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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

WATER DESALINATION ECONOMICS IN NOTHERN EUROPE BASED ON WATER REACTORS

1968

Report prepared by
Atlas Werke GmbH, Bremen - Germany,
BelgoNucléaire S.A., Brussels - Belgium and
Société de Traction et d'Electricité, Brussels - Belgium

Euratom Contract No. 029-66-4 ECIC

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SUMMARY

Water shortage in Western Europe occurs very seldom and in specific areas only. This position will continue to prevail quite generally in most locations. This means that mere conservancy or regulating measures are required.

Water generation may be economically feasible only in specific districts such as those of the Northern coast of the Netherlands and Germany.

On the other hand, the electricity demand will continue to increase much more quickly than the water demand and in this context dual purpose nuclear plants may meet both demands without unduly penalizing the kWh cost.

The Northern Europe population density precludes the likelihood of other than large desalination plants on the mainland.

Technologically and economically, the most suitable desalination process at present is the multiflash system. Such a plant can cope adequately with future demand. The water costs, in fact, fall within the range of prices acceptable in the European Community.

The use of nuclear energy will be precisely suitable in the large capacity range soon required in the fast developing region of the Northern part of the European Community, to cope with the corresponding demographic and industrial expansion.

KEYWORDS

SEA
WATER
DESALINATION
ECONOMICS
REACTORS
EUROPEAN ECONOMIC COMMUNITY

FOREWORD

This report endeavours to give a comprehensive appraisal of the present and future water and electricity supply and demand in the Northern part of the European Community.

It also reviews the measures to be taken to avoid possible shortages, together with their technological and economical implications, and more particularly in the field of combined water and electricity production, using nuclear energy.

Figures pertaining to these fields, together with their degree of reliability, are given wherever possible or available.

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CHAPTER I

INVESTIGATION ON WATER REQUIREMENTS.

INTRODUCTION.

This chapter will deal with future water needs (till 1975) which might not be met with conventional means (storage, water treatment, etc...), in critical areas located in the northern part of the European Community.

The water requirements and prevailing water prices are given. A similar survey of the electricity demand is carried out in the same areas, in order to ascertain the advantages to be derived from a combined production of water and electricity.

The areas surveyed are :

1. Belgium
2. Bremen region
3. Hamburg region
4. Netherlands
5. Lower Saxony
6. Schleswig-Holstein

These districts have each been considered with respect to :

1. Water demand, present and future
2. Available supply
3. Potential shortage
4. Remedial measures
5. Electricity requirements

The corresponding hydrographic maps are shown on :

- Fig. 1. 1. : Belgium
- Fig. 1. 2. : Northern Germany (Bremen, Hamburg, Lower Saxony and Schleswig-Holstein)
- Fig. 1. 3. : Netherlands

The water requirements have generally been classified in accordance with their kind (domestic, industrial, agricultural, waterways). It is understood that these requirements may be met with the same water successively (series operation or recycle).

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The following tables give an idea of industrial water consumption variation trends according to the type of industry and the watershed, respectively

Industry	Yearly consumption, 1.000 m^3				
	1960	1961	1962	1963	1964
Mining	171.835	174.128	178.940	168.658	146.142
Coke and gas works	44.153	39.023	50.085	50.975	50.215
Power stations, thermal	-	-	-	-	73.844
Iron works	567.964	558.623	627.332	672.685	644.811
Chemical	308.631	292.528	281.052	312.332	327.424
Textiles (finishing)	18.802	19.404	18.299	18.808	18.064
Glass	19.625	41.550	19.794	24.490	27.285
Margarine and edible oils	15.495	14.395	14.044	13.557	14.775
Alcoholic drinks	6.667	6.951	6.582	6.992	5.054
Other drinks	18.173	20.480	20.085	19.054	17.808
Food	15.801	15.315	13.357	14.659	16.246
Paper	86.558	82.445	80.712	86.194	85.238
Total	1.293.562	1.284.585	1.331.563	1.426.258	1.426.902

Watershed	Yearly consumption, 1.000 m^3				
	1960	1961	1962	1963	1964
Yser	694	691	721	695	743
Coastal	87.944	79.739	78.117	80.295	89.679
Schelde	355.368	356.190	348.330	382.644	386.366
Maas	800.767	795.330	838.566	892.964	883.265
Rhine	48.784	52.209	65.821	69.590	66.833
Oise	5	26	8	70	17
Total	1.293.562	1.284.585	1.331.563	1.426.258	1.426.902

Another aspect is that a large number of commercial undertakings and industrial plants have their own wells or boreholes whose operation has so far not been effectively measured, controlled or restricted and the corresponding figures of the following table must be considered as indicative only. This is quite understandable in view of the difficulty of enforcing any restriction on the use of such water supplies when such restrictive measures were not urgently required till now.

Origin	Yearly consumption, 1.000 m^3				
	1960	1961	1962	1963	1964
One or more wells	97.346	88.535	86.147	88.331	91.433
River or canal	1.126.640	1.122.731	1.155.800	1.239.701	1.245.313
Public distribution	14.872	15.518	16.816	17.482	18.440
Other origin	54.704	57.401	72.801	80.744	71.716
Total	1.293.562	1.284.585	1.331.563	1.426.258	1.426.902

- Future

No figures can be given at present in view of the past attitude concerning statistics. The general good will obviously lead to a more rational approach. Furthermore, industry being cost-minded before anything else, it will react automatically to any financial pressure. But this financial pressure, on the other hand may discourage potential foreign investments in new industries which are particularly required in the coal district and the South of Belgium.

Another aspect is the amount of pollution that an industry may be allowed to cause. It is abnormal that an industrial user who buys his water at a nominal price should be allowed to do with it what he likes. A correct attitude would be to charge him according to :

- the quantity used,
- the quantity restored (reduction),
- the amount of pollution caused which involves some treatment downstream by a public utility,
- the amount of heat evacuated which prevents reusing the water as coolant for a certain distance downstream. (ref.Commissariat Royal à l'Eau and 29.12.53 by-law).

This aspect of the industrial use of water has led to further recent laws (20.04.65 for instance) and regional water use codes.

Some trends may be gathered regarding future industrial water requirements from the Belgian Ministry of Economic Affairs economic forecasts of product added values for 1970 (See Figure 1.5., where the difference between the total and river-canal drawn amounts of water, corresponds to the figures given for wells, public distribution, etc..., given in the previous table).

d. Waterways

- Present

The amounts of water not essentially required for river down-stream navigation are fed into the canals, as shown hereafter :

- Albert Canal	850.000 m^3/day
- Charleroi-Brussels Canal	50.000 m^3/day
- Flanders Canals (estimated)	740.000 m^3/day

Some of these flows could be reduced quite appreciably down to a minimum corresponding to water requirements along their course if back-pumping was carried out at each lock after the passage of barges. This is only done at present on the Charleroi-Brussels Canal. The minimum flow may also be imposed by other considerations such as public salubrity (case of Ghent), temperature rise (power station condenser cooling requirements), or international obligations (with Holland for instance).

Cooling towers are used in many power stations and industries when required (effect of 29.12.63 by-law).

- Future

The changing pattern and siting of water hungry industries makes future demand predictions rather unrealistic. Some extrapolations have nevertheless been carried out and appear on fig.4. Navigation and pollution are the other main factors to be considered. As mentioned previously, navigation requirements could be minimized by lock back-pumping and pollution regulation is enforceable.

e. General picture.

- Present

At present a few regions show that their underground water reserve has been, or is, in the process of being depleted beyond the point corresponding to a sufficient safety margin. This entails a gradual inland advance of the underground sea water/fresh water interface.

This situation seems to result from the previous position when fresh water supply was only a matter of piping, and pollution or cooling requirements were only very localized, calling for special measures in exceptionally few cases. Fresh water was considered available in almost limitless amounts.

The present position shows that available supplies will not be able to cope with the demand if no adequate preservation or economy measures are taken.

This is illustrated by the example of the Brussels district demand growth (public distribution) :

	Demand in m^3/day						
	1910	1920	1930	1940	1950	1960	1963
Average daily demand	50.000	65.000	96.000	140.000	180.000	185.000	200.000
Peak daily demand	60.000	80.000	120.000	180.000	235.000	235.000	240.000

So far, the Brussels district peak demand has usually been smaller than the peak supply possibilities in summer but the permanent supply possibilities at the end of a dry summer are very often below the maximum peak day demand.

What is disturbing is the large difference between the Brussels district specific consumption of 126 liters/day.inhabitant compared to that of neighbouring cities : Paris : 450 l/d.i.; Basel : 215 l/d.i.; Luxemburg : 332 l/d.i.; Lille : 208 l/d.i. This may quite well be the warning sign of an explosive demand growth characteristic of increased living standards.

- Future

The domestic water future demand has been extrapolated in accordance with previous growth patterns. It remains to be seen whether this approach is correct by comparing the growth patterns in other highly developed countries such as the United States, Great-Britain, Canada, Japan, Germany, Switzerland. This approach is dictated by the unexpectedly large specific consumption difference between the Brussels district and other cities.

The industrial water future demand prediction regarding raw water not of drinkable quality requires a very detailed and painstaking effort to accumulate reliable statistics from which some indicative elements may emerge regarding volumes and growth. These statistics should also cover water reuse and discharge characteristics (pH, impurities, temperature).

The agricultural future requirements will depend in no small measure on the future agricultural policy. This should therefore be worked out by the Ministry of Agriculture.

The future requirements of inland waterways depend essentially on the development program foreseen as well as on international obligations. The Public Works Ministry figures may therefore be extrapolated in accordance with the traffic increase forecasts (if no lock back-pumping is foreseen) and with international obligations.

1.2. - Available supply.

Yearly available supplies are ample and no shortage need be feared in this respect in the near future. What must be achieved though is to provide adequate reserves as the peak demand usually occurs when the supply possibilities are least.

a. - Present.

- Maas watershed

Average rainfall	920 mm per year
Average evaporation	500 mm per year
Area, upstream from Liège	20.800 km^2
Average flow in Liège	
$\frac{(0,920 - 0,500)(20.800 \times 10^6)}{365 \times 86.400}$	277 m^3/sec
Average flow in Liège, measured	273 m^3/sec
Minimum flow in Liège, in very dry periods	30 m^3/sec

- Schelde watershed

Average rainfall	780 mm per year
Average evaporation	490 mm per year
Area, upstream from Antwerp	19.500 km^2
Average flow in Antwerp	
$\frac{(0,700 - 0,490)(19.500 \times 10^6)}{365 \times 86.400}$	179 m^3/sec
Average flow in Antwerp, estimated	80 m^3/sec
Minimum flow in Antwerp, in very dry periods	20 m^3/sec

b. - Future.

- Maas watershed
  - With the implementation of the Dohan-Daverdisse interconnected reservoirs of 1.258 x 10^6 m^3 capacity on the rivers Semois and Lesse, the Maas minimum flow in Liège becomes 67 m^3/sec for two successive dry years.
  - With the Aisne plan, creating a 420 x 10^6 m^3 capacity reservoir, the Maas minimum flow in Liège is increased to 45 m^3/sec.
- Schelde watershed

  A reserve of some 110 x 10^6 m^3 can be provided. This corresponds to a minimum flow increase in Antwerp of some 4 m^3/sec.
- Very little water treatment has been carried out in Belgium till now. Its cost with modern means is of about 1,5 to 2 BF/m^3 (figure correspondint to a 20.000 inhabitants filtration and chemical plant).

1.3. - Potential shortages.

This may occur in dry periods if no preventive measures are taken in time.

a. - Present.

Daily minimum flow in (Maas + Schelde)	4,3 . 10^6 m^3/day
Present domestic demand, average	0,78 . 10^6 m^3/day
Present domestic demand, peak	0,98 . 10^6 m^3/day
Balance available for other uses	(4,3 - 0,98) 10^6 =
(no domestic water recycle)	3,32 . 10^6 m^3/day
Actual demand for navigation (canals)	
available for industry and agriculture	1,8 . 10^6 m^3/day
Agriculture (almost completely lost	
by evaporation)	x1
Flow available for industry	(3,32 - x) 10^6/day
Present demand for industry	4,2 . 10^6 m^3/day
Industry recycle ratio	4,2/3,32 > 1,26

b. - Future (1980 domestic demand and 1975 industrial demand)

Daily minimum flow in (Maas + Schelde) if no supply measures are taken	$4,3 \cdot 10^6\ m^3/day$
Peak domestic demand	$1,6 \cdot 10^6\ m^3/day$
Balance available for other uses excluding domestic water recycling	$(4,3 - 1,6)\ 10^6 =$ $2,7 \cdot 10^6\ m^3/day$
Future demand for navigation (canals) available for agriculture and industry	$2,89 \cdot 10^6\ m^3/day$
Lack of water flow (considering that no domestic water is rejected in waterways)	$0,19 \cdot 10^6\ m^3/day$
Agriculture (considered lost by evaporation)	$x_2 > x_1$
Future needs of industry	$6,71 \cdot 10^6\ m^3/day$
Flow assumed available for industry	$2,89 \cdot 10^6\ m^3/day$
Industry recycle ratio	$6,71/2,89-x_2 > 2,32$

Figure 1.4. shows that a shortage may be feared from 1975 onwards if no remedial measure, such as the Aisne reservoir, is taken and no domestic effluents are rejected in waterways.

1.4. - Remedial measures.

Belgium can thus be characterized as having its potential water shortage in function of the minimum flow in its rivers.

Those shortages can therefore be avoided by :

a. Providing sufficient storage capacity (dams and reservoirs).
b. Reuse after treatment, of domestic effluents.
c. Extensive use of recycling.

The application of these measures should prevent any shortage, even temporary, till the year 2000 at least.

This could nevertheless not always be true locally in view of the possible increasing water pollution in the future.

This will be dealt with in the conclusions of this paragraph.

1.5. - Electricity requirements.

The diagram of electricity demand between 1955 and 1975 can be found in figure 1.6.

One can therefore see that between the years 1965 and 1975 there will be an increase of 3.650 MWe installed power required, of which 1.200 MWe would be of nuclear origin.

In the meantime, if the same minimum flow of $7,9 \cdot 10^6$ m^3/day expected for 1975 would have to be provided by desalination, a maximum of $(7,9 - 4,3)\ 10^6 = 3,6 \cdot 10^6$ m^3/day of seawater would have to be processed.

1.6. - Conclusions.

As mentioned in paragraph 1.4., the statement that no shortage would occur till the year 2000, must be taken with restriction when considering the matter of increasing river pollution.

If no serious effluent control measures are taken or if the treatment cost of these effluents became prohibitive, other methods such as desalination would have to be taken into consideration.

It is however too early yet to forecast with any precision :

a. What will be the amount of pollution to be considered in every location.

b. What legal restrictive measures will be enforced in the meantime.

c. What will be (for every location) the water treatment and recycling cost compared to that of desalination.

This all boils down to considering these matters within the context of the various local conditions.

Available waterway pollution data are given in the following figures :

- Fig. 1.7. : Maas
- Fig. 1.8. : Albert Canal
- Fig. 1.9. : Schelde

Summing it up, the future development trends will be governed by water cost. At present, Belgian water prices vary across the country in accordance with local considerations. As an example, the price of drinking water in Brussels, which was of 0,22 UA/m^3 (x) till very recently, has just been increased to 0,274 UA/m^3.

(x) UA : units of account : 1 US $.

Industry is almost invariably located on or near a river or canal bank. It is thus in a position to receive its cooling water at a minimum cost. It can also draw its water from bank located wells within its own precincts and thus have a very valuable filtering means.

Industry must of course comply with existing laws and by-laws regarding the nature and temperature of its effluents.

2. BREMEN REGION.

2.1. - Demand.

a. Public distribution.

The present demand in the town and the province of Bremen can be ascertained from the figures given on Fig. 1.10 and 1.11.

The extrapolation is based on an annual population increase of 1 % and a water demand increase of 2 %. It should be noted that the demand increased by 40 % from 1955 to 1965.

b. Industrial.

Industrial water consumption in the Bremen region is shown in the same way on Fig. 1.11.

The industrial demand increased in this region by 425 % from 1955 to 1965. This implies that in 1973, the Bremen industry will require 315 . 10^6 m^3 of water.

Fig. 1.12. gives the total amount of water consumed by the Bremen industry and moreover the amount of water flowing through closed circulation systems.

2.2. - Available supply.

a. Domestic.

The domestic water supply of the Bremen region is dominated by the quality aspect (chlorides and hardness) of the main source of supply which is the Waser river itself. This water must be mixed with underground or distant reservoir water.

At present, this water comes from eight locations, and some of it is piped over large distances (250 km). This water supply aspect becomes increasingly critical from year to year as the Weser water quality deteriorates so that the complement required can only be supplied from underground aquifers or reservoirs.

With the present set-up,desalted Weser water will have to be resorted to again in 1980 because water piping over increasing distances would be uneconomical.

b. Industrial.

Fig. 1. 12. shows very clearly that there will be a shortage of water for industry, especially for new undertakings. This is again due to the continuously increasing salt contents of river-water and underground water which involves increasing cost for the chemicals used hitherto for water treatment.

This again emphasizes the economical aspect of the water supply.

Industry has been conscious of the water cost as shown by the following table which shows that it has managed to rely on Weser water or other surface water to an increasing extent.

Year	1957	1959	1961	1963
Subsoil water	23 %	11 %	8 %	8 %
Surface water	77 %	89 %	92 %	92 %

2.3. - Potential shortages and remedial measures.

The shortages have been covered in the supply section. Remedial measures seem to be concentrated on available water treatment, chemical or physical. As long as chemical treatment can be achieved more cheaply than other means, this will have to be resorted to. In the future, the costs of fresh water produced in brackish water make-up plants with a capacity between 50.000 and 100.000 m^3/day would be of about 0,1 UA/m^3, which is the same as the cost of underground water supplied from the village of Wildeshausen.

2.4. - Electricity requirements.

The total power consumption of the Northern German districts of Bremen, Hamburg, Schleswig-Holstein and Lower Saxony for the years 1962, 1963 and 1964 is shown on Fig. 1.29, 1.30. and 1.31. These figures yield a yearly increase of about 8 %. Presently available statistics point to the same rate of increase in the future.

Tables Fig. 1.30. and Fig. 1.31. give the spread out of power demand according to the type of consumer.

2.5. - Conclusions.

In the Bremen region considerable effort is required to guarantee acceptable quality water supply. The Weser water is increasingly deteriorated so that further demand growth must be met from the subsoil.

This is shown out clearly in the following table which gives the amount of water taken from the Weser river compared to that required from other sweet water sources to achieve acceptable quality water.

Year	% coming from Weser	% required from sub-soil or other
1955	67 %	33 %
1960	74 %	26 %
1965	53 %	47 %
1966	45 %	55 %

This is also clearly shown on Fig. 1. 13. which gives the Weser water chlorine ion content.

It must be stressed here that this inferior Weser water quality is also caused by the large amount of effluents led into it and its affluents, right from the springs.

The water cost to the consumer in Northern Germany is made up of two components : that corresponding to the water consumption and that corresponding to its evacuation (and possible treatment). This means that the consumer discharging his effluents in his own septic tank for instance pays only the first part of the cost. This is also the position of agricultural consumers.

Water prices in Bremen are :

- drinking water 0, 15 UA/m^3
- effluent charge 0, 05 UA/m^3 of drinking water

3. HAMBURG REGION.

3.1. - Demand.

a. Public distribution.

The corresponding figures are given on Fig. 1. 14. The extrapolation assumes a 21 % increase from 1965 to 1975. The actual increase from 1955 to 1965 was 20 %. This means that Hamburg will need some 175 . 10^6 m^3 in 1975.

b. Industrial.

The industrial water consumption of the Hamburg region is given on Fig. 1. 14 and 1. 15. The increase between 1955 and 1965 is of 51 %. If an increase of 50 % is reckoned with between 1965 and 1975, the 1975 demand will amount to some 471 . 10^6 m^3.

Fig. 1. 15. shows the total amount of water consumed by the Hamburg industry as well as that recycled in closed systems.

3.2. - Available supply.

a. Public distribution.

As in Bremen, the Hamburg water supply problem is one of quality only (chlorides and hardness mainly) since the main source of supply is the Elbe river. Unfortunately there is a danger that this river's self-cleaning capacity can be exceeded in critical periods in view of the huge amounts of wastes and effluents rejected into it and its effluents upstream.

The obvious control measures are strictly applied in the Hamburg region itself. But this cannot have the effect required since it does not bear upon two main polluting factors : effluents from Eastern Germany and the tide.

The tide has the effect of shuttling a huge amount of water to and fro, which therefore prevents a suitable riverwater self-cleaning. This is even worsened by local effluents which therefore remain in the river bed in this region for considerable periods and have to be disintegrated right there.

The second factor beyond control is the Elbe contamination half way upstream. This contamination comes from the cellulose and carbolic acid contained in the effluents discharged from Eastern Germany which are not easily broken down. Other troublesome effluents are discharged by the potash mines in central Germany.

This has led the Hamburg municipality into deciding to use subsoil water from the Pinneberg region (20 km away) instead of treated Elbe water for meeting the domestic and part of the industrial needs.

b. Industrial.

Fig. 1. 15. shows as for Bremen, that there will be a shortage of water for industry, especially for new undertakings.

The proportion of subsoil to surface water used in industry in Hamburg is shown hereafter.

Year	1957	1959	1961	1963
Subsoil water	20 %	21 %	20 %	18 %
Surface water	80 %	79 %	80 %	82 %

3.3. - Potential shortages and remedial measures.

The shortages have been covered in the supply sections. Remedial measures seem to have been concentrated on a greater use of ground water. Nevertheless local authorities foresee that an increased water demand will again have to be met with Elbe water.

3.4. - Electricity.

See Bremen and Fig. 1.29., 1.30. and 1.31.

3.5. - Conclusions.

As the Weser is for Bremen, the Elbe is an ample water supply source for Hamburg with the restriction that the pollution has to be dealt with. This is clearly shown in Fig. 1. 16. and 1. 17., giving the Elbe water impurities or salt contents at different locations.

Water prices in Hamburg :

- drinking water 0, 143 UA/m^3
- effluent charge 0, 075 UA/m^3 of drinking water

4. THE NETHERLANDS.

4.1. - Demand.

a. Domestic.

- Present (Fig. 1.18.)

360 x 10^6 m^3/year for a total population of some 11.400.000 inhabitants, of which about 95 % are connected up, corresponds to a specific consumption of about 91 liters/day.inhabitant and to an average daily consumption of 0,988 x 10^6 m^3/day.

- Future (Fig. 1.18.)

The future domestic demand can be ascertained from the following figures :

Year	1980	2000
Inhabitants	14,1 x 10^6	19 x 10^6
Specific consumption, l/d.i.	116,5	150
Total consumption, m^3/year	600 x 10^6	1.040 x 10^6
Total average daily consumption, m^3/day	1,644 x 10^6	2,85 x 10^6

b. Industrial.

- Present (Fig. 1.19.)

It is of 700 x 10^6 m^3/year process water, of which 640 x 10^6 m^3/year are discharged as sewage. Some 60 x 10^6 m^3/year are therefore evaporated, incorporated in manufactured products, or refed into the ground (septic tanks, etc...).

The industrial cooling requirements are known only when supplied from sweet or salt water boreholes.

- Future (Fig. 1.19.)

Process water requirements.

Year	1980	2000
Origin, water works, m^3	320 x 10^6	440 x 10^6
Origin, own facilities, m^3	1280 x 10^6	2160 x 10^6
Total, m^3	1600 x 10^6	2700 x 10^6

Cooling water requirements.
No figures are available and are not, in fact, required in view of the huge amounts of water available from the Rhine. But the Rhine water low quality entails corrosion protection expenditure.

c. Agricultural.

- Present

These requirements are of an essentially peak nature. They can be ascertained from a recent peak figure relative to the Maas watershed in a dry year : 75 m^3/sec, occuring in mid July, just at the time when the Maas flow is very small and the Rhine water is most polluted and therefore hardly suitable for agriculture.

A problem similar to that already mentioned for Belgian agriculture i.e. that of salt water ingress into the underlying sweet water table, and impairing the pastures, appeared much earlier in the Netherlands and has been solved very satisfactorily.
This will be dealt with in the supply section.

- Future

These requirements are bound to grow in a spectacular manner in the future though not so much as elsewhere in view of the already quite highly specialized and profit intensive nature of Dutch agriculture.

d. Waterways.

- Present

Maas, average	200 m^3/sec
Maas, minimum	0 m^3/sec
Rhine, average	2.000 m^3/sec
Rhine, minimum	700 m^3/sec

- Future

The nature of these waterways and the countryside level make larger flow requirements unlikely, but as pointed out previously, the Maas flow may not be reduced in quantity or quality.

e. General picture.

- Present

The overall aspect of present Dutch water supply is dominated by :
- unfortunate timing of Maas minimum flow in summer, precisely when the agricultural demand is highest,
- objectionable Rhine water quality during the six dry months.

- Future

The future water demand can be met quite readily with the present and future structures : Rhine regulatory works, Zuider zee and Delta plan.

4.2. - Available supply.

a. Present position.

The actual order of magnitude of Dutch available supply can be gathered from the following figures :

Maas average flow	200 m^3/sec
Maas minimum flow	0 m^3/sec
Rhine average flow	2000 m^3/sec
Rhine minimum flow	700 m^3/sec

Unfortunately, the Rhine water is of objectionable quality during the six "dry" months of the year, precisely when the Maas flow is minimum and the agricultural demand largest. This is the reason why it has so far been more expedient to supply drinking or industrial process water from boreholes, surface water and dunes.

The Zuiderzee lake acts as a handsome seasonal reservoir to balance these supply bottlenecks.

b. Future position.

Although no serious bottleneck is feared, the huge additional reservoirs provided by the Delta plan sea walls provide yet another measure to prevent any water shortage. Very encouraging results have also been obtained from boreholes located on or near the large river banks. The principle involved is similar to that used on the Dutch west coast where recharging the sea shore dunes with sweet water has very effectively protected boreholes inland from salt water infiltration as shown on fig. 1.20.

This aspect is of crucial importance in Holland where such infiltrations can impair or compromise ground water resources around the large river estuaries where the tide must also be taken into consideration and where salt water underground seepage has progressed apace as shown by the watertable salt content.

Subsoil chlorine ion content just below the holocene layer :

Amsterdam	> 5000 ppm
The Hague	≅ 300 ppm
Hoek van Holland	> 5000 ppm
Rotterdam	> 5000 ppm
Dordrecht	300-1000 ppm
Terneuzen	> 5000 ppm
Well (on the Maas NW from 's-Hertogenbosch)	0-300 ppm
Moerdijk	≅ 300 ppm
Reclaimed Zuiderzee polders	1000-5000 ppm, in most locations.

4.3.- Potential shortages.

No potential shortage need be feared right now in view of the large scale works carried out by the Dutch Government Delta plan, sea water seepage control measures.

a. Present.

Daily minimum flow in (Rhine + Maas)	60,48 . 10^6 m^3/day
Present domestic demand, peak	1 . 10^6 m^3/day
Balance available for other uses (no domestic water recycle)	(60,48 - 1) = 59,8. $10^6 m^3$/day
No demand for navigation	
Present demand for industry	1,95 . 10^6 m^3/day
Industry recycle ratio	1,95/59,5 > 0,033

b. Future. (1980)

Daily minimum flow in (Rhine + Maas) if no supply measures are taken	60,48 . 10^6 m^3/day
Peak domestic demand	1,65 . 10^6 m^3/day
Balance available for other uses (no domestic water recycle)	58,83 m^3/day
No demand for navigation	
Future demand for industry	4,38 . 10^6 m^3/day
Industry recycle ratio	4,38/58,83 > 0,075

4.4.- Remedial measures.

Most of these means have already been covered previously as they are carried out and must therefore be included in the actual water resources.

Other means which have not yet been fully implemented are :

- Additional Rhine water impounding into the Zuiderzee when that water is of acceptable quality (in the "wet months"),
- Impounding both Maas and Rhine water in the sweet water lakes which will be formed behind the Delta plan sea walls,
- Improving the Rhine water quality by international action to be taken in Germany and France (potash mines),
- Other resources of interest are boreholes located near a canal or river bank, where the bank itself provides the filtration medium and dune filtered water collected at the dune base,
- Yet another means of increasing the drinking or agricultural water supply is the use of the reservoirs provided by the river loops which were straightened out and can thereby be used for impounding water in the same way as the artificial Zuiderzee and Delta plan lakes, though not on the same time and amount scale.

The most useful task in this respect is that of reducing the Rhine pollution. When this is carried out effectively, it means that Holland has a permanent water supply of 700 x 86.400 x 365 = 22 x 10^9 m^3/year, for a future demand in the year 2000 of some 3,74 x 10^9 m^3/year.

4.5.-Electricity requirements.

The electricity demand progression can be ascertained from fig. 1.21. where it is assumed that a reserve of 27 % is provided in 1965 and only 15 % in 1975.

This huge generating power increase of 4.700 MWe in 10 years does not occur at the same time as a potential water shortage which is not foreseen till very much later, and this when considering ground water supplies only.

4.6.-Conclusions.

With the development plans carried out at present or ear-marked for short term implementation, no shortage danger can be foreseen at all within the next decades.

As always, this statement must be tempered in view of the highly polluted waterways, the Rhine especially. This has forced some Dutch industry to resort to water desalination treatment although located on the Rhine banks. The economics of water treatment are in fact dependent on local considerations and requirements.

Available waterway pollution data are given in the following figures :

- Fig. 1.22. - Rhine
- Fig. 1.23. - Maas.

Industrial water pollution is reduced as much as possible by the users themselves who seem to realize that it pays to keep a sharp eye on their effluents which can thus be reused several times, while the countryside remains attractive and land value is not depreciated.

As elsewhere, water prices vary in the Netherlands according to location and use from 0, 12 UA/m^3 down to 0, 04 UA/m^3 and even less.

Water hungry industry is usually located near a large river or canal from which it draws its cooling water at a nominal charge. Bank located wells are also used to obtain water with a reasonable purity (bank filtration).

A sweet water supply shortage might nevertheless arise in industrial areas located near the sea (IJmuiden, Terneuzen, etc..). In Terneuzen for instance, PZEM considers a dual-purpose plant with a sweet water production capacity of 20.000 m^3/day.

5. LOWER SAXONY (Coastal area)

5.1. - Demand.

a. Public distribution.

No reliable figures can be given for this region since the distribution piping network has only been laid down in 1950 and additional villages are continually connected on to it.

Considerable effort is required in the East Frisian Islands to ensure adequate quality water supply.

The Islands have been characterized by a huge rate of increase in the last few years mainly due to the steadily growing number of tourists.

Annual water consumption in the East Frisian Islands						
	Borkum	Juist	Norderney	Baltrum	Langeoog	Spiekeroog
1957	362.530	127.700	473.070	51.109	131.120	23.045
1958	365.780	154.228	482.190	44.248	157.230	24.600
1959	388.260	187.851	537.149	57.411	146.935	31.815
1960	384.320	202.020	559.584	64.164	152.982	33.632
1961	416.460	187.197	588.896	64.634	150.369	38.515
1962	467.130	192.108	629.282	62.807	147.413	37.097
1963	504.680	236.775	646.213	65.233	145.706	42.720
Increase in percent from 1957 to 1963 :	40 %	86 %	38 %	27 %	11,5 %	86 %

No figures are given for Lower Saxony future domestic demand since the growth trend is not representative yet.

b. Industrial.

As no local demand statistics are available for the coastal area of Lower Saxony, the industrial demand has been estimated from data corresponding to the whole province.

This is shown on Fig. 1.24. and 1.25. which point to a 1955 to 1963 increase in demand of 10 %. Fig. 1.25. gives the total amount of water consumed by the Lower Saxony industry and that flowing in closed systems (recycling).

If the water consumption increases by 15 % from 1963 to 1975, the industrial demand in 1975 will amount to some $600 . 10^6$ m^3.

5.2. - Available supply.

There are some difficulties on the Lower Saxony sea shore (especially in the East Frisian Islands). They correspond to a huge increase in demand (mainly touristic) with scarce available underground water reserves especially of suitable low salinity.

Further inland, the numerous coastal rivers ensure ample supply possibilities as long as pollution problems can be solved, as in the specific cases of Bremen and Hamburg.

5.3. - Potential shortages and remedial measures.

The only Lower Saxony sites where potential shortages exist or may become serious are the East Frisian Islands. This is mainly due to the increased tourist population.

And it is therefore only in those locations that desalination may have to be resorted to since the alternative is to bring water from the continent.

5.4. - Electricity requirements.

See Bremen and Fig. 1.29., 1.30. and 1.31.

5.5. - Conclusions.

Except for the islands and the sea shore, the conclusions for Lower Saxony are the same as for Bremen and Hamburg since this province draws most of its water from the same sources.

The water prices in two towns are given as trend indicative :

1) Oldenburg
   - drinking water 0,163 UA/m^3
   - effluent charge 0,125 UA/m^3 of drinking water

2) Delmenhorst
   - drinking water 0,138 UA/m^3
   - effluent charge 0,118 UA/m^3 of drinking water

6. SCHLESWIG-HOLSTEIN.

6.1. - Demand.

a. Public distribution.

Fig. 1.26. gives the amount of water supplied from 1955 to 1965 This shows a 60 % increase in this period. If the demand increases by 30 % from 1965 to 1975, 107.10^6 m^3 would have to be supplied by public distribution networks of which a part will be taken up by industrial plants.

The islands off the West and East Coasts of Schleswig-Holstein heve seen their requirements increase very significantly in the last few years. This is due to the steadily growing number of tourists.

For Helgoland, for instance, this growth is shown in the table hereafter.

Total amount of water annually received by the water distribution plant of the Isle of Helgoland		
1960	115.000 m^3)	
1965	136.000 m^3)	salinity
1966	168.000 m^3)	3000 - 3500 ppm
(1967)	186.000 m^3)	
Annually available quantity of subsoil water : 210.000 m^3		

Future demand will require new distribution plants in some areas. But meeting the sweet water demand will be much more difficult on the islands than on the mainland and this will occur much sooner.

b. Industrial.

The industrial water demand which is met from municipal sources has been mentioned previously (fig. 1.26.). A larger amount of water used by industry is provided from other sources. This part of the demand increased from 1955 to 1965 by 40 %. If it increases by 40 % between 1965 and 1975, this demand will be of 156.10^6 m^3 of water at the end of this period.

It is also interesting to compare the amount of water used by industry with that which is recycled (see fig. 1.27.).

6.2. - Available supply.

The overall aspect of water supply in Schleswig-Holstein is governed by several major factors. In some areas such as the marshland of the West Coast, salt water already appears in the upper aquifer (as already mentioned for Belgium and the Netherlands). This is borne out by the attitude of the Lübeck municipality. Lübeck draws most of its water from surface water as opposed to subsoil water.

In view of the aquifer high salt content, it is only by drawing increasingly on surface water that Lübeck will be able to meet future demand.

The region on the right bank of the Trave river (see Fig. 1.28.) cannot supply any more subsoil water than at present, as brought out by the already high Cl ion content (up to 2000 mg/liter).

Despite the presence of large reserves of subsoil water in the region between Bad Schwartau, Travemünde and Dänischburg as well as around the Ratzeburg Lake, more than 70 % of the Lübeck consumers are supplied with surface water. This is due to financial considerations.

On the other hand one must mention here the island water supply problem, already dealt with, and very local cases on the mainland (such as the industrial district near Brunsbüttelkoog where the water has to be brought from 50 kilometers).

6.3. - Potential shortages and remedial measures.

The potential shortages have been dealt with in the supply section. Regarding remedial measures, it must be stressed that this is a matter of location. These measures range from distillation type of desalination down to any other measure, the final choice being essentially governed by the water cost which in turn depends on the quality of the water available.

6.4. - Electricity.

See Bremen and Fig. 1.29., 1.30. and 1.31.

6.5.- Conclusions.

The water supply problem in Schleswig-Holstein is similar to that in Lower Saxony, especially regarding the islands and the sea shore.

It is moreover worsened by the high chlorine contents of the subsoil water which increases the difficulties of providing good quality water to large urban areas such as that of Lübeck.

Finally two examples of water prices in the Island of Helgoland and the town of Kiel are given hereafter :

- Price of subsoil water obtained on the island (salinity 3000 to 3500 ppm) :

  0,125 - 0,225 UA/m^3

- Fresh water from the mainland (salinity 300 ppm) :

  3,125 - 3,75 UA/m^3

Water prices in Kiel :

- drinking water 0,13 UA/m^3
- effluent charge 0,08 UA/m^3 of drinking water.

FINAL CONCLUSIONS.

From the various investigations concerning the water problem in the European Community northern coastal areas, the following conclusions can be drawn:

1. Rainfall is ample in Western Europe, and generally speaking, there is no real water shortage to be feared since the amounts available are still far larger than those required. At present, the only imperative is to avoid the conjunction of peak demand with minimum available flow in the rivers.

   This implies "conservancy" (regulating) measures, as opposed to "generating" measures, taking various forms in accordance with local considerations which may be topographical, geological, agricultural or even climatic. These measures are carried out according to their economical merit. The most obvious ones are reservoirs, river flow regulating, forests, etc...

2. These highly industrialized areas must nevertheless deal with an increasingly serious pollution of their main waterways, the corresponding remedial measures being : sewage treatment plants and strict municipal and industrial effluent control.

3. There are however some specific locations where distillation type of desalination could be considered. In the Islands of the northern coast of the Netherlands and Germany, where large amounts of water have to be brought at present from the mainland during the seasonal period where the local subsoil water quality is insufficient, desalination plants could meet this seasonal shortage and improve the drinking water quality by mixing the distillate with the above mentioned subsoil water.

4. Between these water generating measures and the conservancy measures mentioned in paragraph 1 above, but considering the pollution restrictions, there is a whole range of water treatment possibilities which may be chemical, mechanical, etc...

5. The most important point may be that the electricity demand growth is much larger than the water demand growth, except in very few and specific cases.

   This entails that if any desalination plant is foreseen in the Northern areas of the European Community, it will always be possible to combine it in a dual purpose plant, if economically justified as will be shown in Chapter III, since there will never be any difficulty in finding customers for the electrical power generated.

The apparent conclusion seems to be that sea water desalination might not have widespread prospects of being implemented in the surveyed area.

Nevertheless, in a whole range of special cases, the dual purpose could be directly competitive with other water supply measures.

One must bear in mind that a regulating dam cost can go up to $100 . 10^6$ US $, which is the same or more than that of a huge desalination plant.

Furthermore, special considerations such as social or even touristic, may forbid the construction of the foreseen dams. This means that quite local or specific considerations which cannot be forecast at present may alter these general conclusions altogether.

The large population density of Northern Europe makes it very unlikely that other than large desalination plants will ever be considered. This is the reason which guided the choice of the 50.000, 100.000 and 250.000 m^3/ day desalination plant capacities considered in Chapter III.

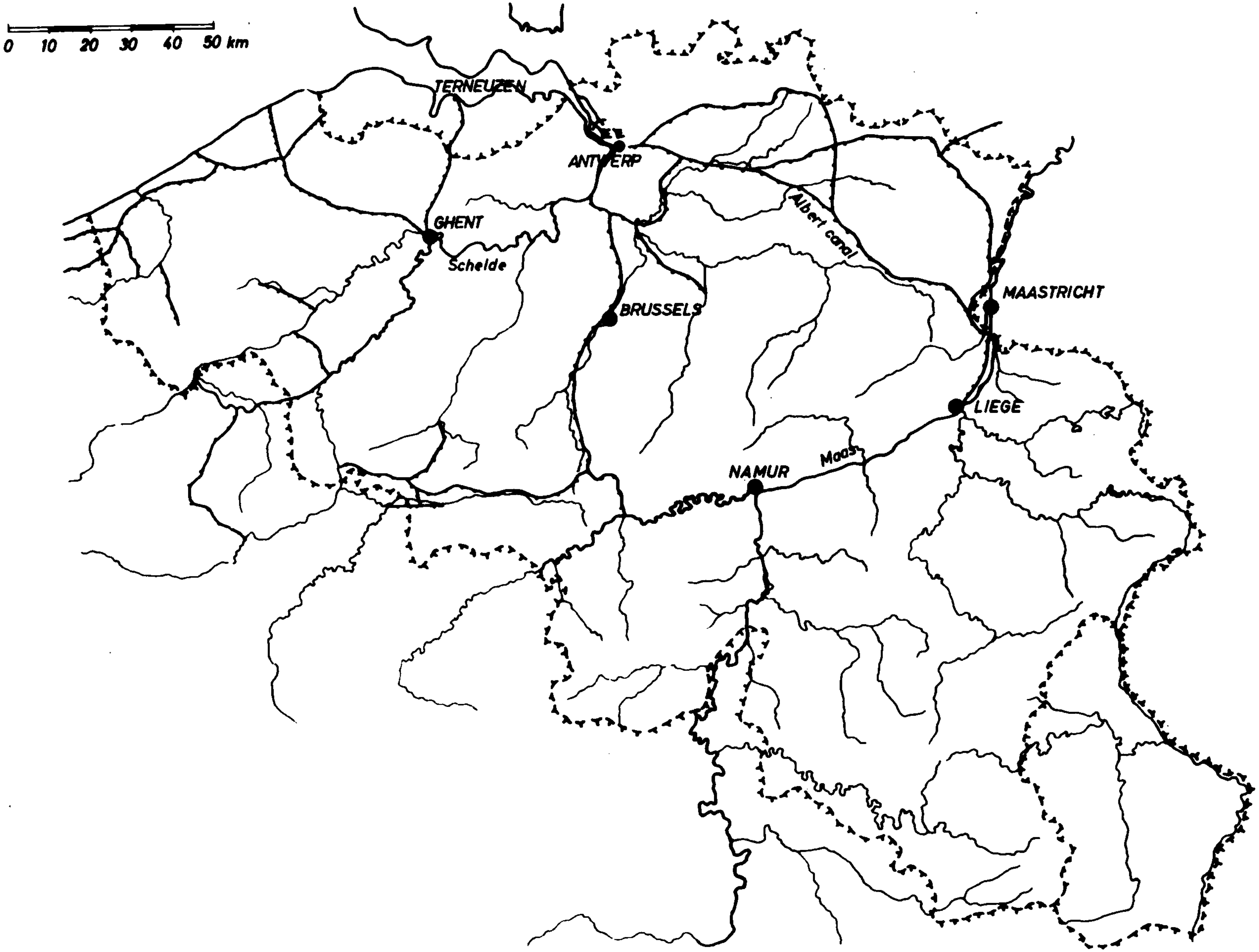

0 10 20 30 40 50 km
TERNEUZEN
ANTWERP
GHENT
Schelde
BRUSSELS
Albert canal
MAASTRICHT
LIEGE
NAMUR
Maas

Fig. 1.1

Fig. 1.2
NORTHERN GERMANY

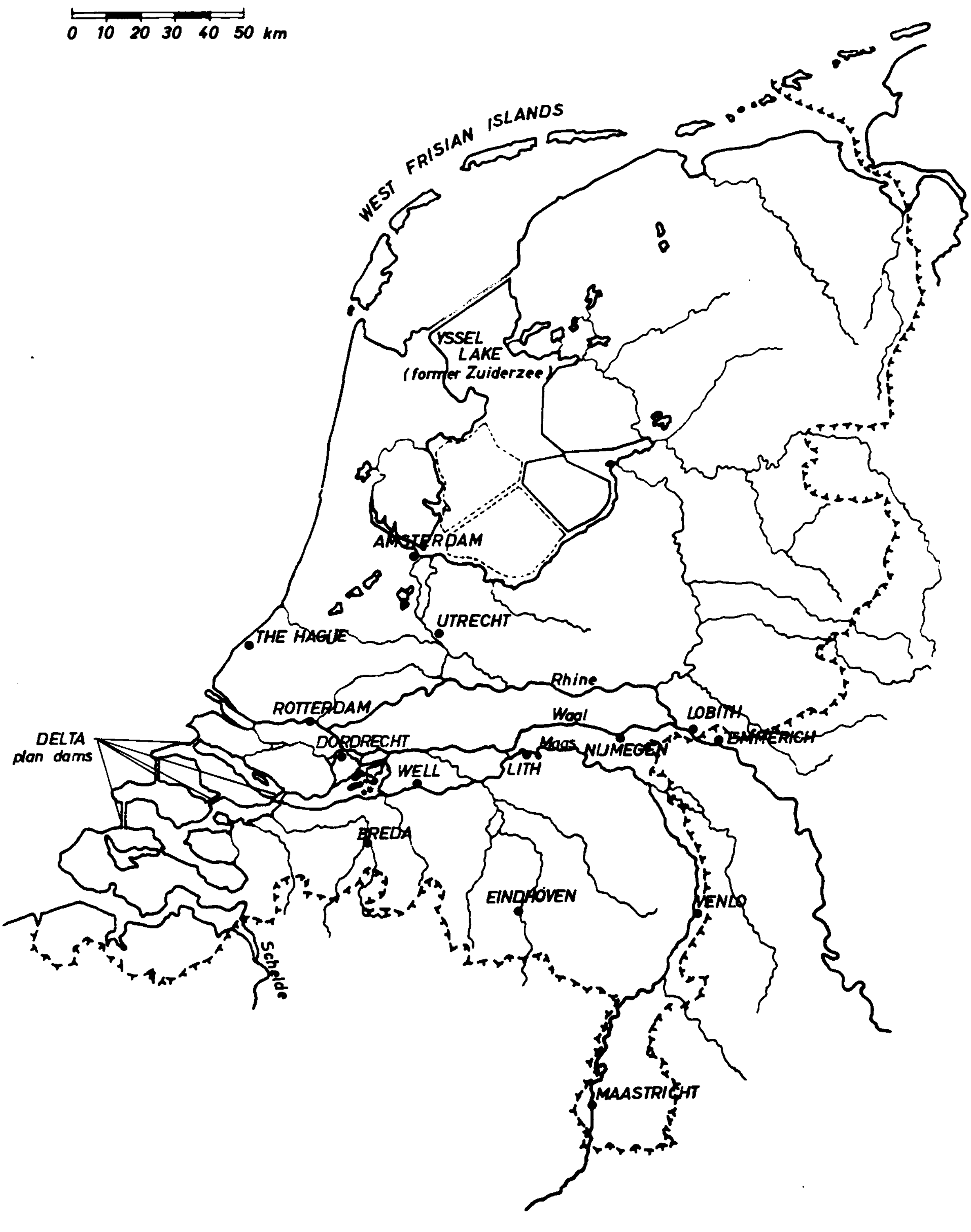


Fig. 1.3
NETHERLANDS

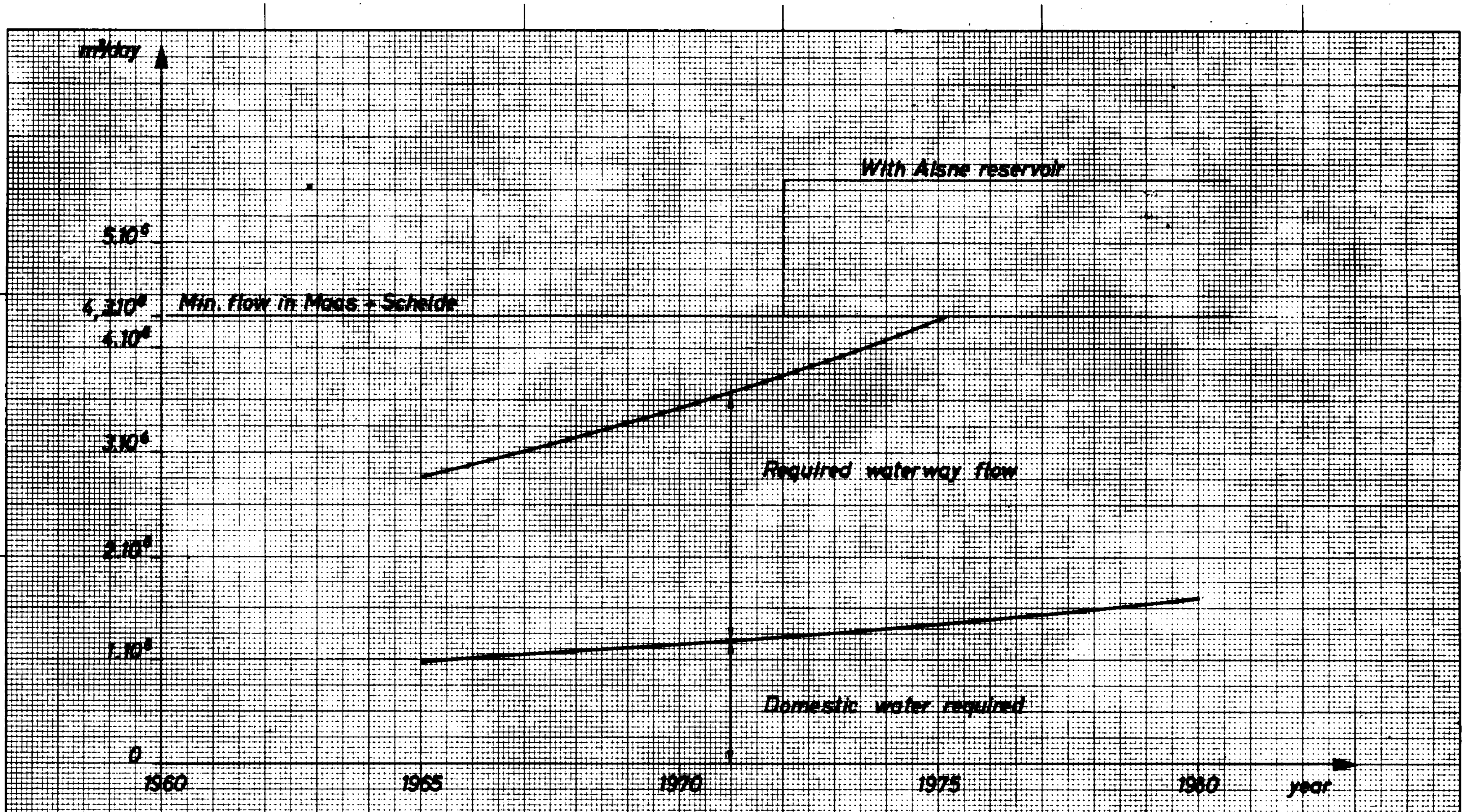


Fig. 1.4

CUMULATED PEAK DOMESTIC WATER DEMAND AND MINIMUM WATERWAY DEMAND IN BELGIUM

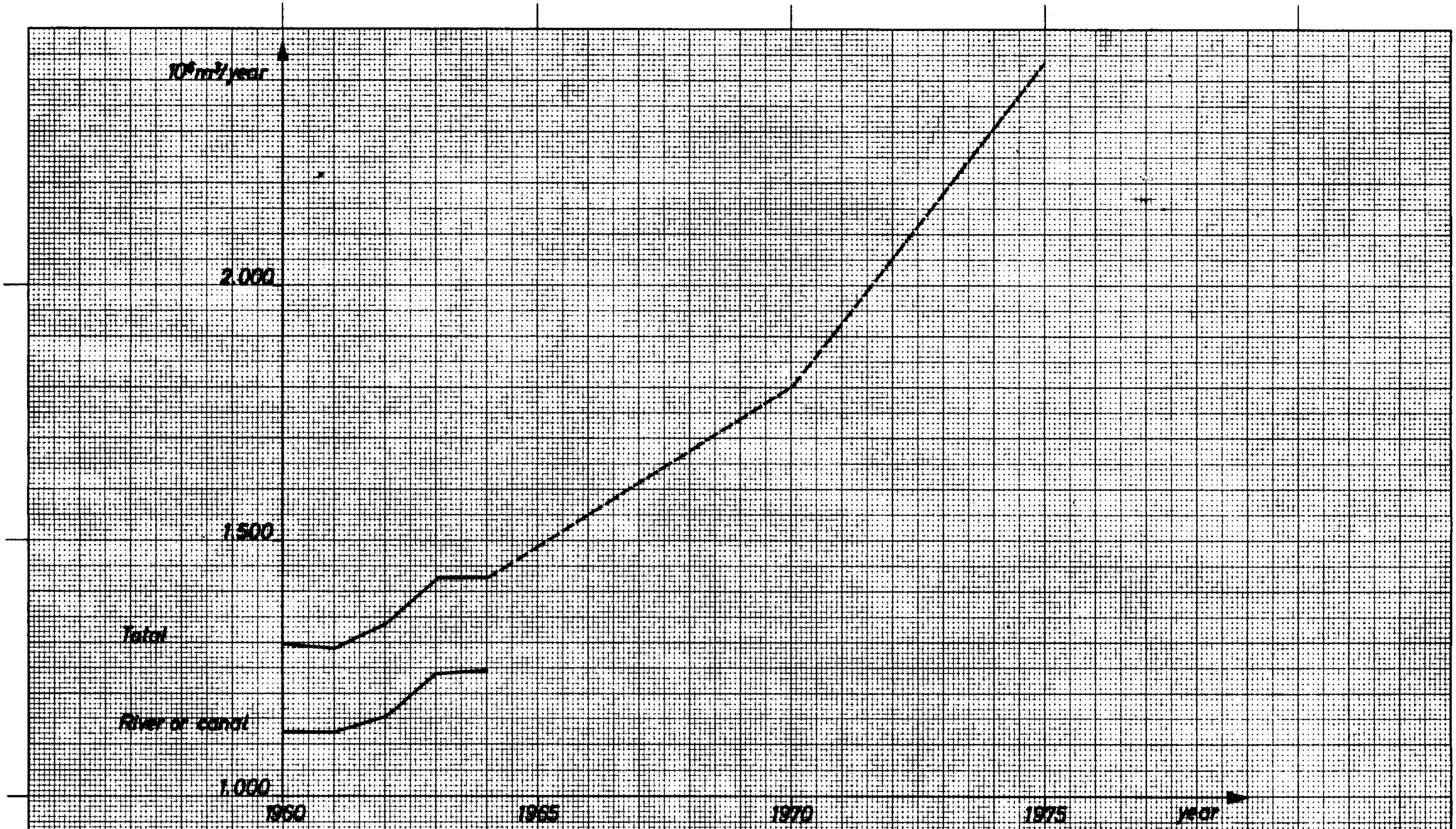


Fig. 1.5

TOTAL INDUSTRIAL WATER DEMAND IN BELGIUM

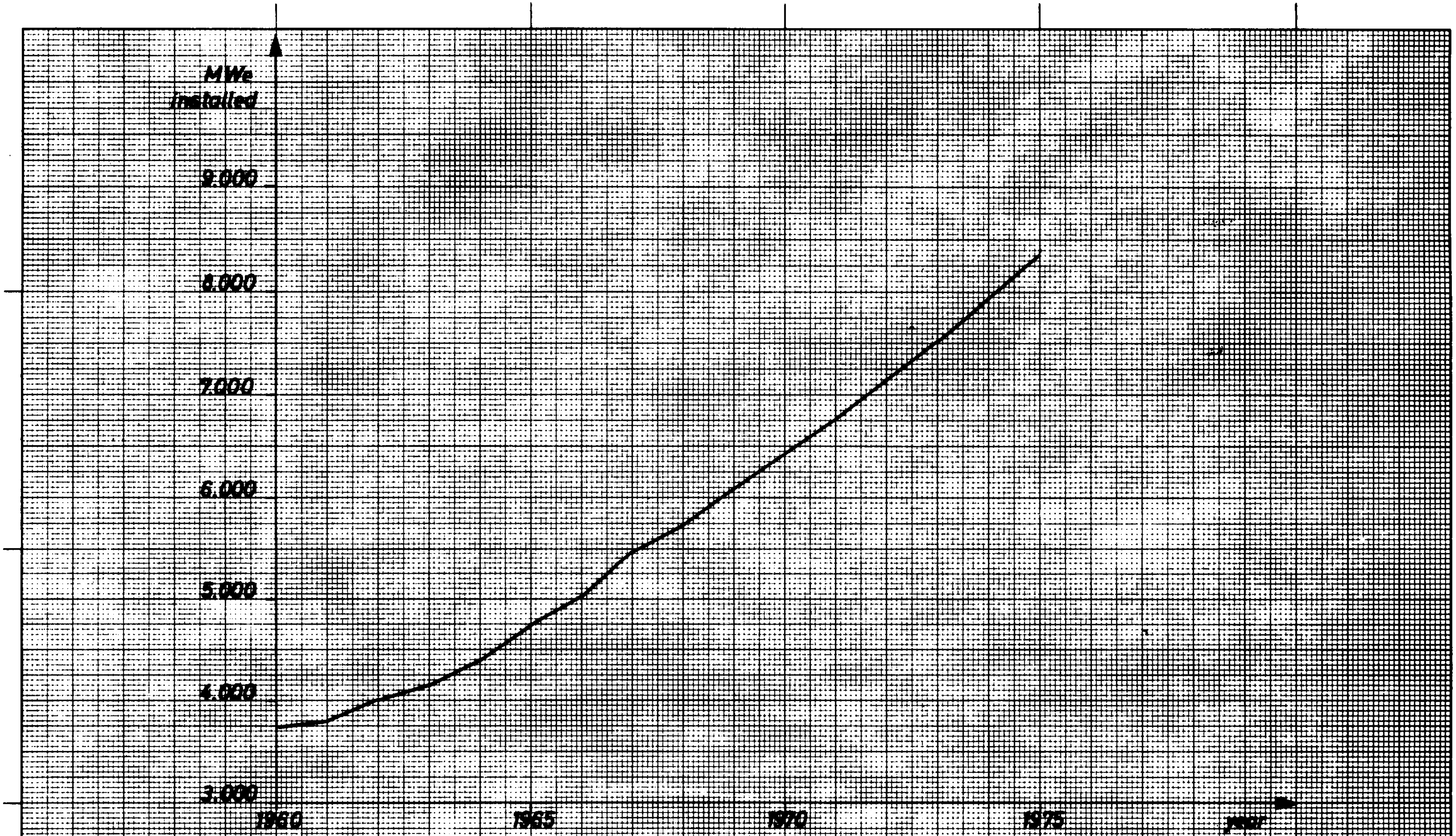
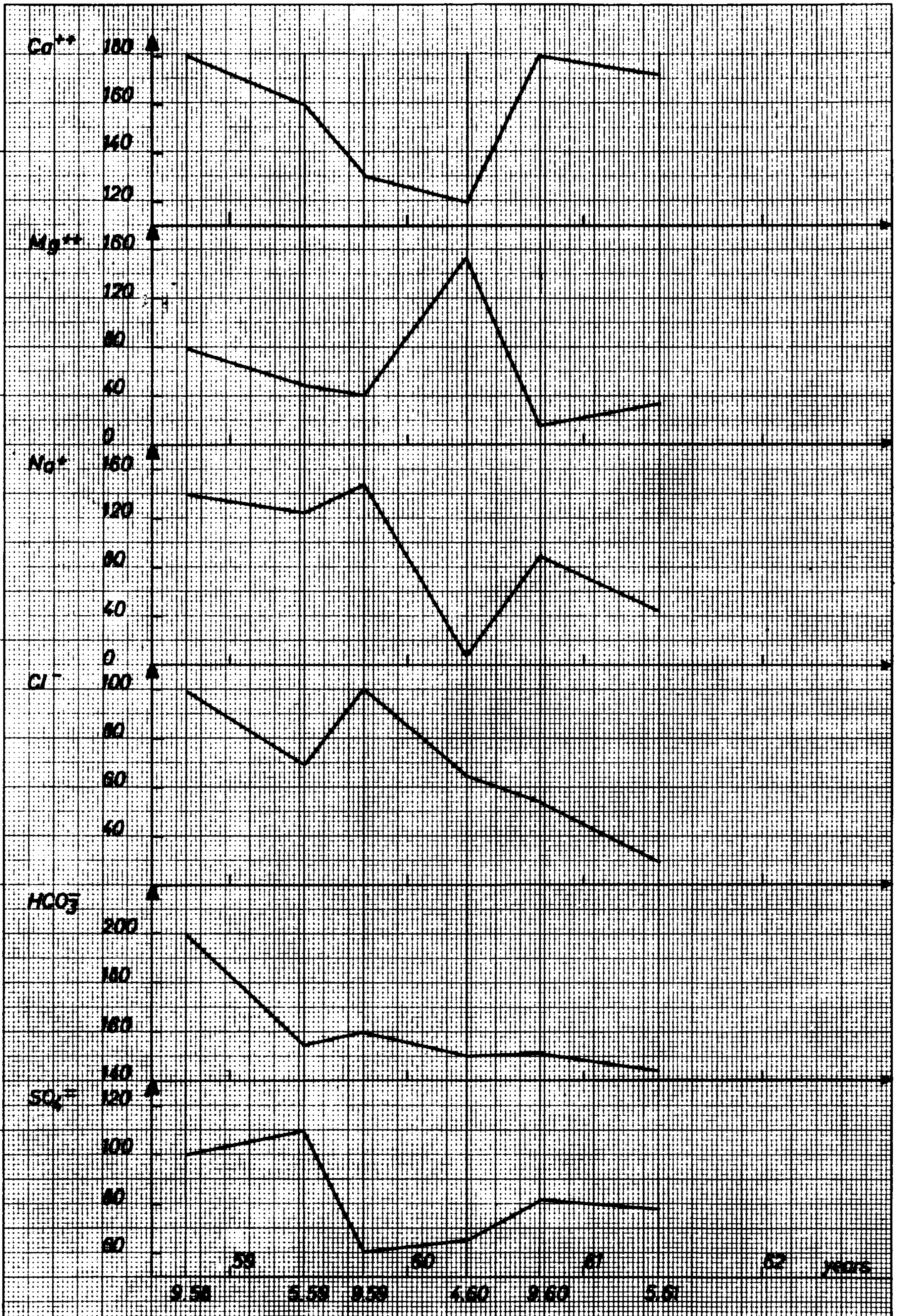
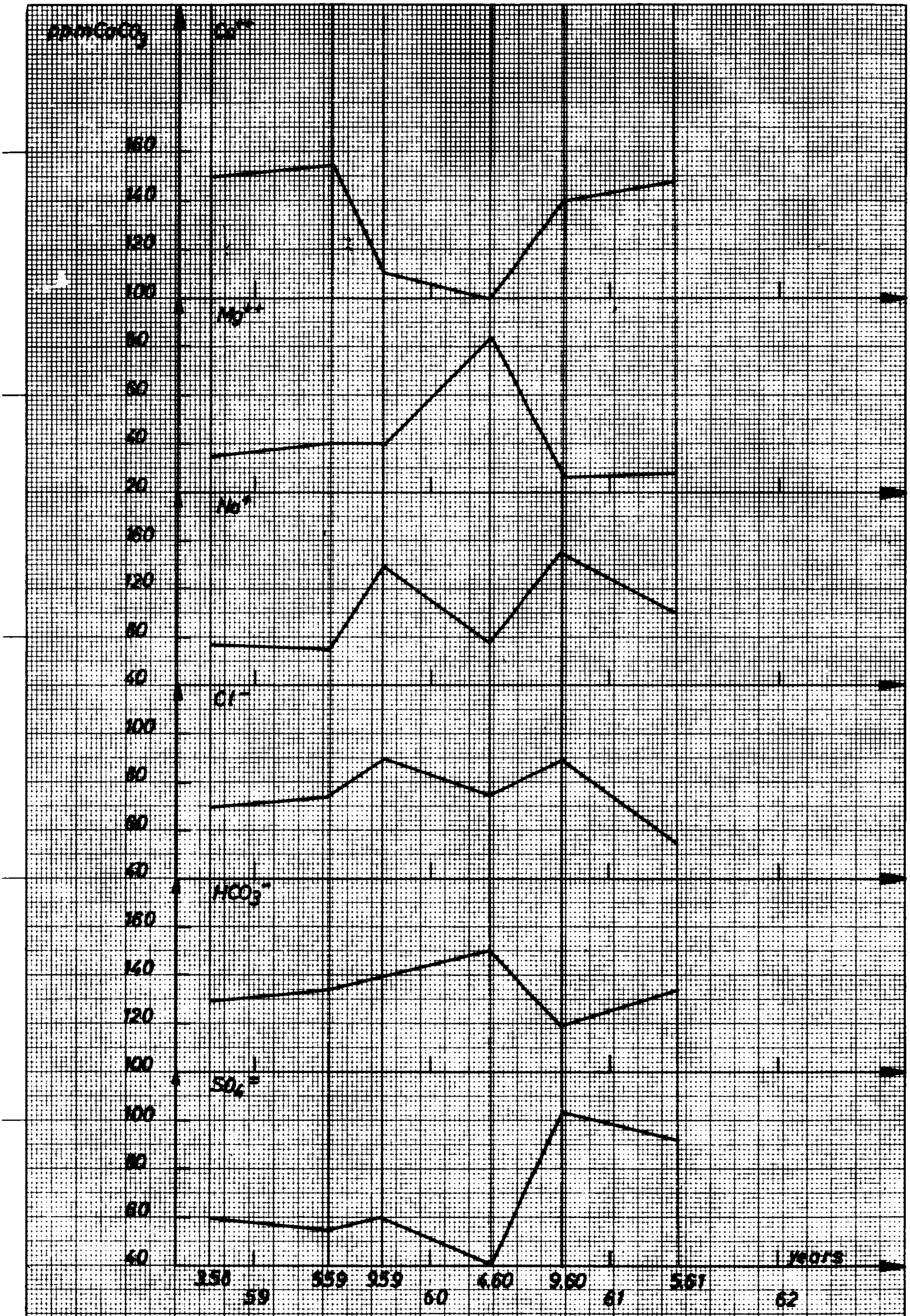


Fig. 1.6
ELECTRICAL GENERATING POWER IN BELGIUM



MAAS WATER IMPURITIES (LIEGE)

FIG. 1-7



ALBERT CANAL WATER IMPURITIES(ANTWERP)

FIG. 18

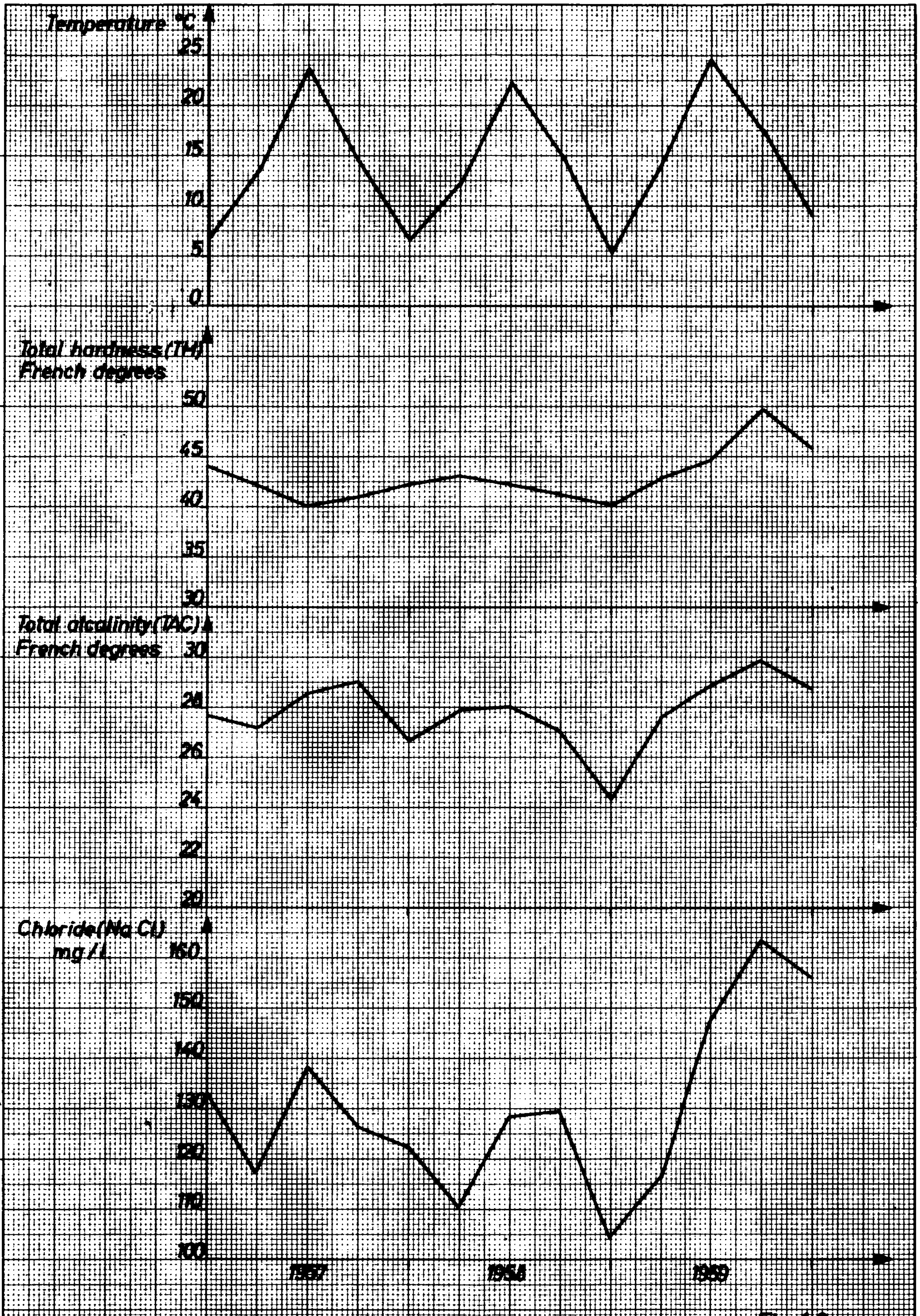
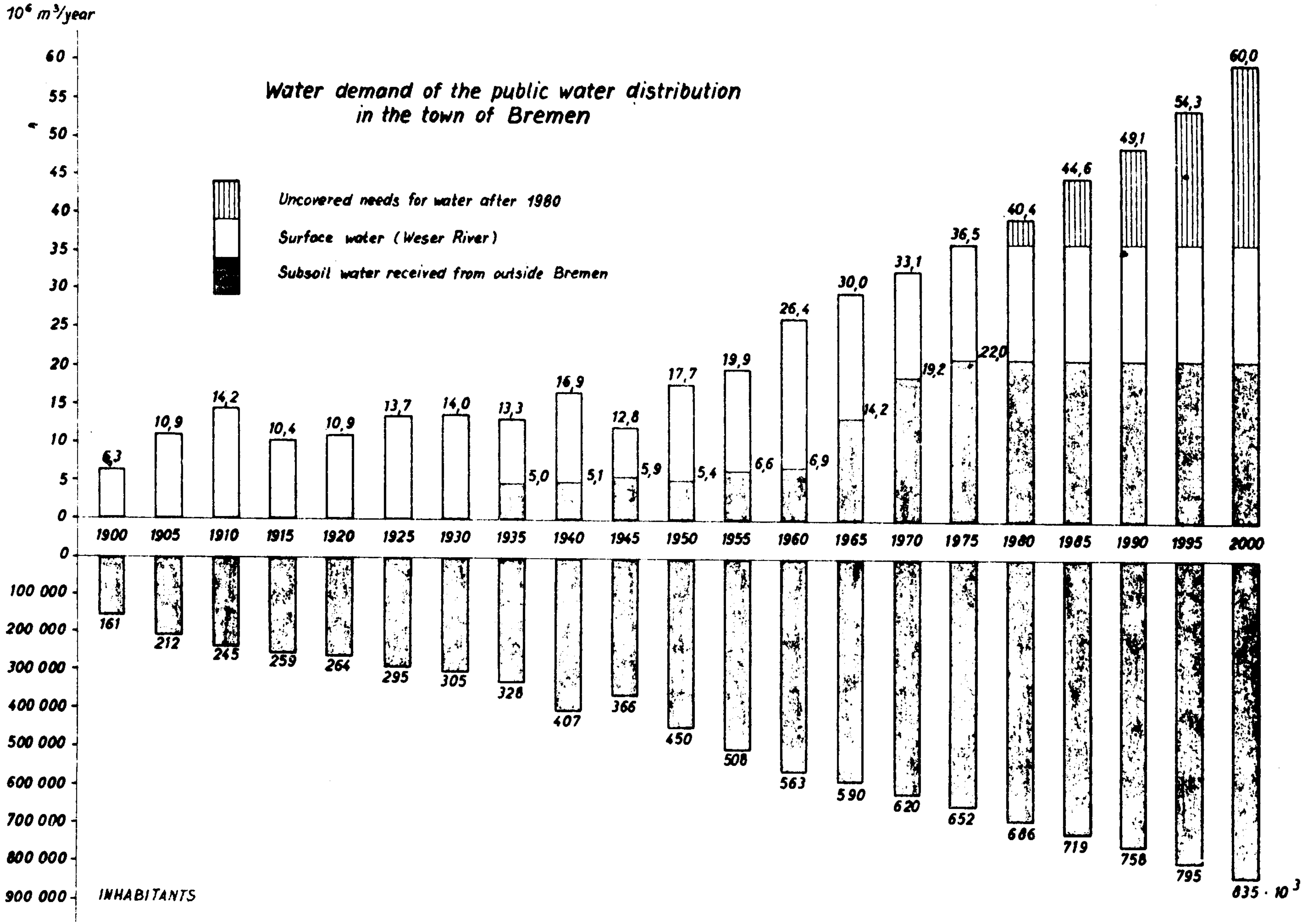


Fig. 1.9

SCHELDE WATER (GHENT)



10⁶ m³/year
Water demand of the public water distribution in the town of Bremen
Uncovered needs for water after 1980
Surface water (Weser River)
Subsoil water received from outside Bremen
60
55
50
45
40
35
30
25
20
15
10
5
0
6,3
10,9
14,2
10,4
10,9
13,7
14,0
13,3
5,0
16,9
5,1
12,8
5,9
17,7
5,4
19,9
6,6
26,4
6,9
30,0
14,2
33,1
19,2
36,5
22,0
40,4
44,6
49,1
54,3
60,0
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
0
100 000
200 000
300 000
400 000
500 000
600 000
700 000
800 000
900 000
INHABITANTS
161
212
245
259
264
295
305
328
407
366
450
508
563
590
620
652
686
719
758
795
835 · 10³

Fig. 1.10

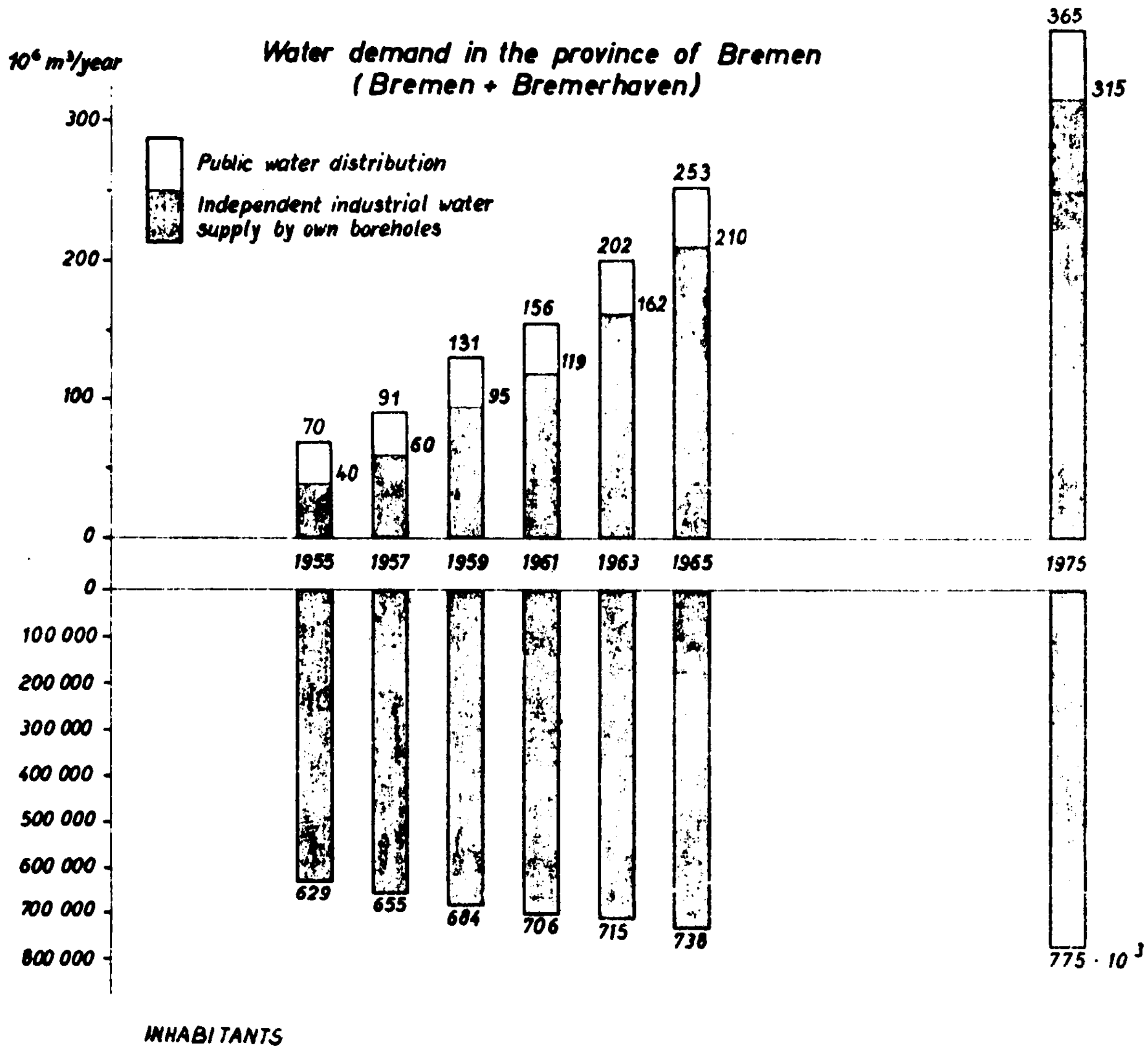

Water demand in the province of Bremen
(Bremen + Bremerhaven)
10⁶ m³/year
300
200
100
0
Public water distribution
Independent industrial water supply by own boreholes
70
40
91
60
131
95
156
119
202
162
253
210
365
315
1955
1957
1959
1961
1963
1965
1975
0
100 000
200 000
300 000
400 000
500 000
600 000
700 000
800 000
629
655
684
706
715
738
775 · 10³
INHABITANTS

Fig. 1.11

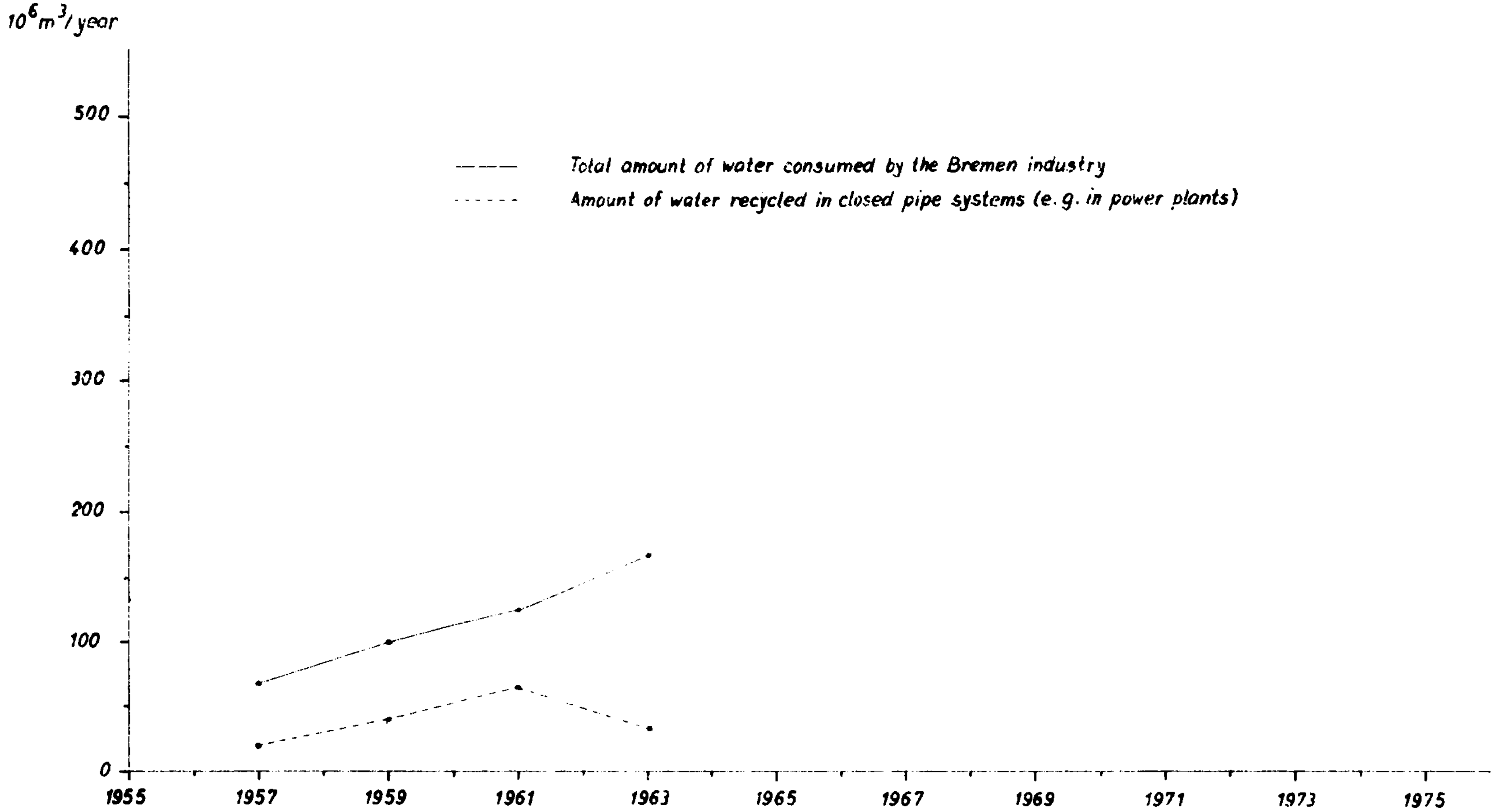
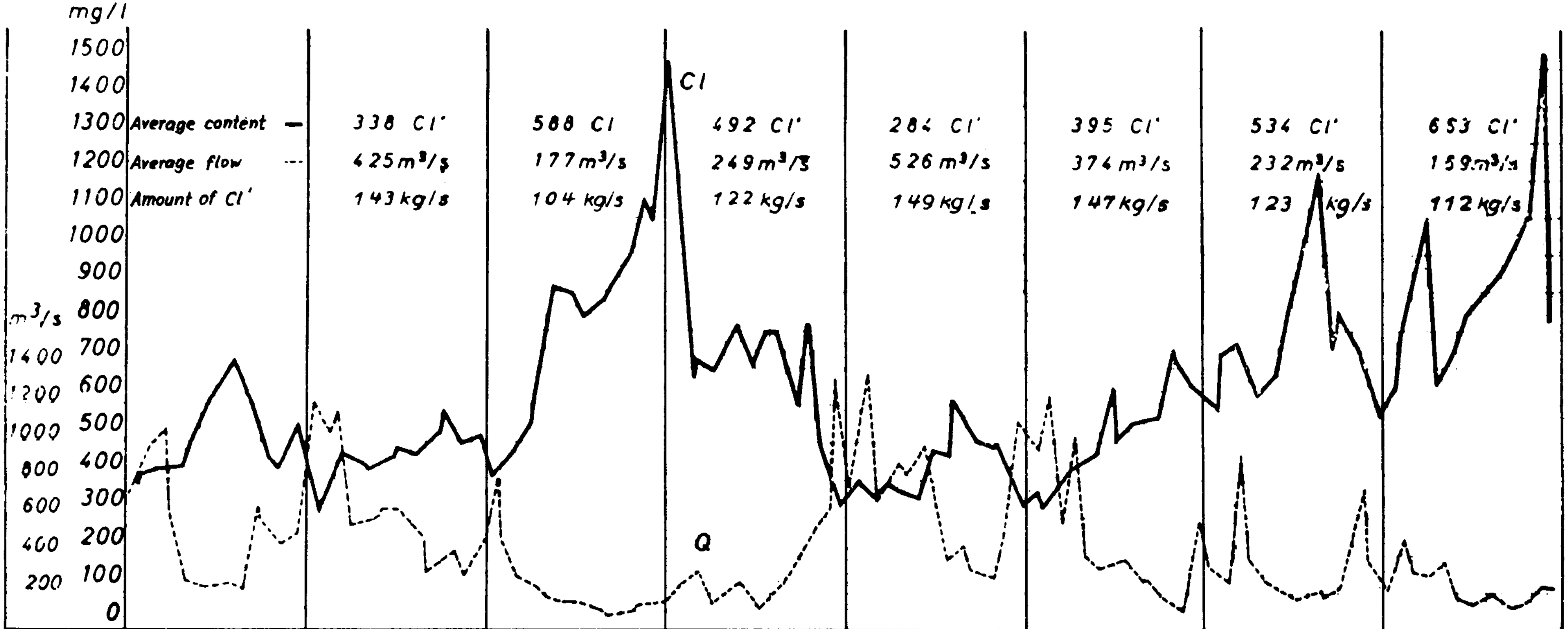


Fig. 1.12

TOTAL AMOUNT OF WATER CONSUMED BY THE BREMEN INDUSTRY
(MOREOVER, AMOUNT OF WATER RECYCLED IN CLOSED PIPE SYSTEMS)



	1957	1958	1959	1960	1961	1962	1963	1964
Cl' content in tap water	Minimum Value	94	130	70	70	95	109	161
	Peak Value	411	843	817	390	549	769	844
	Average Value	234	415	339	216	271	374	417

Chloride - contents (Cl') and average flow (Q) of the Weser - River at Bremen and chloride - contents in tap water (1957 - 1964)

Fig. 1.13

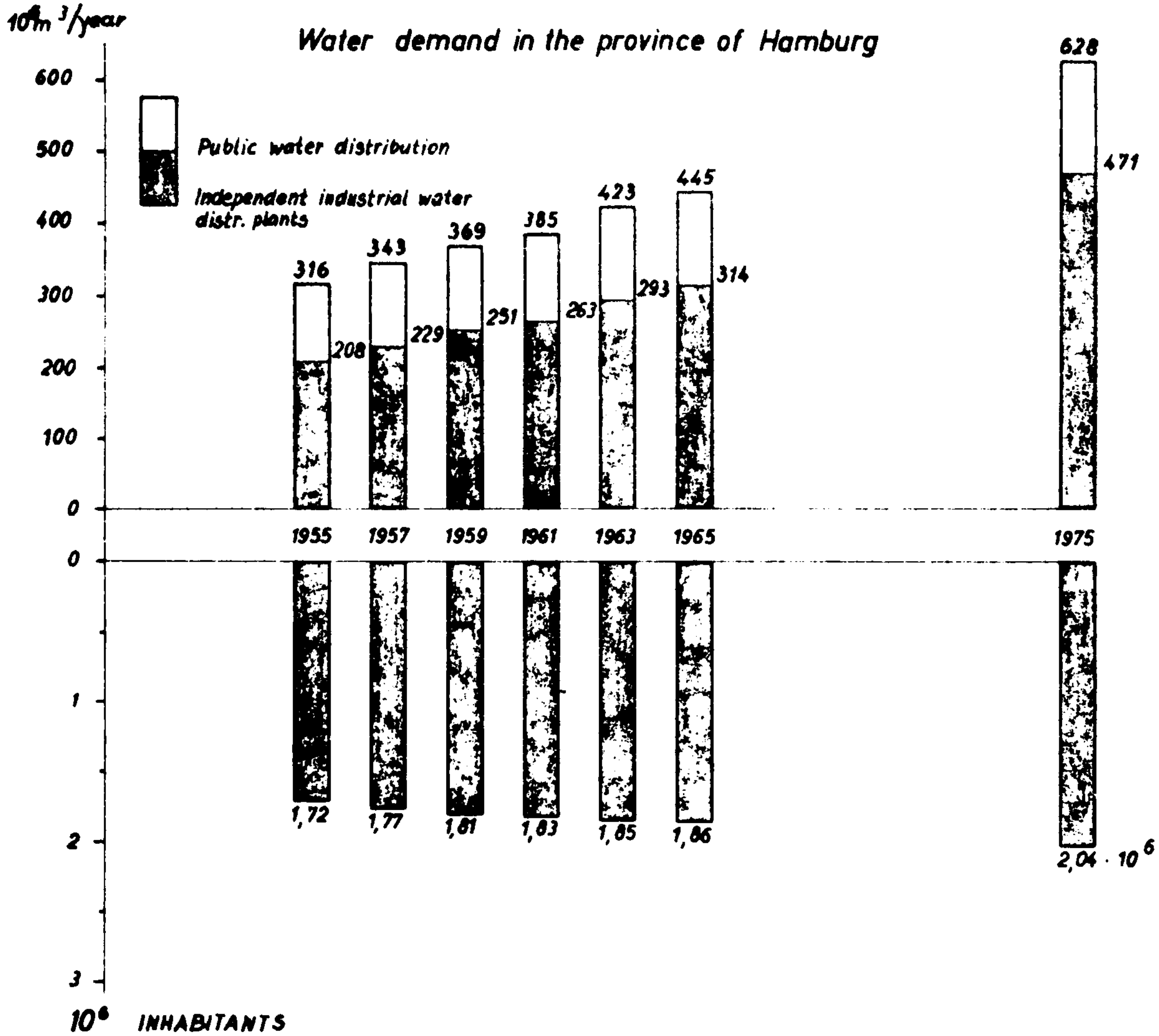
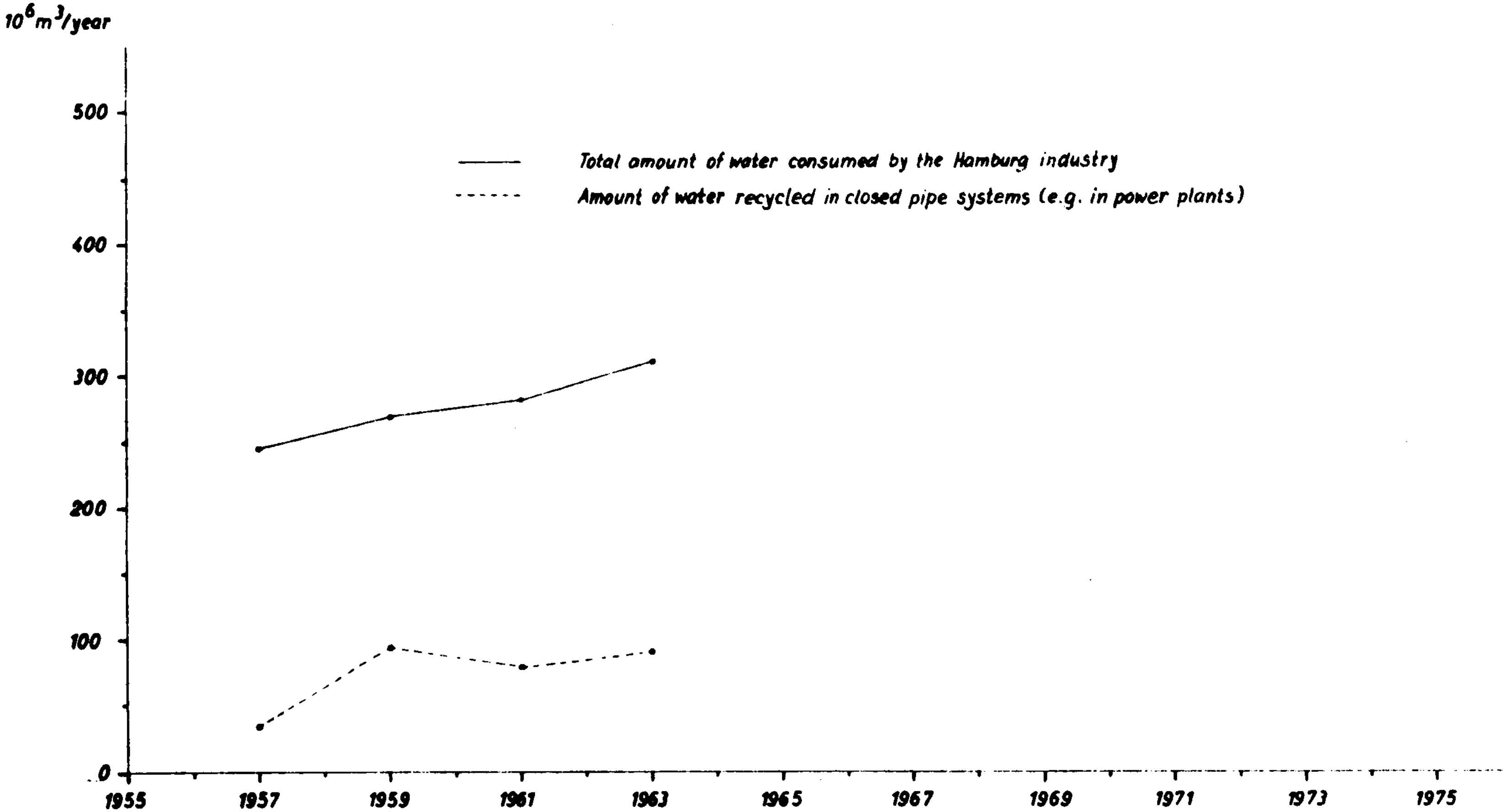
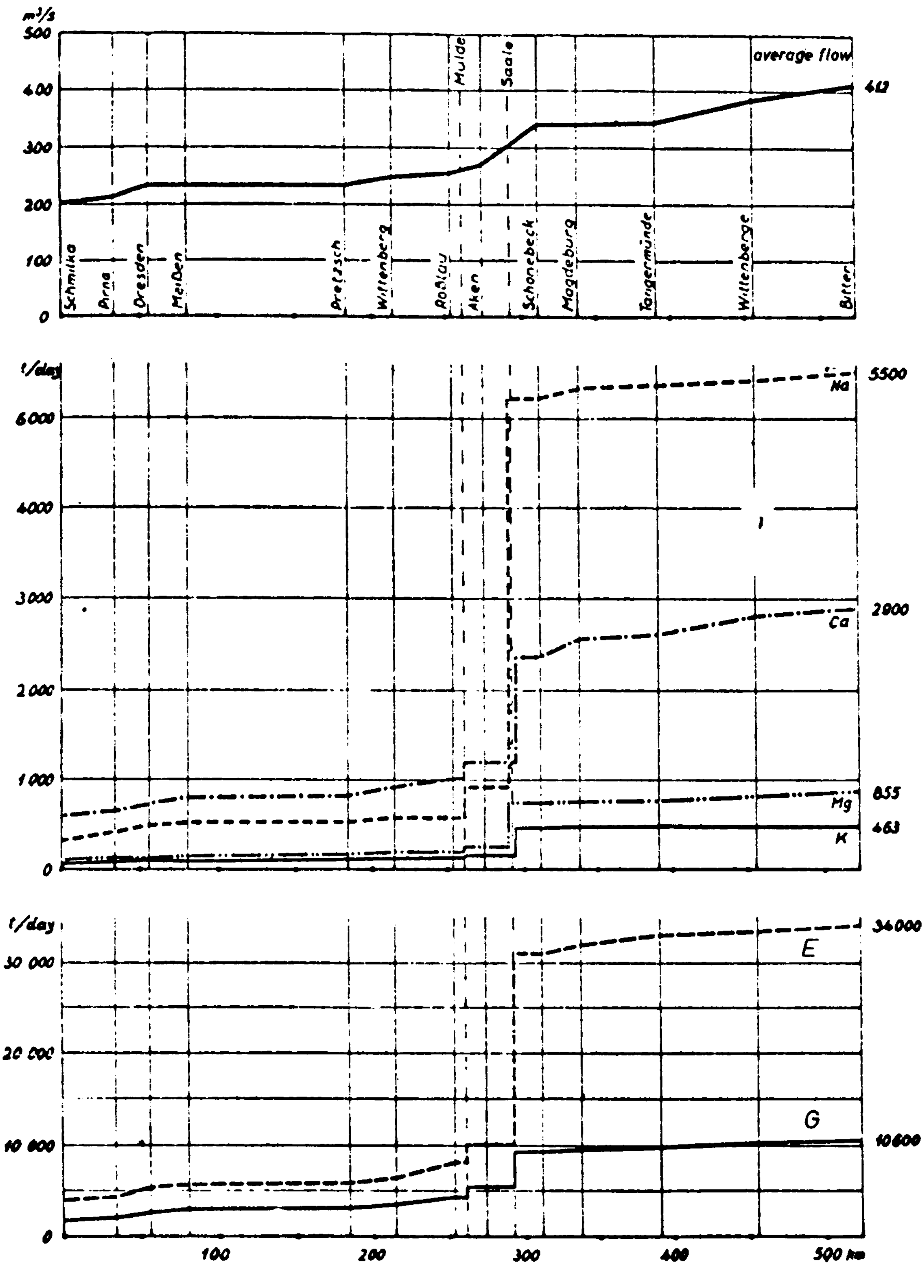

Water demand in the province of Hamburg
10⁶m³/year
600
500
400
300
200
100
0
Public water distribution
Independent industrial water distr. plants
316
208
343
229
369
251
385
263
423
293
445
314
628
471
1955
1957
1959
1961
1963
1965
1975
0
1
2
3
1,72
1,77
1,81
1,83
1,85
1,86
2,04 · 10⁶
10⁶ INHABITANTS

Fig. 1.14



TOTAL AMOUNT OF WATER CONSUMED BY THE HAMBURG INDUSTRY
(MOREOVER, AMOUNT OF WATER RECYCLED IN CLOSED PIPE SYSTEMS)

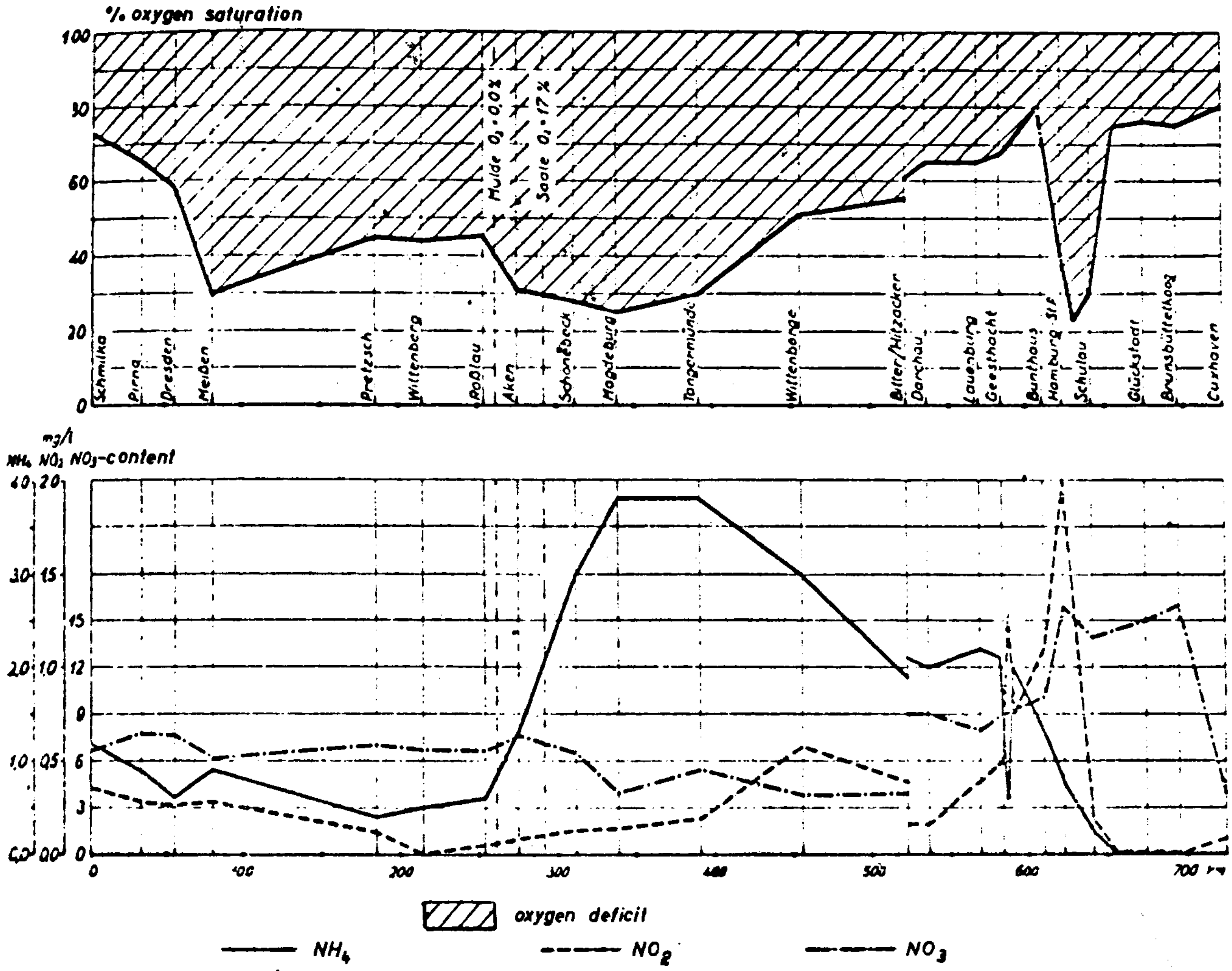
Fig 1.15



K-, Na-, Ca- and Mg-transport and transport of residues from evaporation(E) and glowing(G)(t/day) in the Elbe-River in Eastern Germany (August 1959)

Reference: „Wasserwirtschaft und Wassertechnik" 10. Jg. 1960 Heft 10)

Fig. 1.16



O_2 - NH_4 - NO_2 - NO_3-values of the Elbe-River from Schmilka to Cuxhaven im Aug. 1959

(Reference: „Wasserwirtschaft - Wassertechnik" 10. Jg. 1960 Heft 10)

Fig. 1.17

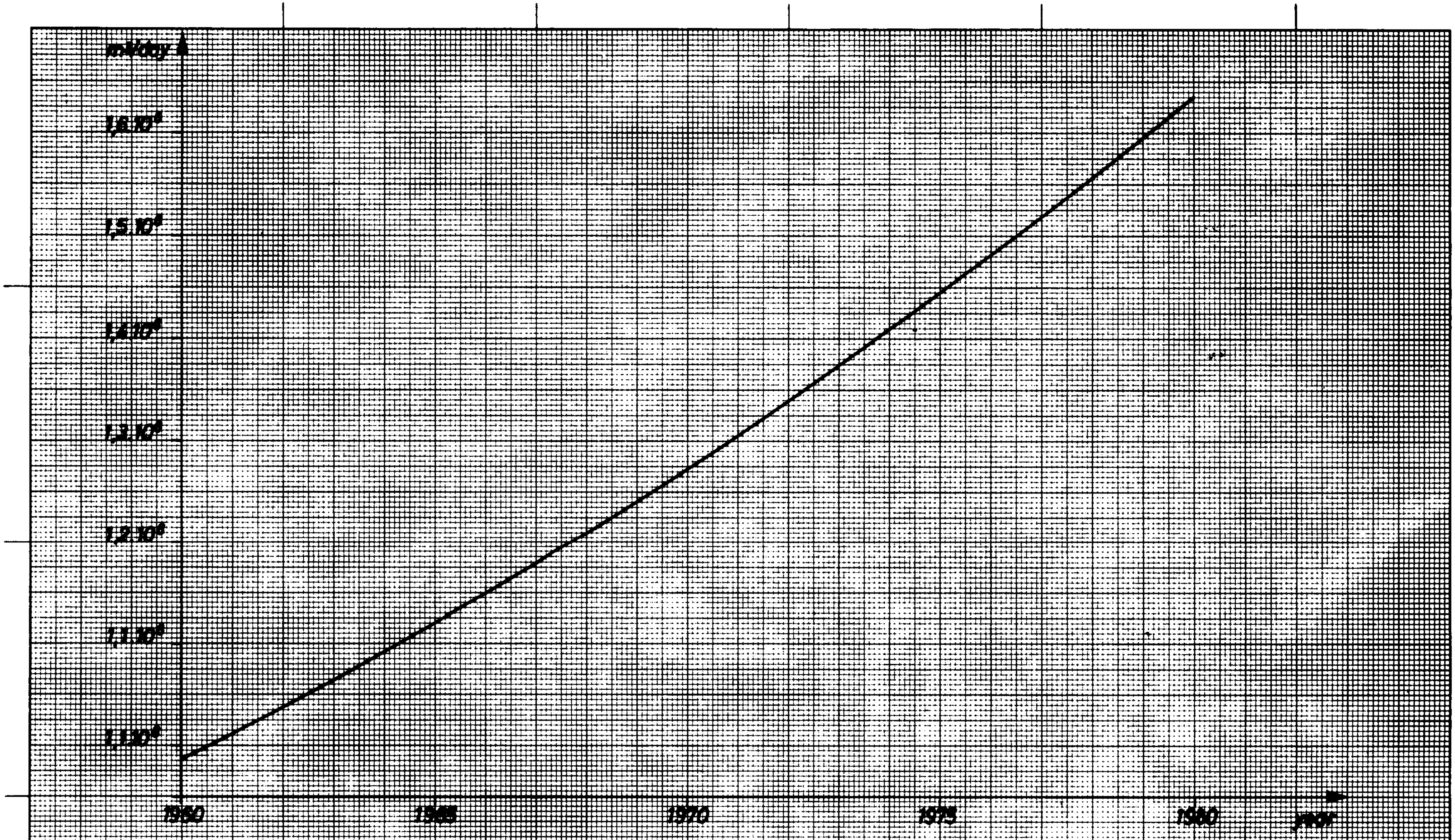


Fig. 1.15

AVERAGE DOMESTIC WATER DEMAND IN HOLLAND

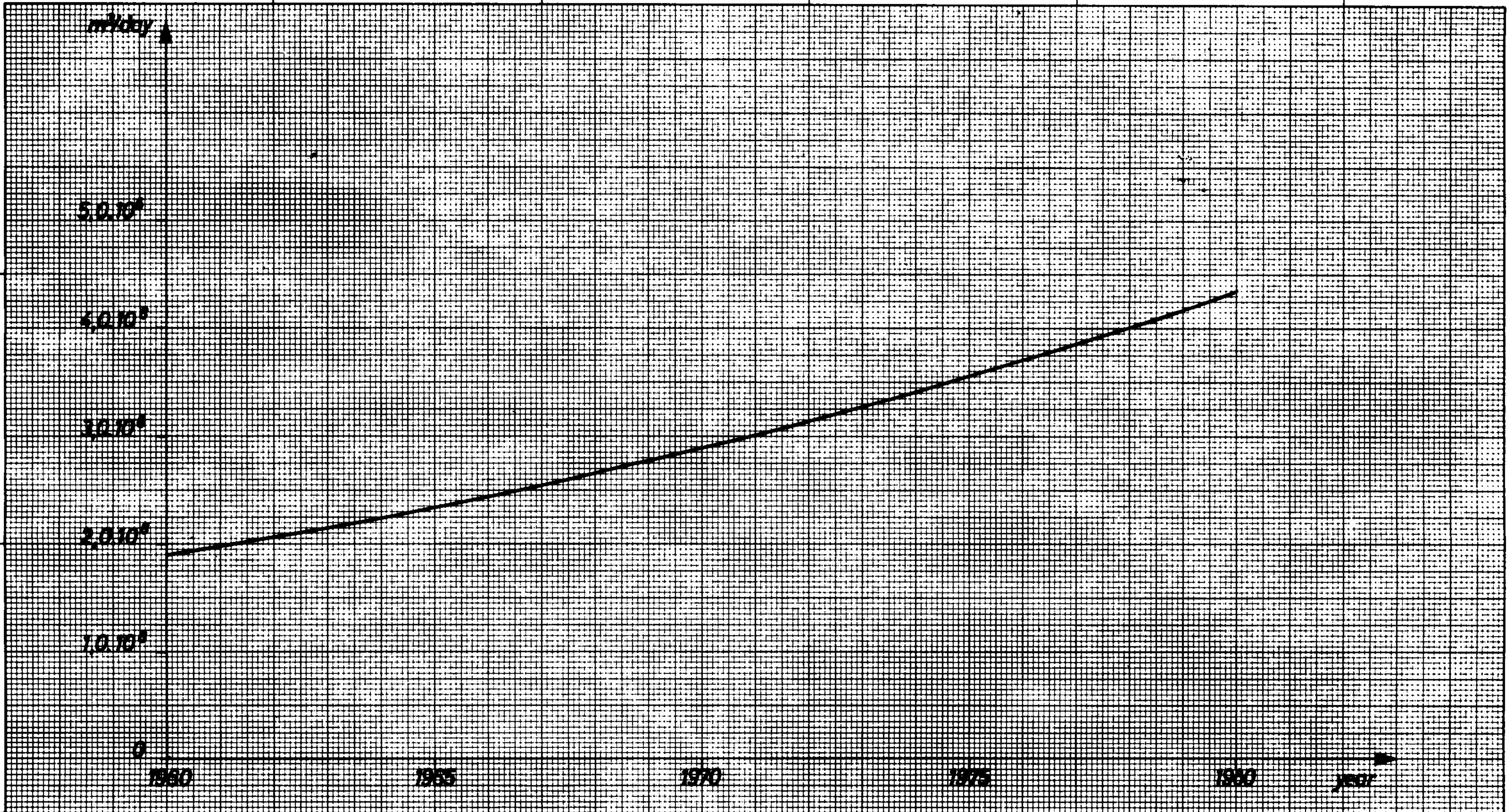


Fig. 1.19

INDUSTRIAL PROCESS WATER DEMAND IN HOLLAND

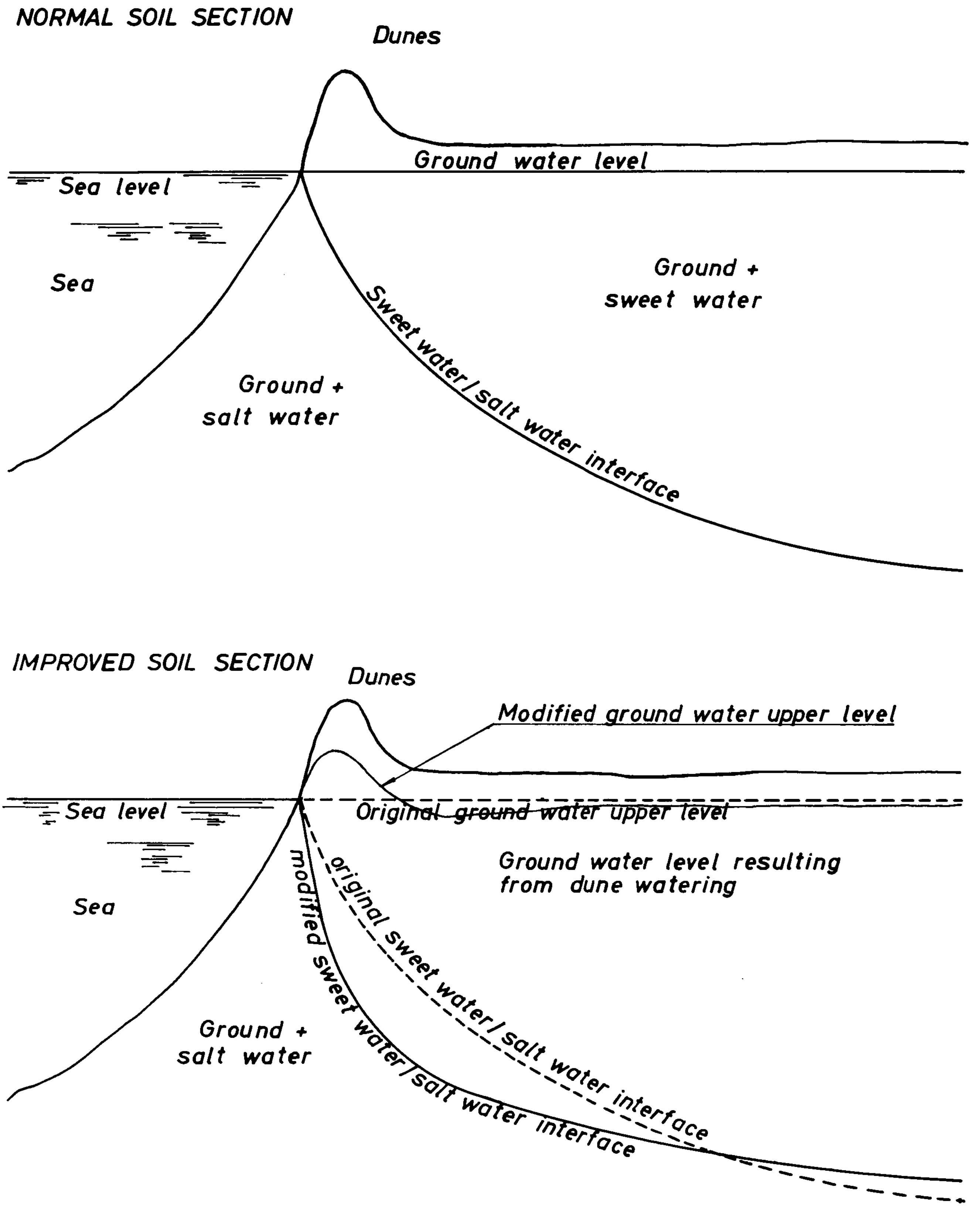

NORMAL SOIL SECTION
Dunes
Ground water level
Sea level
Sea
Ground +
sweet water
Sweet water/salt water interface
Ground +
salt water
IMPROVED SOIL SECTION
Dunes
Modified ground water upper level
Sea level
Original ground water upper level
Ground water level resulting
from dune watering
Sea
modified sweet water/salt water interface
original sweet water/salt water interface
Ground +
salt water

Fig. 1.20

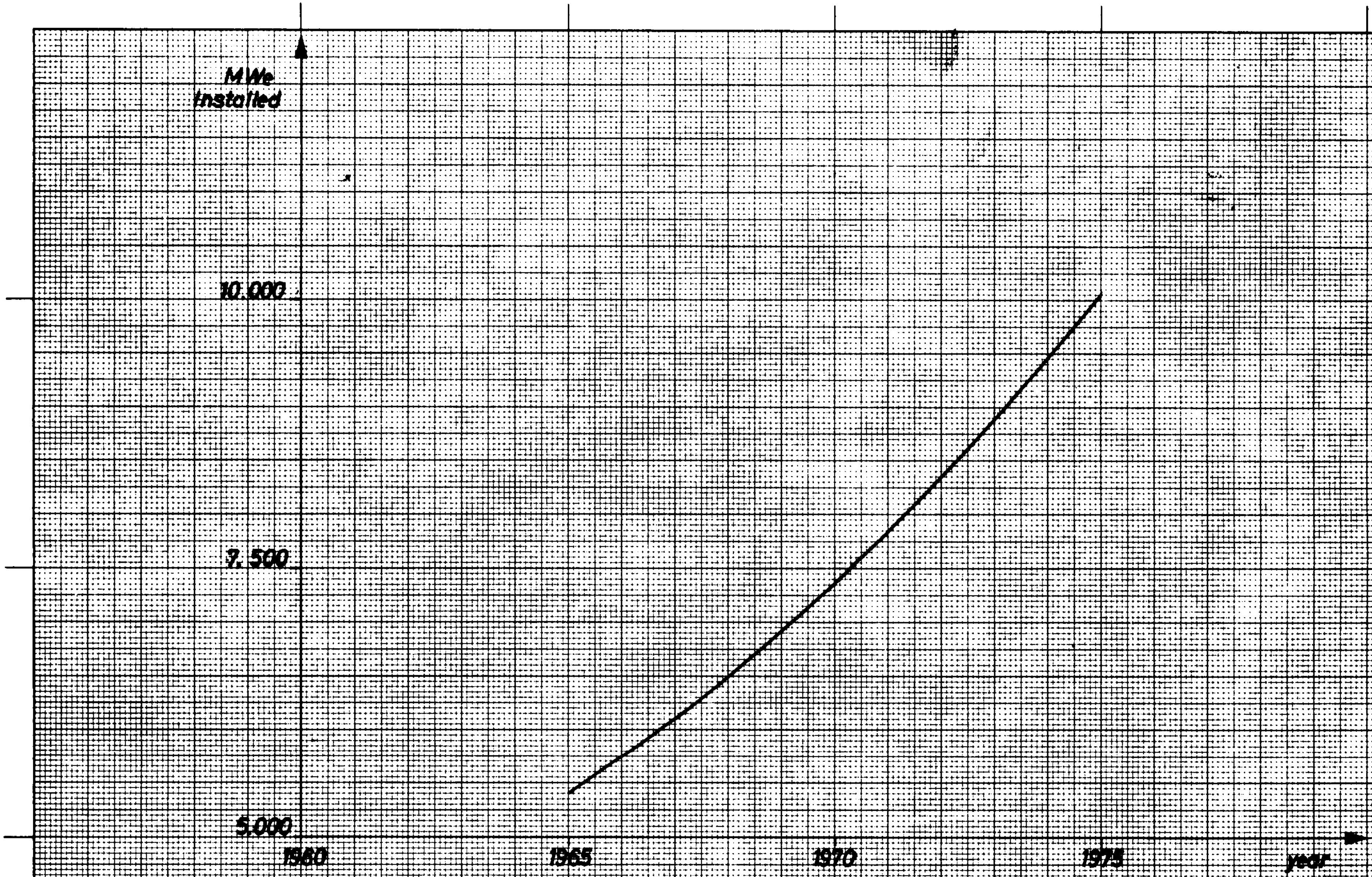
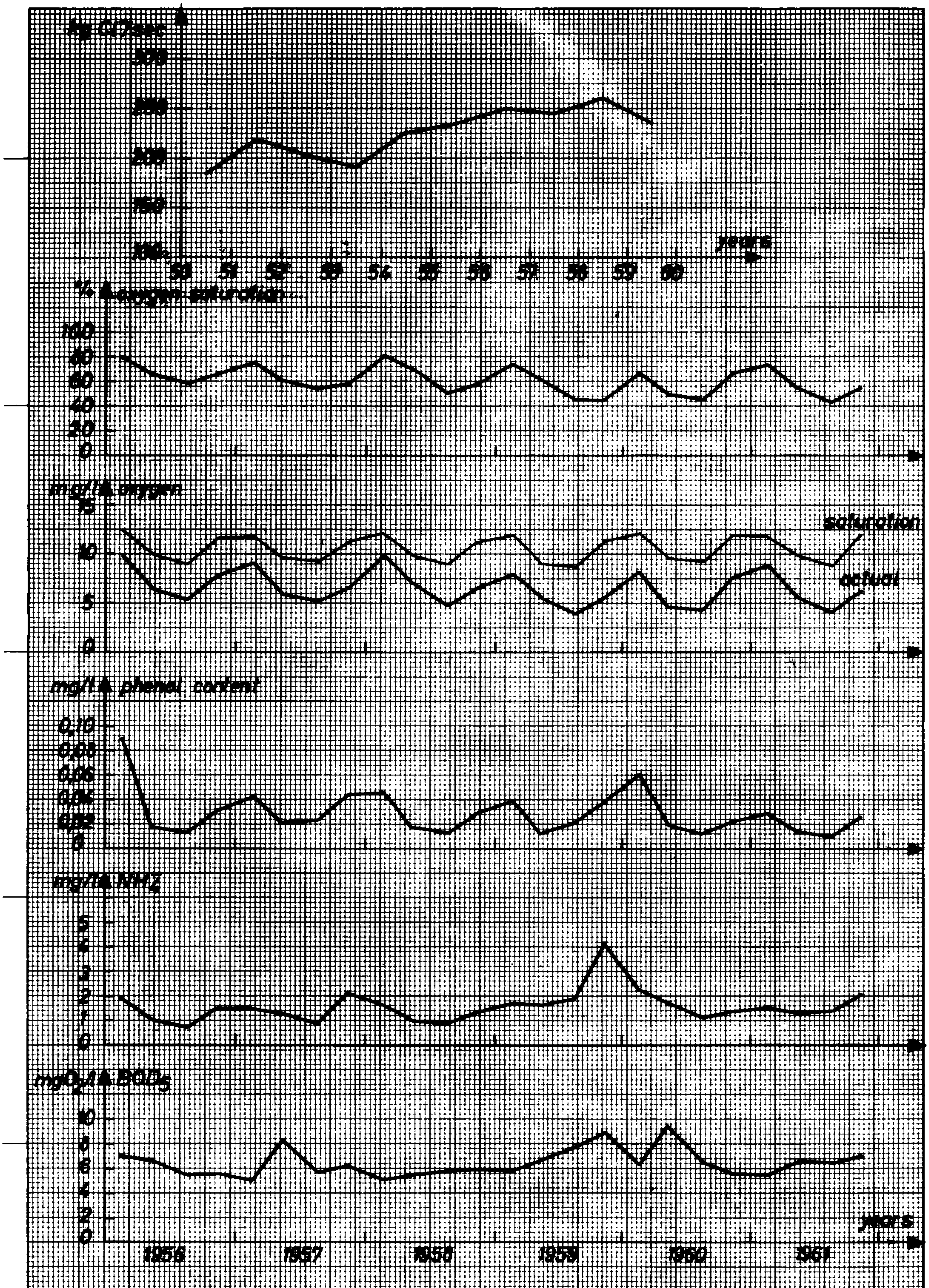


Fig. 1.21

ELECTRICAL GENERATING POWER IN THE NETHERLANDS



RHINE WATER QUALITY
(EMMERICH-LOBITH)

FIG. 1.22

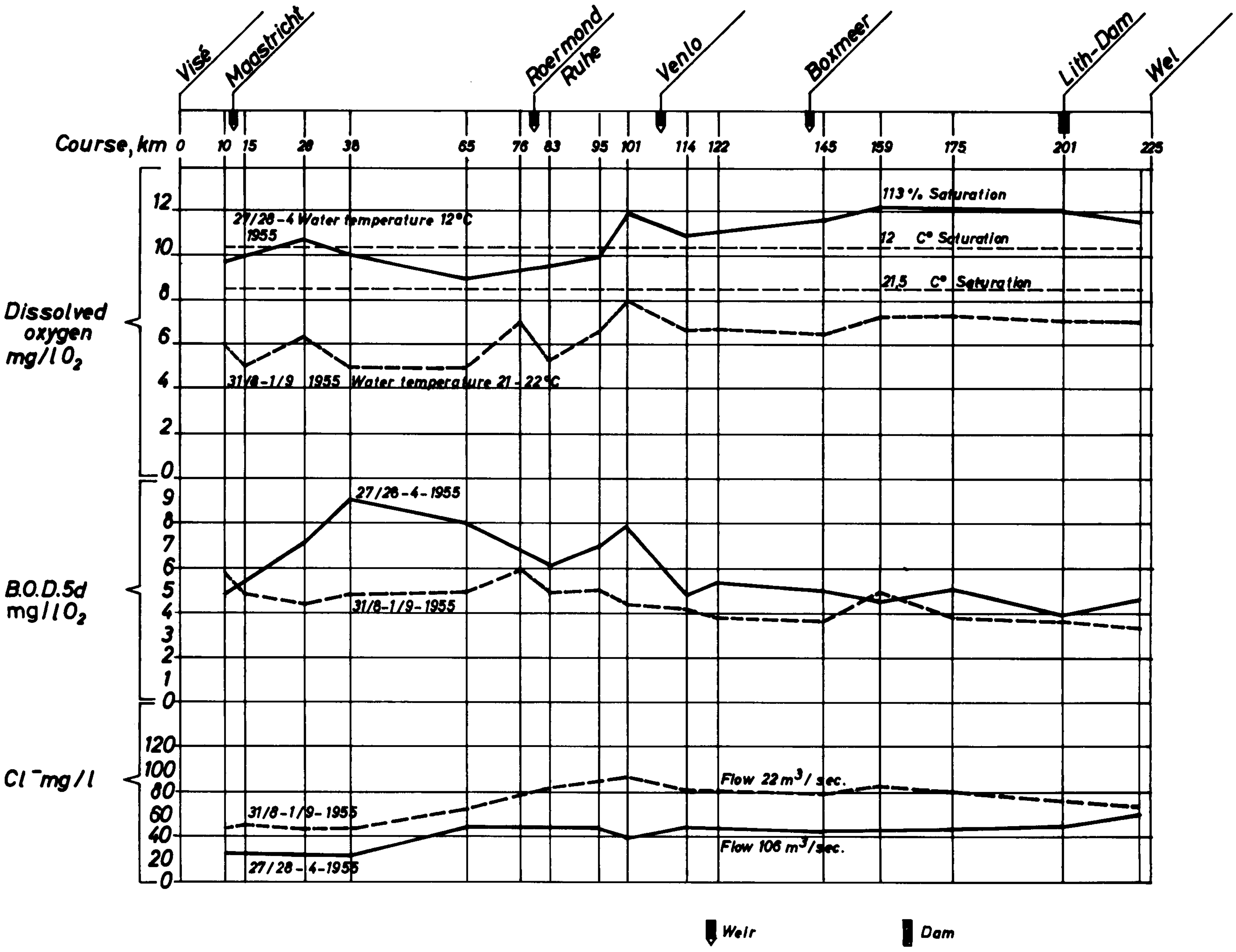


Fig. 1.23

MAAS WATER QUALITY IN THE NETHERLANDS

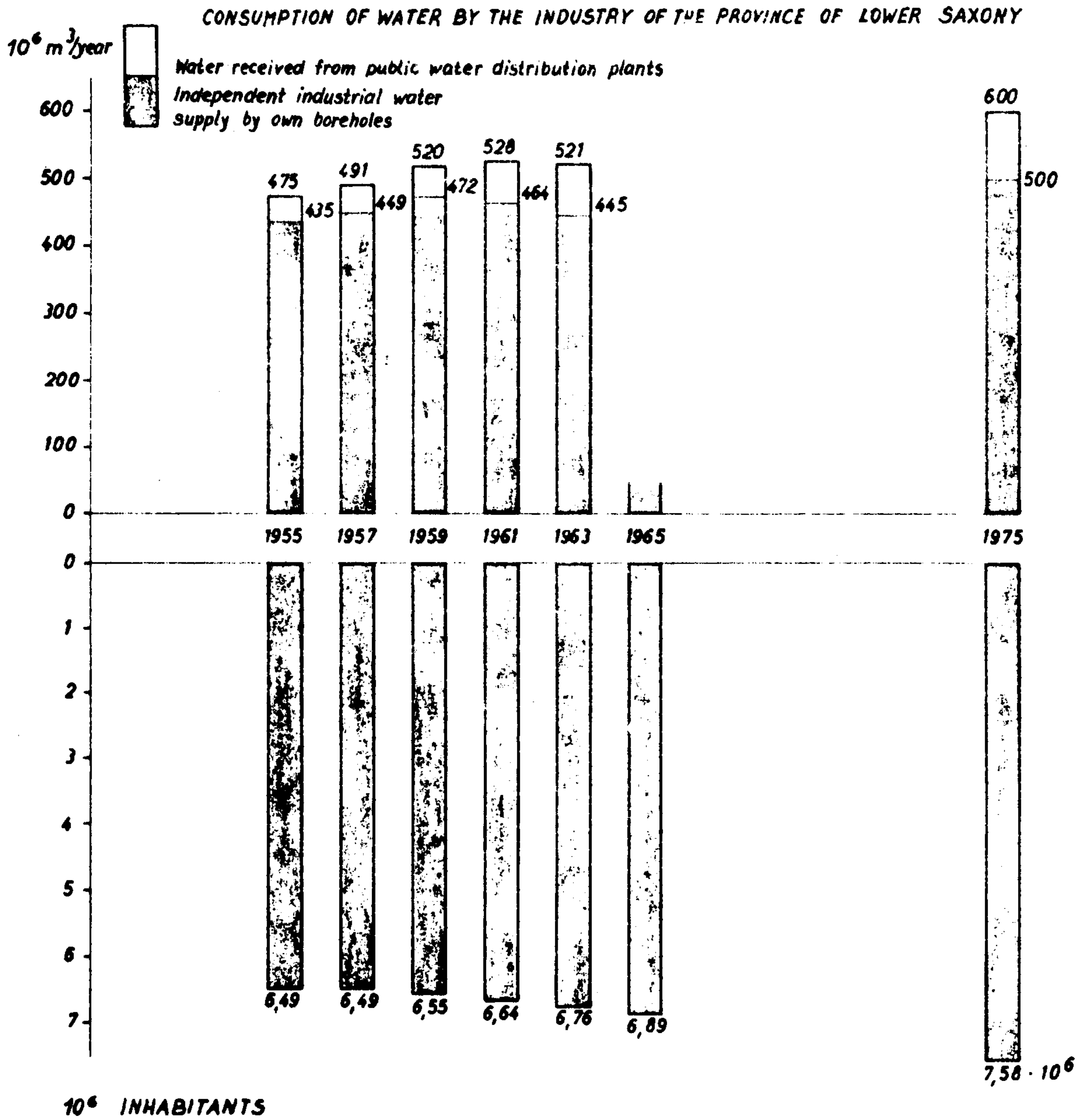
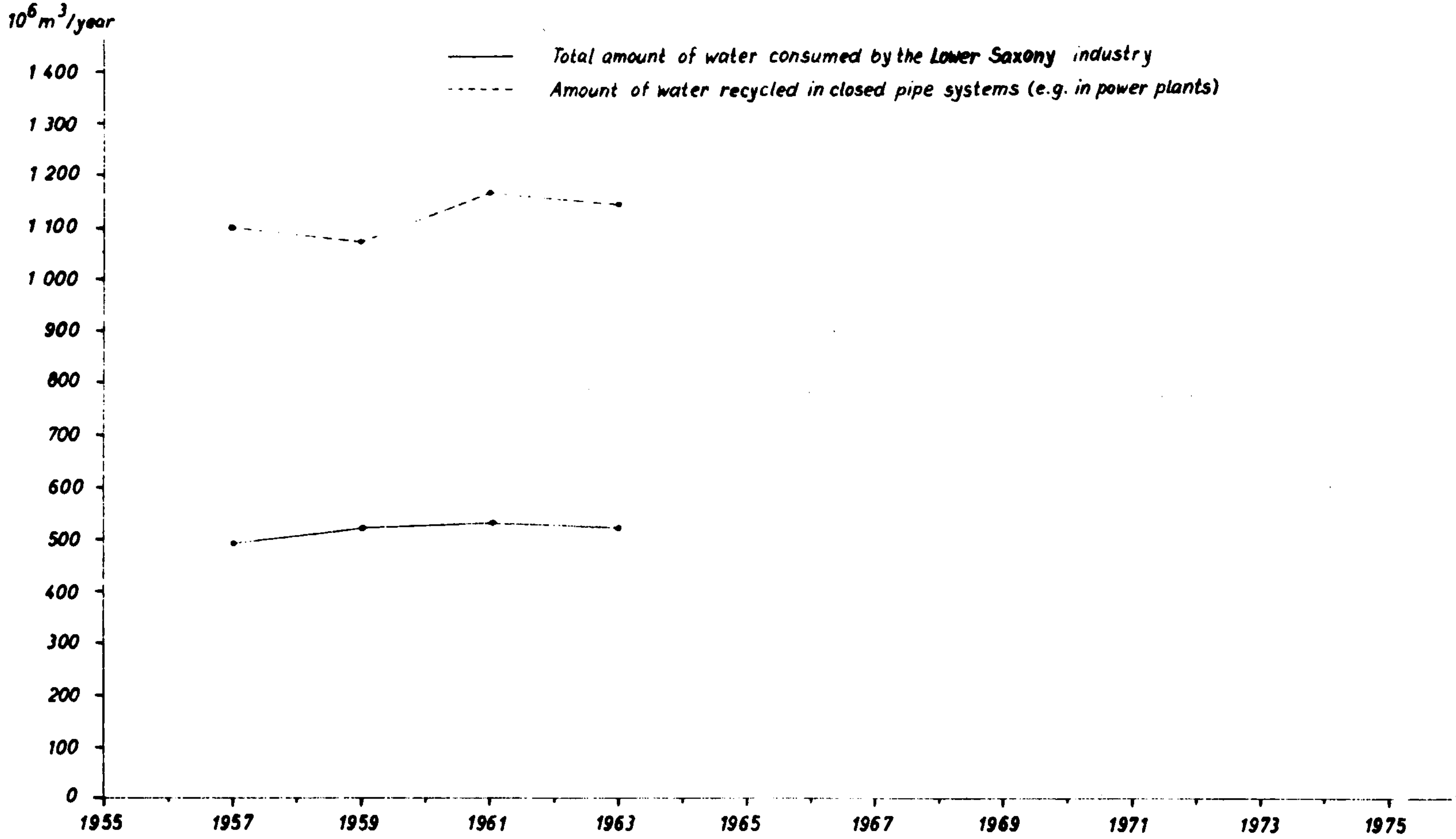

CONSUMPTION OF WATER BY THE INDUSTRY OF THE PROVINCE OF LOWER SAXONY
10^6 m^3/year
Water received from public water distribution plants
Independent industrial water supply by own boreholes
600
500
400
300
200
100
0
475
435
491
449
520
472
528
464
521
445
600
500
1955
1957
1959
1961
1963
1965
1975
0
1
2
3
4
5
6
7
6,49
6,49
6,55
6,64
6,76
6,89
7,58 · 10^6
10^6 INHABITANTS

Fig. 1.24



TOTAL AMOUNT OF WATER CONSUMED BY THE LOWER SAXONY INDUSTRY
(MOREOVER, AMOUNT OF WATER RECYCLED IN CLOSED PIPE SYSTEMS)

Fig. 1.25

Water demand in the province of Schleswig-Holstein

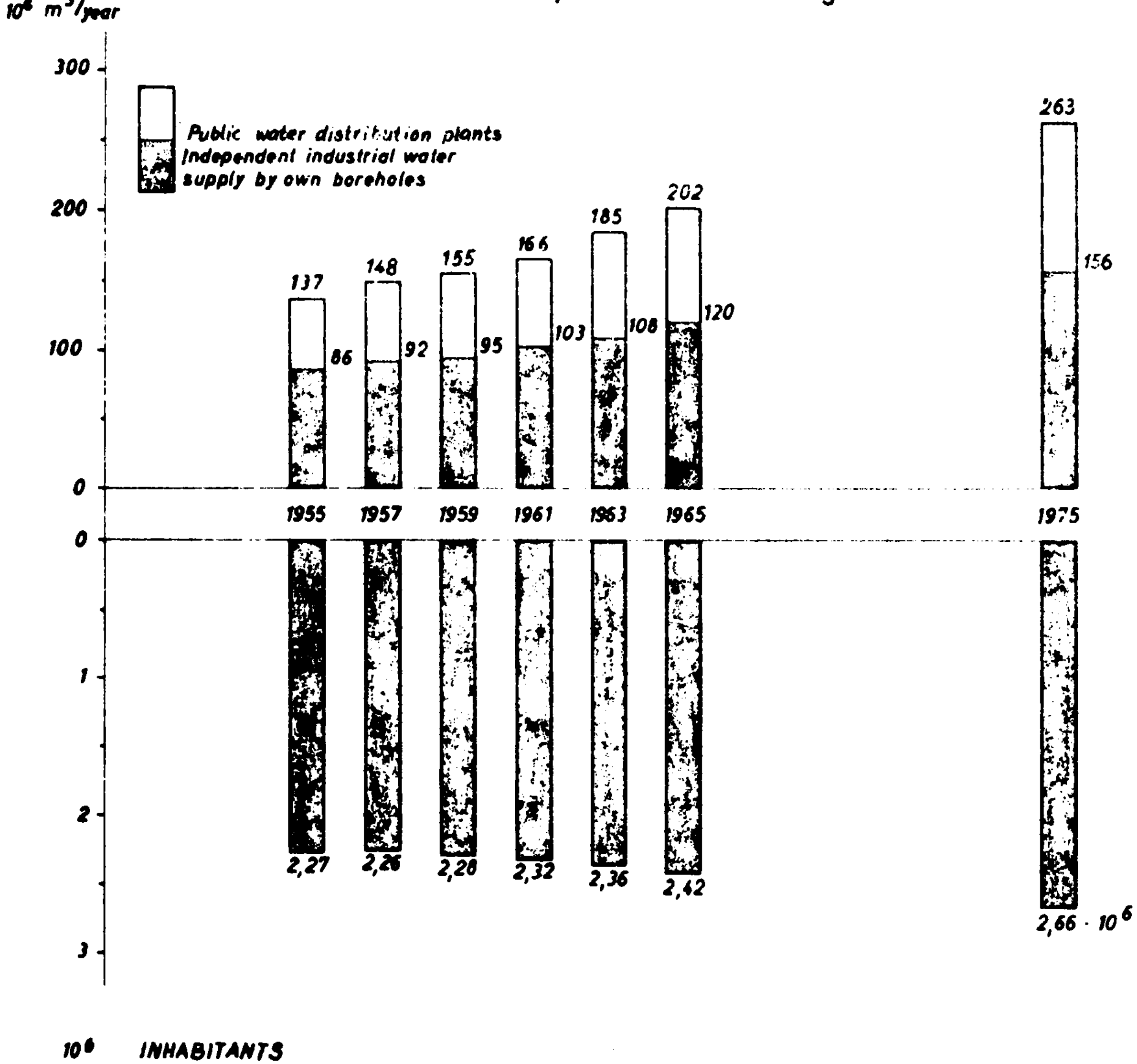
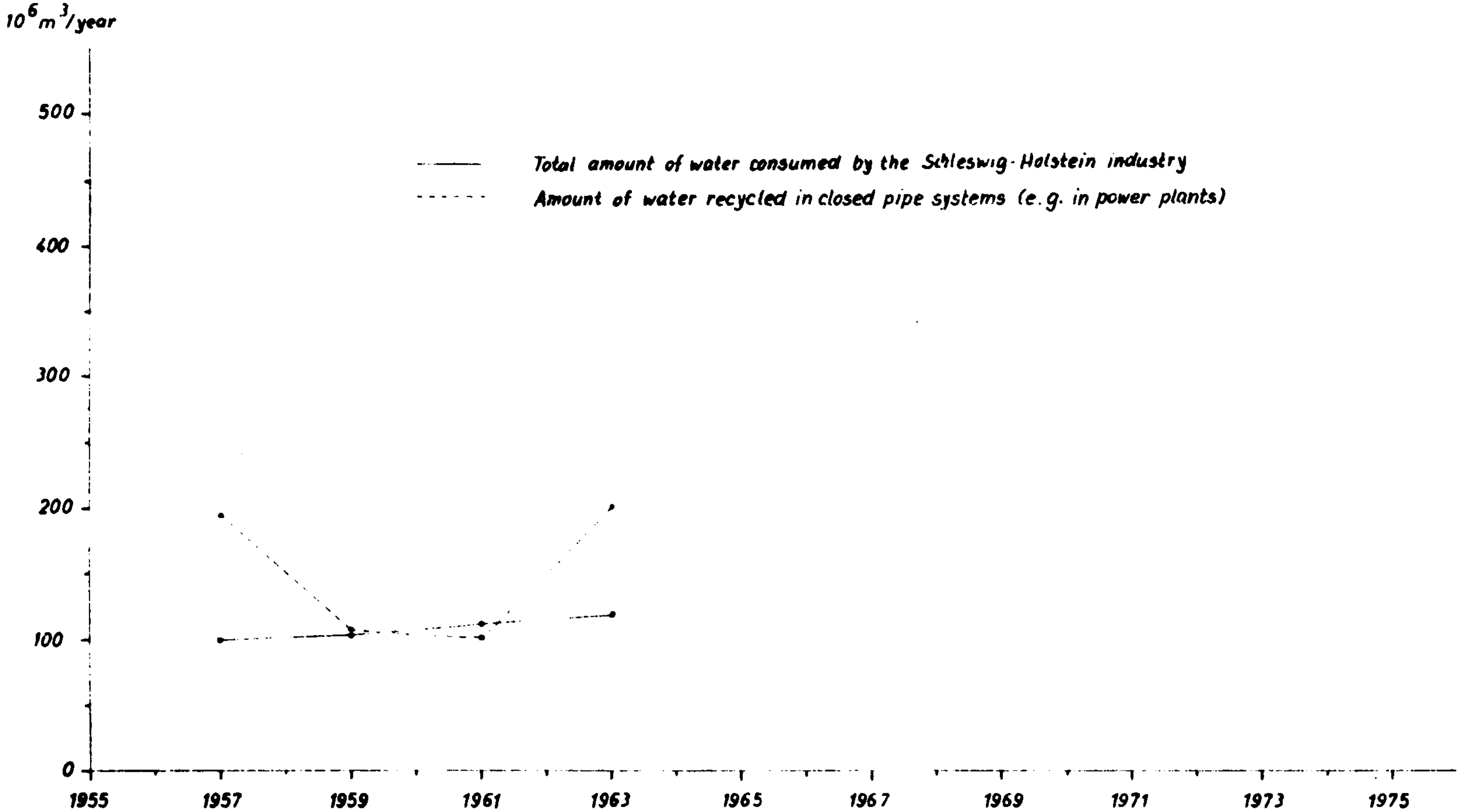
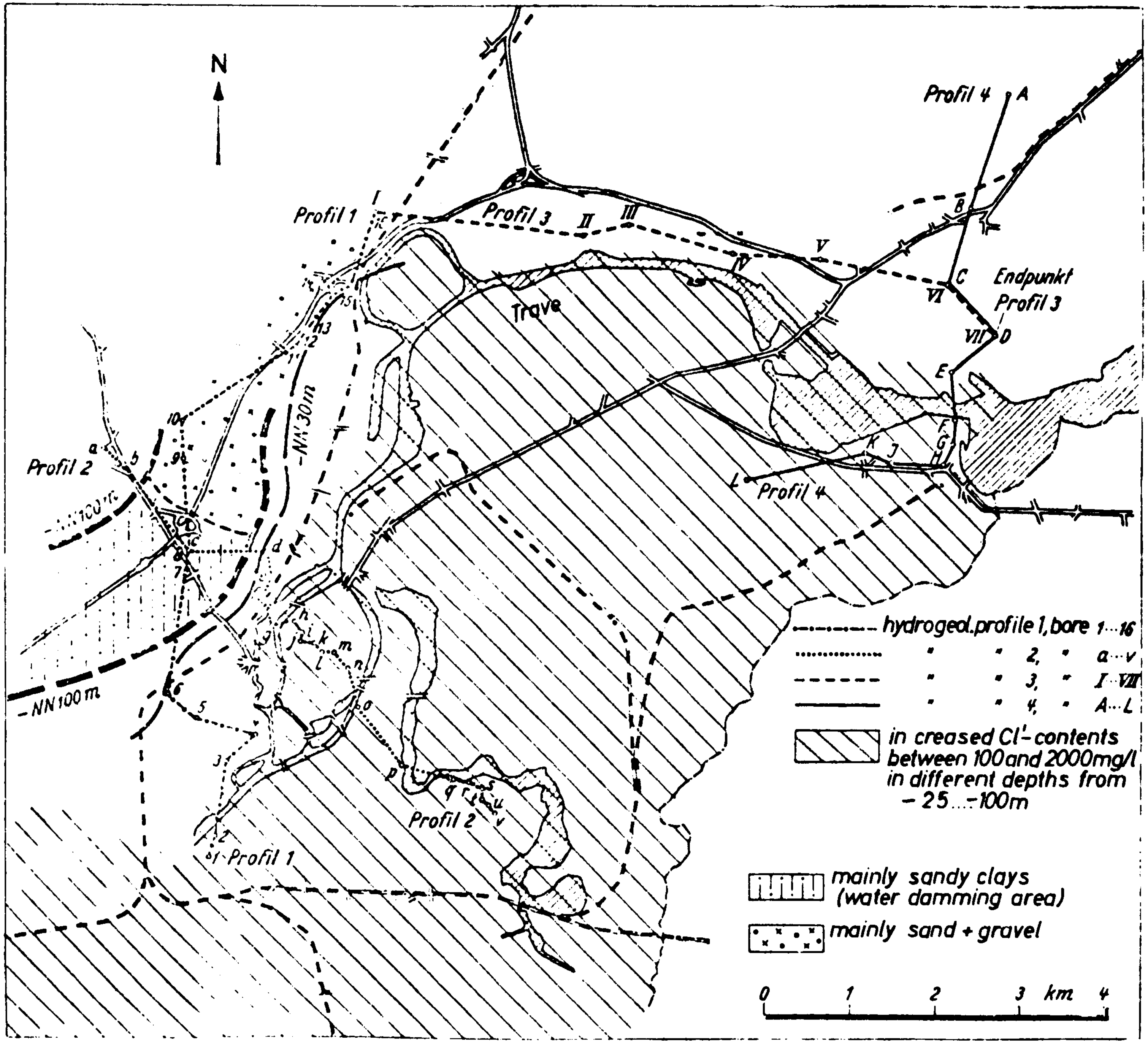


Fig. 1.26



TOTAL AMOUNT OF WATER CONSUMED BY THE SCHLESWIG-HOLSTEIN INDUSTRY
(MOREOVER, AMOUNT OF WATER RECYCLED IN CLOSED PIPE SYSTEMS)

Fig. 1.27



Map with profile-lines and demarcation of the saliferous subsoil water

Fig.1.28

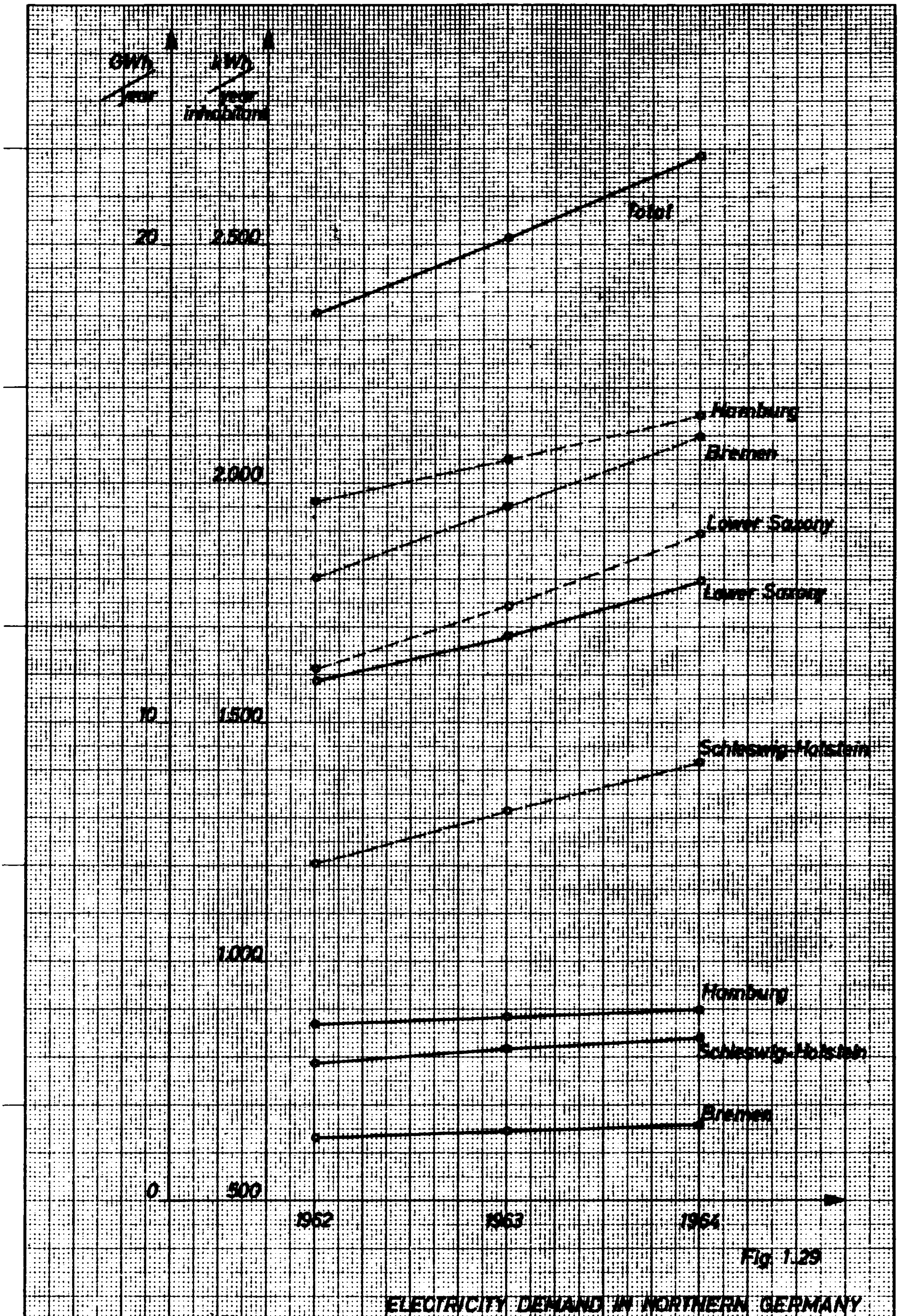


Fig. 1.29

ELECTRICITY DEMAND IN NORTHERN GERMANY

	Schleswig-Holstein GWh	Schleswig-Holstein %	Hamburg GWh	Hamburg %	Nieder-sachsen GWh	Nieder-sachsen %	Bremen GWh	Bremen %
Industry	1224,9	39,4	1293,0	34,0	6271,7	53,1	715,1	50,8
- Self generated power 1)	332,5	27,1	158,1	12,2	2475,2	39,5	77,5	10,8
- Power supplied from the grid	892,4	72,9	1134,9	87,8	3796,5	60,5	637,6	89,2
Public transport services 2)	45,4	1,5	300,5	7,9	282,5	2,4	53,0	3,8
Public utilities	201,0	6,5	258,7	6,8	571,0	4,8	79,0	5,6
Agriculture	212,4	6,8	9,8	0,3	596,4	5,1	4,6	0,3
Domestic	702,2	22,6	1096,1	28,9	1937,7	16,4	334,8	23,8
Trade	437,3	14,1	467,9	12,3	1199,3	10,2	142,6	10,1
Losses and miscellaneous	284,4	9,1	374,0	9,8	942,0	8,0	78,9	5,6
Total current consumption	3107,6	100,0	3800,0	100,0	11800,6	100,0	1408,0	100,0

1) without the electric power required for the operation of industrial power stations.

2) including the German Federal State Railways.

Fig. 130 _ GERMAN FEDERAL REPUBLIC 1963 POWER DEMAND DISTRIBUTION

	Schleswig-Holstein		Hamburg		Nieder-sachsen		Bremen	
	GWh	%	GWh	%	GWh	%	GWh	%
Industry	1346,9	39,8	1358,7	34,2	7019,1	54,2	793,5	51,7
- Self generated power 1)	360,8	26,8	168,1	12,4	2696,4	38,4	76,4	9,6
- Power supplied from the grid	986,1	73,2	1190,6	87,6	4322,7	6,16	717,1	90,4
Public transport services 2)	46,9	1,4	298,8	7,5	330,5	2,5	57,5	3,8
Public utilities	220,3	6,5	271,4	6,8	663,5	5,1	81,7	5,3
Agriculture	221,3	6,5	11,0	0,3	605,6	4,7	4,8	0,3
Domestic	783,0	23,1	1150,4	28,9	2120,5	16,4	358,2	23,3
Trade	464,3	13,7	514,8	13,0	1278,2	9,9	154,4	10,1
Losses and miscellaneous	305,9	9,0	369,2	9,3	930,4	7,2	84,9	5,5
Total current consumption	3388,6	100,0	3974,3	100,0	12947,8	100,0	1535,0	100,0

1) without the electric power required for the operation of the industrial power stations.

2) including the German Federal State Railways.

Fig. 131 _ GERMAN FEDERAL REPUBLIC 1964 POWER DEMAND DISTRIBUTION

CHAPTER II

WATER DESALINATION TECHNOLOGY

INTRODUCTION.

This chapter will cover the various industrial desalination processes available at present and compare them whenever possible; the most economical process nowadays (the multi-flash distillation) will then be described in further detail therein.

Many desalination processes are available today. They are usually based on physical phenomena although some are actually of a physico-chemical nature (ion exchange, electrodialysis). They all require energy.

The processes which have been applied to water desalination were selected in accordance with the resulting sweet water cost with the only exception of the devices used in vital cases.

The industrial processes are :

a) Distillation, single and multiple effect
b) Multi-stage flash evaporation
c) Vapour reheat distillation
d) Vapour compression distillation
e) Electrodialysis
f) Freezing, direct and indirect
g) Ion exchange
h) Organic liquid water absorption
i) Reverse osmosis
j) Hydrate process
k) Ion osmosis.

These processes can be used in combination with one another (14), the main purpose being always to reach a minimum cost for the sweet water.

1. SURVEY OF THE DIFFERENT PROCESSES.

1.1. - Energetical considerations.

Before going into the respective process technological advantages and the corresponding sweet water costs, it must be stressed that the energy required to convert the same quantity of salted water into sweet water varies considerably in nature and magnitude from one process to the other.

The second law of thermodynamics provides a basis for the calculation of the absolute minimum energy required for desalination regardless of the process. For sea water this energy amounts to about 613 kcal/m^3 or 0,72 kWh/m^3 (1) (2).

Somewhat less energy would be required for brackish waters. This is the minimum energy required for an infinitely slow operation and with no losses of any kind.

Actually, every process will require much more and the best figures correspond to about four times the theoretical value.

The energy requirements for six typical processes are given in the following table based on 1965 technology:

Process	Energy required	
	kcal/m^3	kWh/m^3
- Multistage flash distillation	68.150	79,3
- Long tube vertical distillation (LTV)	68.150	79,3
- Electrodialysis$^{(x)}$ (for brackish water only)	5.680	6,6
- Vapour compression$^{(x)}$	40.890	47,6
- Freezing$^{(x)}$	40.890	47,6
- Reverse osmosis$^{(x)}$	11.360	13,2

The energies given for the "electrical" processes $^{(x)}$ are the thermal energies for the appropriate electrical power generation at ≃ 33 % plant efficiency.

For the multistage distillation process, the figures correspond to a capacity of about 5000 m^3/day, 24 stages and a performance ratio of ≃ 8.

1.2.- Process description.

a. Distillation, single and multiple effect (Fig.2.1.)

- Single effect.

Sea water is introduced in a still type structure where it is heated. Part of the water boils leaving behind a concentrated brine which is discharged.

The vapour is condensed by means of the entering sea water which is thus preheated.

- Multiple effect.

Sea water is heated in successive stages where part of it boils. The vapour of one stage is condensed in the next one where the heat exchanged is used to warm the brine up.

The pressure in the successive stages is gradually lowered in order to meet the temperature difference required for the heat exchange.

b. Multiflash distillation (Fig.2.2.) (3)(4)(5)(6)

In multiflash distillation plants, the incoming sea water is first heated up in a large number of preheaters in series. It is finally brought up to the process maximum temperature by heat provided externally (brine heater).

By maintaining adequate pressures in the successive stages, no sea water boiling takes place within the different preheaters thus avoiding scaling.

The hot sea water is then fed back in the different stages where it is evaporated by gradual flashing and where the sea water preheaters act as condensers.

The condensate from the successive stages is used as heat source in the successive preheaters thus achieving a fresh water discharge temperature as low as possible.

Plants operating on this principle have no metal evaporating surfaces subject to possible scaling. To prevent scaling within the brine heater only small quantities of chemical additives are required.

More details about this process, which looks the most promising at present, will be given in paragraph 2 of this chapter.

An attractive alternative flash distillation layout is the so called "long tube vertical" flash distillation (LTV) shown on Fig.2.3.

c. Vapour reheat process (Fig. 2.4.) (4)(7)(8)(9)

The vapour reheat process mainly developed by Othmer, is a multi stage flash type evaporation process wherein no metallic heat exchange surfaces are used either in the evaporating or the condensing stages. The steam generated by flashing in the stages is condensed by direct contact with colder condensate which is thus gradually heated. After the last condensate preheating stage, corresponding to the last stage, the condensate is brought to a maximum preheating temperature by steam heating (condenser).

In one heat exchanger, the condensate is cooled down by oil flowing in the opposite direction : this oil is thus heated up and then brought to the bottom of a second heat exchanger where it flows in the opposite direction to that of sea water which is thus heated up before being fed to the flash evaporating stages. Part of the cold fresh water is refed into the first flashing stage where it is required as vapour-condensing medium. The rest of the sweet water produced is stored.

Such vapour reheat evaporators are the result of logical developments to avoid corrosion and scale problems. However, an auxiliary fluid must be used for heat transfer. This process is very promising if small heat exchangers can be achieved. Othmer has theoretically calculated that a performance ratio of 20 to 30 m^3 of fresh water per ton of steam could be reached.

d. Vapour compression distillation (Fig. 2.5.) (4)(5)(10)

This process is an application of the heat pump. The vapour from sea water is compressed and then condensed. The condensation temperature is therefore slightly higher than that of the sea water evaporation temperature. This condensation is therefore used as the heat source for evaporating the incoming sea water. The compressed steam enthalpy being larger than that of the uncompressed sea water vapour, no heat is required, the surplus energy required being provided by the compressor.

This process requires remarkably small amounts of energy and is thus specially suitable for small and medium capacity plants where other evaporating processes require larger amounts of energy.

The disadvantages are :

- intricate design
- vapour compressor and drive operating trouble
- correspondingly short operating life.

Owing to the large depreciation charges of such plants, the water cost is rather high in spite of the small amount of energy required.

These plants have nevertheless been found interesting where highly qualified operating staff is available and where only a short plant life is required.

e. Electrodialysis (Fig. 2.6.a and b) (11)

Electrodialysis is, in theory, the most convenient brackish water desalination process. The principle is that the salt which is ionized has its ions migrating towards the anode or the cathode according to their respective charge. If sea water is brought in cells whose walls are alternately anion or cation permeable, the salt concentration becomes very much larger in one half of the cells than in the other half if a direct current voltage is applied to the walls. The intensity of ion migration depends on the voltage applied. With increasing salinity the energy required increases so much that the process is no longer economical (Fig. 26.b)

Electrodialysis is therefore cheaper than freezing or evaporation where low salinity or brackish water has to be processed.

One serious electrodialysis drawback is that of producing suitable membranes, that is with adequate operating life.

In these plants, the membranes are set one behind the other as in press filters. They should have high mechanical strength, low electrical resistance and good ion selectivity.

f. Freezing, direct and indirect (Fig. 27.a and b) (4)(10)(12)

In this process, sea water is cooled below the freezing point. Pure ice crystals therefore start floating on it and the liquid salinity increases correspondingly. The crystals are separated from the brine mechanically. The crystals are then washed to remove any salt, and melted. Practically fresh water is thus produced.

The removal of the seawater heat can be carried out directly or indirectly : either at the low vapour pressure corresponding to the freezing temperature or at the higher vapour pressure of an insoluble hydrocarbon added previously to the sea water.

The direct method is generally resorted to.

Another freezing process uses absorption equipment for sea water evaporation instead of a vapour compressor.

The freezing processes have the following advantages over the other distillation processes:

- no scale
- little corrosion
- small heat losses
- theoretically only little energy required (heat of fusion much smaller than vaporisation heat).

The practical conditions are less favourable however. The heat removal (refrigeration) requires more energy than evaporation so that this process is not cheaper than distillation processes at present.

g. Ion exchange (Fig. 2. 8.)

The principle involves exchanging successively cations contained in the sea water within a cation exchanger where cation H^+ is released and anions within an anion exchanger where anion OH^- is released.

h. Organic liquid water absorption (Fig. 2. 9.)

This process also known as liquid-liquid exchange is based on the property of some organic liquids to dissolve larger amounts of water at low than at high temperature.

A cold organic solvent is therefore used to extract water from raw sea water. This water is then separated from the solvent by heating.

i. Reverse osmosis (Fig. 2. 10.) (13)

This process is very promising in view of its simplicity. It is still in the experimental stage. Here, osmosis is made to occur not as in nature, but in reverse. The vital components are the extremely thin plastic membranes through which the water molecules can permeate whereas the salt molecule rate of passage is very much smaller in view of the osmotic pressures.

For fresh water economical production, the pressures which have to be applied are much larger than the osmotic pressure. For sea water, the optimum is about 105 kg/cm^2 (when the osmotic pressure is only of 26 kg/cm^2).

For brackish water, this is of about 70 kg/cm^2 (when the osmotic pressure for a 2000 ppm solid concentration solution is of 14 kg/cm^2).

The fresh water obtained in this way is not altogether without salts, but can be used for drinking and in many other ways.

The process is extremely simple and only requires a small amounts of energy. The main difficulty, so far, is connected with the implementing of membranes with sufficient mechanical strength.

j. Hydrate process (Fig. 2. 11.)

Low molecular weight hydrocarbons, such as propane, form hydrate crystals when in contact with water. The excess propane is vaporized to remove the crystal heat of formation. This propane is recycled after having been compressed and condensed. The hydrate crystals are washed with fresh water produced in the process and are then decomposed again into water and propane which are separated by gravity.

k. Ion osmosis (Fig. 2. 12.) (10)

This process uses ion permeable membranes which allow anions or cations to permeate in one direction only.

The process actually provides its own power except for the pumping energy required in larger plants.

The process is especially valuable for brackish water desalination.

1.3. - Process comparison.

The fresh water cost is the major process comparison consideration. This cost depends considerably on operating cost. Up till now, the process corresponding to the minimum water cost is that of multi-stage flash evaporation. This is why most large scale desalination plants all over the world are designed to operate on this principle. Fig. 2. 13. shows this plainly enough. It lists all plants of more than 500 m^3/day capacity in the world. This table shows that it is the multi-stage flash process which is used most widely. This means that it is the cheapest at present, especially for large units.

These plants have in fact such outstanding advantages, as explained in further details in paragraph 2 of this chapter, that all of them with a capacity larger than 4000 m^3/day, presently in operation, being built or planned are of this type. They are also generally considered in atomic dual-purpose plants.

Tenders for plants with capacities up to 567.000 m^3/day have been presented. Such a power plant has been ordered recently for Southern California. Capacities between 950.000 and 3,8 . $10^6 m^3$/day are planned.

For large capacity sea shore plants the classical multi-stage distillation process is not thermally equivalent to the multi-stage flash process (higher resistance to heat flow). The multi-stage distillation plants are moreover very prone to scaling so that they are practically not used in large units.

According to Othmer (9), the fresh water cost obtained by classical multi-stage distillation cannot be reduced any further whereas this is yet possible with multi-stage flash evaporation.

Among the other distillation processes, vapour compression seems to be suitable for small and medium size plants, as little space is required. On the other hand, capital costs are high.

Electrodialysis is also widely used to-day but it is adversely affected by the organic matter contained in the sea water. As the energy demand depends on the sea water salinity to a considerable extent, electrodialysis cannot be as universally applied as distillation plants.

Freezing has a particular advantage of being corrosion and scale free. The energy demand is relatively small. Freezing plants, however, have components of large volume and desalting is not as thorough as with other processes.

Comparing economically the processes between themselves and without attaching any particular significance to the values given, the following table lists indicative water cost trends for plants of the same capacity operating according to different processes.

Plant capacity : 1000 m^3/d	Water cost in US ¢/m^3
Distillation	50
Electrodialysis	37
LTV	50
Multi flash distillation	30,5

The attention of the reader is drawn to the small plant capacity of this table. The trend is altogether different with large capacities where the multi-stage flash distillation process unit cost decreases much more significantly with size increase than in other processes (see also 2.4. hereafter).

The cost decreases as plant size increases, as shown in the following table, but the rate of decrease also varies very much with the process considered.

Estimated water cost for multi flash evaporation	
Plant capacity (m^3/day)	Water cost in US ¢/m^3
1.000	30,5
10.000	26,4
100.000	13,2
1.000.000	8

2. CONSIDERATIONS ON THE MULTI FLASH DISTILLATION PROCESS.

The multi flash distillation process theory, and the numerous plants, commissioned and in project, have been developed and described at length in a large number of reports and communications. The reader is referred to them and in particular to references (3) (15) (16).

What will be covered hereafter, in accordance with these references, is :

- principles of operation
- performances and energy requirements
- material selection
- advantages of dual purpose plants.

2. 1. - Multi flash distillation operating principles.

The characteristic features of a multi stage flash type distillation plant are shown on Fig. 2. 14, 2. 15 and 2. 16. A basic characteristic of this process is that the amount of sea water required (F) is much larger than the amount of fresh water produced (D). This ratio (F/D) depends on the difference between the incoming sea water temperature and the sea water brine heater exit temperature (Fig. 2. 16.).

The sea water circuit can be arranged in two manners : the "once through" method (Fig. 2. 14.) and the combined "once through" and recirculation method (Fig. 2. 15.). In the second method most of the sea water required is recirculated and its application implies lower scale preventing chemical costs.

2.2. - Performances and energy requirements.

K. Höffer (17) has made thorough investigations on the most important parameters affecting the fresh water cost produced in the multi flash type plants.

According to Höffer's relation, the most important parameters can be determined in advance, especially the total amount of heat required per kg of distillate produced in relation with the number N of flash stages, the incoming sea water temperature t_z, the sea water brine heater exit temperature t_0, and the temperature difference θ_e between the stage saturation temperature and that of sea water leaving the corresponding preheater.

Based on Höffer's relation, diagrams have been drawn showing that the stage number has a very large incidence on the heat required per kg of fresh water produced. For instance, a 10 stage evaporation plant requires about twice as much heat per kg distillate produced than a 30 stage plant (both for t_0 = 100°C).

A 50 stage plant requires in turn 15 % less heat than a 30 stage plant (Fig. 2. 17.).

The heat required is moreover smaller when t_0 is higher, and θ_e and t_z are smaller (Fig. 2. 18., 2. 19. and 2. 20.).

The knowledge of the theoretical amount of heat required for producing 1 kg distillate is however not sufficient to compute the fresh water cost. Over and above the plant operating cost, which already includes the required heat cost, one must take the plant fixed charges into consideration. The plant capital cost depends on the number of stages. The preheater capital cost also increases as θ_e decreases. The optimum θ_e can only be reached by balancing the fixed charges against the corresponding operating charges.

For large scale fresh water production from sea water (more than 1.10^6 m^3/day) in dual or multi purpose plants, considerable fresh water cost decrease may be expected : the outcome of numerous studies is that for normal capital cost, interest rate, depreciation and kilowatthour selling price, fresh water may be produced at 6,25 US ¢/m^3, as in the California project. Increased attention is also paid nowadays to secondary cost factors i.e. reduction of mass flow by means of higher brine concentration in part of the circuit and use of cheaper materials.

To reach the most economical design, one must bear in mind that there is one optimum heat requirement value for any fixed charge value.

To every plant power consumption (whose variation is contrary to that of the number of stages i.e. to the plant size) corresponds one value of the water cost which is made up of the sum of the energy cost and the capital cost (Fig. 2.21.). The curve of this total unit cost goes through a minimum value which corresponds to the optimum design (optimum number of stages and power consumption).

A detailed explanation of these relationships is given by Tribus and Evans (15).

2.3. - Material selection.

Fig. 2.22. lists the materials used in multi flash evaporation plants.

2.4. - Advantages of dual purpose plants.

In the usual processes used for large scale production of sweet water from sea water, dual purpose plants (electricity + fresh water with flash distillation) are the best nowadays.

These dual purpose plants have been built or planned in several versions. Significant water cost decrease is expected from them. In a dual purpose nuclear power plant of 3.000 MWth (corresponding to 1.700 MWe and 567.000 m^3/day) such as planned for Southern California it is hoped to reach fresh water cost produced from sea water of about 6,25 US ¢/m^3 (Fig. 2.23 and page 42).

In a large dual purpose plant, savings arise not only from larger production units but also from the fact that part of the equipment is common (see a) and from smaller operating costs (see b).

As another example, the following table gives a comparison between the single and dual purpose plant water costs according to Allis-Chalmers.

Plant type	Net power MWe	Fresh water production (m^3/day)	Capital costs (10^6US $)	Operating costs (10^5US $/year)
1. Electricity only	1480	0	204	14
2. Water only	0	3,1 . 10^6	530	21
3. Sum of 1 + 2	1480	3,1 . 10^6	734	35
4. Dual purpose plant	1480	3,1 . 10^6	619	23

The reader will find further details regarding this point in the very exhaustive Catalytic Construction Company report, ref. (18) from which the following conclusions are nevertheless taken :

"In nearly all cases where plant conditions of size, energy source, fixed charge rate, and power credit factor are equal, water is produced more cheaply in the dual purpose cases. This difference varies from 15 % to infinity for, in some cases of large dual purpose plants operating under a power credit factor of 6 mills or higher, water production could be fully subsidized. There appear certain cases where the water-only plant may be competitive. If the plant size is small, resulting in a low power credit, and the fixed charge rate is high, imposing a greater penalty on the dual purpose plant due to its larger capital investment, then the water-only plant may be economically justifiable.

All dual plants exhibit rather impressive reductions in water cost with increase in plant size up to approximately the 600 MWt input energy level, at which point, under the conditions of this study, the curve of water cost vs plant size flattens. Although this general effect is to be expected in this type of economic system, where a large initial capital investment is required for the first increments of production, the point at which the effect is manifested is primarily influenced by the ground rules employed. In this study, a principal determinant is the modular approach to increasing plant capacities."

Regarding the dual purpose plant savings, one may underline the following points :

a. Capital cost savings.

Where using multi purpose plants, unit capital costs are decreased because the equipment costs are only marginally increased for the larger powers required.

Among the equipment common to both purposes, the main items are :

- the desalination plant brine heater is the power plant condenser (at higher pressure and temperature),
- the water intake and discharge,
- the circulating pumps and piping,
- the miscellaneous operating facilities such as railway sidings, roads, workshops, offices, trucks, etc...

b. Operating cost savings.

As the power generating and the desalination plants both require very large investments, a high load factor must be achieved in order to decrease the overall operating costs as much as possible; the ideal would be to operate on base load only. By using the power plant heat of condensation as heat source for the desalination plant, the operating costs are reduced to a considerable extent.

By pooling the supervising and operating services, these running expenses are also smaller for a combined unit than for two independent plants of the same capacity.

These savings require of course a carefully thought out organization to make them really effective. Fig.2.24. is a dual purpose plant personnel organigram, both in functions and numbers, for different capacities.

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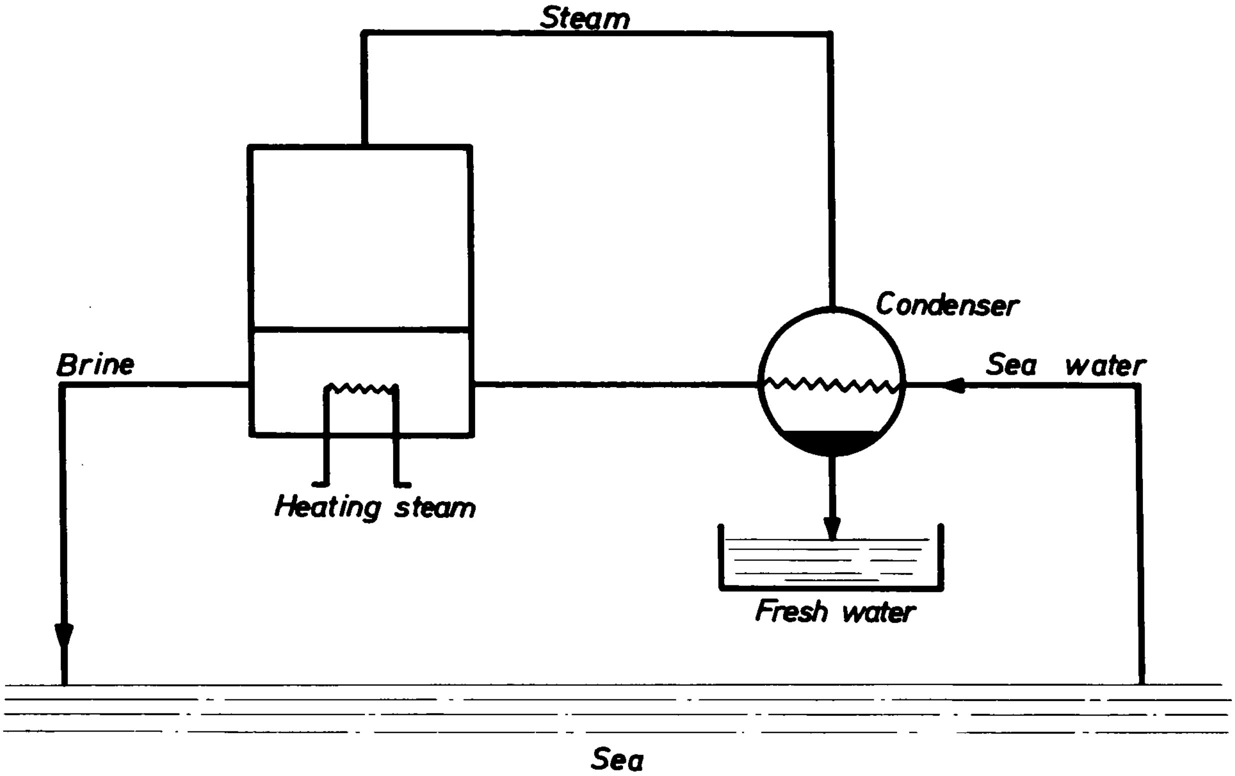
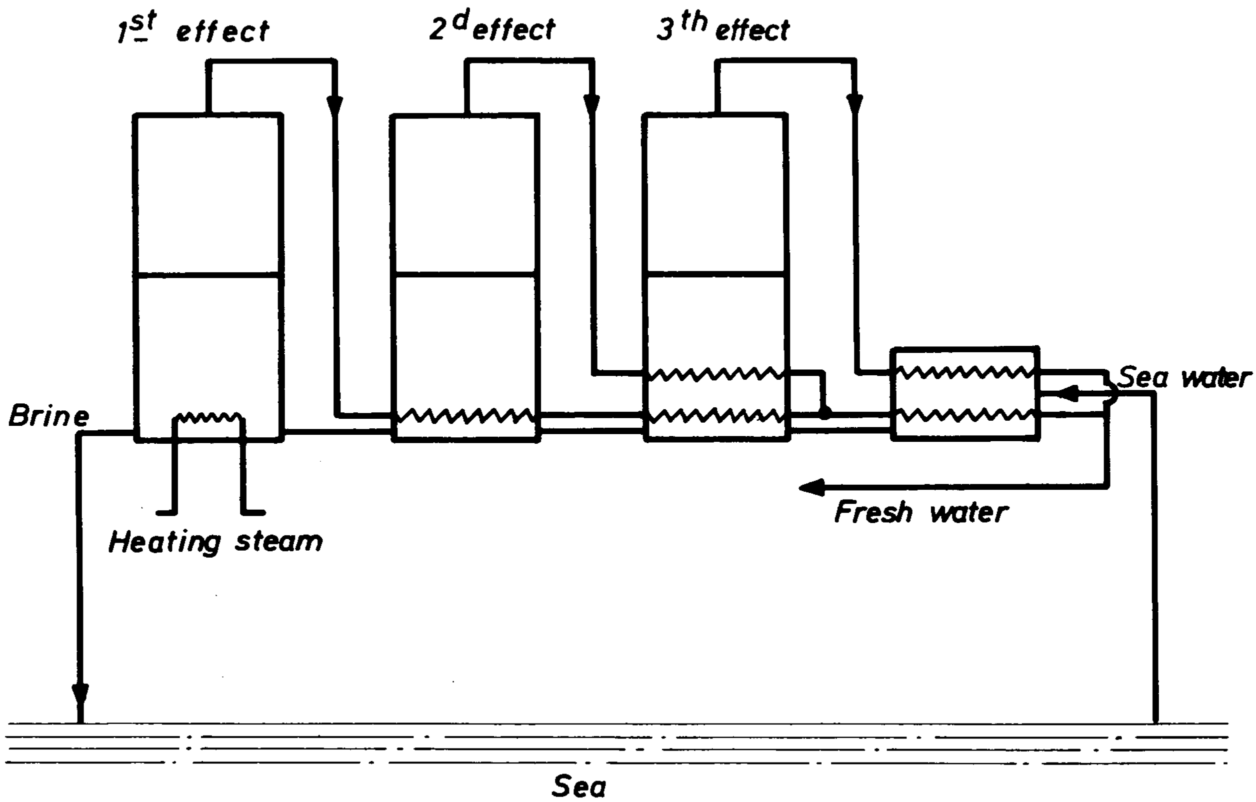


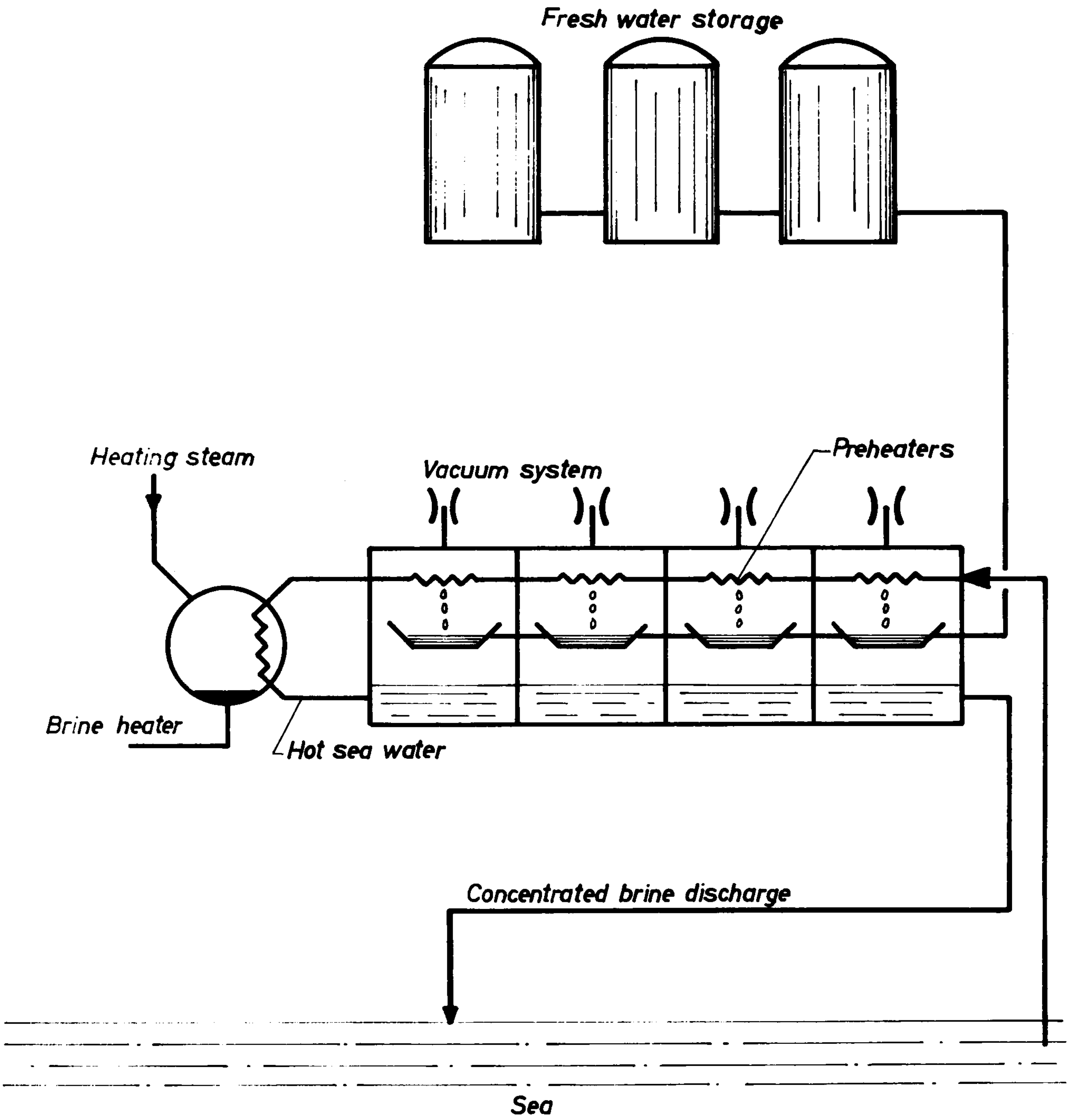
a : SINGLE EFFECT DISTILLATION



b : MULTIPLE EFFECT DISTILLATION
(backward feed)

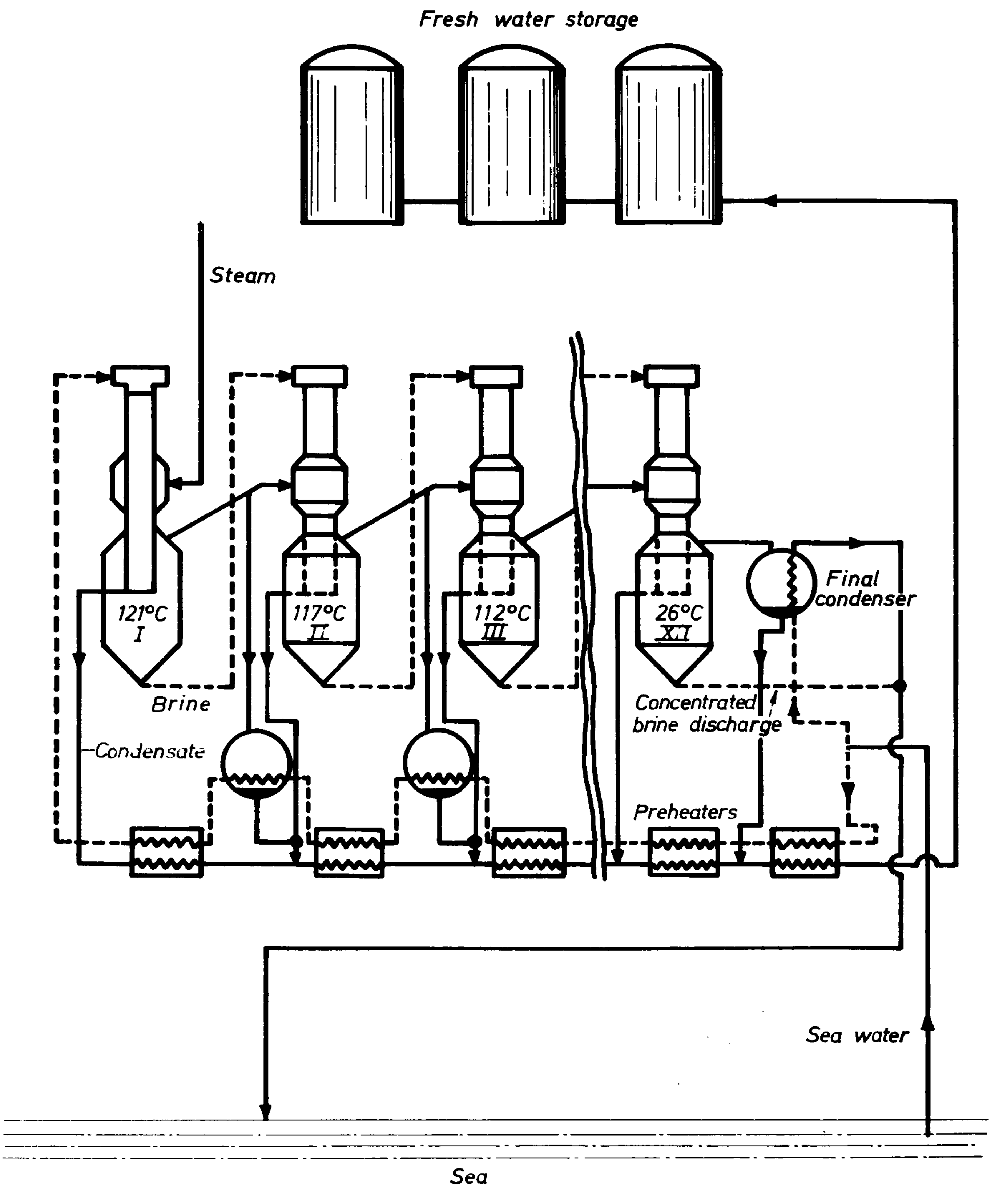
DISTILLATION PROCESS

FIG: 2.1



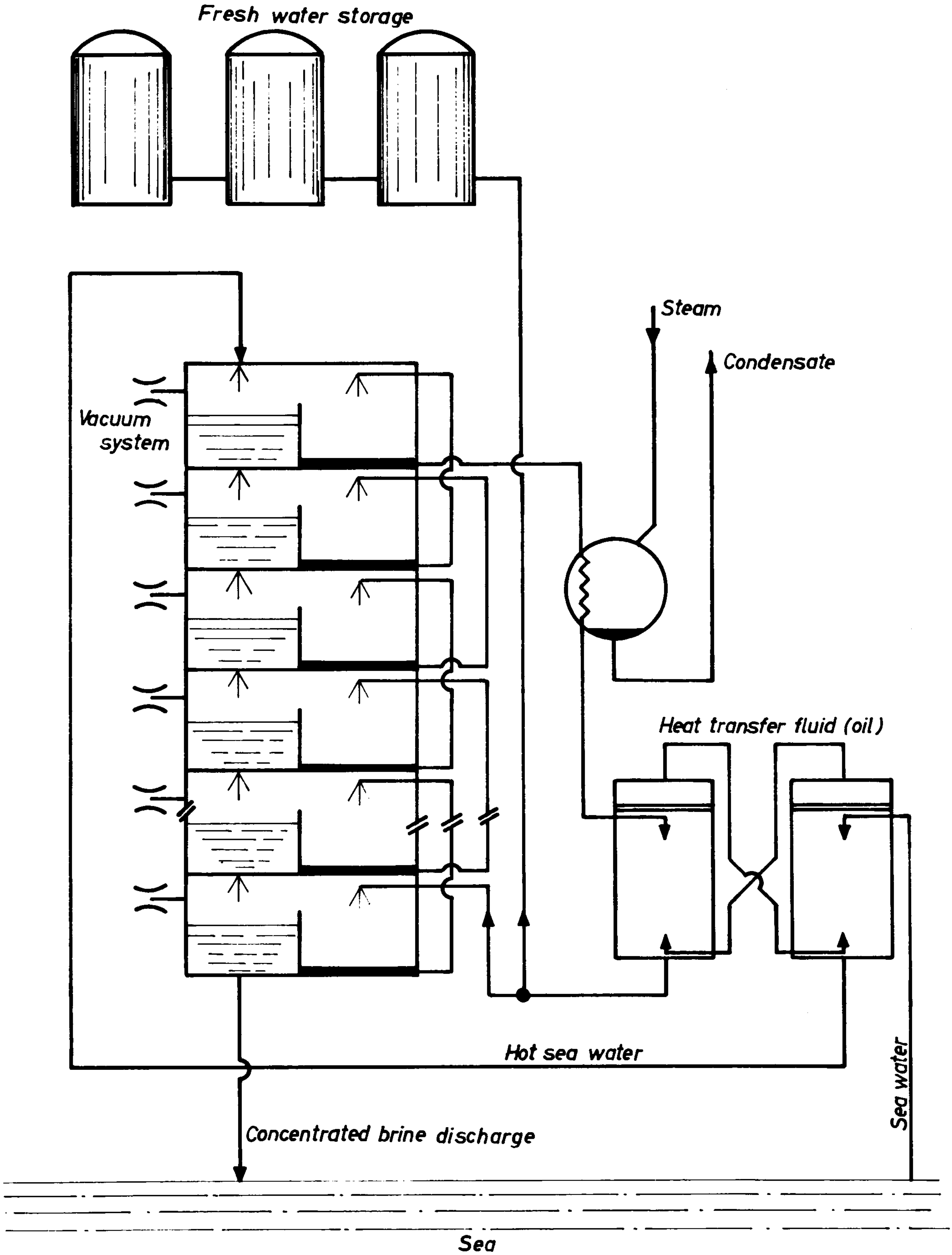
MULTIFLASH DISTILLATION

FIG. 2.2.



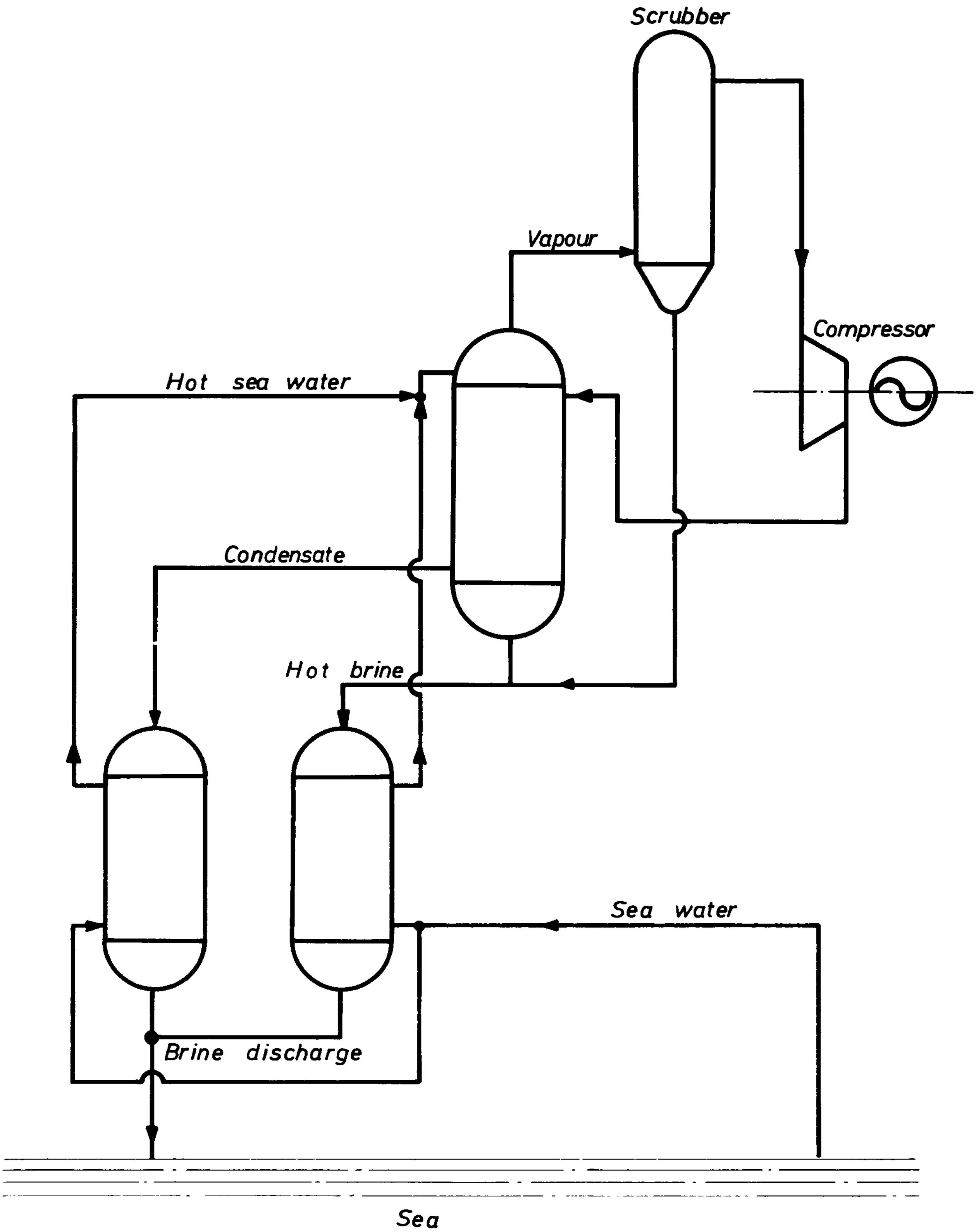
LONG TUBE VERTICAL FLASH SYSTEM

FIG. 2. 3.



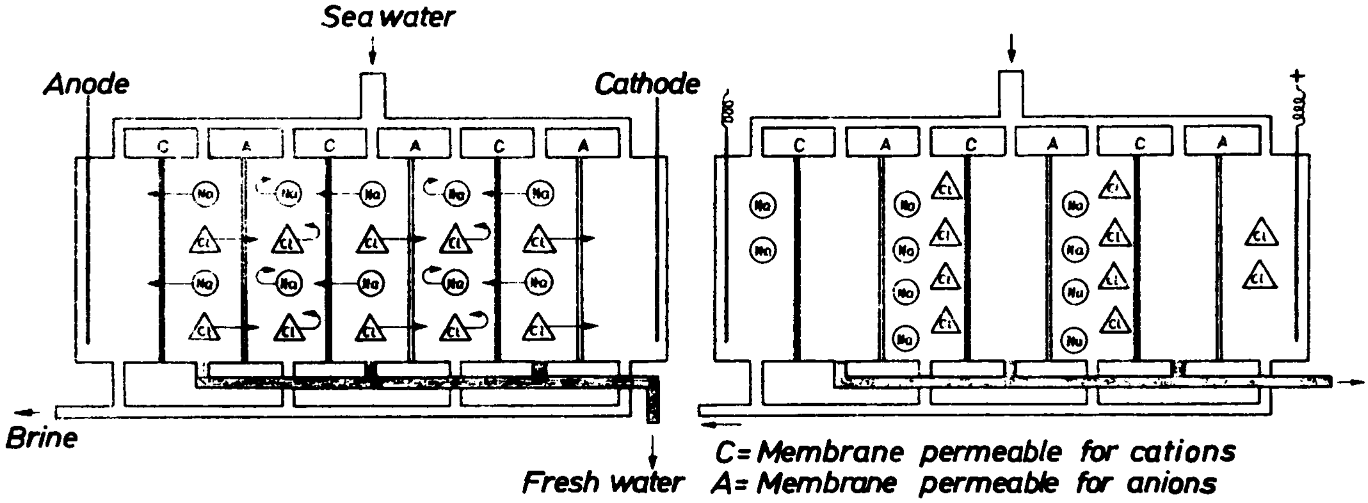
VAPOUR REHEAT PROCESS

FIG. 2.4.

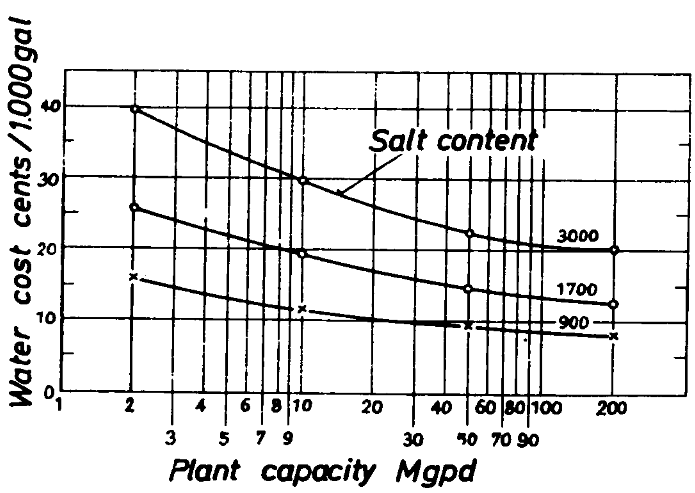


VAPOUR COMPRESSION DISTILLATION

FIG. 2.5

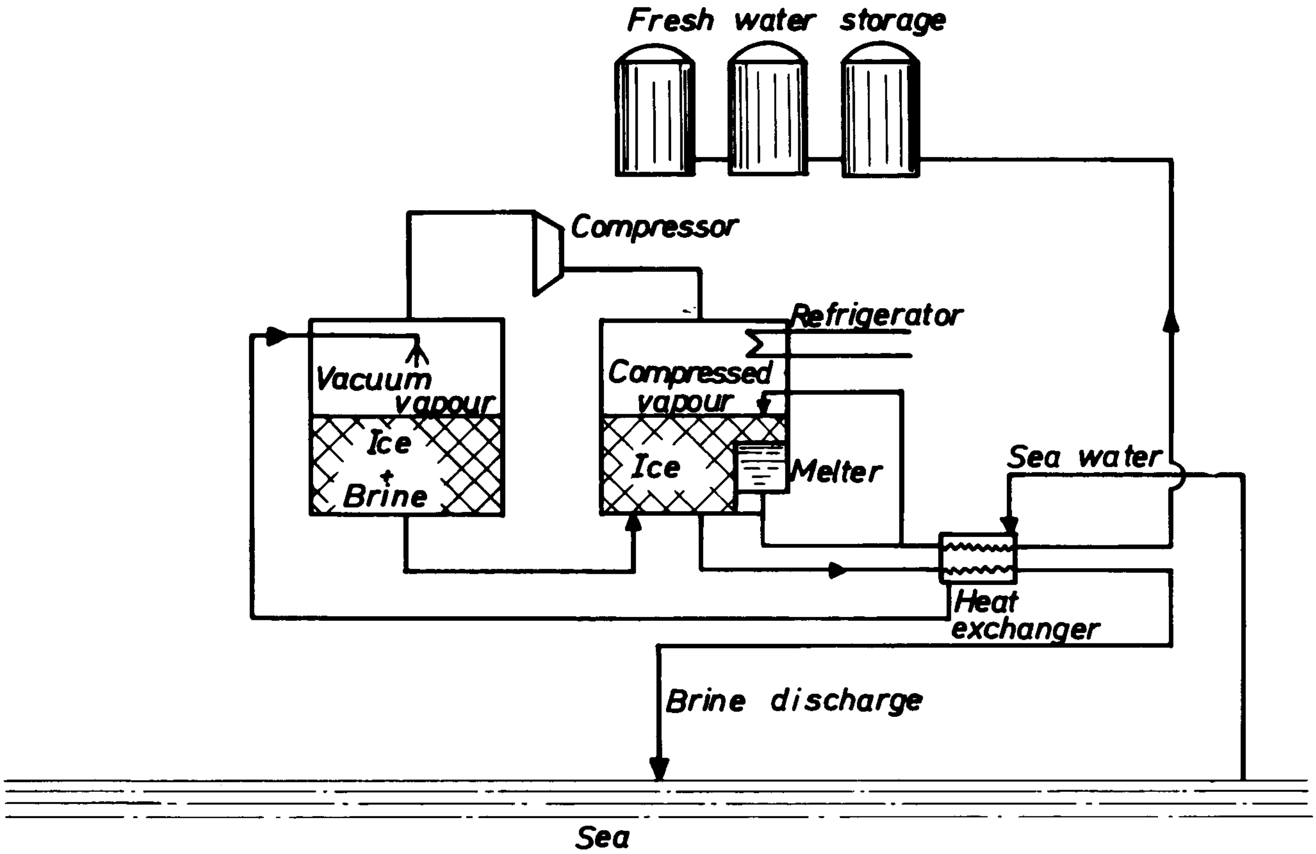


a. ELECTRODIALYSIS DESALINATION PRINCIPLE

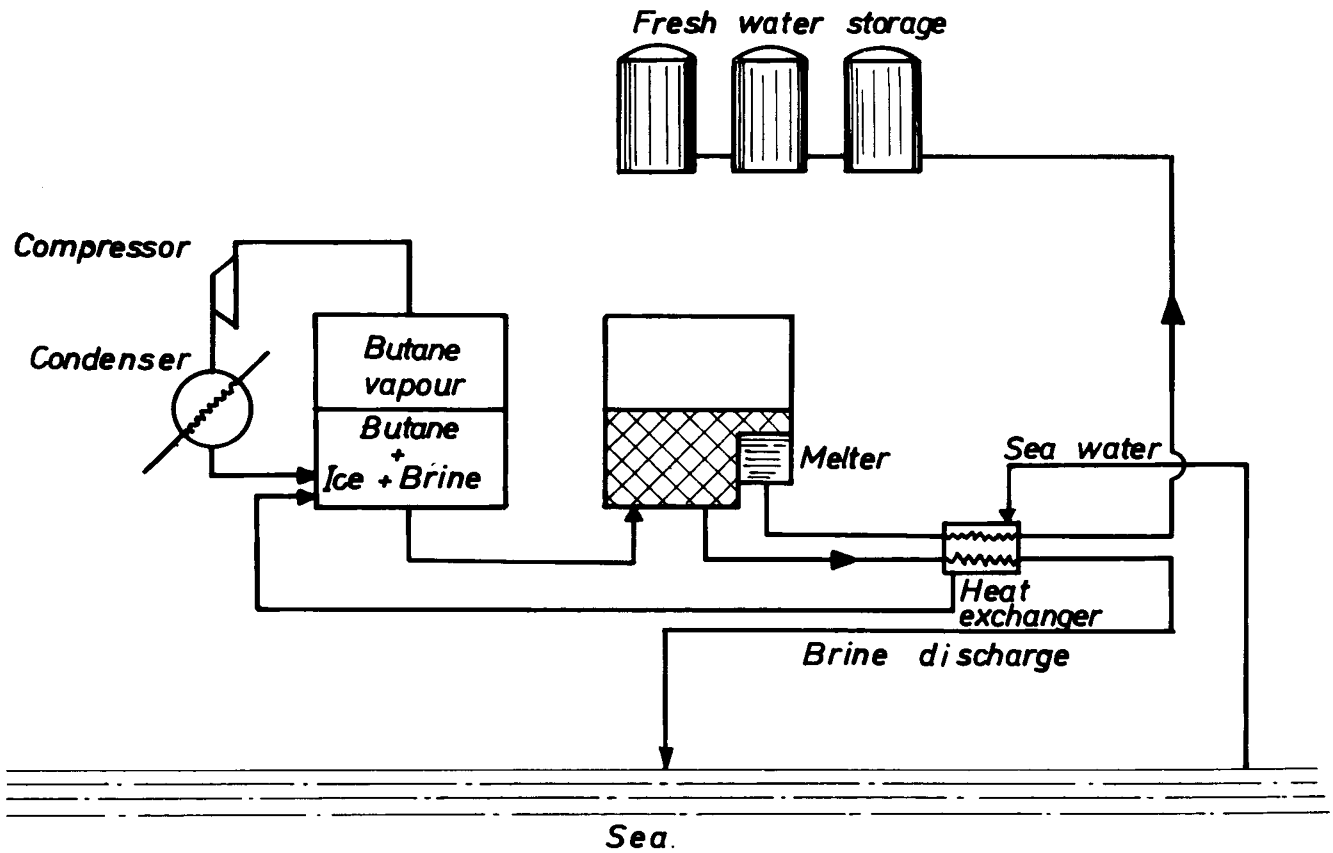


b. ELECTRODIALYSIS WATER COSTS VERSUS PLANT CAPACITY FOR DIFFERENT SALT CONTENTS

FIG. 2.6

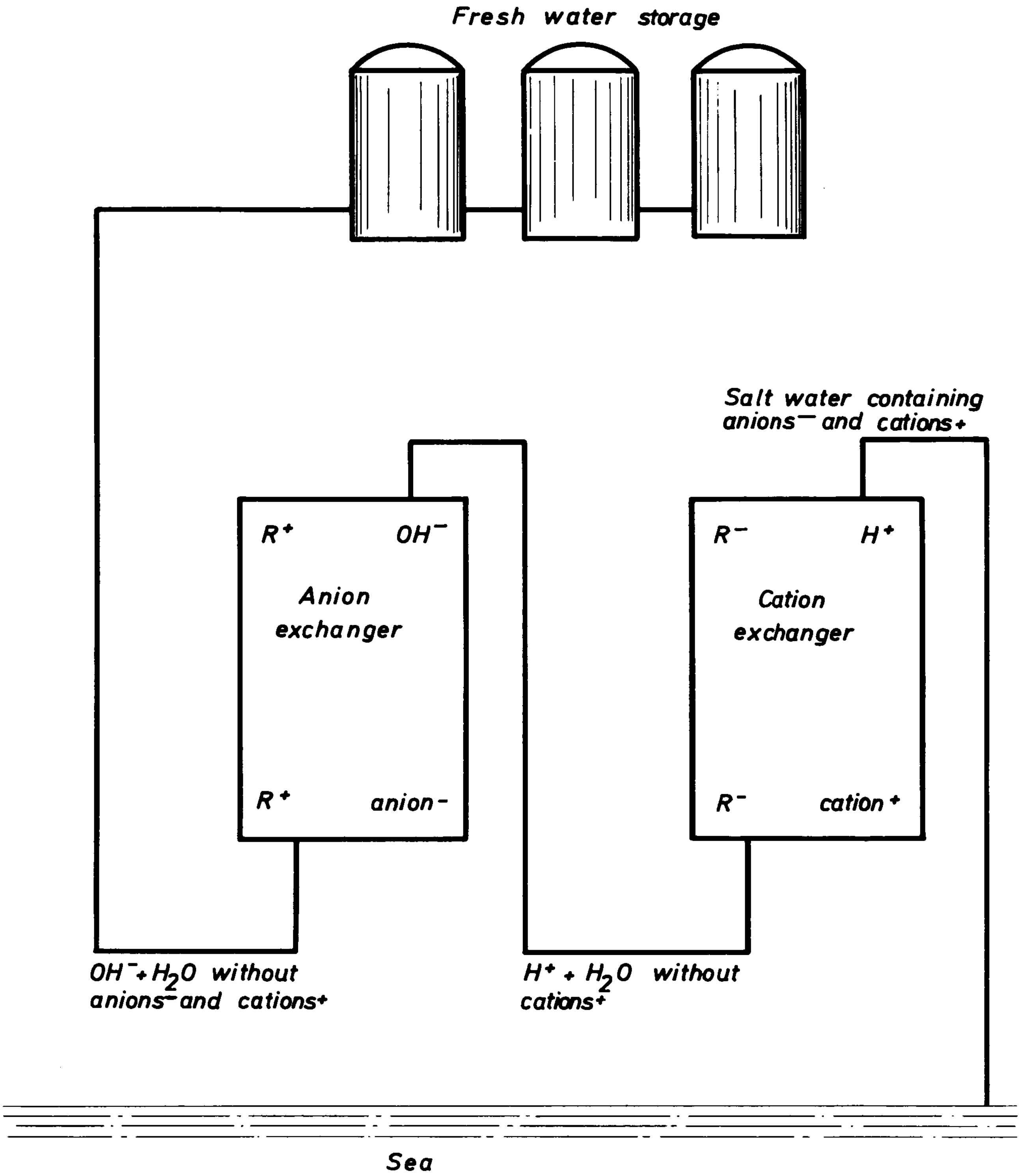


a. DIRECT FREEZING



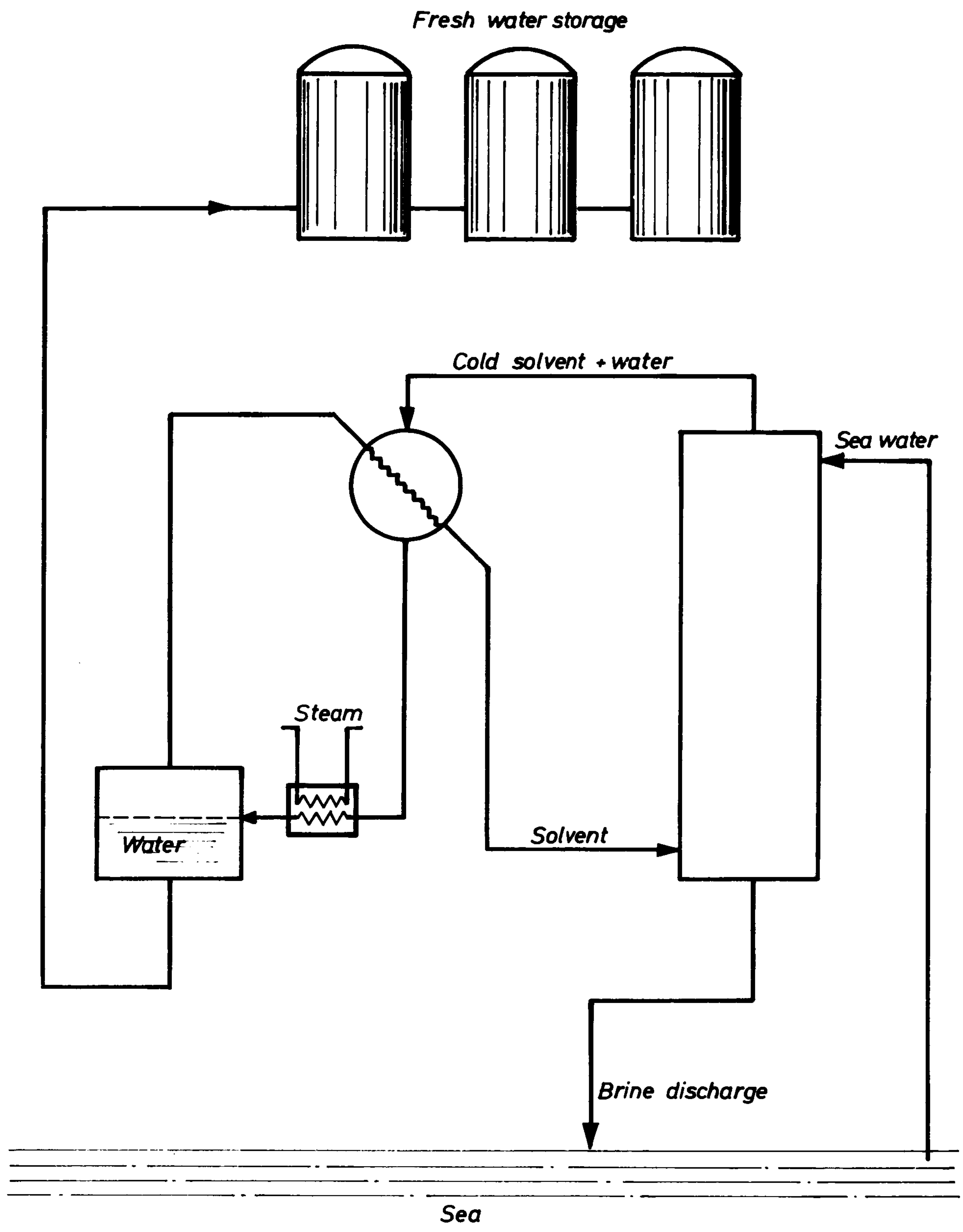
b. INDIRECT FREEZING

FIG. 2.7



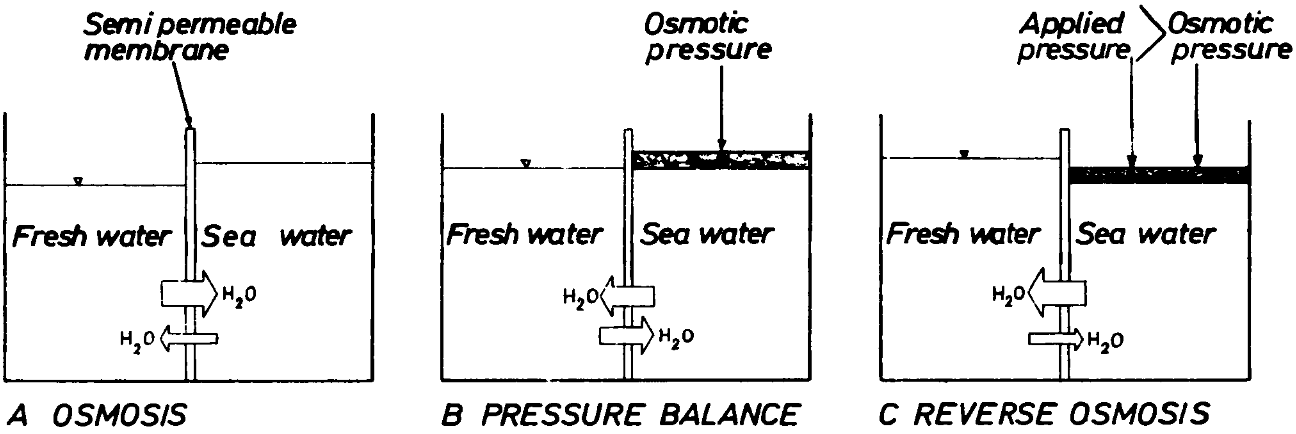
ION EXCHANGE

FIG. 2.8



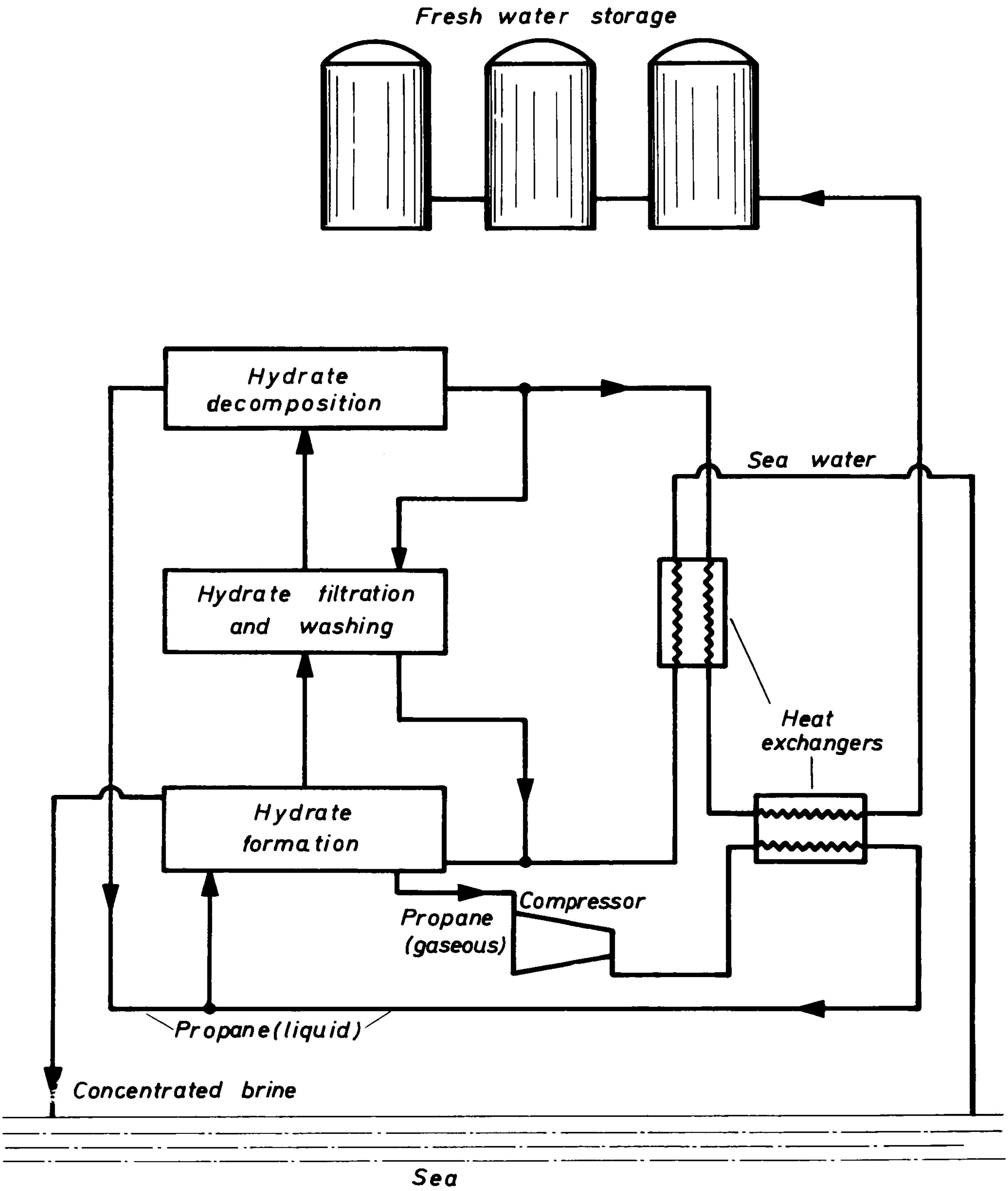
ORGANIC LIQUID WATER ABSORPTION

Fig. 2.9



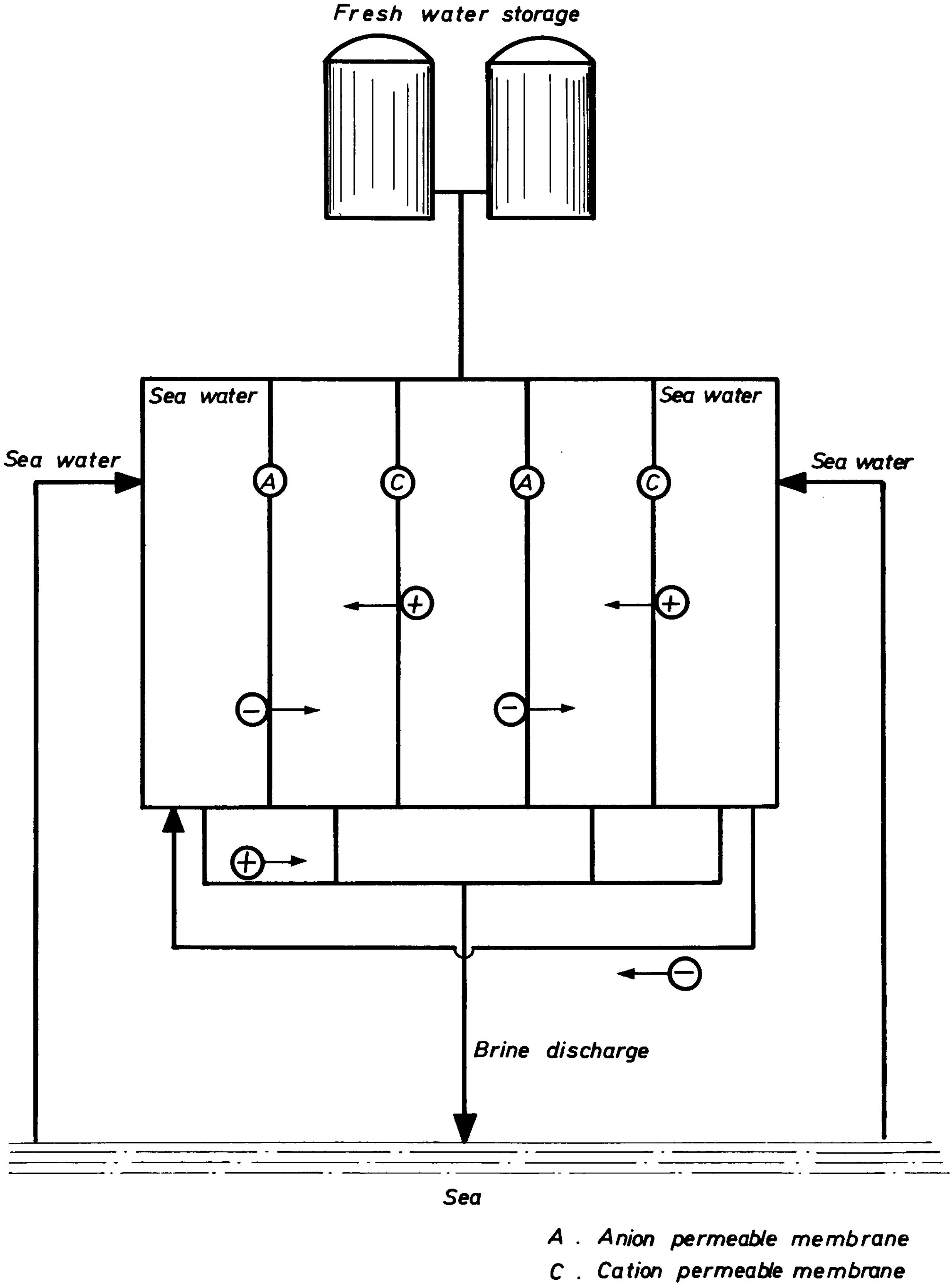
REVERSE OSMOSIS PRINCIPLE

FIG. 2.10



HYDRATE PROCESS

FIG: 2.11



ION OSMOSIS

FIG: 2.12

Fig. 2.13 - LIST OF PLANTS IN OPERATION WITH CAPACITY LARGER THAN 500 m^3/ day

Location	Number of units	Total capacity (m^3/day)	Process	Date of commissioning	Kind of water processed
Aden	1	1060	Submerged tubes		Sea water
Argentina					
Buenos Aires	1	570	Distillation		
Aruba	5	10200	Submerged tubes	1958	Sea water
	1	3030	Flash evaporation		Sea water
Bahamas					
Nassau N.P.I.	2	5450	Flash evaporation	1962	Sea water
Clipton Pier	2	4560	"	1962	Sea water
Bermudas					
K. Ed. VII Hospital	1	590	Flash evaporation		Sea water
Kindley A.F. Base		758	Thermo-compression		Sea water
Chile					
Chanaral	1	1000	Flash evap.		Sea water
Curacao					
Peenstraat	2	3800	Subm. tubes	1958	Sea water
Mundo Nobo	1	1350	Subm. tubes	1950	Sea water
Mundo Nobo	2	4000	Subm. tubes	1959	Sea water
Mundo Nobo	1	6100	Flash evap.		Sea water
Mundo Nobo	1	6000	Flash evap.		Sea water
Mundo Nobo	2	13000	Flash evap.		Sea water
Cuba					
Guantanamo	3	8500	Flash evap.		Sea water
Cyprus					
Br. Army Base	1	1260	Flash evap.		Sea water
England					
Tilbury, Essex	4	2400	LTV		Sea water
Ferrybridge	1	2830			
Ratcliffe	1	2830			
Guernesey	1	2300	Flash evap.	1960	Sea water

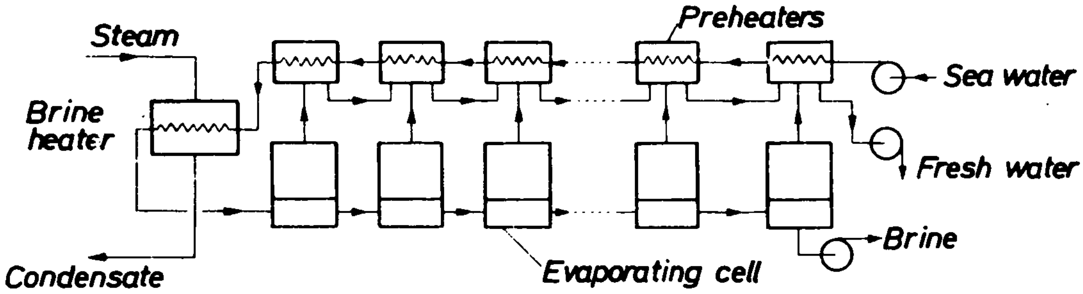
Germany					
Bremen	1	500	Flash evap.	1966	Brackish water
Stuttgart	1	1250	LTV		
Goldenberg	1	552	LTV		
Helmstedt	2	1100	LTV		
Iran					
Khark	2	1360	Flash evap.	1960	Sea water
Sirip-Agip	1	600	Flash evap.		Sea water
Israel					
Eilath	1	3800	Flash evap.	1964	Sea water
Sodom	1	960	Subm. tubes		Sea water
Eilath		900	Freezing	1964	Sea water
Italy					
Taranto	2	4600	Flash evap.		Sea water
Taranto	3	2300	Flash evap.		Sea water
Mirafiori	1	1150	Subm. tubes		Sea water
SNAM Proge.	2	1210	Flash evap.		Sea water
Sardinia	1	770	Flash evap.		Sea water
Kuwait					
City	4	9650	Flash evap.	1957	Sea water
Khafji	2	4000	Flash evap.	1960	Sea water
Mina al Ahmadi	1	2750	Flash evap.		Sea water
Mina al Ahmadi	1	2750	Flash evap.		Sea water
Mina al Ahmadi	1	1380	Flash evap.		Sea water
Shaiba	5	23000	Flash evap.		Sea water
Shaiba	1	570	Flash evap.		Sea water
Shuwaikh	2	9200	Flash evap.		Sea water
Shuwaikh	2	9200	Flash evap.		Sea water
Shuwaikh	10	5150	Subm. tubes		Sea water
Shuwaikh	1	920	E-Dialysis	1963	Sea water
Shuaiba	3	13800	Flash evap.		Sea water
Malta					
Valetta	1	4600	Flash evap.		Sea water
Grand Harbour		4545- (27270)	Flash evap.	1965	Sea water
The Netherlands					
Pernis	1	2900	Flash evap.		
Peru					
El Alto	1	760			Sea water
Quatar					
Doha	2	6800	Flash evap.	1963	Sea water
Doha	2	1360	Flash evap.	1959	Sea water
Doha	1	900	Subm. tubes	1954	Sea water

../...

Saudi Arabia					
Neutral zone	1	1900	Flash evap.		Sea water
Spain					
Canary Islands	1	2500	Flash evap.	1964	Sea water
Ceuta	2	4000	Flash evap.	1965	Sea water
South Africa					
Welkom	4	9120	E-Dialysis	1959	Brackish water
Lüderitz	1	550	Flash evap.	1961	Sea water
U.S.S.R.					
Kasakstan		5000	LTV		
U.A.R.					
Abu Zenima	1	2300	Distillation		
U.S.A.					
Arizona					
Buckeye	3	2460	E-Dialysis		
California					
San Diego	1	3800	Flash evap.	1962	Sea water
Point Larna	1	3800	Flash evap.	1963	Sea water
Morro Bay	1	570			
Moss Landing	2	1420	Flash evap.		
Catalina Isl.	1	570	Distillation		
New Mexico					
Roswell	1	3800	Thermo-compression	1963	Brackish water
North Carolina					
Weightsville	1	760	Freezing		
Pennsylvania					
Philadelphia	1	550	Flash evap.		
Marcus Hook	1	1140	Subm. tubes		
Southern Dakota					
Webster	1	950	E-Dialysis		
Tennessee					
TVA Paradise	2	1580	Flash evap.		
TVA Bullrun	1	640	Flash evap.		
Texas					
Freeport	1	3800	LTV	1961	Sea water
Port Mansfield		950	E-Dialysis		
Choc. Bayou	1	3400	Flash evap.		
Handley	1	550	Flash evap.		

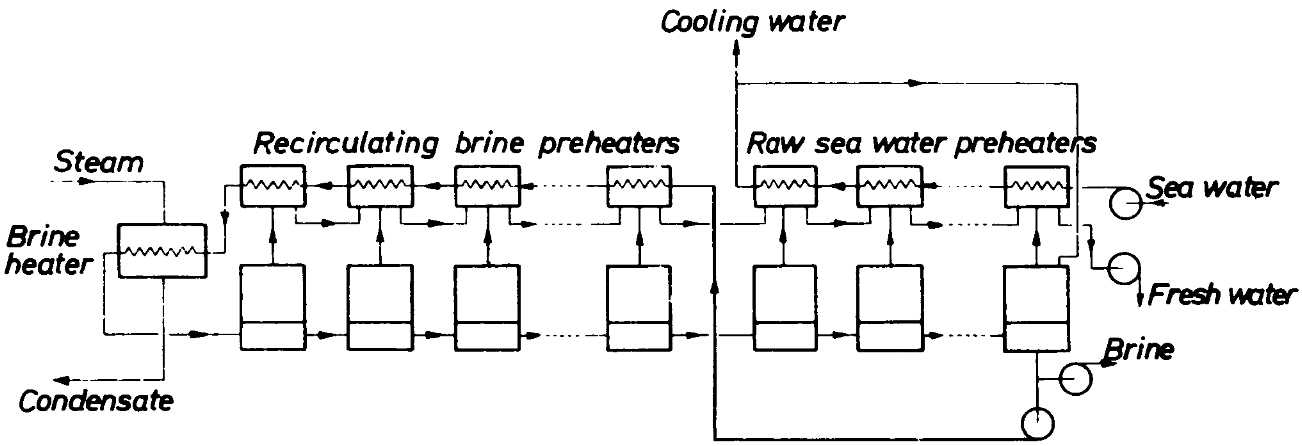
.../....

Virginia					
Storm MT.	2	1200	Flash evap.		
Possum PT.	1	710	Flash evap.		
Virgin Islands					
St. Thomas	1	1050	Flash evap.	1962	Sea water
St. Thomas	1	3800	Flash evap.		Sea water
St. Croix	1	5700	Flash evap.		Sea water
Johnson Islands					
AEC	1	570	Flash evap.		
Venezuela					
Las Piedras		1700			Sea water
Cardon	1	5450	Flash evap.		Sea water
Piritu	1	1540	Flash evap.		Sea water



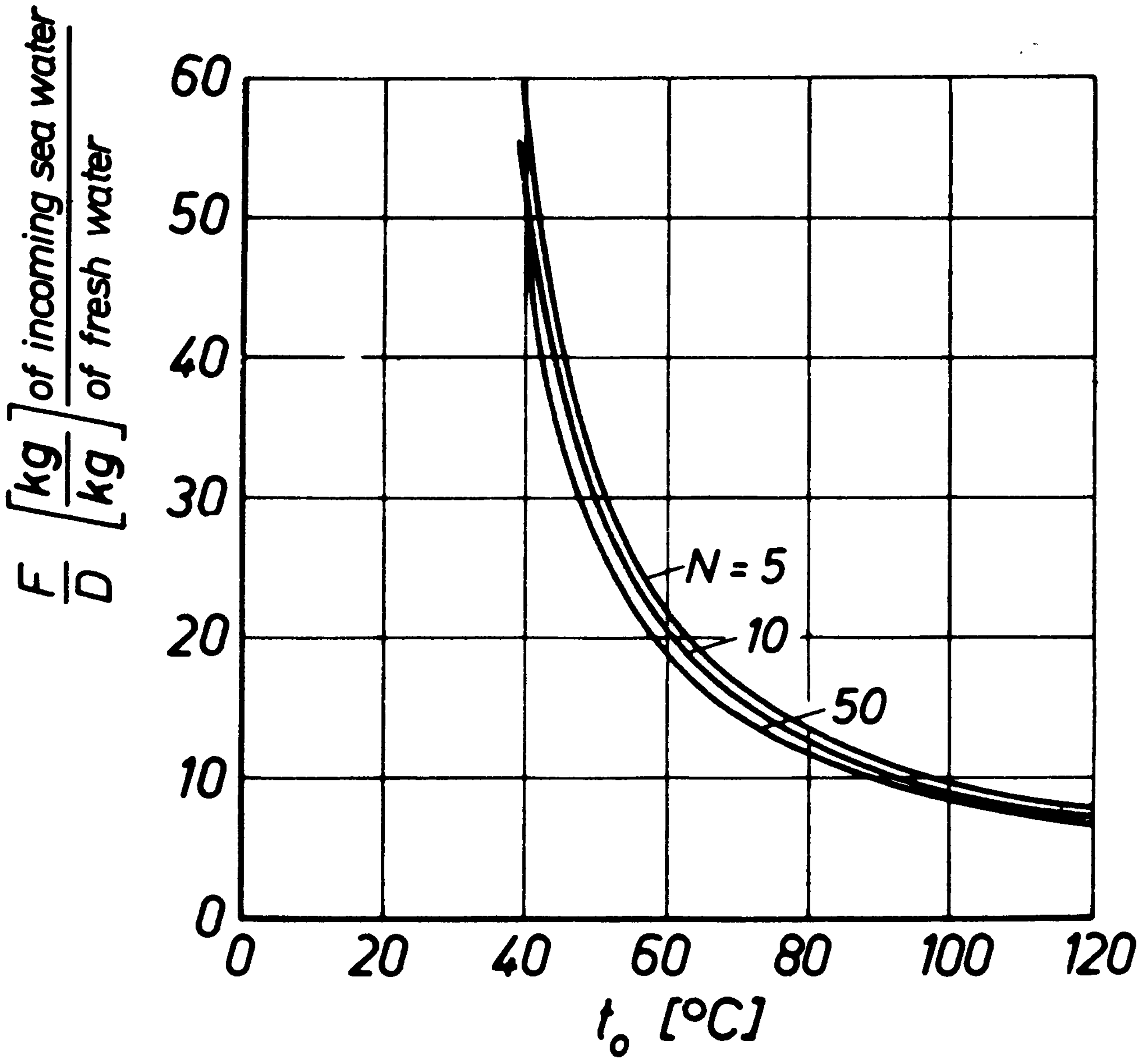
ONCE THROUGH FLASH DISTILLATION FLOW-SHEET

FIG: 2.14



COMBINED ONCE THROUGH AND RECIRCULATION FLASH DISTILLATION FLOW-SHEET

FIG: 2.15

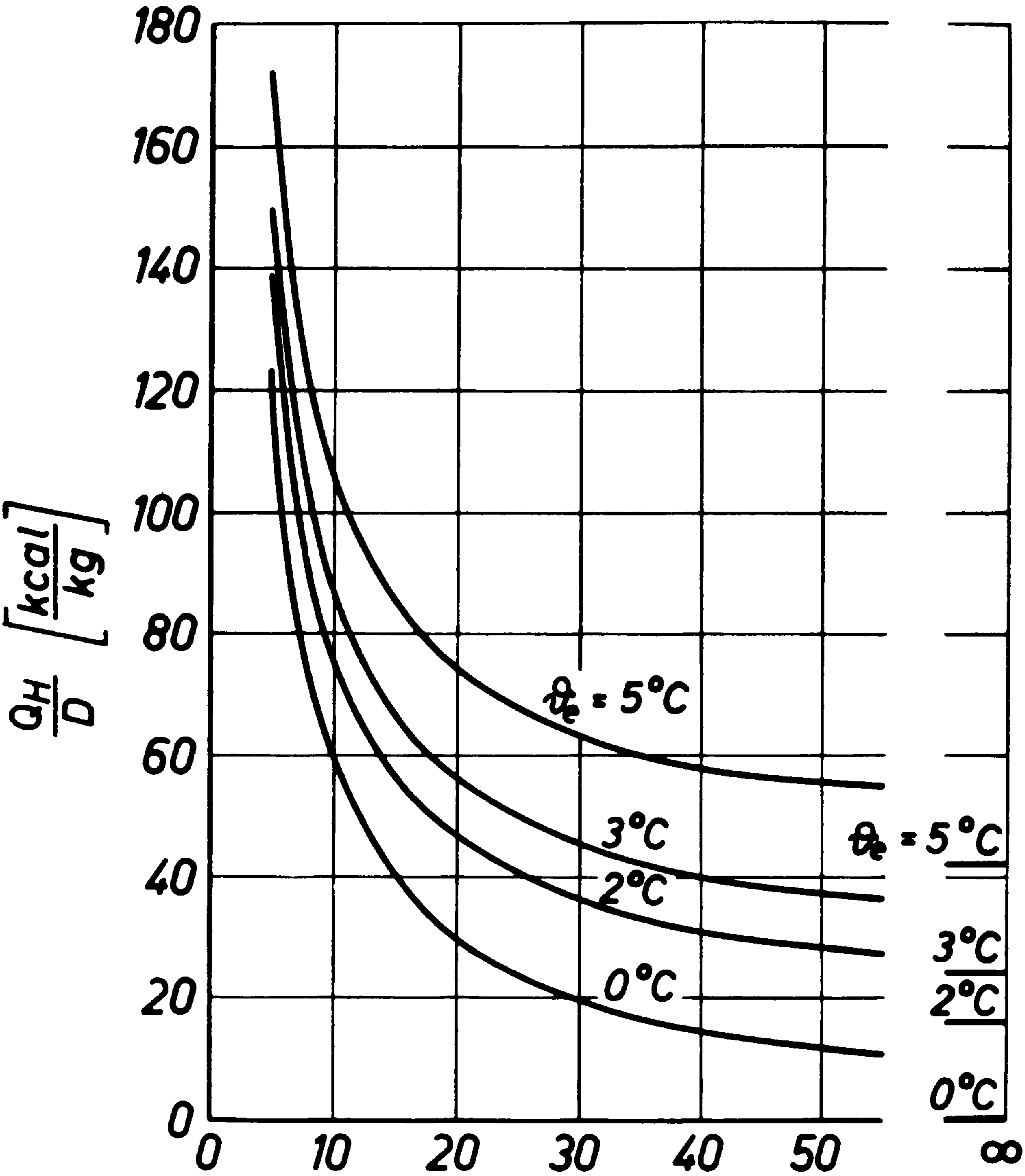


SEA WATER INLET TEMPERATURE $t_z = 25\,°C$
TEMPERATURE DIFFERENCE IN THE STAGES $\theta_e = 3\,°C$

RELATION BETWEEN THE BRINE HEATER EXIT TEMPERATURE AND THE [F/D] RATIO FOR DIFFERENT NUMBER OF STAGES

FROM K.HÖFFER (17)

FIG. 2.16

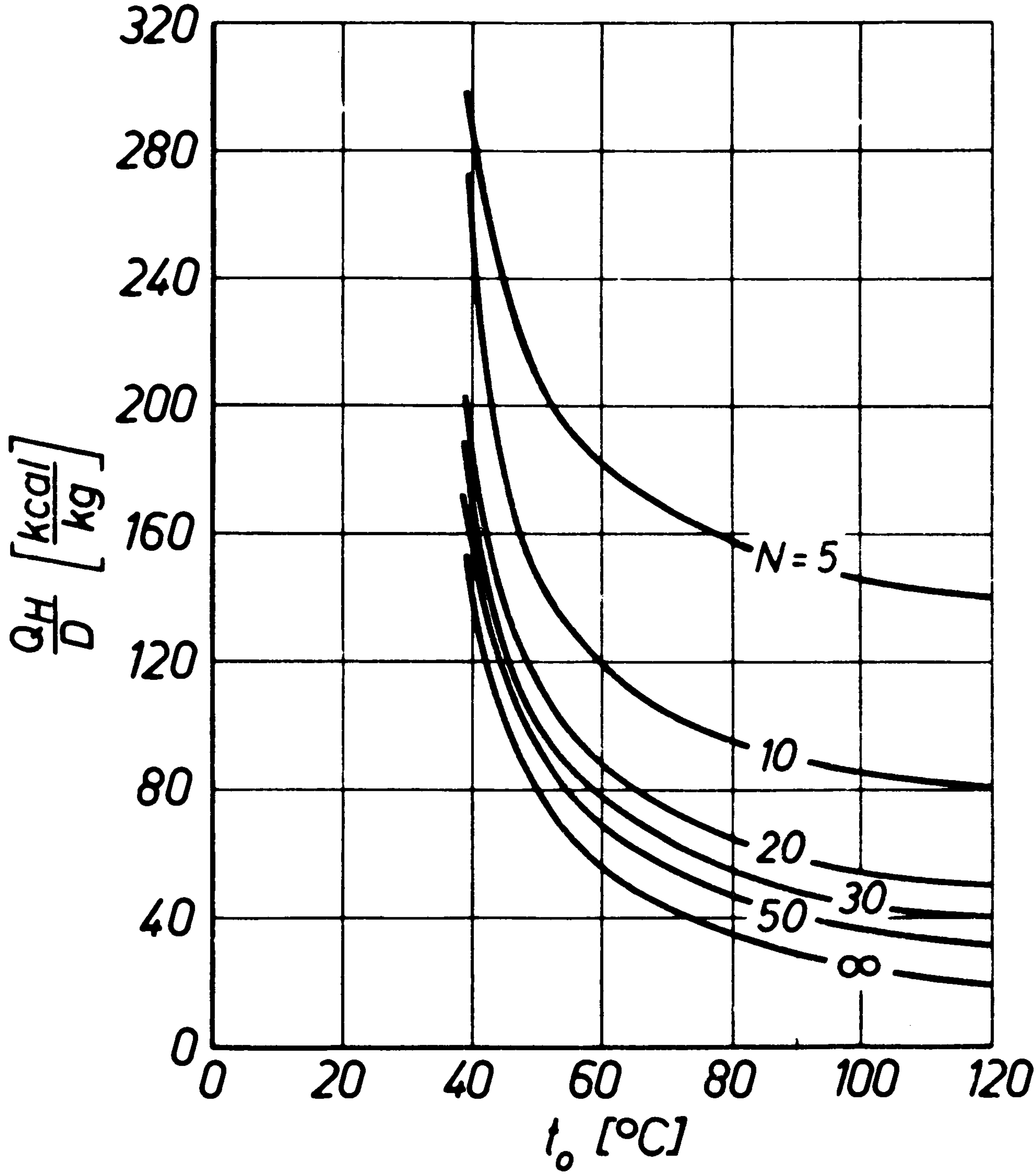


INCOMING SEA WATER TEMPERATURE $t_z = 25$ °C
SEA WATER BRINE HEATER EXIT TEMPERATURE $t_o = 100$ °C

HEAT CONSUMPTION PER Kg. FRESH WATER PRODUCED VERSUS THE NUMBER OF STAGES

FROM K. HÖFFER (17)

FIG. 2.17

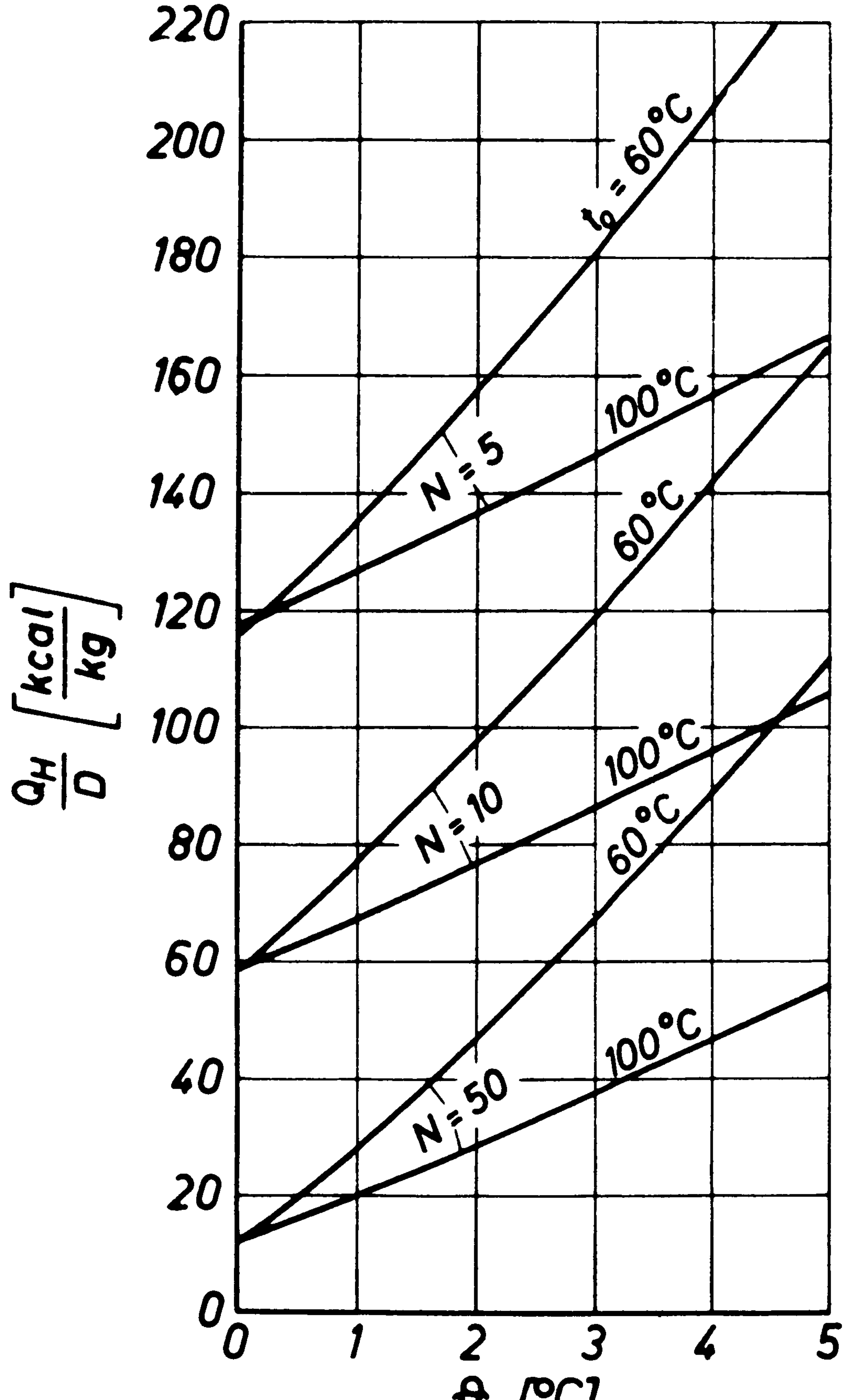


INCOMING SEA WATER TEMPERATURE t_z = 25 °C
TEMPERATURE DIFFERENCE IN THE STAGES Θ_e = 3 °C

HEAT CONSUMPTION PER Kg. OF FRESH WATER PRODUCED VERSUS SEA WATER BRINE HEATER EXIT TEMPERATURE FOR DIFFERENT NUMBER OF STAGES

FROM K. HÖFFER (17)

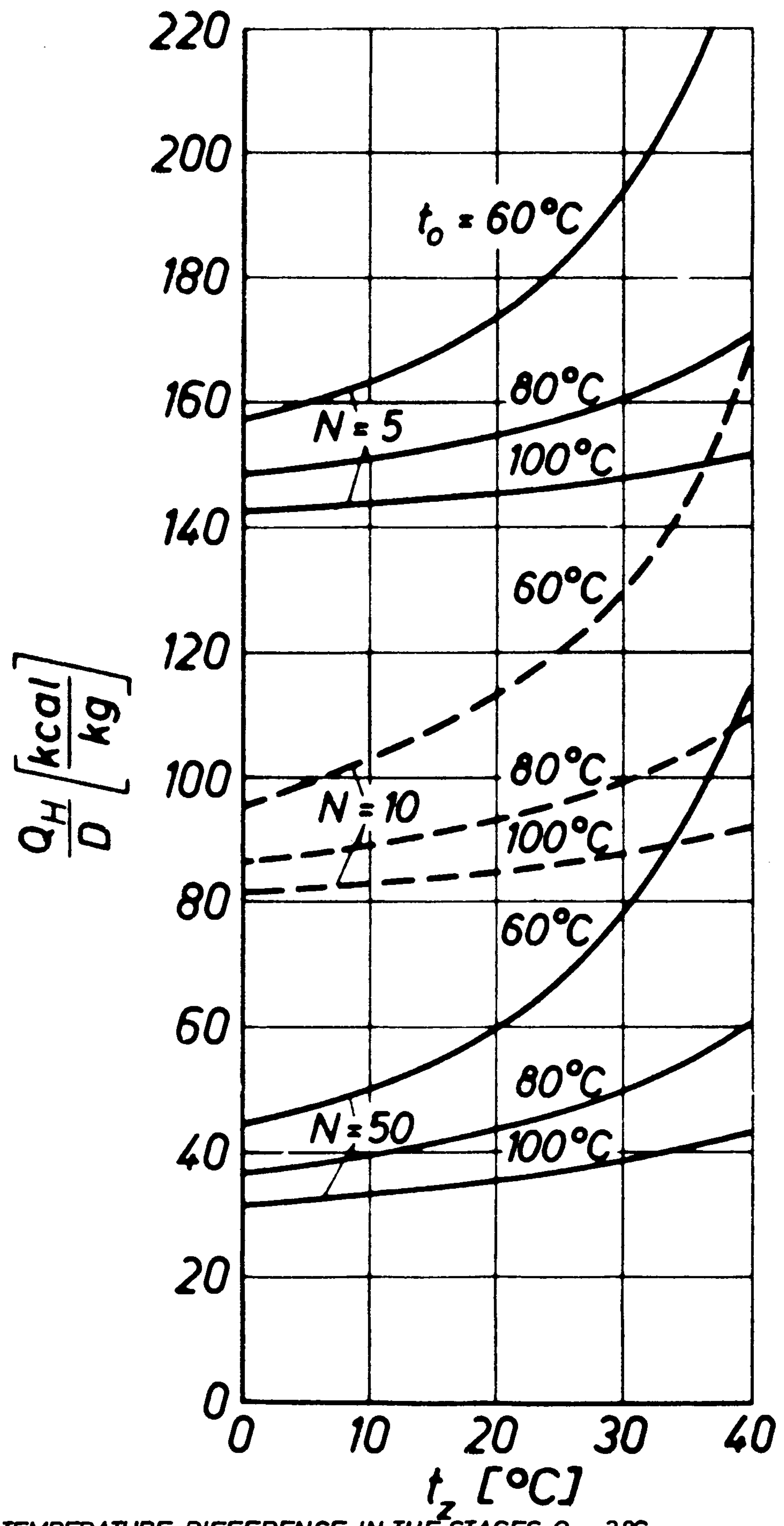
FIG. 2.18



INCOMING SEA WATER TEMPERATURE $t_z = 25°C$

HEAT CONSUMPTION PER Kg. OF FRESH WATER PRODUCED VERSUS TEMPERATURE DIFFERENCE IN THE STAGES FOR DIFFERENT VALUES OF t_0 AND N

FROM K. HÖFFER (17) FIG: 2.19

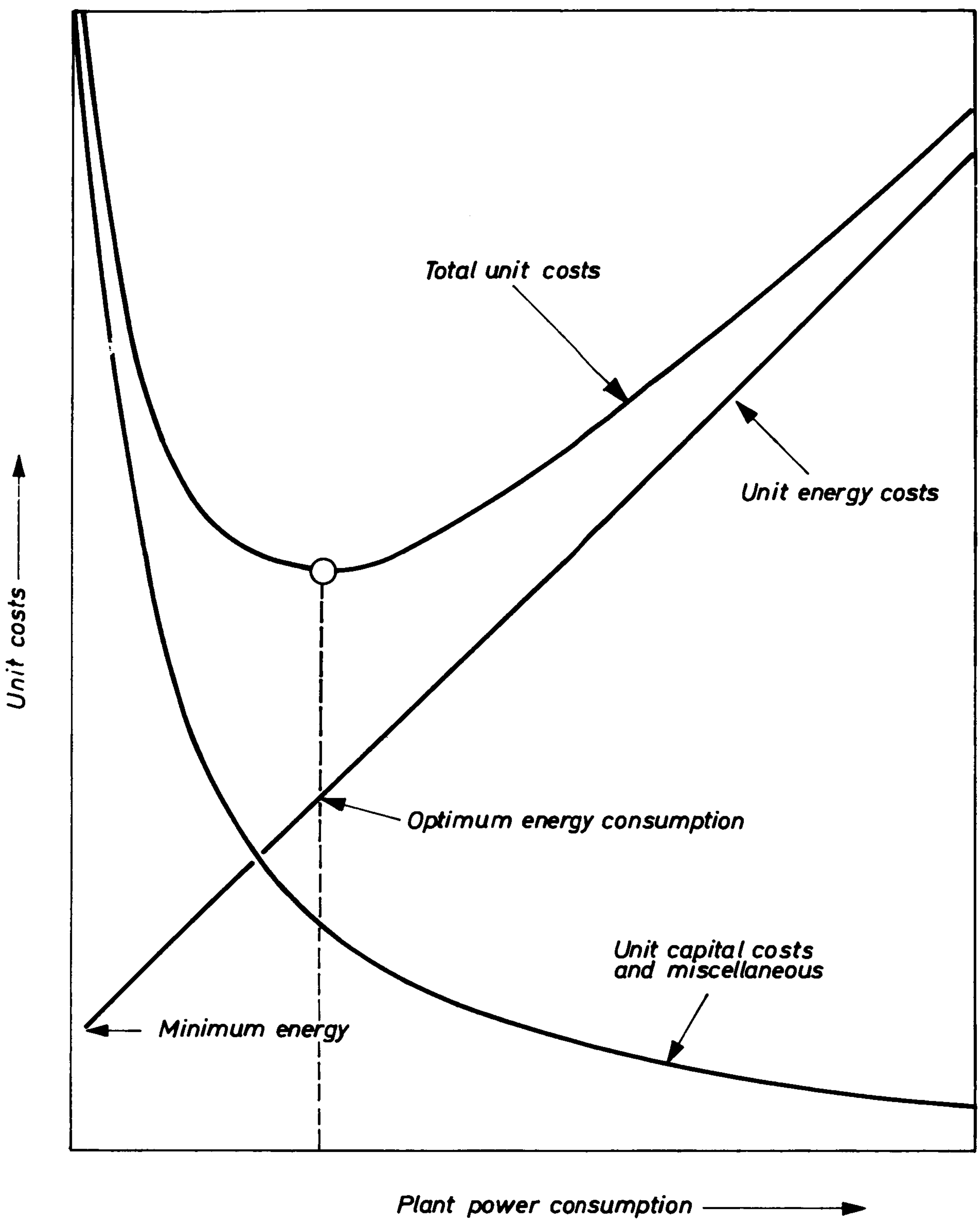


TEMPERATURE DIFFERENCE IN THE STAGES Θ_e = 3°C

HEAT CONSUMPTION PER Kg OF FRESH WATER PRODUCED VERSUS THE INCOMING SEA WATER TEMPERATURE FOR DIFFERENT VALUES OF t_o AND N

FROM K. HÖFFER (17)

FIG. 2.20



SCHEMATIC DIAGRAM OF COST OPTIMIZATION BETWEEN THE PLANT POWER CONSUMPTION AND FRESH WATER COSTS ACCORDING TO TRIBUS

FIG. 2.21

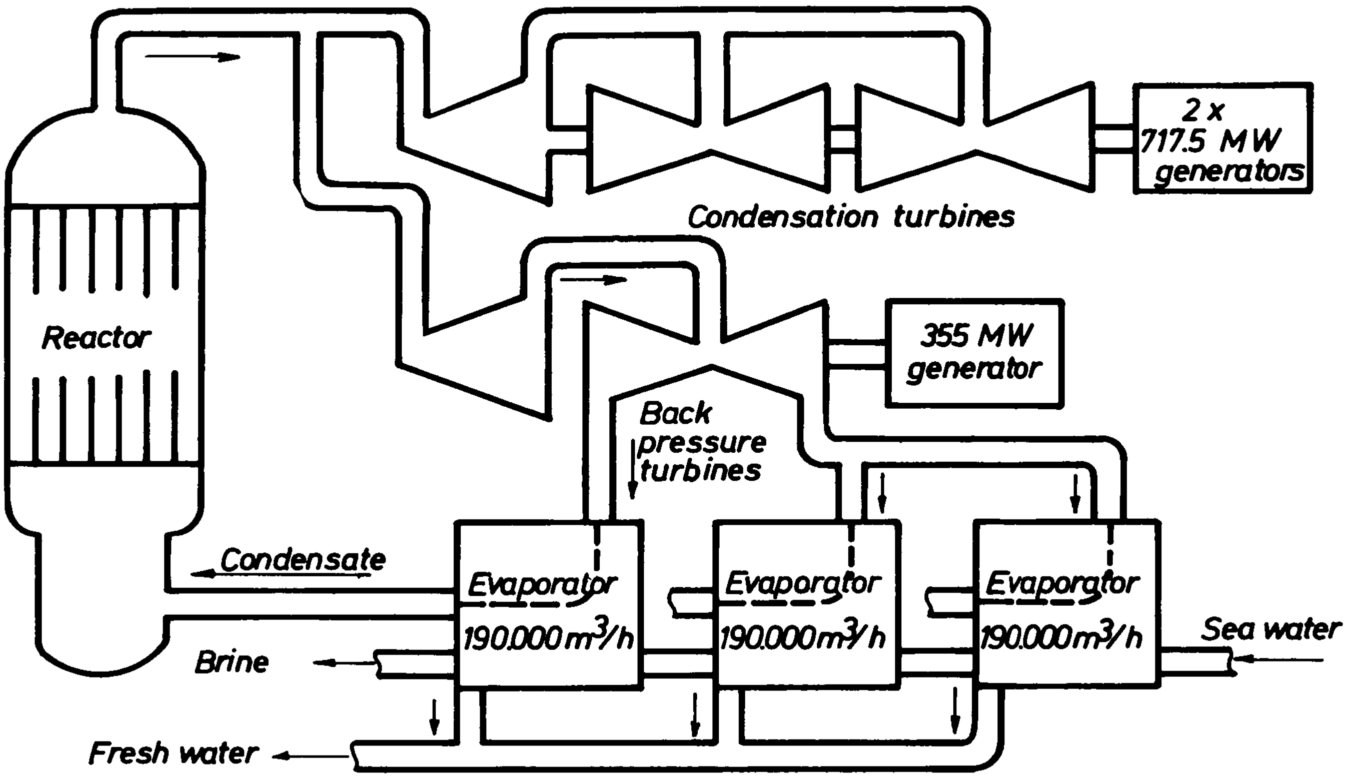
Fig: 2.22 _ SURVEY OF MATERIALS USED IN FLASH EVAPORATION PLANTS

A. - Raw sea water till 50°C.

Evaporator shells	1. Lined steel 2. Cu Ni 10 Fe 3. Lined concrete
Condenser piping	1. So Ms 76 (ASTM B 111Alum. Brass) 2. So Ms 71 (Admiralty) 3. Cu Ni 30 Fe (Cupronickel 30 % Ni) 4. Cu Ni 10 Fe (Cupronickel 10 % Ni) 5. Titanium
Pumps	1. G-Sn Bz 10 (ASTM 1 A cast alloy) 2. Ni-Resist Type 1 B or Type D
Sea water piping	1. Concrete cylinder piping 2. Asbestos cement 3. Glass fiber reinforced plastic piping 4. Cast iron
Valves	1. Rg 5 (ASTM 4 A cast alloy) 2. G-Sn Bz 10 (ASTM 1 A cast alloy) 3. GG, rubber lined grey cast iron
Expansion joints	1. X 10 Cr Ni Ti 18 9 (AISI 321 Stainless steel) 316 SS(AISI 316 stainless steel) 2. Tombac 3. Monel 4. Neoprene, reinforced
Sieves	1. Steel 2. Brass 3. Cu Ni

B. - Degassed sea water.

Evaporator shell	1. Lined concrete 2. Lined steel 3. Ni-Resist Type 1 B or Type D
Condenser piping	1. So Ms 76 (ASTM B111 Alum. Brass) 2. Cu Ni 10 Fe (Cupronickel 10 % Ni) 3. So Ms 71 (Admiralty) 4. Steel 5. Titanium
Pumps	1. G-Sn Bz 10 (ASTM 1 A cast alloy) 2. Ni-Resist Type 1 B or Type D 3. 316 SS (AISI 316 stainless steel) 4. Steel
Fresh water piping	1. Steel 2. Lined steel
Expansion joints	1. X 10 Cr Ni Ti 18 9 (AISI 321 Stainless steel) 316 SS (AISI 316 stainless steel) 2. Tombac 3. Monel 4. Reinforced neoprene
Weirs	1. Lined steel 2. So Ms 76 (ASTM B 111 Alum. Brass) 3. Cu Ni
Separators	1. Cu Ni 2. Monel 3. Inoxyda 90



NUCLEAR DUAL PURPOSE PLANT LAY OUT
(Water and power combined production)
(from Catalytic Report)

FIG. 2.23

Plant manager (1)

Assistant plant manager (1)

Maintenance

Maintenance engineer (1)

Chief electrician (1)
Control engineer (1)
Chief fitter (1)

Function / Size MW_{th}	200	600	1000	1500
Fitter	5	6	7	8
Electrician	2	2	3	3
Technician	2	2	3	3
Total	9	10	13	14
Fitter	5	5	7	8
Electrician	2	2	3	3
Technician	2	2	2	2
Total	9	9	12	13

Operation

Shift engineer (1)
Assistant shift eng. (0,0,1,1)

Shift supervisor (5)
Assistant shift supervisor (0,0,5,5)

Function / Size MW_{th}	200	600	1000	1500
Shift operating personnel				
Total	14	14	18	18
Shift operating personnel				
Total	20	21	24	24

→ Power generation (upper block)
→ Desalination (lower block)

Supervision

Function/Size MW_{th}	200	600	1000	1500
Operation planning engineer	1	1	1	1
Laboratory technician	1	1	1	1
Total	2	2	2	2
Plant engineer	1	1	1	1
Chemist	1	1	1	1
Chem. laboratory technician	2	2	2	2
Total	4	4	4	4

General services

Supervisor (1)

Function / Size MW_{th}	200	600	1000	1500
Commercial department clerks	2	3	4	4
Gate keeper	2	2	3	3
Watchman	3	3	3	3
Total	7	8	10	10
Commercial department clerks	1	2	2	2
Accounts	1	1	1	1
Purchase	1	1	1	1
Gate keeper	2	2	3	3
Watchman	2	2	2	2
Total	7	8	9	9

The figures correspond to the personnel requirements for the various capacities considered

2-24 Combined power generation and desalination plant organization chart (from Catalytic Report)

CHAPTER III

DESALINATION ECONOMICS IN THE EUROPEAN COMMUNITY

INTRODUCTION

The purpose of this chapter is to evaluate the economical merits of sea water desalination in the northern part of the European Community, using nuclear energy.

The reference reactors chosen for this analysis are of the light water (BWR and PWR) type.

1. In the first part of this chapter, the cost of the steam discharged from the power turbine and to be used in a multi flash distillation plant will be studied.

   The computation will be carried out using the capital cost prevailing in the European Community.

   Regarding the electricity costs, two points of view will be taken :

   a/ That of power producing utilities which give to the steam which has been diverted from electricity production, a value equal to that of the average cost of the non produced kWhe.

   b/ That of a fresh water producing utility which must sell its electricity to a power generating and distributing utility, which would only agree to pay for it a price lower than its own generating cost.

2. From the steam costs computed, the fresh water costs of the corresponding optimized multi flash plants will be worked out.

1. EXHAUST STEAM COST COMPUTATION.

1.1. - Preliminary considerations.

a. The purpose of the following computation is to work out the cost of steam generated in a nuclear power plant whose condenser pressure is 2, 1 and 0,35 ata.

This low-pressure steam will be used as the heat source for a desalination plant operating jointly with the nuclear power plant.

b. Since this plant generates power and produces sweet water simultaneously, certain assumptions must be made regarding the spreading of the costs over these two end products.

In Europe such a dual purpose plant will be interconnected with an existing power grid.

If the main purpose is to generate power (electrical), thus considering steam as a by-product, it is normal to assume that the kWh value is the same as the kWhe cost of an equal electrical power nuclear plant generating electricity only (Fig. 3. 1. a).

On the other hand, if the main purpose of the dual purpose nuclear plant is to produce steam to be used in a desalination plant, with the generated electricity considered as a by-product the kWh will have to be sold at a value eventually lower than the reference value found previously. Sample values of this kWh value have been used in computations. This value is therefore independent from the kWh cost of the dual purpose nuclear plant.

The desalination plant is considered as a customer who purchases the steam calories produced in the power plant condenser. Fig. 3. 1. b shows this concept and the respective boundaries of the desalination and power plants.

c. The power plant balance sheet gives the possibility to find out the steam cost at the condenser inlet by equating the costs (financial charges, operating and fuel costs) and the incomes (sale of kWh to the grid and of steam calories to the desalination plant).

The reference nuclear power plant technical characteristics correspond to those of a light water type plant (BWR for instance) of 1900 MWth (600 MWe net), as this size may be considered as typical for Europe in the next decade and sufficient to feed desalination plants of up to 250.000 m^3/day.

On the other hand, the results of this report are still correct if the specific costs (capital costs, operating costs, fuel costs) are the same even if the power is different from the contemplated 1900 MWth. Moreover, the thermodynamic cycles have been worked out for a unit flow of 1 t/h in the nuclear boiler and may thus be adapted to any power.

The data from which the reference nuclear power plant kWhe cost can be worked out, are taken from the Euratom economic forecasts for nuclear power plants after 1970.

When the kWh is considered as a by-product, a value of 3 mills/kWh for the 1970-79 period and 2 mills/kWh for the 1980-89 period has been assumed; these are the reference prices to be used at present according to Euratom.

d. The steam calorie cost computation, when produced in a 1900 MWth dual purpose nuclear plant has been carried out for the following parameter values :

- condenser steam temperature : 120°C, 99°C and 72°C
- periods : 1970/79 and 1980/89
- financial charges, as % of overall capital cost : 8,1 %, 10 % and 13 %.

1.2. - Reference power generating plant technical and economic data and kWh cost computation.

a. Technical data.

- Nuclear boiler

Thermal power	1900 MWth
Thermodynamic characteristics of the steam at the boiler outlet :	
pressure	70 ata
temperature	284°C
enthalpy	662 kcal/kg
water content	0,2 % max.
flow	3270 t/h
feed water temperature	160°C

- Turbo-generator-condenser unit and feed water unit

Condenser pressure	≃ 0,04 ata
Condenser temperature	≃ 28,6°C
Gross electrical power	630 MWe
Net electrical power	600 MWe

b. Economic data.

The values to be given to the economic parameters required for computing the kWh cost are those of Euratom's study on economic prospects for nuclear power plants after 1970 and which are given in table 1 hereafter :

Table 1

Estimated economic parameters of nuclear power stations commissioned after 1970

	Unit	1970/79	1980/89
I_e : capital cost	UA[xx]/kWe	160	135
C_c : fuel cycle cost[x]	mills/kWh	2,0	1,75
d_e : operation, maintenance + insurance cost	UA/kWe.year	3,5	3,0

(x) This cost covers all the fuel cycle expenses and incomes, including those relative to the fissile product recovery from the irradiated fuel.

(xx) UA : unit of account = 1 US $.

c. kWh cost computation.

The table 1 figures give the possibility of computing the kWh cost as a function of the financial charges being 8,1 %, 10 % and 13 % per year, of the total capital investment.

For these financial charges, table 2 gives :

- the fixed charges, F, in UA/kWe.year
- the proportional charges, P, in mills/kWh
- the kWhe cost, C_e, in mills/kWh for a plant operating period of 7000 hours per year.

The kWh cost is related to the yearly plant operating period, u, (in hours/year) by the following equation :

$$C_e = \frac{F}{u} + P$$

Table 2 Reference nuclear power plant kWh cost			
	Units	1970/79	1980/89
Capital immobilization charges : 8,1 %			
F : Fixed charges[x]	UA/kWe.year	16,5	13,9
P : Proportional charges[xx]	mills/kWh	2,0	1,75
C_e : kWh cost for operating period of 7000 hours/year	mills/kWh	4,36	3,73
Capital immobilization charges : 10 %			
F : Fixed charges[x]	UA/kWe.year	19,5	16,5
P : Proportional charges[xx]	mills/kWh	2,0	1,75
C_e : kWh cost for operating period of 7000 hours/year	mills/kWh	4,79	4,11
Capital immobilization charges : 13 %			
F : Fixed charges[x]	UA/kWe.year	24,3	20,5
P : Proportional charges[xx]	mills/kWh	2,0	1,75
C_e : kWh cost for operating period of 7000 hours/year	mills/kWh	5,47	4,68

[x] Financial, operating, maintenance and insurance charges

[xx] Fuel cycle cost

1.3. - Dual purpose power generating and steam producing nuclear plant characteristics.

a. Computation assumptions.

The nuclear boiler characteristics will be identical to those of the reference plant nuclear boiler, i.e. :

Thermal power	1900 MWth
Boiler outlet steam characteristics :	
pressure	70 ata
temperature	284°C
enthalpy	662 kcal/kg
flow	3270 t/h
Feed water temperature	160°C

A simplified thermodynamic cycle computation has been carried out assuming :

- pressure loss between the boiler vessel and the turbine first blades	5 %
- internal isentropic efficiency	0,85(x)
- turbine mechanical efficiency	0,99
- generator efficiency	0,986
- auxiliaries electrical power(xx)	30 MWe

b. Dual purpose power generating and steam producing nuclear plant characteristics for producing 72°C steam.

The condenser pressure is 0,35 ata, corresponding to a 72°C steam temperature. Fig.3.2. shows the plant complete thermodynamic cycle(xxx) and its main characteristics for a unit steam flow of 1 t/h at the boiler outlet.

For the 3270 t/h corresponding to the nuclear boiler power of 1900 MWth, the plant gross electric power is 559 MWe, and its net electric power 559 - 30 = 529 MWe. The condenser available heat flow is 1150 Gcal/h, corresponding thermally to a 2200 t/h flow of dry saturated steam at 72°C.

(x) This value is only valid for high condenser pressures ($\geqslant$ 0,35 ata)

(xx) Including the circulating water pumping power

(xxx) This thermodynamic cycle has been very simplified and it was assumed for instance that the water subcooling took place at the feedwater cycle beginning.

c. Dual purpose power generating and steam producing nuclear plant characteristics for producing steam at 99°C.

The condenser pressure is 1 ata, corresponding to a 99°C steam temperature. Fig.3.3. shows the plant thermodynamic cycle for a unit high pressure steam flow at the boiler outlet.

For 3270 t/h (nuclear boiler power of 1900 MWth), the combined nuclear plant yields are :

Gross electrical power	484 MWe
Net electrical power : 484-30	454 MWe
Condenser available heat flow	1210 Gcal/h

This condenser heat flow corresponds to 2400 t/h of dry saturated steam at 99°C.

d. Dual purpose power generating and steam producing nuclear plant characteristics for producing steam at 120°C.

The condenser pressure is 2 ata, corresponding to a 120°C steam temperature. Fig.3.4. shows the plant thermodynamic cycle for a unit high pressure steam flow at the reactor vessel outlet.

For a 3270 t/h flow (nuclear boiler power of 1900 MWth), the combined nuclear power plant yields are :

Gross electrical power	430 MWe
Net electrical power : 430-30	400 MWe
Condenser available heat flow	1260 Gcal/h

This condenser heat flow corresponds to 2500 t/h of dry saturated steam at 120°C.

1.4. - Dual purpose nuclear power plant exhaust steam cost.

a. Computation method.

The steam cost computation will be carried out from the financial balance pertaining to the mixed power plant, excluding the desalination plant.

The dual purpose nuclear power plant annual charges (excluding those of the desalination plant) are :

- Charges corresponding to the plant capital cost : $D'_i \cdot i$

  where D'_i = power plant capital cost; including the condenser which was designed for high temperature operation (monel tubes), the circulating water pumps, pipes, intake and discharge structures.

  i = financial charge rate (8,1 %, 10 % and 13 %)

- Operation, maintenance and insurance expenses : D'_e
- Fuel expenses : D'_c

The dual purpose nuclear power plant annual income is derived from :

- sale of kWh to the grid : $P'_e u C_e$

where P'_e = dual purpose nuclear power plant net electrical power
u = plant full power yearly operating period
C_e = dual purpose nuclear plant electrical power value.

- sale of steam calories to the desalination plant : $Q u C_v$

where Q = dual purpose plant condenser heat flow (in Gcal/h)
u = plant full power yearly operating period
C_v = heat value to the desalination plant (UA/Gcal).

Equating the annual charges with the income gives :

$$Q u C_v + P'_e u C_e = D'_i i + D'_e + D'_c \qquad (1)$$

Knowing Q, P'_e and C_e, D'_i, D'_e and D'_c must be worked out so that the steam calorie cost C_v may then be computed.

The dual purpose nuclear power plant capital cost will be worked out as a function of that, D_i, of the reference nuclear power plant of equal thermal power. This gives :

$$D'_i = kD_i = kP_e I_e$$

where k = dual purpose nuclear plant to same thermal power reference nuclear plant capital cost ratio
P_e = reference plant net electrical power
I_e = reference plant capital cost per kWe (UA/kWe)

The dual purpose power plant operating charges are assumed equal to those of the reference power plant. This means that :

$$D'_e = P_e d_e$$

where d_e = total yearly operating, maintenance and insurance costs, in UA/kWe.year

The fuel costs are the same for both plants since their thermal power is identical; these costs are :

$$D'_e = P_e u C_c$$

where C_c = fuel cycle cost, in UA/kWh

When power generation is the combined nuclear plant main purpose, the kWh value is equal to the kWh cost in the reference plant, or :

$$C_e = \frac{I_e i + d_e}{u} + C_c \quad \text{(in UA/kWh)}$$

where I_e, i, d_e, u and C_c have their previous meaning.

Equation (1) thus becomes :

$$Q u C_v = I_e i\,(kP_e - P'_e) + d_e(P_e - P'_e) + uC_c(P_e - P'_e)$$

which can be written as :

$$C_v = \frac{P'_e}{Q} C'_e \tag{2}$$

$$\text{with } C'_e = \frac{I_e i \dfrac{kP_e - P'_e}{P'_e} + d_e \dfrac{P_e - P'_e}{P'_e}}{u} + C_c \frac{P_e - P'_e}{P'_e} \tag{3}$$

This cost C'_e takes the same form as the nuclear reference power plant kWh cost C_e but with the financial charges multiplied by

$$\frac{kP_e - P'_e}{P'_e}$$

whereas the operating and fuel costs are multiplied by

$$\frac{P_e - P'_e}{P'_e}$$

Cost C'_e meaning is seen immediately if it is remembered that the dual purpose nuclear plant annual cost is $P'_e u(C_e + C'_e)$; C'_e is therefore the kWh extra cost compared to that of the same power reference plant when the exhaust steam calorie is supposed to be valueless.

When water desalination is the dual purpose nuclear plant main aim, the kWh value depends on the network's economic conditions.

If C_e is this value in UA/kWh, equation (1) becomes :

$$QuC_v = kP_eI_e + P_ed_e + P_euC_c - P'_euC_e$$

or :

$$C_v = \frac{P_e}{Qu}(kI_e + d_e + uC_c) - \frac{P'_e}{Q}C_e$$

b. <u>Dual purpose nuclear power plant exhaust steam cost when electric power generation is the main aim.</u>

The kWh value is equal to the reference power plant kWh cost.

- Dual purpose nuclear power plant 72°C exhaust steam Gcal cost.

  The corresponding plant technical characteristics were worked out in 2.3.b. They are :

  P'_e = 529 MWe

  Q = 1150 Gcal/h at 72°C

  P_e = 600 MWe

  The nuclear dual purpose power plant capital cost can be taken from 5 to 7 % lower than that of the reference plant.

  This difference is due to the following factors :

  - The turbine is simpler (fewer L.P.casings and steam bleeds)
  - Fewer feedwater heaters
  - Lowering of generator and main transformer power.

  The value of k therefore lies between 0,95 and 0,93. Entering these values of P_e, P'_e, Q and k, and the 2.2.b table 1 values for d_e, I_e and C_c in relations (2) and (3) yields the steam Gcal cost.

  For each period and financial charge rate considered, table 3 gives :

  - the fixed charges, in UA/Gcal.year
  - the proportional charges, in mills/Gcal
  - the Gcal cost, in mills/Gcal, for 7000 hours operation per year.

The lower values correspond to k = 0,93 and the upper ones to k = 0,95.

Table 3

72°C steam Gcal cost

	Fixed charges UA/$\left[\frac{Gcal}{h}\right]$ xyear	Proportional charges mills/Gcal	Total cost in mills/Gcal for u = 7000 hours/year
1970-79			
i = 8,1 %	544 to 679	124	200 to 220
i = 10 %	620 to 786	124	212 to 235
i = 13 %	740 to 359	124	229 to 260
1980-89			
i = 8,1 %	461 to 576	108	174 to 187
i = 10 %	526 to 667	108	184 to 203
i = 13 %	628 to 811	108	197 to 224

- Dual purpose nuclear power plant 99°C exhaust steam Gcal cost.

  The corresponding plant technical characteristics were worked out in 2.3.c and are :

  P'_e = 454 MWe

  Q = 1210 Gcal/h at 99°C

  P_e = 600 MWe.

  The nuclear dual purpose power plant capital cost can be taken to be from 7 to 10 % lower than that of the reference plant. This entails $0,9 < k < 0,93$. Entering the above P_e, P'_e, Q and k values and the I_e, d_e and C_c values of table 1 of 2.2.b in relations (2) and (3) yields the steam Gcal cost.

  For each period and financial charge rate considered, table 4 gives :

  - the fixed charges, in UA/Gcal.year
  - the proportional charges, in mills/Gcal
  - the Gcal cost (in mills/Gcal) for 7000 hours operation per year.

The lower values correspond to k = 0, 9 and the upper ones to k = 0, 93

Table 4

99°C steam Gcal cost

	Fixed charges UA/[Gcal/h] x year	Proportional charges mills/Gcal	Total cost in mills/Gcal for u = 7000 hours/year
1970-79			
i = 8, 1 %	1323 to 1539	242	430 to 462
i = 10 %	1559 to 1799	242	464 to 497
i = 13 %	1900 to 2214	242	513 to 557
1980-89			
i = 8, 1 %	1138 to 1303	211	373 to 397
i = 10 %	1321 to 1523	211	401 to 429
i = 13 %	1608 to 1872	211	440 to 478

- Dual purpose nuclear power plant 120°C exhaust steam Gcal cost.

  The corresponding plant technical characteristics were worked out in 2.3.d and are :

  P'_e = 400 MWe

  Q = 1260 Gcal/h at 120°C

  P_e = 600 MWe.

  The nuclear dual purpose power plant capital cost can be taken to be 9 to 12 % lower than that of the reference plant. This entails $0,88 < k < 0,91$. Entering the above P_e, P'_e, Q and k values in relations (2) and (3) as well as the I_e, d_e and C_c values of table 1 of 2.2.b, yields the steam Gcal cost.

  For each period and financial charge rate considered, table 5 gives :

  - the fixed charges, in UA/Gcal.year
  - the proportional charges, in mills/Gcal
  - the Gcal cost, in mills/Gcal, for 7000 hours operation per year.

The lower values correspond to k = 0,88 and the upper ones to k = 0,91.

Table 5 120°C steam Gcal cost			
	Fixed charges $UA/\left[\frac{Gcal}{h}\right]$ x year	Proportional charges mills/Gcal	Total cost in mills/Gcal for u = 7000 hours/year
1970-79			
i = 8,1 %	1873 to 2059	317	584 to 612
i = 10 %	2182 to 2411	317	629 to 661
i = 13 %	2670 to 2967	317	698 to 741
1980-89			
i = 8,1 %	1587 to 1744	278	504 to 526
i = 10 %	1848 to 2042	278	542 to 570
i = 13 %	2259 to 2510	278	600 to 636

c.- Dual purpose nuclear power plant exhaust steam cost where water desalination is the main aim.

The kWh value is here 3 mills/kWh for the 1970/79 period and 2 mills/kWh for the 1980/89 period.

The computations were based on the same data as those used for the computations of par. b above, except for the kWh value, and the results are given in table 6 b.

1.5.- Conclusions.

Tables 6 a and b hereafter are a summary of the dual purpose power plant steam Gcal cost (value to the desalination plant) and kWh value (reference nuclear power plant kWh cost or kWh value governed by the plant main purpose) as functions of the main economic (number of hours of full power operation per year, financial charge rates) and technical (exhaust steam temperature) factors.

The tables 6 a and 6 b Gcal cost is the arithmetic mean of the costs computed with the minimum and maximum values assumed for coefficient k(dual purpose to reference nuclear power plant capital cost ratio). The error on the steam Gcal cost resulting from the lack of accuracy on the k coefficient value is usually smaller than 5 %.

When computing the desalination plant sweet water cost it must nevertheless be remembered that :

a. The steam Gcal cost has been computed considering the following capital costs common to the power and desalination plants :

   - condenser designed for 0,35, 1 or 2 ata operation,
   - circulating water piping, valves and fittings,
   - circulating water pumps,
   - circulating water intake and discharge structures.

   The capital costs have been charged to the power plant as follows :

   - condenser : reference plant condenser cost ($p \simeq 0,04$ ata) + about 1 M UA to take into account the special operating conditions met with ($p = 0,35$, 1 or 2 ata, circulating water at about 65, 92 or 113°C),
   - circulating water piping, valves, fittings, intake and discharge structures : same cost as the corresponding reference plant equipment,
   - circulating water pumps : the cost charged to the combined power plant is that corresponding to the reference plant. Supplementary capital costs resulting from special operating conditions (larger T.D.H. corresponding to higher head losses) will be charged to the desalination plant.

b. A part of the circulating water pump power (corresponding to that of the reference plant raw water pumps) is included in the dual purpose power plant auxiliaries' power; it is therefore only that extra power corresponding to a larger T.D.H. which has to be charged to the desalination plant.

Taking these remarks into account, the tables6 a and 6 b kWh and steam Gcal costs give the possibility of optimizing the desalination plant to be added to the combined nuclear power plant and to compute finally the desalination plant sweet water cost.

The figures listed in tables 6 a and 6 b are plotted on Fig.3.5., 3.6. and 3.7.

Table 6 a

Dual purpose power generating and steam producing nuclear plant technical and economic data

Main purpose : power generating

kWh value : reference nuclear power plant kWh cost

Condenser steam temperature	72°C		99°C		120°C	
Technical data						
Thermal power	1900 MWth		1900 MWth		1900 MWth	
Net electrical power	529 MWe		454 MWe		400 MWe	
Steam calories available	1150 Gcal/h		1210 Gcal/h		1260 Gcal/h	
Condenser pressure	0, 35 ata		1 ata		2 ata	
Economic data for 7000 hours operation per year	1970/79	1980/89	1970/79	1980/89	1970/79	1980/89
- Generated power value (mills/kWh)						
for i = 8, 1 %	4, 4	3, 7	4, 4	3, 7	4, 4	3, 7
i = 10 %	4, 8	4, 1	4, 8	4, 1	4, 8	4, 1
i = 13 %	5, 5	4, 7	5, 5	4, 7	5, 5	4, 7
- Condenser steam calorie cost (mills/Gcal)						
for i = 8, 1 %	210	180	446	385	598	515
i = 10 %	223	193	481	415	645	556
i = 13 %	245	210	535	459	720	618

Table 6 b

Dual purpose power generating and steam producing nuclear plant technical and economic data

Main purpose : desalination

kWh value : fixed (3 mills/kWh for 1970/79, 2 mills/kWh for 1980/89)

Condenser steam temperature	72°C		99°C		120°C	
Technical data						
Thermal power	1900 MWth		1900 MWth		1900 MWth	
Net electrical power	529 MWe		454 MWe		400 MWe	
Steam calories available	1150 Gcal/h		1210 Gcal/h		1260 Gcal/h	
Condenser pressure	0, 35 ata		1 ata		2 ata	
Economic data for 7000 hours operation per year	1970/79	1980/89	1970/79	1980/89	1970/79	1980/89
- Generated power value (mills/kWh)	3, 0	2, 0	3, 0	2, 0	3, 0	2, 0
- Condenser steam calorie cost (mills/Gcal)						
for i = 8, 1 %	833	983	954	1039	1027	1069
i = 10 %	1045	1163	1151	1205	1213	1224
i = 13 %	1381	1446	1463	1466	1505	1471

1.6.- Comparative cost of steam produced in a conventional dual purpose fossil fueled plant, with 120°C condenser temperature.

a. Technical data.

As for the nuclear plants, the reference power is of 600 MWe net.

The dual purpose plant characteristics are :

P_e = 600 MWe

P'_e = 415 MWe

Q = 870 Gcal/h

condenser steam flow : 1654 t/h
condenser pressure : 2 ata
condenser temperature : 120°C

b. Economic data.

I_e	= capital cost	100 UA/kWe (1)
d_e	= operating, maintenance and insurance costs	2,5 UA/kWe.year (1)
fuel consumption		2000 kcal/kWh (1)
fuel cost, delivered		10 UA/tec
		12 UA/tec
		15 UA/tec

1 tec = equivalent of 1 ton of coal = 7000 kcal
i = interest rate corresponding to the financial charges 10 %
u = yearly plant utilization 7000 hours

The fuel cost C_c is therefore :

$2,857 \times 10^{-3}$ UA/kWh for a fuel cost of 10 UA/tec

$3,429 \times 10^{-3}$ UA/kWh for a fuel cost of 12 UA/tec

$4,286 \times 10^{-3}$ UA/kWh for a fuel cost of 15 UA/tec

(1) EUR/2773.e.- First target programme for the European Atomic Energy Community - March 1966

c. Combined conventional plant steam cost where power generating is the main purpose.

The kWh value is equal here to a single purpose equal thermal capacity conventional power plant kWh cost.

The steam cost is :

$$C_v = \frac{1}{Q} \left[\frac{(kP_e - P'_e)\, i\, I_e + d_e (P_e - P'_e)}{u} + C_c \right]$$

and the kWh cost is :

$$C_e = \frac{i I_e + d_e}{u} + C_c$$

Using the values of paragraphs a) and b), gives (Fig. 3. 8.)

Fuel cost (UA/tec)	kWh cost (10^{-3} UA/kWh)	Steam cost (10^{-3} UA/Gcal)
10	4,64	889
12	5,22	1010
15	6,07	1192

d. Combined conventional plant steam cost where water desalination is the main purpose.

The steam cost is :

$$C_v = \frac{P_e}{Q} \left[\frac{k I_e i + d_e}{u} + C_e \right] - \frac{P'_e}{Q} C_e$$

where C_e is the electrical power value in 10^{-3} UA/kWh. For typical C_e values of 3 and 2 x 10^{-3} UA/kWh, the steam costs are (Fig. 3. 8.)

Fuel cost (UA/tec)	Steam cost, in 10^{-3} UA/kWh, for : $C_e = 3 \times 10^{-3}$ UA/kWh	$C_e = 2 \times 10^{-3}$ UA/kWh
10	1672	2149
12	2067	2544
15	2658	3135

Nomenclature.

UA = Unit of Account = 1 US $

C_e = kWh value to the network (UA/kWh)

C_v = steam calorie value to the desalination plant (UA/cal)

Q = reference nuclear power plant condenser heat discharge rate(cal/h)

F = fixed charges : financial, operating, maintenance and insurance charges (UA/kWe.year)

P = proportional charges : fuel cycle cost (UA/kWh)

k = dual purpose to reference nuclear power plant capital cost ratio

u = power plant use (hours/year)

i = financial charge rate

The following symbols apply to the reference or the dual purpose nuclear power plant according to the superscript ' (for instance : P_e = reference plant power, P'_e = dual purpose plant power)

D_i = power plant capital cost (UA/year)

D_e = operation yearly expenditure (UA/year)

D_c = fuel cycle yearly expenditure (UA/year)

I_e = unit capital cost (UA/kWe)

d_e = unit operating expenditure (UA/kWe.year)

D_c = fuel cycle cost (UA/kWh)

P_e = net electric power (kWe)

2. WATER COST COMPUTATION

2.1. - General considerations

In the European Community it is the intermediate size dual purpose plant of 200 to 1500 MWth and 50.000 to 250.000 m^3/day capacity which is suited to local conditions, and more specifically in Northern Europe (See Chapter 1, Conclusions).

This has governed the choosing of water production capacities of 50.000, 100.000 and 250.000 m^3/day for the combined plants analyzed hereafter and heated with fossil or nuclear fuel.

The European Community normal financial charges have been used in computing the water cost.

The value of the electrical power was worked out according to :

a) plant main purpose : power generating
b) plant main purpose : desalination
(See details in the first paragraph of this Chapter).

On the other hand, two different periods were considered :

a) 1970-79
b) 1980-89

All data correspond to a 129°C exhaust steam temperature.

129°C was taken as reference saturation temperature value throughout this study since it is the maximum which may be considered in desalination technology of today.

Lower temperatures could be considered. Numerous theoretical studies have however shown that no advantage can be derived from their use here, and that is the reason why most large plants are designed for this temperature range (1, 2, 3).

For the three plant capacities mentioned above, the water costs are worked out hereafter as in a balance-sheet.

The balance-sheet for a desalination plant corresponds to :

- expenditure	:	financial charges, operating expenses, exhaust steam cost, consumed electrical energy cost
- income	:	water sale.

$$\underbrace{D_i . i + D_o + D_s + D_p}_{\text{Expenditure}} = \underbrace{D_w}_{\text{Income}}$$

D_i = desalination plant capital cost, made up of the construction cost and indirect first cost.

i = fixed charge rate

D_o = desalination plant operating expenses

$D_s = P_s . u . C_s$ = exhaust steam cost

where P_s = steam flow
u = plant utilization factor
C_s = exhaust steam unit cost

$D_p = P_p . u . C_e$ = consumed electrical energy cost for the desalination plant

where P_p = consumed electrical energy, MW
u = plant utilization factor
C_e = electrical energy cost

$D_w = P_w . u . C_w$ = water sale income

where P_w = plant water production
u = plant utilization factor
C_w = water value.

2.2.- Evaluation of the various costs.

a. Basic data.

The values used hereafter are those resulting from Euratom studies and corresponding to European Community conditions :

i = 8,1 %, 10 % and 13 % per year
u = 0,8

C_e is selected in accordance with the combined plant main purpose (power generating or water production) and the period considered (1970-79; 1980-89).

b. Capital costs.

Based on the capital cost for numerous optimized plants (3), specific capital costs were worked out. They have been plotted on graphs from which sufficiently accurate interpolations could be made for the values required here.

United States indirect capital costs are about 30 to 35 % of the total, compared to some 10 % in Europe. Furthermore, salaries making up a large part of the construction costs, are lower in Europe than in the United States. This entails lower small and medium plant capital cost in Europe than in the United States.

For the plants considered here this advantage is offset by the more rational methods of american manufacturers. That is why the same capital cost values were used in this study. This is dealt with in further detail in the final conclusions. The following points should be remembered regarding the diagrams:

Graphs 3.9. and 3.10., resulting from an optimization study, show up clearly the incidence of fixed charge rate and energy selling price on the specific capital cost. For higher fixed charge rates lower capital cost is advisable. For high energy selling prices, water production plant cost should be reduced.

Table 7 shows the detailed capital costs.

c. Operating expenses.

Specific operating expense values (See Fig. 3.11.) have been deducted from the above mentioned study (3) and adapted according to wages and salaries prevailing in Europe.

As may be seen on the graph, the specific operating expenses decrease with plant capacity, as expected. The figures are the same for fossil or nuclear fueled plants.

d. Exhaust steam cost.

This cost is the product of the exhaust steam cost by the specific steam requirement. Steam cost was given in Chapter III, 1, of this study for the various operating conditions.

These steam costs suppose that the desalination plant is working all the time when the electrical plant is running so that the investment of the low pressure end of the turbine and the associated equipment can be avoided.

If only partial amount of exhaust steam is needed for desalination, the above computed steam costs are still valid. Bleed steam is then used and the flow in the downstream portion of the turbine, condenser reheaters etc. is reduced by that same amount. Cost reduction versus the reference single purpose plant are thus possible by reducing turbine blades length or the number of low pressure casing etc. in the same proportion as the steam flow diverted.

Exhaust steam requirements were taken from (3). Fig. 3. 12. and 3. 13. are plots of the specific values. It should be noted here that they show that specific steam amounts increase for an electrical energy cost increase. This is explained by the fact that with increasing electrical energy cost the exhaust steam cost becomes smaller, and the performance ratio of the evaporating plant may thus be lowered.

This in turn implies an evaporating plant capital cost reduction, with a simultaneous steam cost increase affecting the initially reduced steam cost only marginally. The final result is thus that with increasing steam cost the evaporating plant performance ratio (sweet water to steam ratio) must also increase. The same sort of relationship holds for the fixed cost rate.

In our opinion, the specific steam consumption figures corresponding to a capacity of about 50.000 m^3/day are not accurate enough and should therefore be considered as indicative only.

e. Electrical energy.

These figures, coming from (3), have been adapted as in d. (Fig. 3. 14. and 3. 15.).

A reverse relationship must be found here since larger capacity plants must use more electrical power. To ascertain the desalination plant electrical consumption it was taken into account that the cooling water pump power consumption had already been charged to the power plant.

2.3.- Water costs.

Tables 8 to 12 give the water costs based on the different above mentioned assumptions.

It can be seen that, for smaller sizes, the steam cost has a small influence and hence no definite advantage can be drawn from the smaller cost of nuclear steam.

For large size plants it is shown clearly that nuclear energy can lead to cheaper water costs.

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(200 to 1500 MWth) for Combined Water
and Power Production
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Table 7

Water plant capital cost charges

(U.A. 10^6/year)

fixed charge rate	power (mills/kWh)	50.000 m^3/day	100.000 m^3/day	250.000 m^3/day
Dual plant, fossil fueled				
10 %	6,07	1,028	1,803	3,53
10 %	5,22	1,05	1,892	4,015
10 %	4,64	1,063	1,955	4,12
10 %	3	1,104	2,13	4,78
10 %	2	1,13	2,235	5,14
Dual plant, nuclear fueled				
8,1 %	4,4	1,06	1,862	3,52
8,1 %	3,7	1,07	1,905	3,56
10 %	4,8	1,293	2,27	3,96
10 %	4,1	1,306	2,325	4,26
13 %	5,5	1,7	2,95	5,15
13 %	4,7	1,7	2,95	5,32
8,1 %	3	1,113	1,97	3,85
10 %	3	1,32	2,36	4,42
13 %	3	1,7	2,982	5,66
8,1 %	2	1,123	2,055	4,17
10 %	2	1,347	2,153	4,88
13 %	2	1,7	3,02	5,835

Table 8

Dual purpose power generating and water producing nuclear plant technical and economic data

Main purpose : power generating

kWh value : reference nuclear power plant kWh cost

Condenser steam temperature	129°C					
Condenser steam pressure	2,67 ata					
Technical data Water production	50.000 m^3/day		100.000 m^3/day		250.000 m^3/day	
Economic data for 7000 hours operation per year	1970/79	1980/89	1970/79	1980/89	1970/79	1980/89
- Generated power (mills/kWh)						
for i = 8,1 %	4,4	3,7	4,4	3,7	4,4	3,7
i = 10 %	4,8	4,1	4,8	4,1	4,8	4,1
i = 13 %	5,5	4,7	5,5	4,7	5,5	4,7
- Condenser steam calorie cost (U.A.¢/Gcal)						
for i = 8,1 %	65	56	65	56	65	56
i = 10 %	70	61	70	61	70	61
i = 13 %	78	67	78	67	78	67
- Water production costs (U.A. ¢/m^3)						
for i = 8,1 %	13	12	11	11	9	8
i = 10 %	(*) 14	14	13	12	10	10
i = 13 %	(*) 16	16	15	15	12	11

(*) approximate value

Table 9

Dual purpose power generating and water producing nuclear plant technical and economic data

Main purpose : desalination

kWh value : fixed (3 mils/kWh for 1970/79, 2 mills/kWh for 1980/89

Condenser steam temperature	129°C					
Condenser steam pressure	2,67 ata					
Technical data Water production	50.000 m^3/day		100.000 m^3/day		250.000 m^3/day	
Economic data for 7000 hours operation per year	1970/79	1980/89	1970/79	1980/89	1970/79	1980/89
- Generated power (mills/kWh)	3,0	2,0	3,0	2,0	3,0	2,0
- Condenser steam calorie cost (U.A.¢/Gcal)						
for i = 8,1 %	105	108	105	108	105	108
i = 10 %	123	123	123	123	123	123
i = 13 %	152	147	152	147	152	147
- Water production costs (U.A.¢/m^3)						
for i = 8,1 %	13	13	12	11	10	9
i = 10 %	(*) 15	15	14	13	11	11
i = 13 %	(*) 18	18	16	16	13	13

(*) approximate value

Table 10

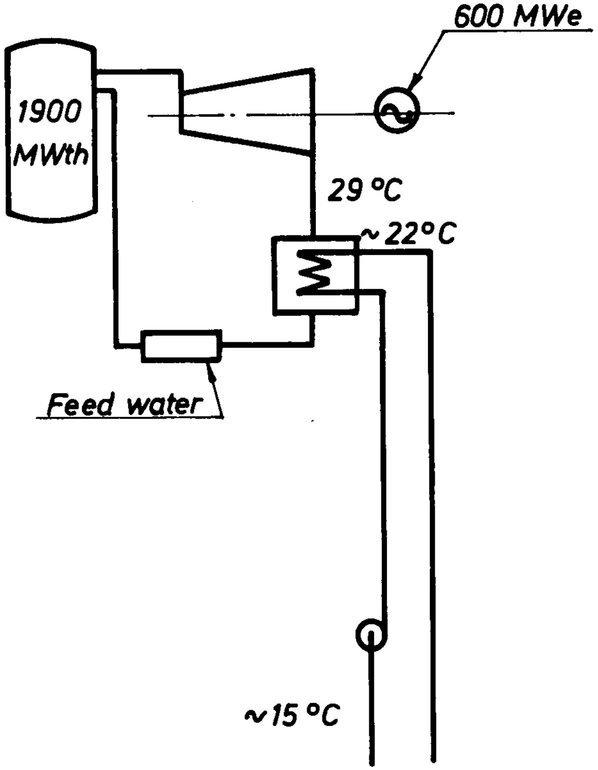
Dual purpose power generating and water producing fossil fueled plant Main purpose : power generating kWh value : reference fossil fueled power plant kWh cost									
Condenser steam temperature	129°C								
Condenser steam pressure	2,67 ata								
Technical data Water production	50.000 m^3/day			100.000 m^3/day			250.000 m^3/day		
Economic data for 7000 hours operation per year	cost of fuel (u.c./tec)			cost of fuel (u.c./tec)			cost of fuel (u.c./tec)		
	10	12	15	10	12	15	10	12	15
- Generated power value (mills/kWh) for i = 10 %	4,64	5,22	6,07	4,64	5,22	6,07	4,64	5,22	6,07
- Condenser steam calorie cost (U.A.¢/Gcal) for i = 10 %	89	101	119	89	101	119	89	101	119
- Water production costs (U.A.¢/m^3) for i = 10 %	14	14	15	13	13	14	11	12	12

<u>Table 11</u>

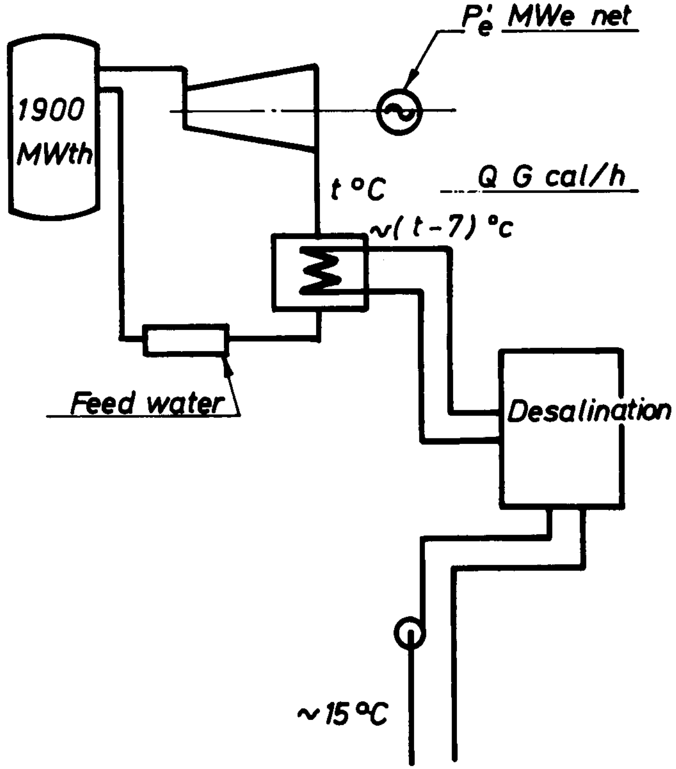
Dual purpose power generating and water producing fossil fueled plant Main purpose : desalination kWh value : fixed (3 mills/kWh for 1970/79)									
Condenser steam temperature	129°C								
Condenser steam pressure	2,67 ata								
<u>Technical data</u> Water production	50.000 m^3/day			100.000 m^3/day			250.000 m^3/day		
<u>Economic data for 7000 hours operation per year</u>	cost of fuel (u.c./tec)			cost of fuel (u.c./tec)			cost of fuel (u.c./tec)		
	10	12	15	10	12	15	10	12	15
- Condenser steam calorie cost (U.A.¢/Gacl) for i = 10 %	167	207	266	167	207	266	167	207	267
- Water production costs (U.A.¢/m^3) for i = 10 %	16	17	19	15	16	18	14	15	16

Table 12

Dual purpose power generating and water producing fossil fueled plant Main purpose : desalination kWh value : fixed (2 mills/kWh for 1980/89)									
Condenser steam temperature	129°C								
Condenser steam pressure	2,67 ata								
Technical data Water production	50.000 m^3/day			100.000 m^3/day			250.000 m^3/day		
Economic data for 7000 hours operation per year	cost of fuel (u.c./tec)			cost of fuel (u.c./tec)			cost of fuel (u.c./tec)		
	10	12	15	10	12	15	10	12	15
- Condenser steam calorie cost (U.A.¢/Gacl) for i = 10 %	215	254	314	215	254	314	215	254	314
- Water production costs (U.A.¢/m^3) for i = 10 %	17	18	20	16	17	19	14	15	17



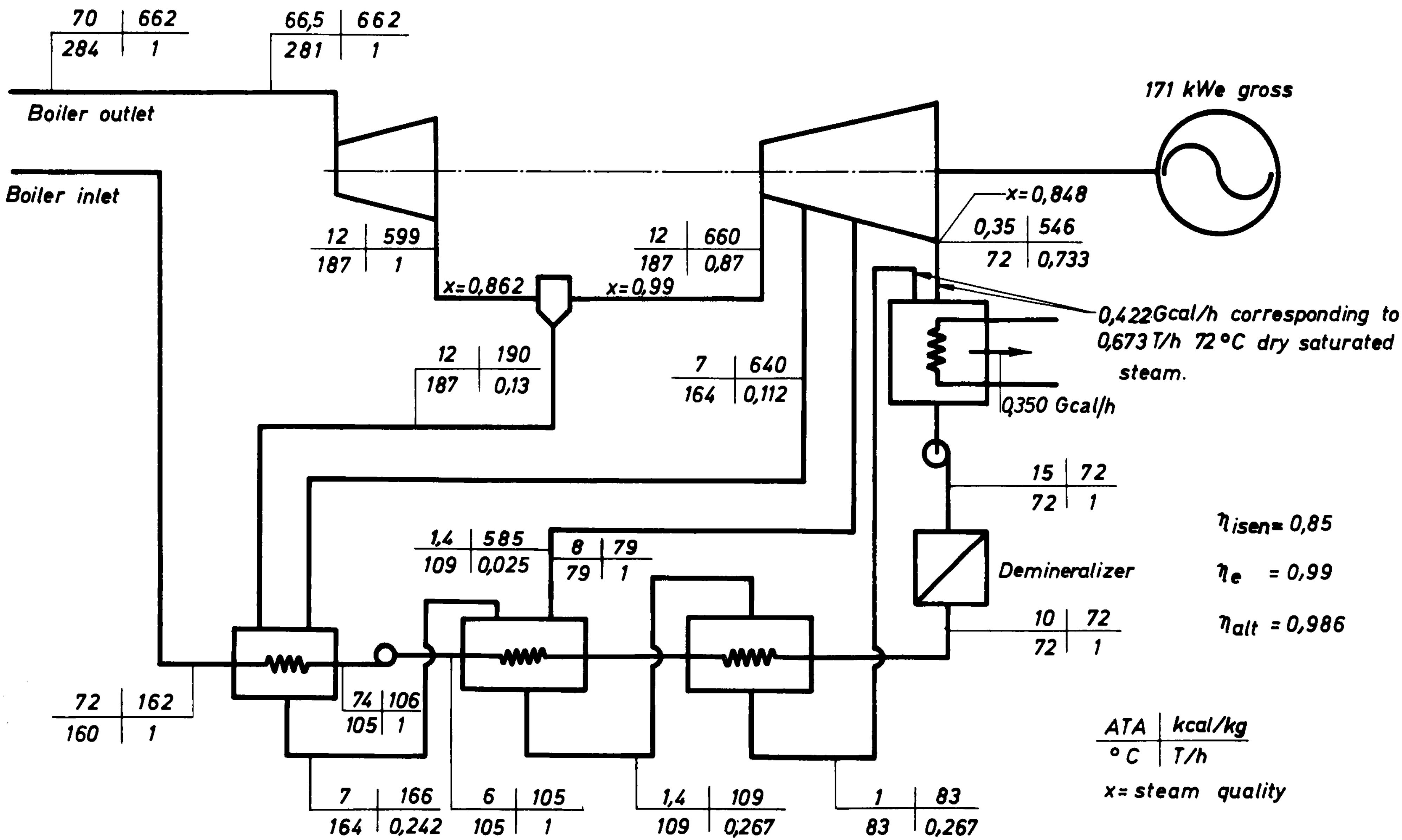
a. REFERENCE POWER GENERATING PLANT



b. POWER GENERATING AND STEAM PRODUCING DUAL PURPOSE PLANT

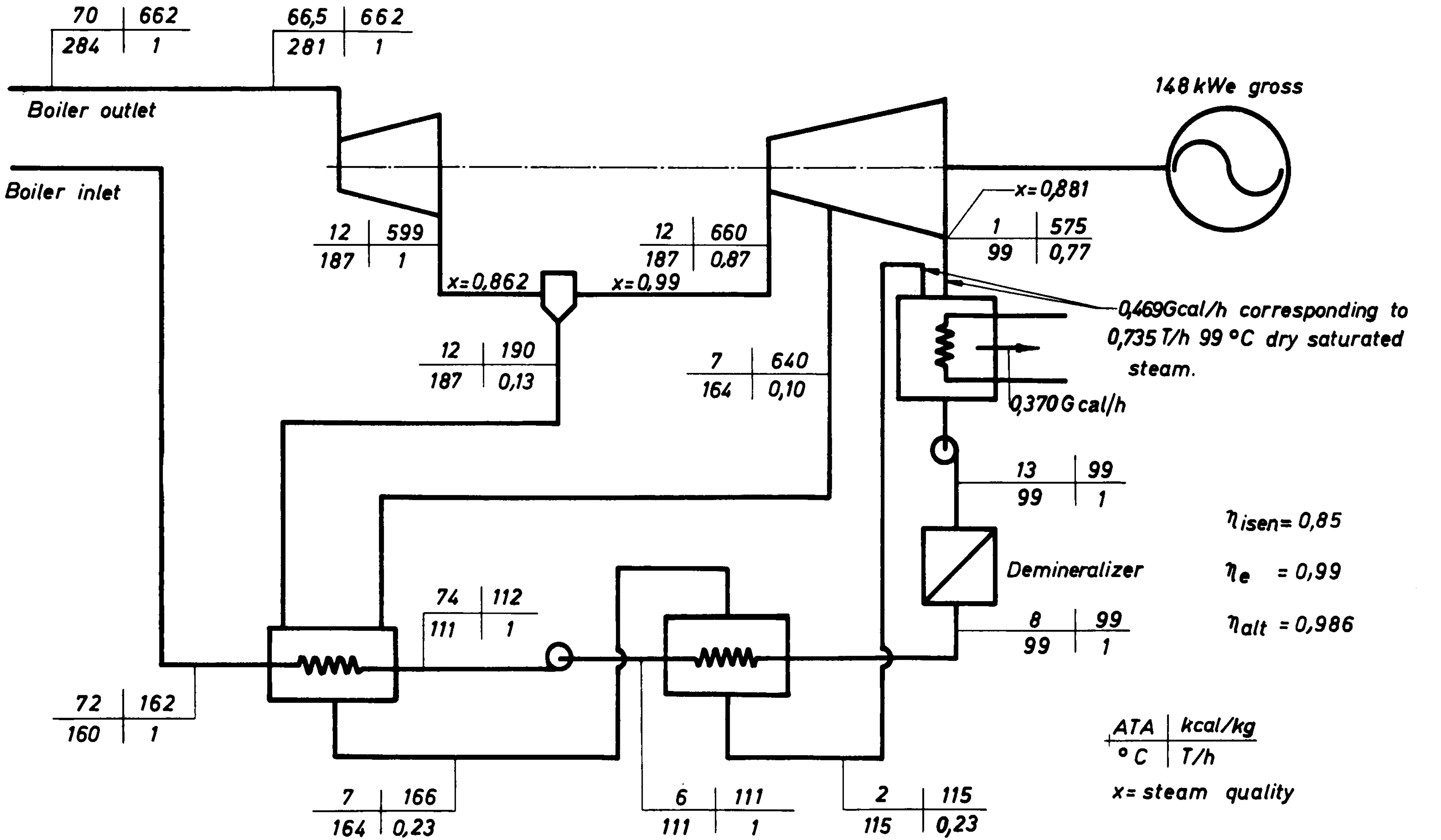
DUAL PURPOSE NUCLEAR PLANT BASIC FLOW-SHEETS

FIG. 3.1



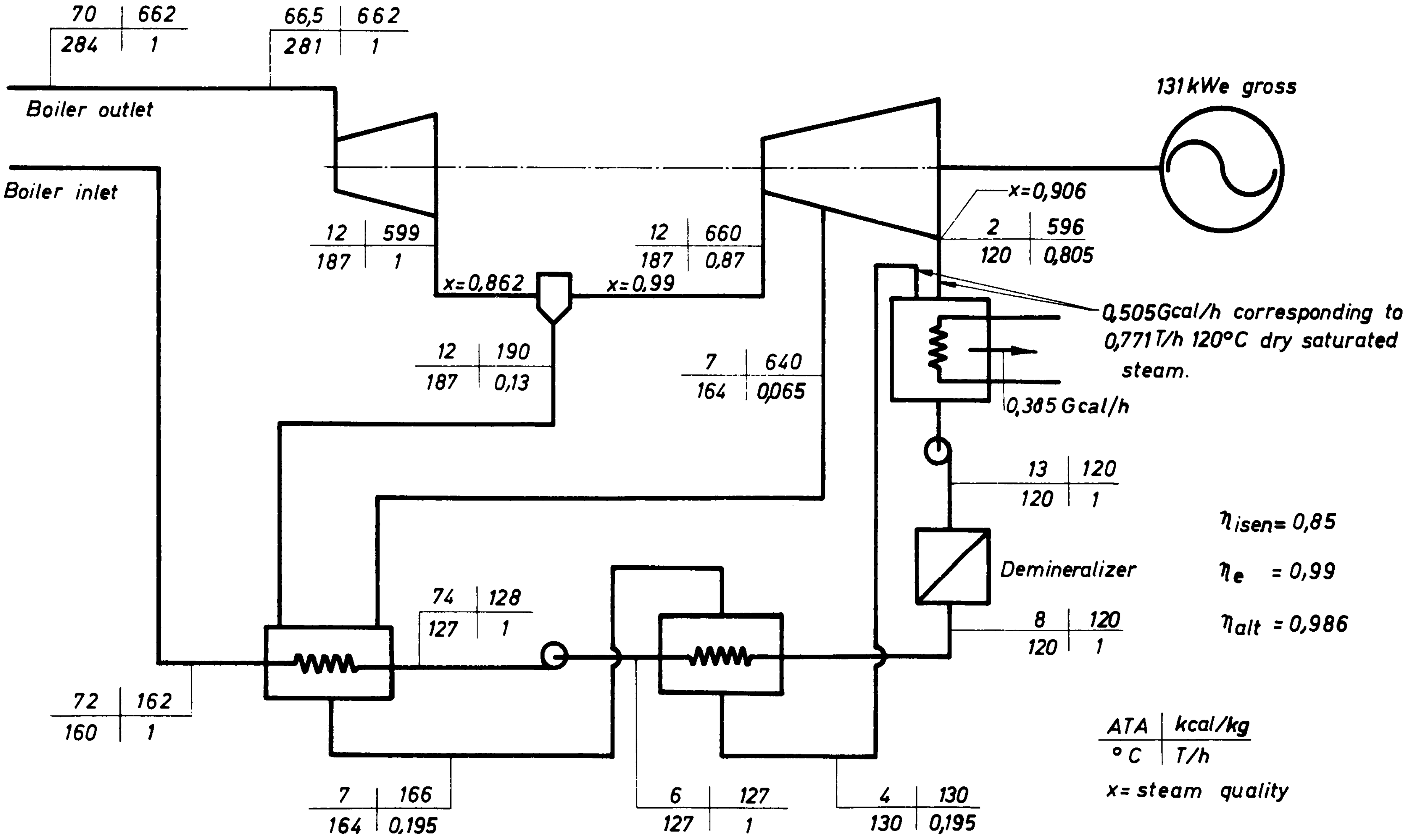
DUAL PURPOSE NUCLEAR PLANT THERMODYNAMIC CYCLE PRODUCING 72°C STEAM

FIG. 3.2.



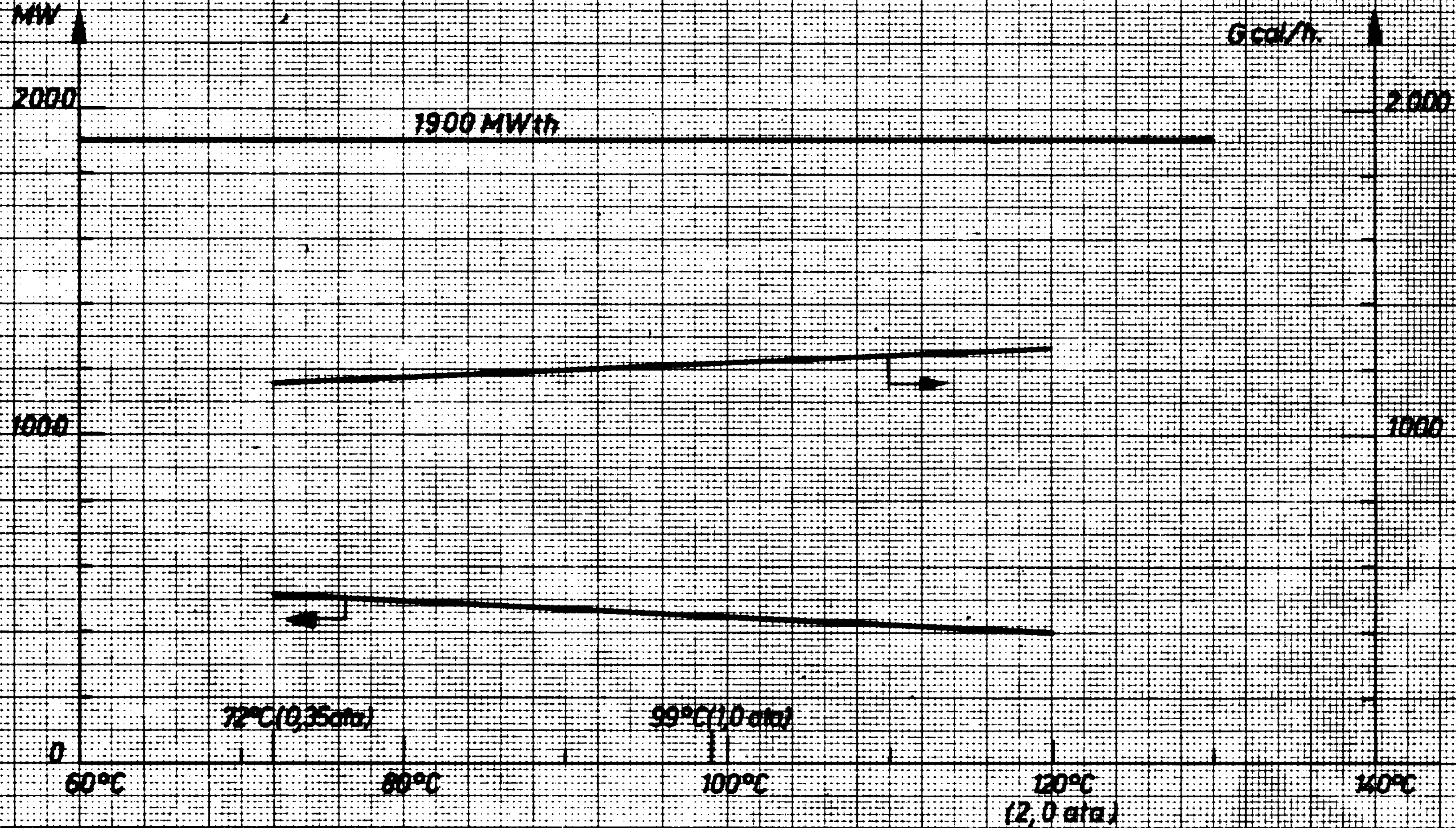
DUAL PURPOSE NUCLEAR PLANT THERMODYNAMIC CYCLE PRODUCING 99 °C STEAM

FIG. 3.3



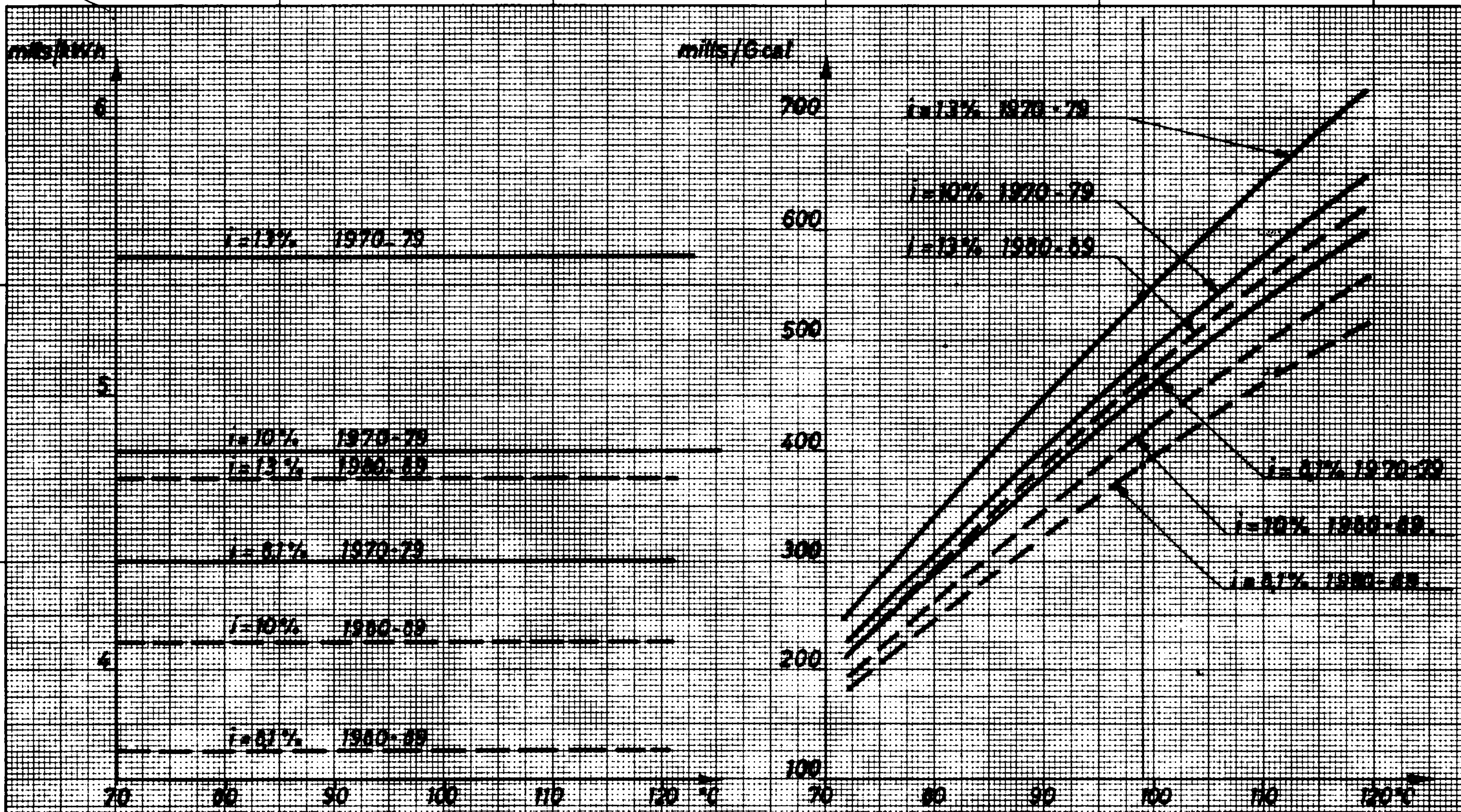
DUAL PURPOSE NUCLEAR PLANT THERMODYNAMIC CYCLE PRODUCING 120°C STEAM

FIG. 3.4.



ELECTRICAL POWER AND EXHAUST STEAM HEAT PRODUCTION VERSUS EXHAUST STEAM TEMPERATURE FOR A CONSTANT THERMAL POWER NUCLEAR PLANT

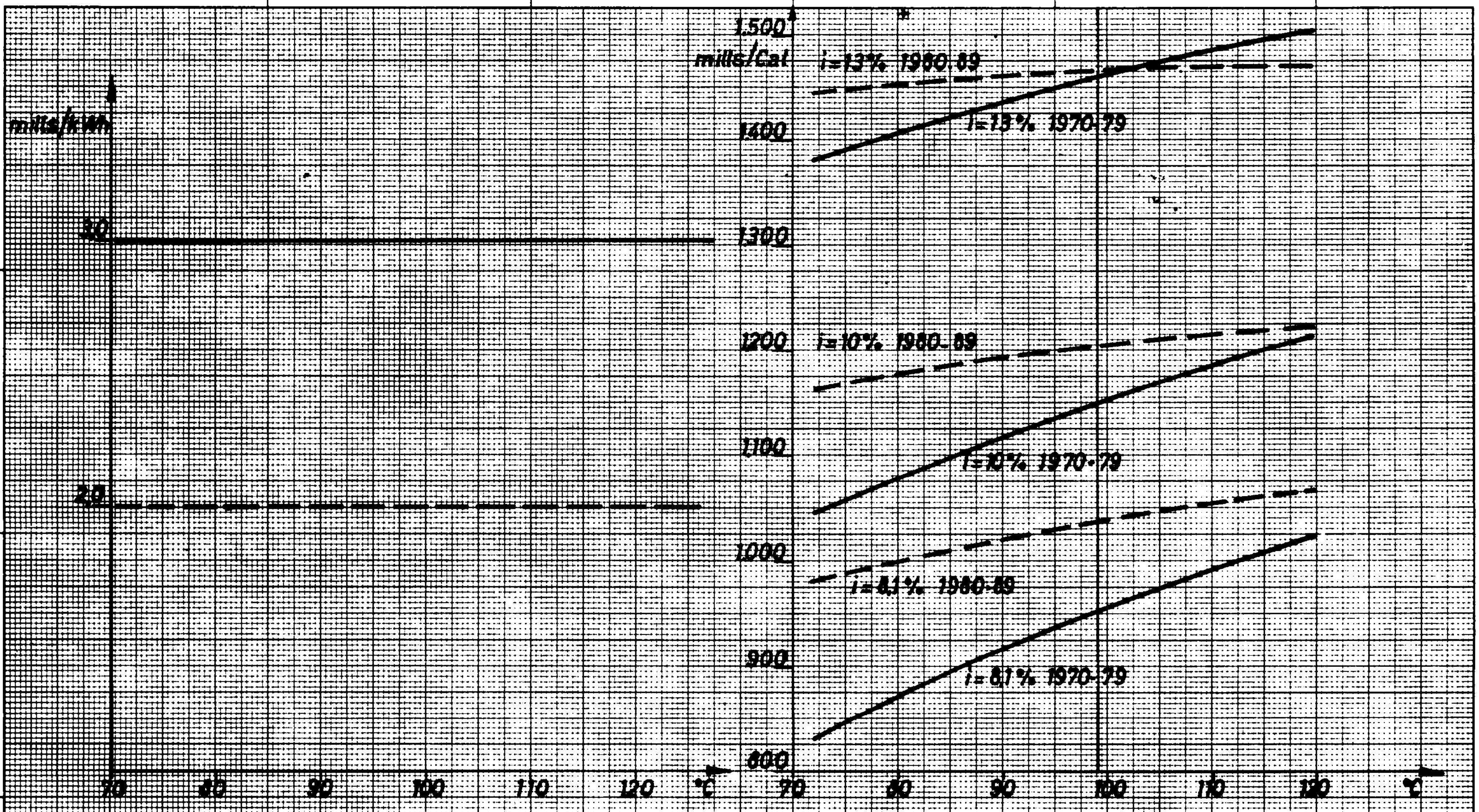
FIG: 3.5



kWh VALUE AND G cal. COST IN A DUAL PURPOSE NUCLEAR PLANT

MAIN PURPOSE : kWh PRODUCTION

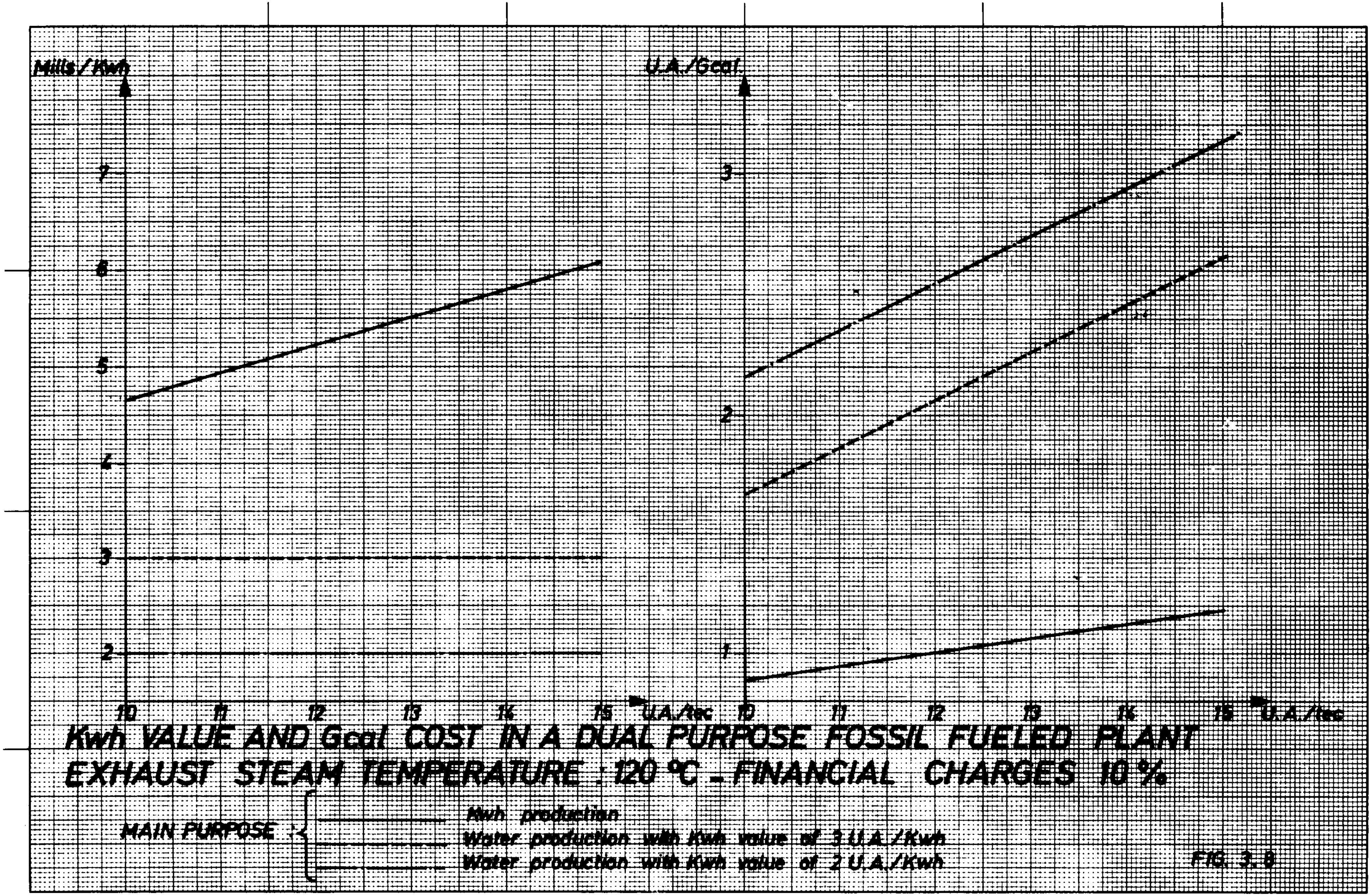
FIG. 36



kWh VALUE AND Gcal COST IN A DUAL PURPOSE NUCLEAR PLANT

MAIN PURPOSE : WATER PRODUCTION

FIG. 3-7



Kwh VALUE AND Gcal COST IN A DUAL PURPOSE FOSSIL FUELED PLANT
EXHAUST STEAM TEMPERATURE : 120 °C – FINANCIAL CHARGES 10 %

FIG. 3.8

Specific investments

water plant - dual plant, fossil fueled

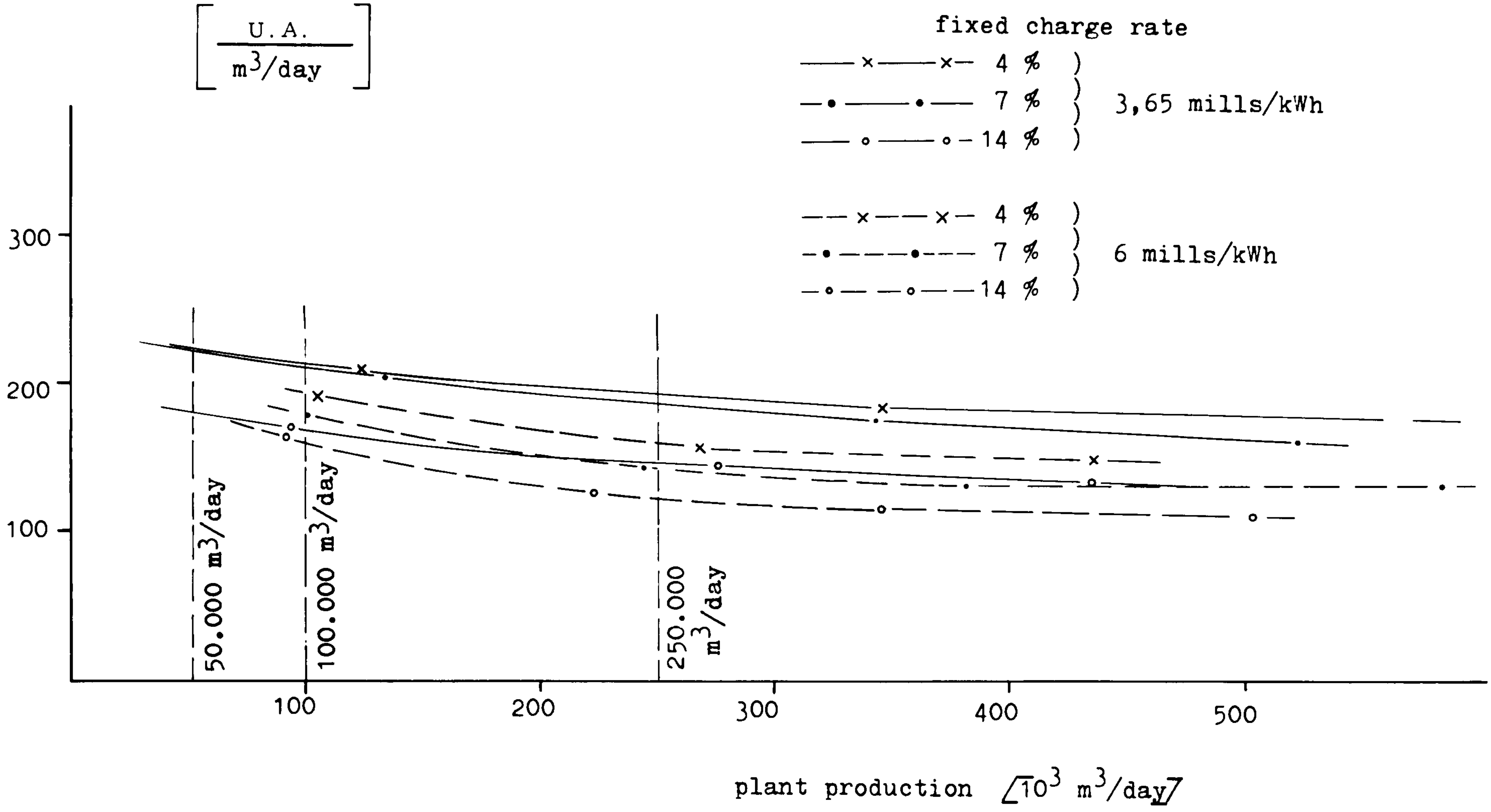


Fig. 3.9

Specific investments

water plant - dual plant, nuclear fueled

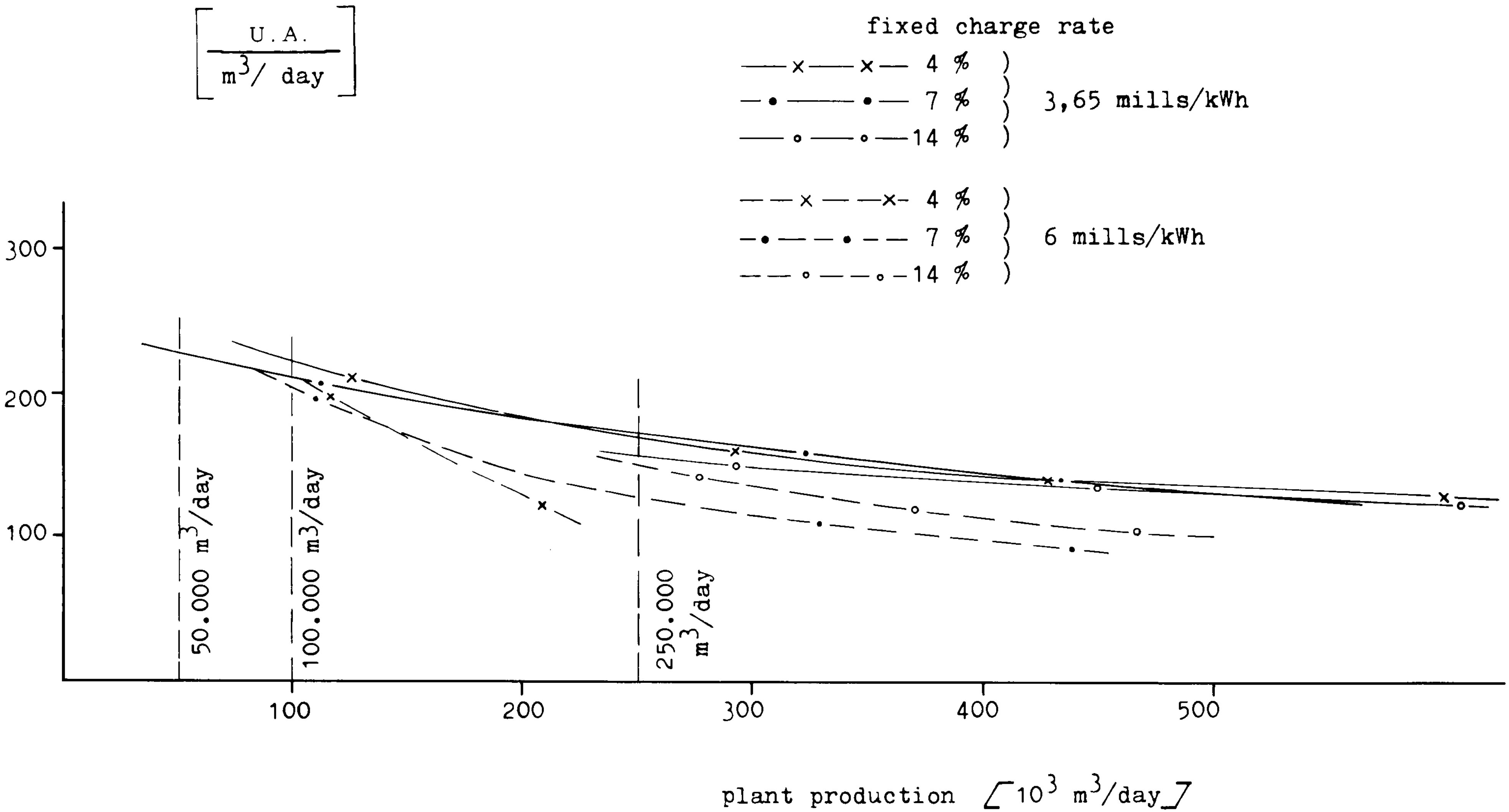


Fig. 3.10

Specific operating costs

water plant - dual plant case

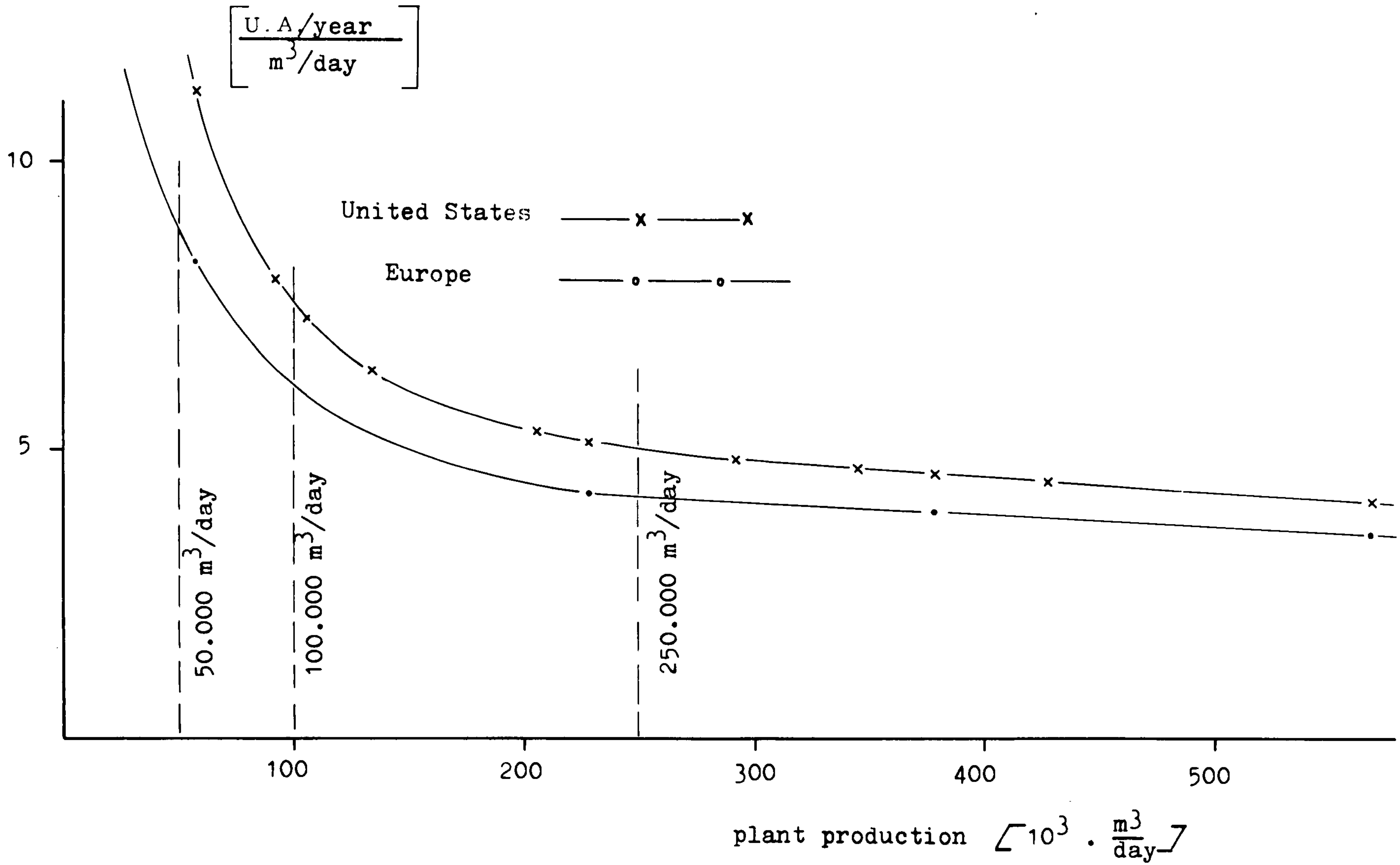


Fig. 3.11

Specific steam requirements

water plant - dual plant, fossil (resp. nuclear) fueled

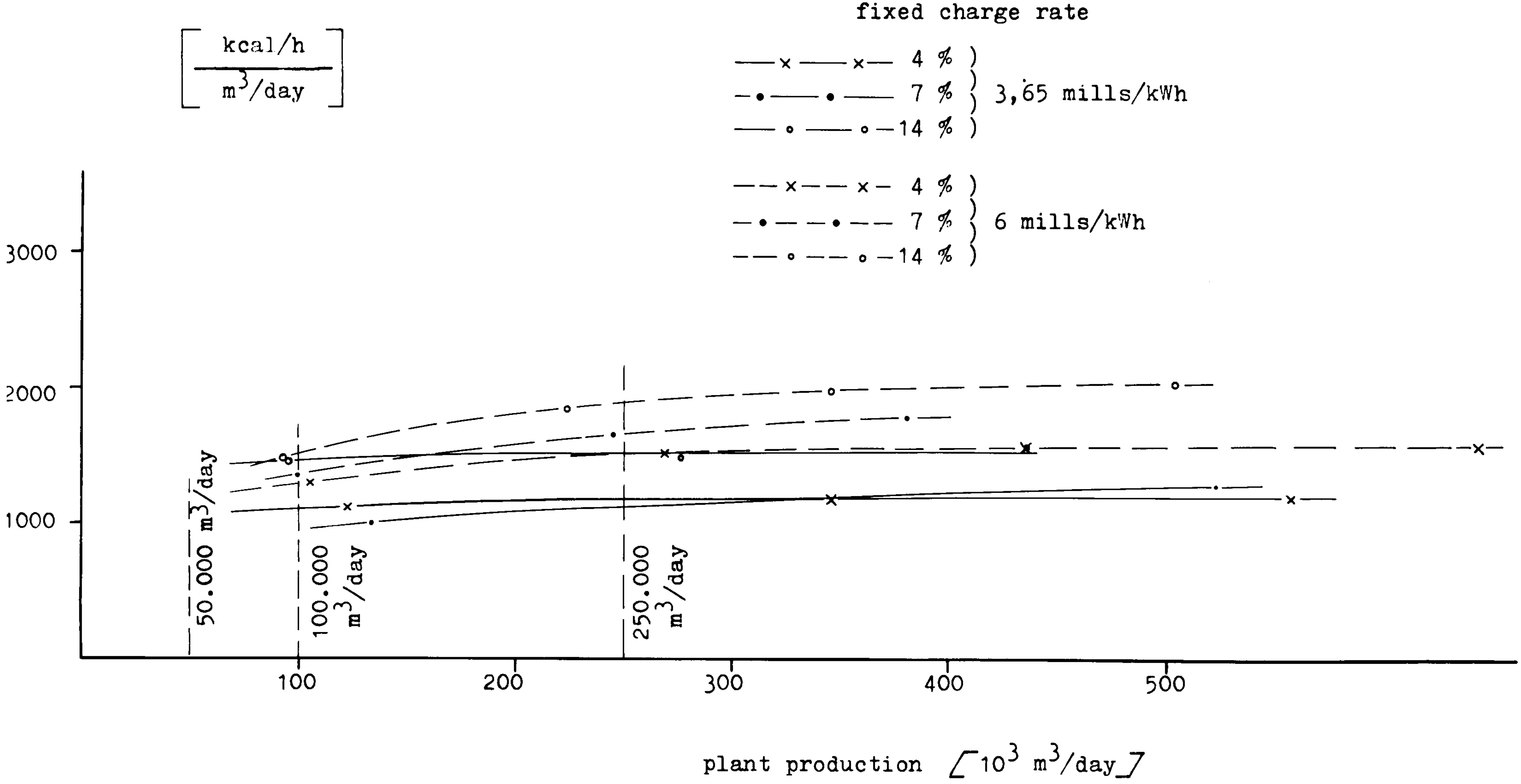


Fig. 3.12

Specific steam requirements

water plant - dual plant, fossil (resp. nuclear) fueled

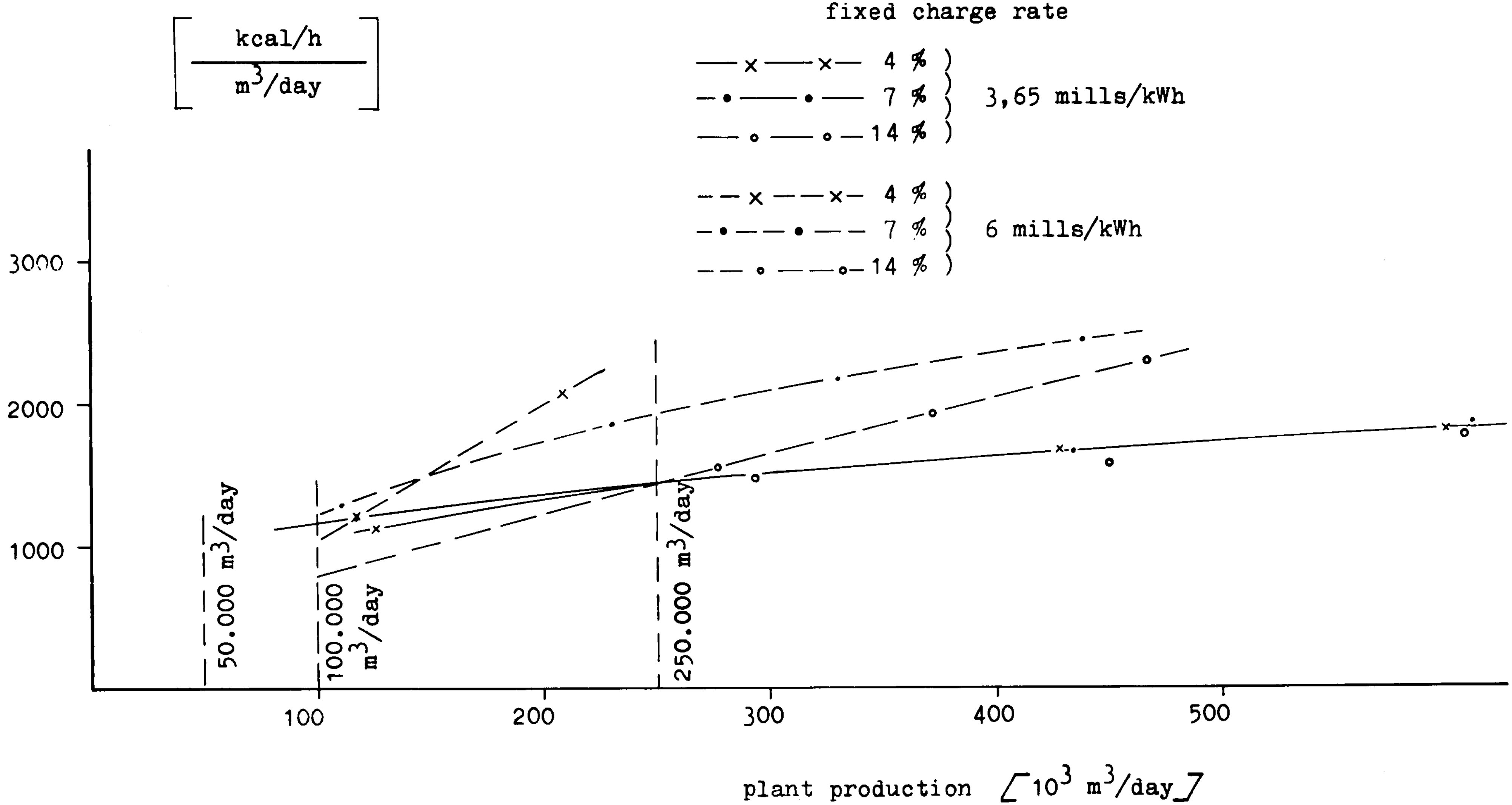


Fig. 3.13

Specific electrical consumption

water plant - dual plant, fossil (resp. nuclear) fueled

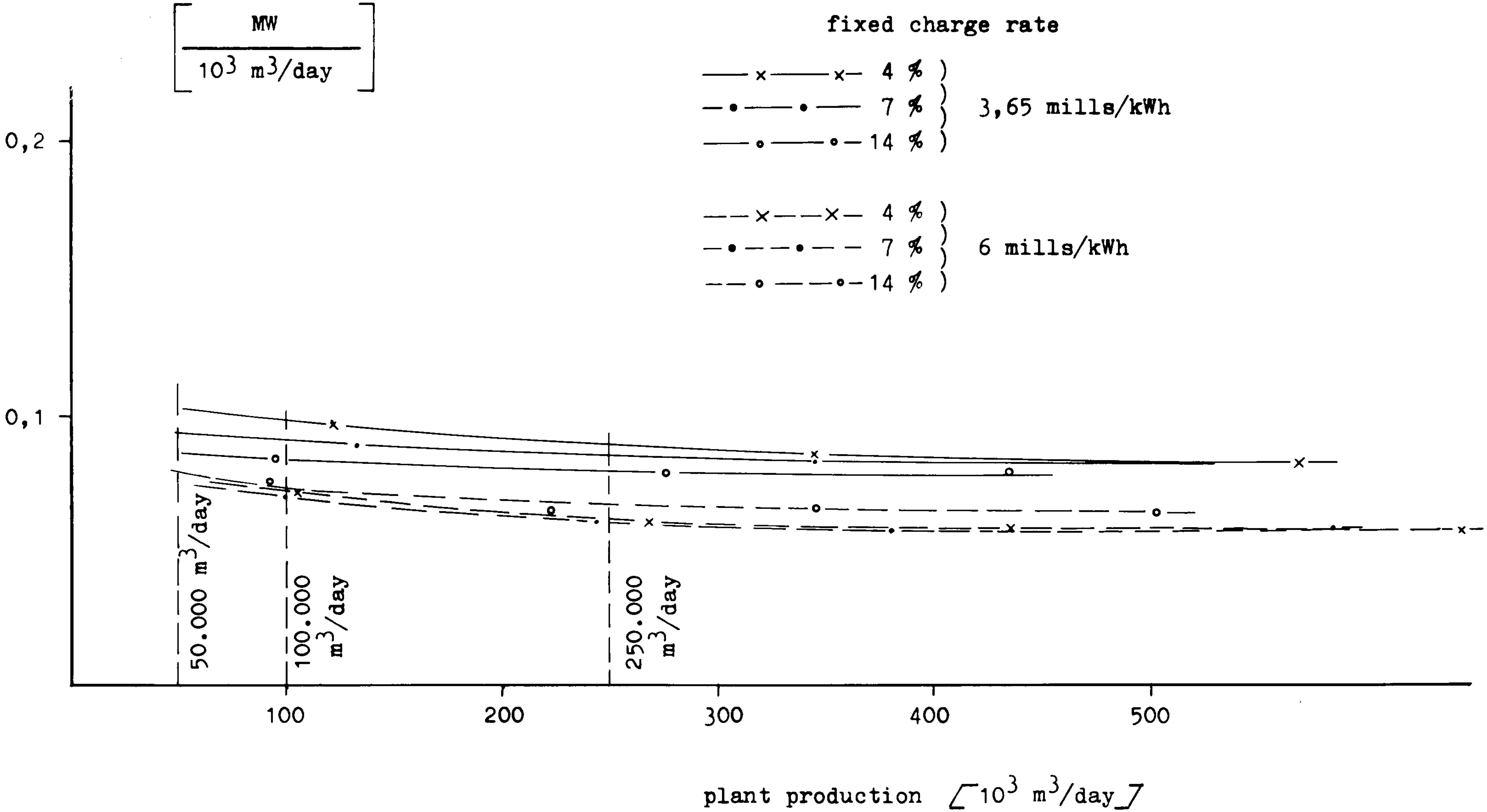


Fig. 3.14

Specific electrical consumption

water plant - dual plant, fossil (resp. nuclear) fueled

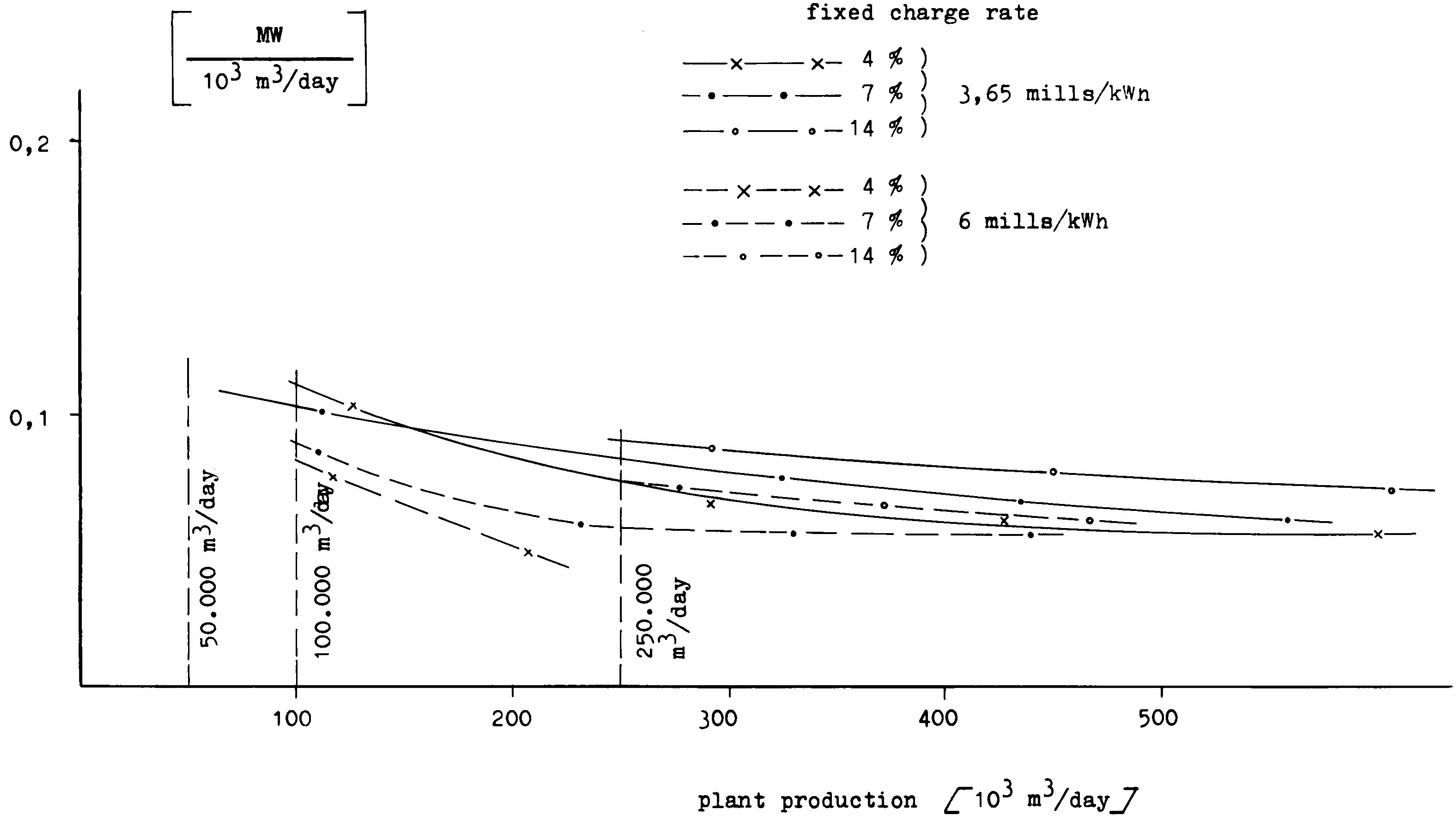


Fig. 3.15

GENERAL CONCLUSIONS

- Water shortage in Western Europe occurs very seldom and in specific areas only. This position will continue to prevail quite generally in most locations. This means that mere conservancy or regulating measures are required.

  Water generation may be economically feasible only in specific districts such as those of the Northern coast of the Netherlands and Germany.

- On the other hand the electricity demand will continue to increase much more quickly than the water demand and in this context dual purpose nuclear plants may meet both demands without unduly penalizing the kWh cost.

  The population density of the Northern part of the E.E.C. precludes the likelihood of other than large desalination plants on the mainland.

- Technologically and economically the most suitable desalination process at present is the multi-flash system. Such a plant can cope adequately with future demand. The corresponding water costs worked out in this study, falling within the range of prices acceptable in the European Community, show this up.

- It was however outside the scope of the present study to give accurate economical or technical data on local implementation possibilities.

  To ascertain these figures, it would be required to draw up the plans of a large combined nuclear power and desalination plant to be located in a Northern Europe region such as that around Bremen, Hamburg, Antwerp or Ghent.

  It is only within the framework of such a project that the position in the Northern part of the E.E.C. can be examined more thoroughly, especially in its technical and economical aspects. This is furthermore very important for European development in these regions.

  Such a project can then be used as the framework for a first plant implementation in the Northern part of the E.E.C.

- The use of nuclear energy will be precisely suitable in the large capacity range soon required in that fast developing region of the Northern part of the E.E.C., to cope with the corresponding demographic and industrial expansion.

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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