used to install the tubes, 60% of this foreign exchange cost could be saved.

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INTRODUCTION:

One of the ways in which foreign exchange can be saved and local labor utilized is to substitute local products for imported products. In this report we looked at the size of the savings which are possible if concrete shell heat exchangers are substituted for imported steel or cast iron heat exchangers. In particular, we are focusing on the power steam condenser market. because it appears to be a particularly attractive one. Vacuum operation gives rise to compressive stress in the shell and low temperatures reduce the problem of differential thermal expansion. Furthermore, this is the largest single market. The total heat energy for power production is about equal to that for industrial case. All steam power systems use condensers while many industrial systems do not, as the steam is used for process heating or the heat is not converted to steam at all.

In the first part of this report the method of calculating the market for steam condensers will be described. Then an example problem will be worked on. A tabulation will give the results for all LDC's. Detailed calculations for most of these countries will appear in appendicies.

THE CALCULATION OF EXPENDITURES FOR STEAM CONDENSERS IN LDC'S,

A diagram of the power system which we are considering is shown on Figure 1.

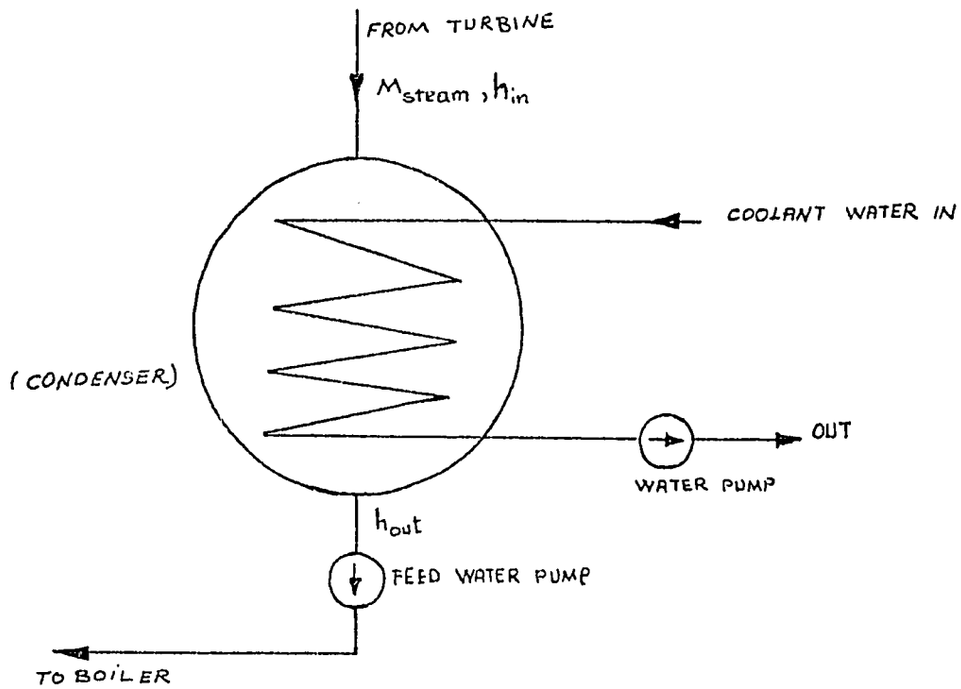

Figure (1)

REJECTED HEAT IN CONDENSER,

$$Q = M_{steam}(h_{in} - h_{out}) \text{ Btu/hr} \quad \ldots \quad 1°$$

where $M_{steam} = mA.^{(*)}$

Since we know the installed electrical capacity (E_E) of a country, we can define the total energy consumption in a condenser as Q. And we let [η] = Thermal efficiency of a power plant.

Rejected heat in condenser becomes

$$Q = \frac{1 - \eta}{\eta} E_E \quad \text{kwh/year} \quad \ldots \quad 2°$$

On the other hand, we have

$$E'_E = P \times E \quad \text{kwh/year} \quad 3°$$

The difference between E_E and E'_E comes from the load factor of the power

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*"m" has been tabulated for different type of power plants on table -1-

plant in one year periodic working hours. Hence, we define the load factor as,

$$(*)_{F(\text{load factor})} = \frac{\text{kw} - \text{hr/year}}{(\text{kw capacity})\text{hr/year}} = \frac{E'_E}{E_E} \quad . \quad . \quad . \quad . \quad 4°$$

Substitution of 4°, 3° into 2° gives us the heat loss as

$$Q = \frac{1 - \eta}{\eta} \; \frac{E \cdot P}{F} \quad \text{kwh/year} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 5°$$

If we assume 1 working year = 8760 working hours and 1kwh = 3412 Btu.

$$Q = 0.38 \cdot \frac{1 - \eta}{\eta} \cdot \frac{E \times P}{F} \quad \text{Btu/hr} \quad . \quad . \quad . \quad . \quad . \quad 6°$$

Combination of eq. 6° and eq. 1° gives the need of the condenser area.

$$A = 0.38 \; \frac{1 - \eta}{\eta} \cdot \frac{E \cdot P}{F} \cdot \frac{1}{m\Delta h} \; (ft^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad 7°$$

Since cost of condenser is a linear function of its area. For this, the formula that has been shown in <u>The U.S. Energy Problem Vol. II</u> (Reférence 1)

$$\$ = 240000 + 2{,}8A(ft^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 8°$$

Formula 8° gives the total cost of the condenser.

INVESTMENT PER YEAR -

Basically, electrical energy consumption of a country will be increased from one year to the next by an increase of its GNP/capita and population. This fact causes an increase in its condenser area. If we assume that the replacement capacity is negligible, the investment per year will be

$$\Delta\$ = (240000 + 2{,}8A_2) - (240000 + 2{,}8A_1)$$

$$\Delta\$ = 2.8\,(A_2 - A_1) \quad \text{or}$$

$$\Delta\$ = 2.8\Delta A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 9°$$

where $[\Delta A] = ft^2/\text{year}$

Since $A = A(E_E)$ (from eq. 7°)

<u>We may find the increase in area by considering the electrical energy increase</u>

* an average load factor has been calculated by using load duration graph of a power plant in appendices.

of a country.

$$E_E = GNP\left(\frac{E}{GNP}\right)P \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 10°$$

$$\frac{dE_E}{dt} = \frac{dGNP}{dt}\left(\frac{E}{GNP}\right) P + GNP \cdot \frac{d}{dt}\left(\frac{E}{GNP}\right)P + GNP \cdot \left(\frac{E}{GNP}\right) \cdot \frac{dP}{dt} \quad . \quad . \quad . \quad 11°$$

where, $\frac{d}{dt}\left(\frac{E}{GNP}\right) = \frac{d}{dGNP}\left(\frac{E}{GNP}\right) \cdot \frac{dGNP}{dt} = \frac{(dE/dGNP) \times GNP - E}{GNP^2} \times \frac{dGNP}{dt}$

Eq. 10° becomes

$$\frac{dE_E}{dt} = E \times P\left(\frac{1}{GNP} \cdot \frac{dGNP}{dt}\right) + E\,\frac{dP}{dt} + \frac{dGNP}{dt}\left(\frac{dE}{dGNP} - \frac{E}{GNP}\right) \quad . \quad . \quad . \quad 12°$$

Statistical results show that electrical energy per capita (E) vs. GNP per capita is approximately a straight line passing through zero. So,

$$\frac{dE}{dGNP} - \frac{E}{GNP} \cong 0$$

The result is the following:

$$\frac{dE_E}{dt} = E \times P\left[\left(\frac{1}{GNP} \cdot \frac{dGNP}{dt}\right) + \left(\frac{1}{P} \cdot \frac{dP}{dt}\right)\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 13°$$

However, $\frac{dGNP}{dt} = \varepsilon GNP, \qquad \frac{dP}{dt} = \zeta P$

If we substitute into eq. 13°

$$\frac{dE_E}{dt} = E \cdot P(\varepsilon + \zeta) \qquad \text{kwh/year} \quad . \quad . \quad . \quad 14°$$

From Equation 7°

$$A = C \cdot E_E$$

$$\frac{dA}{dt} = C\,\frac{dE_E}{dt}$$

or

$$\frac{dA}{dt} = C \times E \times \underline{P}\,(\varepsilon + \zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 15°$$

$C = \frac{A}{E \times P}$ substition into Eq. 15° yields to

$$\frac{dA}{dt} = A(\varepsilon + \zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 16°$$

As a result, the investment per year may be expressed as

$$\Delta\$ = 2.8A(\varepsilon + \zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 17°$$

ASSUMPTIONS THAT HAVE BEEN DONE IN THE CALCULATIONS

Before beginning the calculations it is worthwhile to mentionsome assumptions.

1. Although the load factor changes from country to country, it has been assumed to be the same value for every country (F = 0,48).
2. Power plants' thermal efficiencies are between 35% and 45%. This valu varies depending on the capacity of the power plant, reheat - regenera tive cycles which are used on the system and so forth. However, in the calculations an average value has been used (η = 0.40)
3. As we can see from table 1 "m" lb/hr ft^2 condensation rate of each type plant slightly differs from each other. This result causes same order of difference in condensers' cost. Therefore, the calculations have been done for one type of power plant, i.e. the Bull Run plant.
4. Steam plants have been assumed to provide the total electrical power needs.

EXAMPLE

<u>SPAIN</u> has been taken as an example.

GNP/capita = \$730

(From chart I)

E = 1408 kwh/year

<u>P</u> = 32,621 10^6

(from Eq. 3°) $E'_E = 32,621\ 10^6\ 1408 = 460\ 10^8$ kwh/year

Installed capacity $E_E = \frac{460\ 10^8}{0,48 \cdot 8760} = 11000$ MW

Condenser capacity $Q = \frac{1 - 0.4}{0.4} \cdot 11000 = 16500$ MW or

$Q = 16500\ 10^3\ 3,412\ 10^3 = 56,5\ 10^9$ Btu/hr

$m = 5.9$ lb/hr ft^2

(From table I)

$\Delta h = 940$ Btu/lb

$$A = \frac{Q}{m\Delta h} = \frac{56,5\ 10^9}{5,9\ 940} = 10,20\ 10^6\ ft^2$$

Cost of condenser

$$\$ = 240000 + 2,8\ 10,20\ 10^6 = (0,24 + 28,2)\ 10^6$$

$$\$ = 28,44\ 10^6 \text{ dollars}$$

Investment/year $\varepsilon = 4.4\%$ $\zeta = 1\%$ (from Table II)

$$\Delta\$ = 2,8\ 10,20\ 10^6 (0.044 + 0.01) = 1,540,000 \text{ dollars/year}$$

The results that have been shown on tables II through IV are not a complete picture of less developed countries all over the world. Some countries have been left out. For those countries:

1. The population is in the range of 0.2 ÷ 5 million.
2. Electrical energy consumption per capita is very small (25 ÷ 100kwh/year). Therefore, the costs are negligibly small. The countries which are not included are listed below.

1. Upper Volta
2. Somalia
3. Kwanda
4. Nepal
5. Mali
6. Laos
7. Madagascar
8. Togo
9. Cameroon
10. Senegal
11. Mauritania
12. Liberia
13. Muscat and Oman
14. Ivory coast
15. Jordan
16. Albania

17. Mongolia
18. Singapore
19. Trinidad and Tobago
20. Swaziland
21. Jamaica
22. Malta

CONCLUSIONS:

1. The expenditures for condensers in sixty-four less developed countries have been calculated. Total investment per year = $13,401,000
2. Yearly expenditures for condensers vary in the range of $1.500.000 (India) to $ 16000(Cyprus). It is estimated that 60% could be labor and 40% imported materials instead of 100% imported.
3. In countries such as Spain, Brazil because of their large energy consumption per capita and medium size population it is worth investing in them. For some countries like India, the electrical energy consumption per capita is small. Large population causes the investment to be large.

NOMENCLATURE:

A	Condenser total area (ft^2)
E	Electrical energy consumption per capita, per year (kwh/year, capita)
E'_E	Total electrical energy consumption of a country (kwh/year) (without prime indicates the energy that has been drawing from the power plant)
F	E'_E/E_E Load factor of the power plant.
h	Enthalpy (Btu/lbm)
$\underline{m}$	Condensation rate per unit area (lbm/hr ft^2)
$\underline{P}$	Population (Million)
GNP	Gross national product ($)
ε	$\frac{1}{GNP} \cdot \frac{\Delta GNP}{\Delta t} \times 100$ GNP growth rate (%)
ζ	$\frac{1}{\underline{P}} \cdot \frac{\Delta P}{\Delta t} \times 100$ Population growth rate (%)
η	thermal efficiency of the power plant (%)
M_{steam}	Total condensate steam per hour lbm/hr
h_{in}	Enthalpy of the steam coming into the condenser Btu/lbm
h_{out}	Enthalpy of the water going out of the condenser Btu/lbm.
Q	Rejected heat in the condenser Btu/hr
C	$0{,}38 \frac{1-\eta}{\eta} \cdot \frac{1}{F} \cdot \frac{1}{m\Delta h}$ constant term $\frac{hr\ ft^2}{Btu}$

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TABLES AND CHARTS

TABLE-I

	BULL RUN	COLBERT		GALLATIN		KINGSTON		PARADISE		WIDOWS CREEK	
		1-4	5	1-2	3-4	1-4	5-9	1	2	7	8
M (lb/hr)	$1,89 \times 10^6$	$8,79 \times 10^5$	$1,21 \times 10^6$	$1,08 \times 10^6$	$1,29 \cdot 10^6$	$4,36 \cdot 10^5$	$8,8 \cdot 10^5$	$3,03 \cdot 10^6$	$3,03 \cdot 10^6$	$2,38 \cdot 10^6$	$1,2 \cdot 10^6$
A (Ft^2)	$3,2 \times 10^5$	$9,5 \times 10^4$	$2,6 \cdot 10^5$	$9,5 \times 10^5$	1×10^5	$6 \cdot 10^4$	$8 \cdot 10^4$	$3 \cdot 10^5$	$3 \cdot 10^5$	2×10^5	$1,1 \cdot 10^5$
m ($lb/hr\,ft^2$)	5,9	9,2	4,65	1,14	12,9	7,25	11	10,1	10,1	11,9	10,9
Δh (Btu/lb)	940	984	969	939	939	940	952	958	959	971	963

Condenser properties of various power plants

COUNTRY	GNP/CAPITA U.S. $	E_E/CAPITA kWh/YEAR	POPULATION $\times 10^{-6}$	INSTALLED CAPACITY (MW)	CONDENSER CAPACITY BTU/Hr $\times 10^{-9}$	CONDENSER AREA $Ft^2 \times 10^{-6}$	COST OF CONDENSER U.S. $ $\times 10^{-6}$	GNP GROWTH RATE ε %	P. GROWTH RATE ξ %	INVESTMENT PER YEAR. U.S. $ $\times 10^{-6}$.
EUROPEAN COUNTRIES										
SPAIN	730	1408	32,621	11000	56,5	10,20	28,44	4,4	1,0	1.54
GREECE	740	830	8,803	1720	8,8	1,58	4,64	8,5	0,8	0,41
ASIA/NEAR EAST										
TURKEY	300	200	33,55	1600	8,2	1,48	4,39	4,7	2,5	0,30
IRAN	310	300	29.20	2090	10,8	1,94	5,64	8,5	3,0	0,62
ISRAEL	1360	2037	2.745	1340	6,324	1,23	4,14	3,9	2,4	0,245
CYPRUS	830	800	0,600	114	0,58	0,105	0,535	3,9	1,5	0,016
KUWAIT	3540	4000	0,800	760	3,90	0,70	2,2	5.25	8,2	0,265
SAUDI ARABIA	360	200	8							
YEMEN	70	70	5,90							
IRAQ	260	244	8,634	1160	5,95	1,07	3,24	5,25	2,6	0,235
SYRIA	210	135	5,701							
ASIA/SOUTH EAST										
INDIA	100	100	523,803	12600	64,5	11,5	32,74	2,0	2,6	1,50
PAKISTAN	100	46	123,163	1340	6,324	1,235	3,63	0,7	2,7	0,118
AFGANISTAN	80	80	17,40	334	1,7	0,307	1,10	1,25	2,5	0,032
PHILIPPINES	130	167	39,400	1560	8,1	1,46	4,34	2,2	3,4	0,23
MALAYSIA	330	200	11,100	530	2,7	0,485	1,60	3,1	2,9	0,082
CEYLON	180	150	12,900	460	2,35	0,425	1,44	0,8	2,4	0,0385
ASIA/FAR EAST										
CHINA (TAIWAN)	270	741	13,466	2370	12,2	2,2	6,34	8,8	2,3	0,68
S. KOREA	180	174	30,470	1260	6,5	1,18	3,54	7,2	2,2	0,31
THAILAND	150	92	33,693	740	3,85	0,69	2,18	2,6	3,3	0,114
S. VIETNAM	130	47	17,414	195	1,00	0,132	0,755	4,5	2,1	0,0335
INDONESIA	100	100	124,9	2960	15,2	2,74	7,89	2,2	2,9	0,39
BURMA	70	30	28,5	204	0,96	0,172	0,72	2,6	2,3	0,0236
CAMBODIA	120	100	7,3	174	0,89	0,16	0,69	2,6	3,0	0,0250
CHINA	90	60	772,9	1100	5,65	1,02	3,09	6,0	1,8	0,222
N. VIETNAM	90	40	21,6	205	1,06	0,19	0,77	2,0	2,1	0.022
N. KOREA	250	200	14,3	680	3,50	0,63	2,0	5	2,8	0,138

COUNTRY	GNP/CAPITA U.S. $	E_E/CAPITA kWh/YEAR	POPULATION $\times 10^{-6}$	INSTALLED CAPACITY (MW)	CONDENSER CAPACITY BTU/HR. $\times 10^{-9}$	CONDENSER AREA $Ft^2 \times 10^{-6}$	COST OF CONDENSER U.S. $\times 10^{-6}$	GNP GROWTH RATE ε %	P. GROWTH RATE ξ %	INVESTMENT PER YEAR U.S. $\times 10^{-6}$
LATIN AMERICA										
BRAZIL	250	433	88,209	9100	46,5	8,4	23,74	7,4	2,8	2,4
CHILE	480	734	9,351	1640	8,4	1,51	4,44	5,1	1,9	0,294
COLOMBIA	310	338	20,043	1620	8,3	1,5	4,44	3,0	3,2	0,26
MEXICO	530	480	47,627	5450	28	5,05	14,44	2,8	3,3	0,87
ARGENTINA	820	758	24,700	4460	23,0	4,12	11,84	2,0	1,4	0,39
CUBA	310	556	8,270	1090	5,6	1,01	3,68	3,0	1,9	0,14
COSTA RICA	450	500	1,900							
EL SALVADOR	280	216	3,6							
GUETEMALA	320	300	5.3							
HONDURAS	260	102	2,8							
NICARAGUA	370	200	2,1							
BOLIVIA	150	140	4,8							
DOMINICAN REP.	290	250	4,4	4750	24,4	4,4	12.54	2,4	2,9	0,65
ECUADOR	220	140	6,3							
PANAMA	580	500	1,5							
PARAGUAY	230	200	2,5							
PERU	380	500	14,0							
URUGUAY	520	680	2,9							
VENEZUELA	950	120	11,1							
HAITI	70	32	5,4							
PUERTO RICO	1340	500	2,9							
AFRICAN COUNTRIES										
UNITED ARAB REP.	175	210	31,693	1590	8,2	1,48	4,39	3,0	2,9	0,245
ALGERIA	220	100	14,50	345	1,78	0,32	1,14	0,5	2,9	0,0305
TUNISIA	220	170	5,3	214	1,12	0,20	0,80	3,1	2,7	0,0325
LIBYA	1020	500	1,9	226	1,16	0,21	0,83	2,8	3,1	0,0350
NIGERIA	70	50	56,5	672	3,451	0,625	4,160	0,5	2,6	0,0545
ETHIOPIA	70	15	24,212							
GHANA	170	310	8,376							
KENYA	130	100	11,200							

COUNTRY	GNP/CAPITA U.S. $	E_E/CAPITA Kwh/YEAR	POPULATION $\times 10^{-6}$	INSTALLED CAPACITY (MW)	CONDENSER CAPACITY BtU/Hr $\times 10^{-9}$	CONDENSER AREA. $Ft^2 \times 10^{-6}$	COST OF CONDENSER U.S. $\times 10^{-6}$	GNP GROWTH RATE ε %	P. GROWTH RATE ξ %	INVESTMENT PER YEAR U.S. $\times 10^{-6}$
MALAWI	50	50	4,60							
MORRACCO	190	150	16,30							
RHODESIA	220	180	5,20							
TANZANIA	80	100	13,60	3260	16,8	3,05	8,74	1,83	3,0	0,410
UGANDA	110	100	8,80							
ZAMBIA	220	180	4,40							
CONGO	90	80	17,80							
SUDAN	100	100	16,30							
TOTAL				80312	415,1431	74,8355	224,235			13,4010

K+E 10 X 10 TO THE INCH 46 0780
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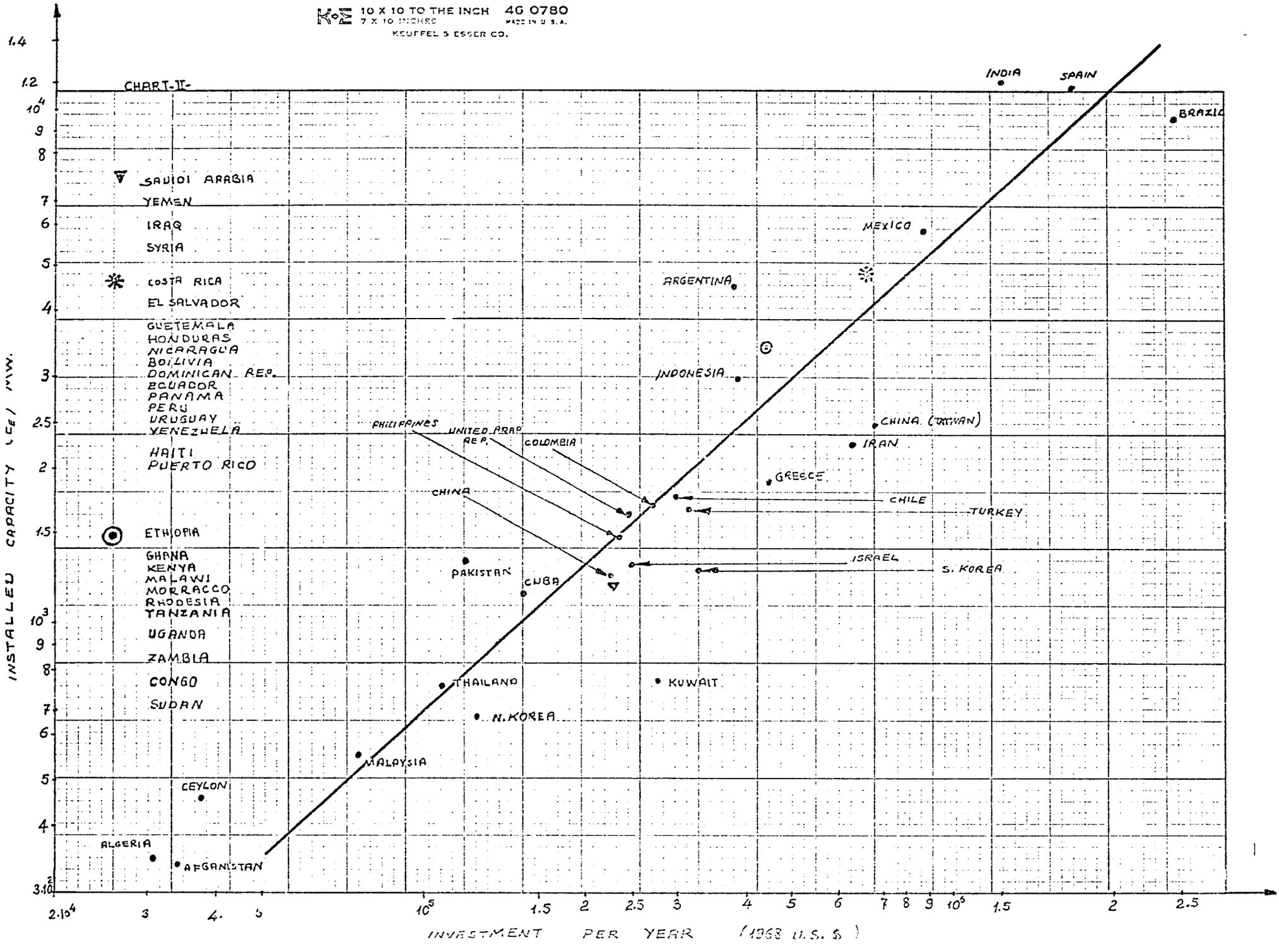

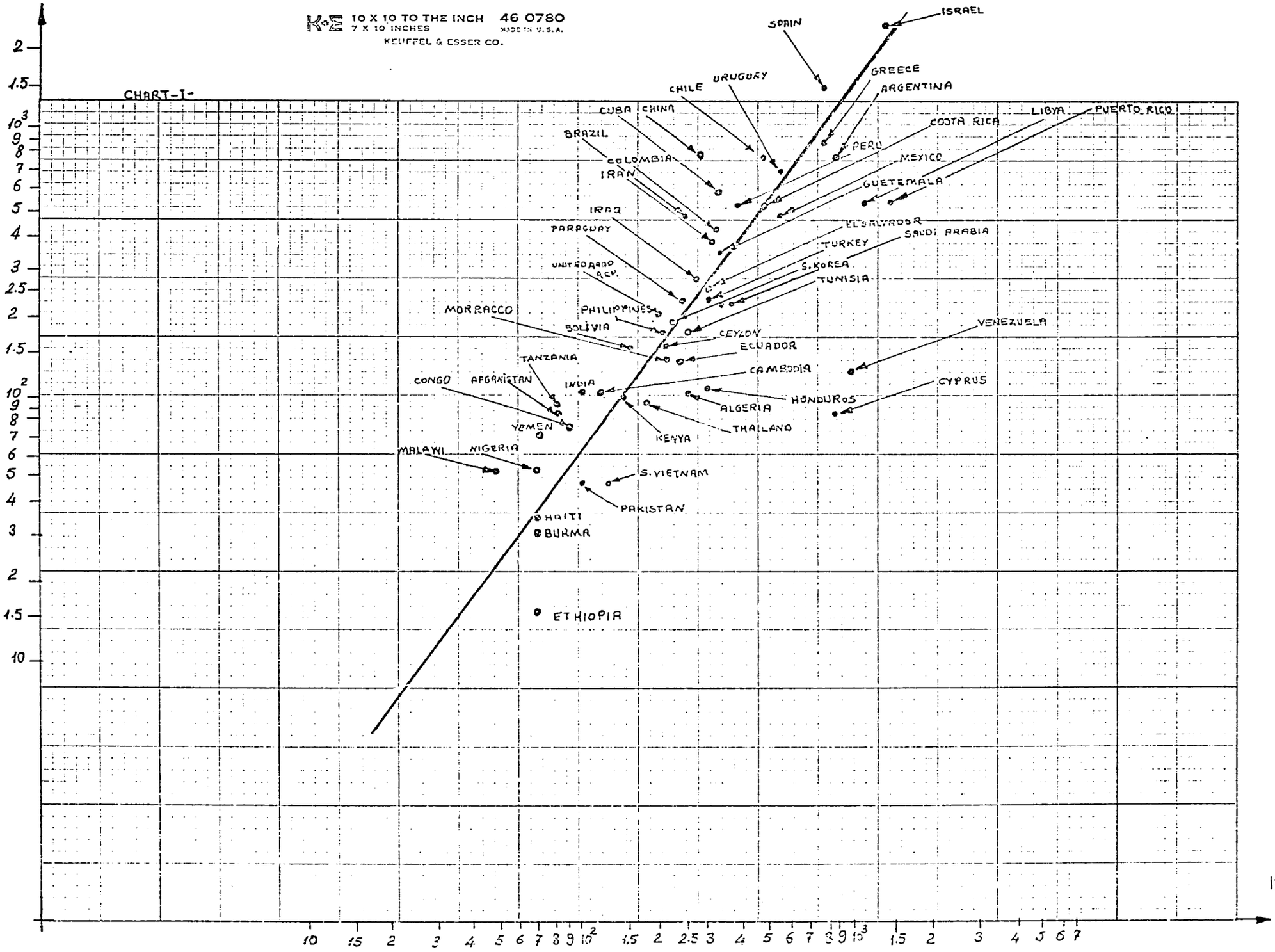
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