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MODERNIZATION AND MECHANIZATION OF SALT INDUSTRIES BASED ON SEAWATER IN DEVELOPING COUNTRIES

Proceedings of Expert Group Meeting

Rome, 25 - 29 September 1968

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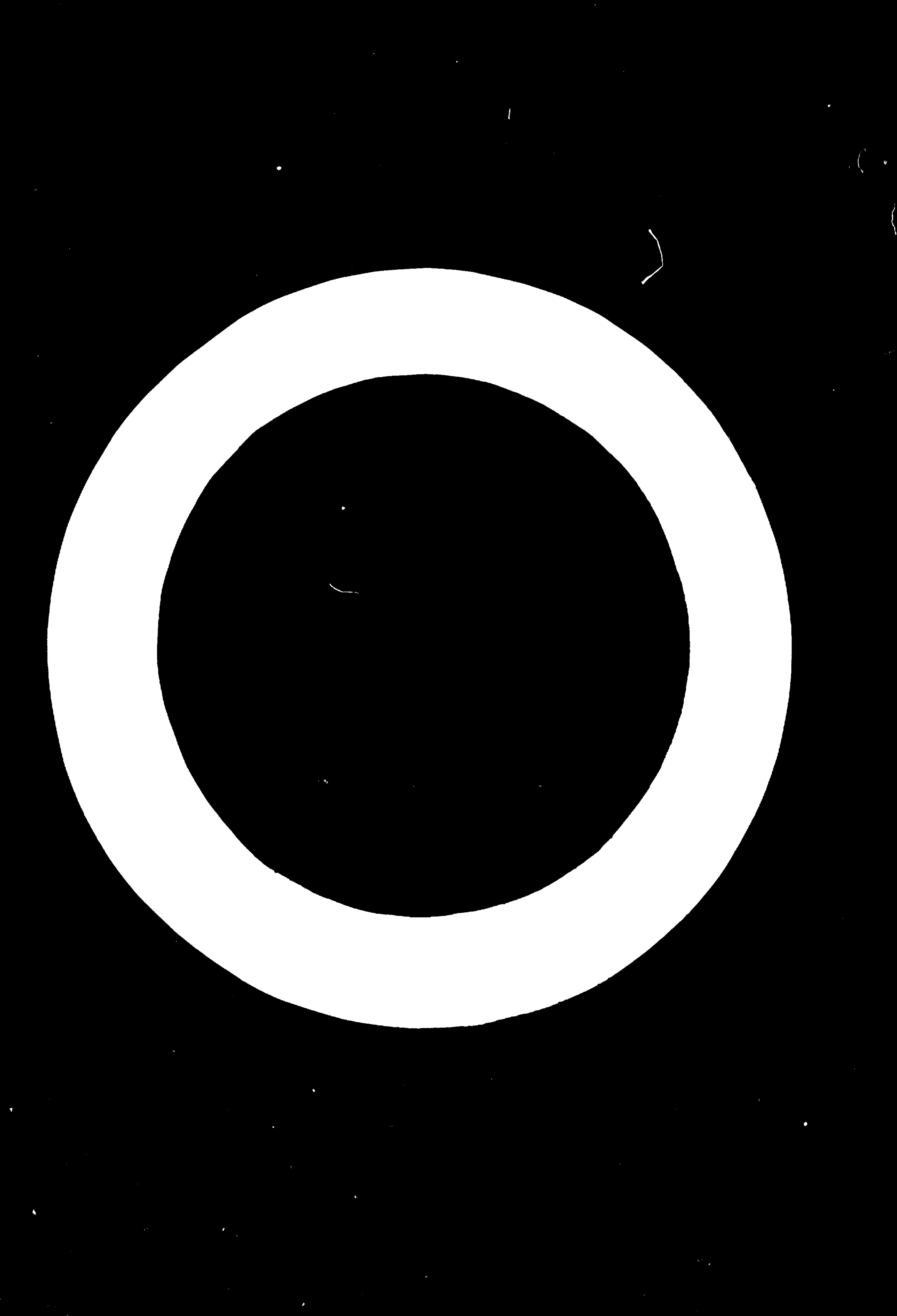

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Contents

Explanatory notes

A slash (/) represents the word "per".

Dollars ($) refers to US dollars unless otherwise specified.

40 Peruvian sols were equivalent to 1 US dollar in 1969.

Units and conversion factors

1 inch (in) = 2.540 centimetres (cm)

1 foot (ft) = 30.48 cm

1 mile = 1.6093 kilometres (km)

1 acre = 0.4047 hectare = 4,047 square metres

1 imperial gallon = 4.545 litres

1 US gallon = 3.785 litres

1 pound (lb) = 0.453 kilogram (kg)

Ton refers to metric ton of 1,000 kilograms (2,200 pounds), unless otherwise specified.

1 long (English) ton = 1.016 metric ton = 1,016 kg

1 short (US) ton = 2,000 lb = 0.910 metric ton

1 part per million (ppm) = 1 gram per metric ton

s.g. indicates specific gravity

^{o}Be = degrees Baumé (10^{o}Be = 10 per cent NaCl; 0^{o}Be = 0 per cent NaCl)

1 kVA = 1 kilovolt ampere

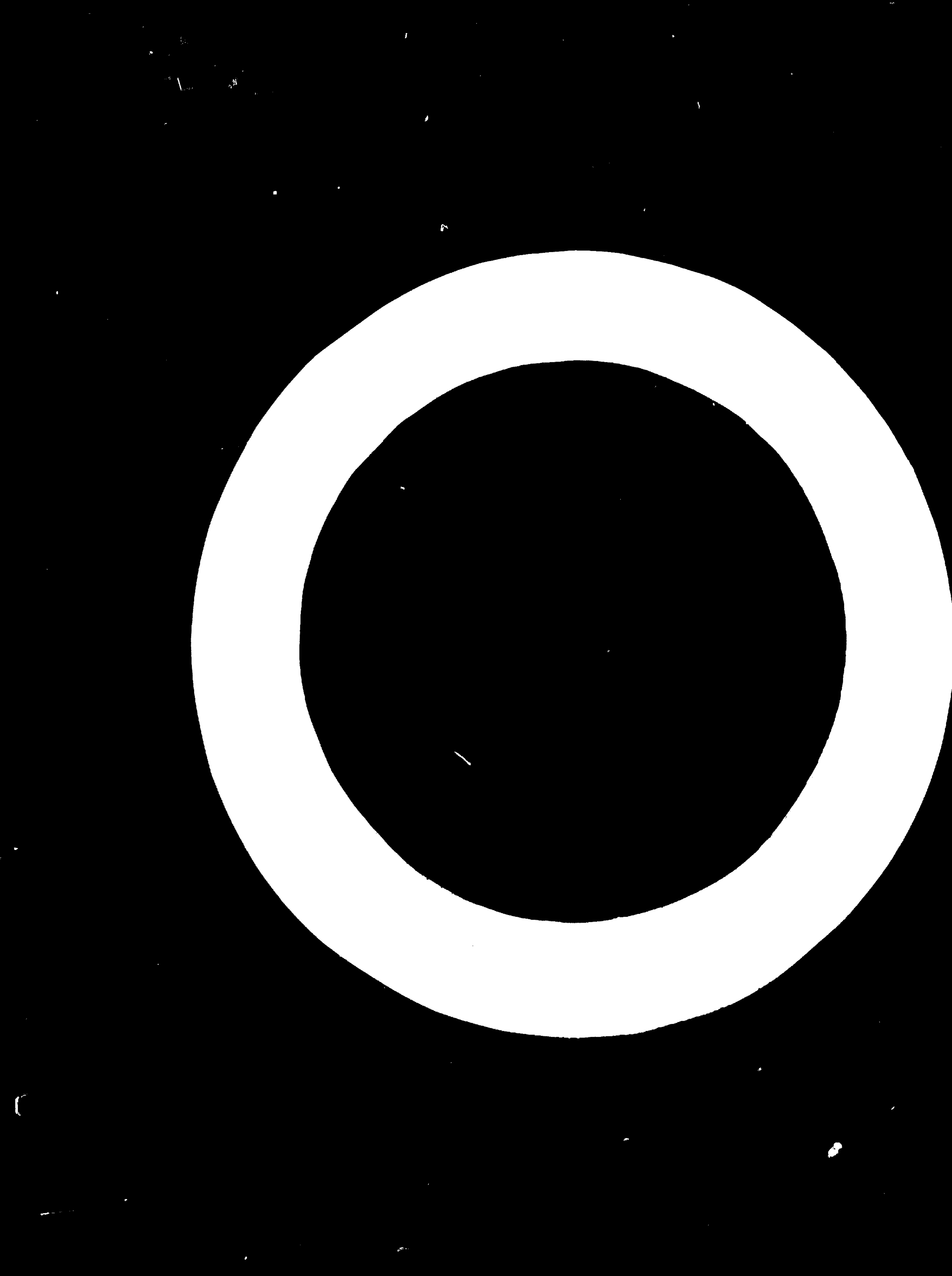
1 kWh = 1 kilowatt hour

1 horsepower (hp) = 0.746 kilowatts (kW)

Foreword

The nine papers included in this publication were written for an expert meeting on the modernization and mechanization of salt industries, held in Rome, Italy, from 25 to 29 September, 1968. With the exception of the first paper, by V. M. Bragagnini, they were prepared by consultants commissioned by UNIDO. Summaries of the papers were published in 1969 in the report of the meeting: Modernization and Mechanization of Salt Industries Based on Seawater in Developing Countries (ID/26). The report also included a summary of the conclusions and recommendations of the expert group.

The views and opinions expressed in the articles are those of the consultants and do not necessarily reflect the views of the Secretariat of the United Nations.



1. THE PERUVIAN SALT INDUSTRY

Victor M. Bragagnini A.*/

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Introduction

The present situation and future prospects of the Peruvian salt industry are outlined. Sea-saltworks and brine springs produce more than 90 per cent of the country's salt consumption. Rock-salt deposits in the mountain and forest areas of Peru are also large potential sources of supply, but owing to their remoteness from large population centres, inadequate communication and transport, and the steadily rising cost of extraction, many old rock-salt mines have been closed. It is doubtful whether their modernization and expansion will be feasible in the foreseeable future.

However, the outlook for the expansion of the coastal sea-salt industry is a different matter. Large deposits of salt in natural conditions favourable to solar-salt harvesting, the proximity of large urban centres, low freight rates and Government planning of improved port facilities indicate that this sector will soon be able to provide reliable sources of salt where modern refineries can be installed. It should then be possible to meet the entire Peruvian domestic and industrial demand and to develop salt exports.

The production of coarse salt in Peru has been sufficient to meet the demand, but refined salt of the standard required for human consumption is not produced in adequate quantity. The industry also does not satisfy the requirements for various types of salt used by the chemical industry; its demands have increased recently from 10 per cent of the total domestic and industrial consumption to more than 38 per cent.

The Peruvian Government has approved the installation of three modern salt-refining plants; two are on the coast and one in the mountains. Of course, these three plants must be an integral part of an over-all development scheme for the mechanization and modernization of the entire salt industry.

HISTORY AND LAW

All Peruvian salt production is controlled by the salt monopoly (Estanco de la Sal). This State agency is a subsidiary of the Peruvian National Bank. The Salt Monopoly is responsible for the production of an adequate supply of good-quality salt at a fair price for human consumption and as an industrial raw material.

When the Salt Monopoly was established in 1896, some salt deposits were owned and operated by private individuals or local communities, but the Salt Monopoly has always bought and marketed their salt. The Peruvian Government has exercised control and fixed moderate prices for table salt in areas lacking good transport facilities.

To promote industrial development and especially the growing demand for chemical products and derivatives based on salt, in 1957 the Peruvian Government enacted Law 12712 authorizing industrial concessions to harvest salt for use in basic industries of national importance. This law has been amended several times. A new set of regulations was enacted as Supreme Decree No.057-68-HC on 19 March 1968. Two concessions have been granted in the Huacho and Otuma salt deposits to Alcalis Peruanos S.A. and Química del Pacifico S.A. for use in the manufacture of caustic soda.

SALT CONSUMPTION IN PERU

Domestic and industrial salt consumption is given in table 1. Until 1959, the marketing of all salt was controlled by the Salt Monopoly, therefore the tonnage is accurate. The production and consumption of industrial salt by private concessions since 1959 are not included.

The data in table 1 below for the ten-year period 1957 to 1966 provide a basis for assessing the present position of the industry.

Table 1

Salt marketed by the Salt Monopoly in Peru
(tons)

Year	Domestic	Industrial	Total
1957	69,701	18,105	87,806
1958	71,629	18,925	90,554
1959	76,409	20,951	97,360
1960	81,441	21,358	102,799
1961	83,782	18,589	102,371
1962	92,357	17,537	109,894
1963	93,262	16,812	110,074
1964	95,517	15,217	110,734
1965	93,699	13,286	106,985
1966	101,541	7,167	108,708

In 1965, there was a drop in the consumption recorded by the Salt Monopoly because a private firm sold more than 10 million kg of salt to individuals and factories. Furthermore, 3.3 million and 4.3 million kg of special salt were imported in 1964 and 1965 for various industrial purposes but principally by the Southern Peru Copper Corporation for the treatment of copper ore in Department of Moquegua, southern Peru.

Since 1960, there has been an apparent decline in the consumption of industrial salt. This trend, which has become more marked in recent years, began in 1960, when concessionnaires began to harvest salt instead of buying it from the Salt Monopoly. The consumption figures for domestic salt also include salt used by industrial firms that prefer this type of salt despite its slightly higher price, because its quality is better or because it is crushed. Consequently, although the Peruvian domestic and industrial salt consumption remains approximately constant each year, the sale of industrial salt is decreasing sharply.

Salt classification

It should be noted that the Salt Monopoly classifies salt in its statistics only as domestic or industrial. Almost all salt is supplied in its natural form as rock salt from mines or granular salt from evaporation ponds. It is generally not processed because of the absence of washing and refining plants, although the Institute for Technical Standards and Certification (Instituto de Normas Técnicas y Certificación: INANTIC) issued a system of specifications and grades for domestic and industrial salt in June 1966. These specifications provide for the compulsory iodization of table salt as prescribed by Law 9188 in support of the endemic goitre campaign sponsored by the Ministry of Public Health and Social Insurance.

An increasing proportion of solar salt is now given a modicum of processing by milling or grinding. It is used as cooking salt; small quantities are iodized for distribution to areas where goitre is prevalent.

The 101,541 tons of domestic salt sold in Peru in 1966 can be divided into the following classes: granular (solar or rock) 67,452 tons; crushed (granular) 30,610 tons; improved (iodized) 1,617 tons and refined (table salt) 1,862 tons. But 9,169 tons of the total domestic consumption were used in industry.

Present consumption of domestic and industrial salt

Domestic salt. The yearly per capita consumption of domestic salt in Peru averages 7.69 kg. Consequently, as the population of Peru is about 12 million inhabitants, the supply of domestic salt does not at present exceed 96 million kg per annum, but the rate of population growth is approximately 2.8 per cent per annum. Regardless of increased efforts to produce refined salt to specifications, the limits imposed by the fixed per capita level of domestic salt consumption cannot be exceeded unless the export of salt is developed.

The consumption of cooking salt (ground salt) is constantly increasing, although its quality is very similar to that of common solar salt in its natural state; it is merely ground in hammer mills. The resulting grains are small and uneven. The salt is not dried or screened, but it is suitable for domestic consumption in the absence of refined or washed salt.

The only appropriate type of table salt, which is also being used temporarily in the food-processing industry, is the refined salt produced at the small thermo-compression plant built in Lima in 1954 which has an average daily output of only 6 tons. The consumption figures in table 2 do not show the demand for this type of salt, because production is at present totally inadequate to meet demand. All salt for domestic consumption should be refined or, at any rate, washed and screened. Consumption of this kind of salt could then rise to the estimated total demand for domestic salt of 90,000 tons per annum.

Table 2

Sales of refined salt in Peru
(tons)

Year	Lima and Callao	Elsewhere in Peru	Total
1958	1,522	424	1,946
1959	1,358	34	1,392
1960	1,419	113	1,532
1961	1,869	193	2,062
1962	1,686	24	1,710
1963	1,743	4	1,747
1964	1,965	-	1,965
1965	1,173	-	1,173

The small output of the thermo-compression plant is consumed entirely in Lima, which has a population exceeding 2 million. Although commercial firms and supermarkets have imported refined salt to augment the supply, the demand is not completely satisfied.

Industrial salt. In the developed countries the industrial sector uses 90 per cent of the total salt production, but in Peru most salt is consumed domestically. Between 1896 and 1900, the ratio of domestic to industrial consumption was 59 to 41 per cent. In 1966, however, it was 85 and 15 per cent; although the increase in total consumption had been considerable, the industrial use of salt had not risen proportionally. It is hoped that it will increase with the establishment of new industry. One of the growing industries in Peru which depends on salt is caustic soda manufacture for paper and polyvinyl chloride production. Private firms have invested $15 to $16 million in this industry; $6 to $7 million have been invested in a new project for manufacturing paper in the forest region.

About 40,000 tons of industrial salt are produced annually by two concessionaire firms for their own use primarily in the manufacture of caustic soda and its derivatives. The Salt Monopoly marketed another 16,336 tons. Therefore, the total consumption of industrial salt is 56,336 tons; the ratio of domestic to industrial consumption is 62 to 38 per cent.

There is also a project for the refining and flotation processing of minerals which is designed to replace all imported reagents. This project will cost $16 million and will require approximately 30,000 tons of high-purity salt per annum at a very low price and also hydrochloric acid produced from salt by electrochemical plants.

Another project for the manufacture of sodium carbonate should replace 30,000 tons of imports per annum. The cost will be approximately $10 million for a plant with a capacity of 100 tons/day; the annual saving in foreign exchange would be about $2 million.

The special use of salt in road building to stabilize soil with a mixture of gravel, sand, gypsum or lime could be feasible in the arid areas on the Peruvian coast with many salt deposits. Unlike other materials such as asphalt and cement, salt is cheap, easy to use and readily available. However, the process has yet to be tried.

The problem of supplying domestic salt in the required quality and quantity is insignificant compared with the importance and implications of the salt industry's expansion in complementing general economic growth. In addition to the national benefits from these investments, there is the equally important factor of the employment created by the building, equipping and operation of these industrial plants.

Consumption forecasts for 1972

On the basis of the 3.66 per cent growth rate in salt consumption recorded for the period 1956 to 1962, the Peruvian consumption of different types of salt is estimated at 223,000 tons in 1972:

	tons
Domestic salt	124,800
Industrial salt produced by the Salt Monopoly	40,200
Industrial salt produced by concessionaires	58,000
Total	223,000

An additional consumption of 180,000 tons by the industrial projects previously mentioned increases the total projected demand in 1972 to 403,300 tons:

Table 3

Projected demand for salt in 1972

(tons)

	Southern area	Central area	Northern area	Total
Domestic salt	26,300	59,000	39,200	124,800
Industrial salt produced by the Salt Monopoly	14,300	98,800	6,400	119,500
Industrial salt produced by concessionaires		134,000		134,000
Industrial salt for special uses (including animal husbandry)	4,500	17,000	3,500	25,000
Total	45,100	308,800	49,100	403,300

These figures are conservative estimates. It would be technically advisable to establish three salt production centres; each should contain harvesting facilities and a refining plant.

RESOURCES FOR SALT PRODUCTION

The salt resources of Peru include sea salt, rock salt and salt from brine springs. When the Salt Monopoly assumed the responsibility for salt production, there were more than 166 saltworks throughout the country. Many unsurveyed deposits are in the Peruvian desert.

The construction of roads in the interior has made it possible for many areas to receive salt from the coast or from the larger saltworks. Some saltworks that were close to towns are now uneconomic. The Salt Monopoly has therefore reduced the number of saltworks by closing about 134 and limiting operations to large saltworks. Peru now has 25 saltworks including eight sea-saltworks, eleven rock-salt mines and six brine springs. Four other saltworks operate during the summer months only; another three are leased to private individuals for the supply of salt to small communities to prevent the clandestine exploitation of nearby deposits.

Sea salt

Salt beds have been formed by seawater close to the surface of beaches. The subsurface brine retained by sandstone and other porous rocks is probably from captive seawater, but much brine is formed by the dissolution of salt layers from previous eras. Almost all the saltworks on the Peruvian coast have salt beds of this type except the Puite rock-salt deposits.

The sea-saltworks are of prime interest both because they can be easily worked and because they have large reserves. They now provide 83 per cent of the output of domestic salt: in 1966, there were 93,330 tons of sea salt in the total output of 111,721 tons of domestic salt. The sea-saltworks also produce half of Peru's industrial salt.

In the northern area of Peru are situated the Colán, Negritos and Las Garzas saltworks, those of the Sechura Group (Zapayal, García and El Cerro), and the Cañacmac, Casma and Guadalupito saltworks. There are also some small saltworks in the Department of Tumbes, such as those at Palo Santo, Bocapán and El Abejal, which operate seasonally. Salt crystallizes in small lagoons during the summer months; the output is low and fills only a small proportion of local needs during the harvest months.

A standard example of a barrier-type saltworks is the Colán saltworks (in Department of Piura) which is situated 100 to 120 m inland. A natural sandbank or dike creates a small lagoon parallel to the shore line for approximately

1.5 km, where salt crystallizes. There is an opening in the sandbank through which seawater enters the lagoon. The present production at Colán is not very large, but the site would lend itself to the construction of artificial ponds giving a much higher yield of solar salt.

The Sechura Group now comprises the Zapayal, García and El Cerro saltworks, although previously there were many other saltworks in the Sechura desert. The Sechura Group and the Cañacmac saltworks, Department of Lambayeque, form together the largest salt reserves in the whole country. It is located within the Sechura desert area between the Departments of Piura and Lamabayeque; it covers more than 1 million hectares and extends from the District of Sechura, Piura to the District of Móroppe, Lambayeque.

The Compañía Bayovar S.A., which holds concessions for phosphate production in the Sechura desert, believes that the solar evaporation of subterranean brines to obtain potassium chloride would also yield 70 per cent of common salt or an annual output of 4 million tons which is 30 times the total salt consumption of Peru. At present, the Salt Monopoly only produces enough salt from these saltworks to supply the northern departments; in 1966, the output of the Sechura Group was 7,913 tons and that of the Cañacmac saltworks 16,241 tons. If the Compañía Bayovar project was implemented, the by-product salt would enable large-scale salt exports if docks, inexpensive marine transport and good desert roads were available.

If the Compañía Bayovar project does not materialize, the Virrillá estuary near the García and Zapayal salt deposits is an ideal site for solar evaporation plants. It has an area of 1,400 hectares and conditions such as natural creeks permitting the inflow of seawater, the desert climate of constant sunshine and heat in every season and the absence of rain and strong winds that are particularly favourable to pond crystallization. There are stratified salt deposits to facilitate saturation of the brine.

At present, the Salt Monopoly's operations are limited to harvesting granular salt which crystallizes naturally in lagoons in the Virrillá estuary. In the Zapayal and El Cerro saltworks, salt blocks are cut with axes from the beds of rock salt. This type of industrial salt is popular in animal husbandry, where it is used instead of manufactured blocks, especially in areas bordering on Ecuador.

The main production difficulties are the lack of good communications and the distance from consumer centres. The Zapayal saltworks are about 100 km from the city of Piura and 60 km of this distance is desert tracks; a truck takes more than 4 hours to reach Piura. The El Cerro saltworks are more distant; the travelling time is 6 hours. Similarly, the Cañacmac saltworks are 70 km from the District of Mórrope; lorry transport takes more than 7 hours by road and sand track. These disadvantages make the salt considerably more expensive, since the freight rate from Cañacmac to Lambayeque is more than 100 sol/ton and from Zapayal to Piura 76 sol/ton. The freight charges are offset by the ease with which the salt is produced. It occurs in beds 15 to 20 cm thick covered by approximately 30 cm of sand; the harvesting of salt is simply removing the sand, breaking the salt with picks and crowbars, and packing the pieces of salt for dispatch. The relatively low cost of this simple operation counterbalances the high transport costs.

Finally, the northern area's salt resources include the Guadalupito and Casma saltworks. The former was a private concern before the Salt Monopoly was established and belongs to the Negociación Agrícola Guadalupito S.A.; until 1965 the Salt Monopoly purchased and marketed the entire output. But recently under Law 12712, the company has marketed salt (principally to the fishing industry around Chimbote). Therefore its production is not included in the statistics of the Salt Monopoly.

The central area of the country includes the departments of Ancash, Huánuco, Junín, Cerro de Pasco, Ayacucho, Huancavelica, Ica and Lima. In 1966, the Salt Monopoly sold 56,917 tons of salt (56 per cent of the total domestic consumption) in this area. These figures do not include the production of private industrial firms, which in 1966 was about 40,000 tons. This area is not only the most densely populated but also has the highest per capita salt consumption, which exceeds 10 kg in Lima and Callao.

Fortunately, the central area has two large sources of supply: the Huacho and the Otuma saltworks near Lima. The Pan-American Highway, which is the main Peruvian road, runs down the coast; in the interior there is another first-class road and the Peruvian Central Railway. These saltworks also supply departments in the northern and southern areas. Of the 88,625 tons of salt produced by sea-saltworks, 51,785 tons have been harvested in Huacho.

The Huacho saltworks has two slight advantages over Otuma: the cost of transport to Lima and Callao is 60 sol/ton, whereas the journey from Otuma to Lima is 285 km, and the cost is 120 sol; furthermore, Huacho salt can be marketed directly in the large population centres.

Georg Petersen investigated the Huacho saltworks for Alcalis Peruanos S.A. He reported that these saltworks have sizable potential reserves and that conditions and facilities are favourable for immediate development to increase production. According to the report, there are 45 million m^3 of concentrated brine, 12 million metric tons of dissolved salt and 45,265,500 tons of rock salt.

The Otuma saltworks has a high output which is aided by the dry, warm climate which prevails almost all the year. Each pond is harvested at 30-day intervals; the average yield is 50 to 60 kg/m^2. The present ponds are only 20 by 30 metres in size, but Otuma had the third largest production in 1966 with an output of 9,117 tons; it was marketed mainly in the southern area of the country, but consignments are occasionally sent to Lima.

Química del Pacifico S.A. also holds a concession of 54 hectares in the Otuma saltworks, where three 4,000 m^2 ponds have been dug. The production method resembles that of the Salt Monopoly but it is mechanized with a tractor and rake which scrapes up the salt and deposits it in heaps. It is then taken to the caustic soda plant in Callao for a light washing.

The reserves at Otuma are sufficient for an annual production exceeding 100,000 tons. It would be economic to introduce a system of pond evaporation supplied with deep brine by pumps and to install washing facilities. Perhaps the only problem is that sand particles blown into the ponds by the wind are present in the salt crystals.

In the southern area, there are virtually no sea-saltworks. The 1966 local consumption of 10,836 tons was met by consignments from Otuma, the Pichu-Pichu brine springs and minor rock-salt deposits.

Brine springs

There are many springs in the sierra and forest areas which contain brine at 20°Be. Small amounts of brine were formerly evaporated in copper pans over wood fires in the northern forest area in the Department of San Martín. These springs are no longer operated commercially, but in remote villages brine from these springs are used directly in cooking.

All the brine springs of the Salt Monopoly are in the southern area: Maras and San Sebastián, Department of Cuzco; Napa, Tiquillaca, Muni and Azángaro, Department of Puno; and Pichu-Pichu, Department of Arequipa. Only Maras, Azángaro and Pichu-Pichu have large outputs.

The Maras saltworks are 2,750 m above sea level in the Province of Urubamba, Department of Cuzco and are 45 km from Cuzco by a first-class road. There are about 5,000 small ponds of varying size (the average size is 4 m^2). The annual production of approximately 2,000 tons (1,523 tons of domestic and industrial salt in 1966) is by solar evaporation during the rainless months from June to November. The 20°Be brine which emerges in the upper part of a small ravine is collected in small ditches and channelled to the tiered ponds. The rate of brine flow is approximately 100 litres/minute throughout the year. About 40 m below the first brine outflow point, there is another spring a few metres from the stream bed. Although its rate of flow is 120 litres/minute, it is not used because the surrounding ground is level and is therefore unsuitable for building evaporation ponds. One solution would be to pump the brine up to the upper outflow point, but the Salt Monopoly has not deemed it advantageous to do this yet. Since the flow from these two points is 220 litres/minute of brine at 20°Be, it can be estimated that even with a simple evaporator an output of approximately 30 tons/24 hours or 9,000 tons/year could be obtained. This production would meet present consumption in the Departments of Apurímac, Cuzco, Puno and even Arequipa, although the first three towns alone have a potential market for 12,000 tons a year.

In fact, the salt which could be produced at Maras by forced evaporation would replace the granular salt now used: it would be a better-quality table salt provided that it were refined. The granular or coarse salt now produced at Maras is of poor quality because it contains clay from the pond bottoms.

The Salt Monopoly has a project for a plant to produce 20,000 tons/year using the two existing outflow points of the springs. Extraction from the underlaying rock-salt layers would be too expensive because the strata are very deep and irregular.

The saltworks at the lagoon of Azángaro are 3,800 m above sea level and and supply all of the Department of Puno and parts of the Departments of Cuzco and Apurímac. The possibility to stabilize production by mechanical means and thus avoid the reduced production during years of heavy rainfall should be studied.

The Pichu-Pichu saltworks are 4,300 m above sea level in the Department of Arequipa and are similar to the beach deposits. The salt mixed with borax, potash and other chemical substances occur in the dried lake bed as surface deposits which are precipitated each year when the rains dry. Until recently, the concession to extract borax from the lake was granted to Borax Consolidated S.A., which worked them only sporadically. However, the Salt Monopoly retained the salt rights.

In some parts of the lake, crystallized borax predominates, while in others salt predominates. The salt is swept into small heaps between June and October when there is no rain. Then it is transported by mule to the storage depots and by lorry to the city of Arequipa.

The production of Pichu-Pichu is naturally determined by climate; in years of scanty rainfall output has exceeded 3,000 tons. In 1966, however, production was only 318 tons. The salt layers are only a few centimetres thick, but they extend over the entire lake bed; underneath them is a layer of soft mud which prevents the use of motor vehicles.

The installation of a refinery or equipment designed to increase production is not feasible: there is no possibility to improve the brine saturation process by installing a source of supply and thus ensure continuous production throughout the year; furthermore the salt contains borax and potash impurities which detract from its quality. The most practical solution might be to develop a washing plant provided that the cost was not out of proportion to the potential productions.

METHODS OF SALT PRODUCTION

Survey of the general development

In view of its advantages in the production and marketing of salt and the large area of many saltworks, the Salt Monopoly has undoubtedly lagged in the modernization of extraction techniques and the introduction of new methods of refining, particularly in the production of table salt. The unsuccessful efforts of the Salt Monopoly to obtain the allocation of development funds have prevented planning the modernization of its production methods. The annual budget estimates for the Salt Monopoly only cover current operating expenses of personnel, materials and tools; there are no provisions for an effective expansion programme for the industry, which still operates with primitive and antiquated methods. Of the 25 saltworks under the administration of the Salt Monopoly, only at the Huacho saltworks is there a modicum of mechanization. In all other saltworks, picks, shovels and wheelbarrows are still used for harvesting salt. The partial use of mechanical equipment for harvesting and transport in the larger saltworks would reduce the present labour force by 75 per cent and consequently achieve a substantial reduction in production costs.

Until 1930, all refined table salt was imported from England and Germany at considerable cost and with a consequent drain on the country's foreign exchange resources. In 1930, a refining plant with an approximate daily output of 4 tons was established, but its production was halted in 1954. This plant operated on the vacuum evaporation system and was equipped with a small vacuum pan that was not adapted for continuous operation. The poor-quality salt produced in this plant was marketed in Lima.

A small mill installed at the Huacho saltworks in 1928 is still in operation. This plant has been extended by the installation of two further mills and provides ground salt mainly for Lima and neighbouring towns. The salt produced is not of good quality because of its irregular grain size; it is neither screened, washed nor dried.

In 1956, the Ministry of Health operated seven salt-iodization plants as part of its campaign against goitre which is prevalent in certain areas of the country. The plant is basically a hammer mill driven by a Lister 24 hp engine and a hand-operated mixer. They were installed at the Yurumarca and Huacho saltworks and in the cities of Ayacucho, Chimbote, Huaraz, Cuzco and Rodriguez de Mendoza. The salt was ground and mixed with a potassium iodate and bicarbonate of soda. The resulting ground salt was unsatisfactory for human consumption because most of the rock salt contained a considerable amount of clay impurities. Therefore, the production was discontinued and only sea salt was iodized. In 1963, these plants came under the authority and control of the Salt Monopoly. Iodized salt is now produced only at the Huacho and Cañacmac saltworks and in the city of Cuzco for distribution to areas where goitre is common.

In 1962 and 1963, two complete crushing plants with daily capacities of 1.5 and 2 tons were installed at the Puite and Cañacmac saltworks by Standard-Messe, Düsseldorf. They include a hammer crusher, a Condux prong mill, and an elevator and hoppers. Good milling is achieved, particularly with the salt produced at the Puite saltworks, which is at present used as table salt.

In 1954, a new salt refining plant was set up in Lima. This plant, which represents the first step in modernization of the salt industry, was constructed by Salt Chemical, Inc., New York. It has a rated capacity of 22 tons/24 hours of operation. The salt is refined by the thermo-compression system, in which the vapour from a single-action evaporating vessel is recompressed in a closed circuit. Here a blower driven by a Caterpillar diesel engine raises the pressure from 1 to 2 atmospheres. The plant is automatically controlled by electric motors from a single central control panel. Mechanical equipment introduces measured quantities of additives, such as iodine or magnesium carbonate, and also packs the salt in cartons. Initially the plant was equipped with two 60 kW Murphy electric generating sets, which were operated alternately, but later these sets were superseded when industrial electric power was supplied from the State network.

Due to mechanical shortcomings in its installation, lack of experience in its operation and above all failure to take account of the available raw material, the daily output of this plant has averaged only 6 to 7 tons, which is far below its rated capacity. Its output has consequently been insufficient to satisfy the demands for which it was established. Even 14 years after its establishment, the operation was precarious.

The above developments are the only attempts to mechanize some aspects of the salt industry, and in substance the production methods of the saltworks remain old-fashioned.

Harvesting sea salt at Otuma and Huacho

The methods of extracting salt from seawater are generally similar; the only difference is at the Cañacmac and Sechura saltworks, where salt beds are mined and there is no attempt to crystallize salt in ponds. Only the Huacho saltworks has any mechanization; there the salt is transported from the ponds to the storage areas in small wagons hauled by diesel locomotives on a Decauville narrow-gauge railway.

The three salt deposits of greatest present potential are those at Otuma, Huacho and in the Sechura group. In view of the importance of these deposits and the fact that they are of different types, the harvesting methods will be discussed.

The salt resources at the Otuma saltworks in the Department of Ica consist of saturated brine which remains at a constant level less than 30 cm below the ground surface. The salt ponds are excavated in the lowest places below the permanent level of the brine, and natural infiltration keeps the ponds constantly full of brine. Therefore solar-salt production is continuous throughout the year. At the Huacho saltworks in the centre of the country, the brine level is lower and varies with the season. Water from the seasonal rains flows from the surrounding high mountains through the permeable ground into the basin where the Huacho saltworks are located. This water becomes mixed with the residual brine of the basin and rises close to the surface of the basin.

The salt ponds at Huacho are approximately 1.20 m below the ground level. Infiltration during the heavy rains, usually from January to March, fills the ponds with weak brine to a depth of 50 to 70 cm. Solar evaporation brings the brine to the saturation point; then salt begins to be precipitated out. This process continues until the brine depth is 5 to 10 cm. The variation in the brine level makes the operation intermittent and consequently gives a lower volume of production than when the brine level is constant. The inflow of fresh water results in a fall in the specific gravity of the brine; therefore production is low in years of heavy rainfall.

Although the salt from Cañacmac and Sechura in the north of the country is called sea salt, it is not extracted by the normal system of solar evaporation but from beds in the subsoil. A thin overlying layer of sand is removed, and the compact bed of salt is then cut into blocks or lumps which are either crushed into ground salt or sold in the form of lump or rock salt.

Salt is extracted manually with crowbars, picks and shovels at the Otuma, Huacho and Sechura saltworks. The workers generally stand in the salt ponds during the extraction and primary washing of the granular salt and wear rubber boots for protection against the brine in the ponds. In most of the sea-saltworks, payment is by piece work; a fixed amount is paid for a unit (wagon-load or wooden skipload) of previously established weight. A daily wage is paid for other work such as transport and crushing.

<u>The Salt Monopoly's Otuma saltworks</u>

At the Salt Monopoly's Otuma saltworks, evaporation is continuous throughout the year; the salt is harvested once a month during the dry season and every 30 to 50 days during the rainy winter season. The harvesting of the salt is continuous because in a longer interim between harvests, the brine below the surface of the salt would evaporate. The salt would then harden, and its harvest would be more difficult.

Both domestic and industrial salt are produced. Domestic salt is washed in the natural brine pond when it is harvested. This first washing of the crude salt gives clear, white salt. Industrial salt is sandy, because it is produced in ponds which are highly contaminated with sand after the windy season. This sand cannot easily be extracted by the single-washing method used at present. Of the 10,133 tons produced by the Salt Monopoly at Otuma in 1966, approximately 10 per cent was industrial. The crude salt has a fine crystal structure with an average grain size of approximately 5 mm. Since there are no processing facilities at Otuma, all the salt is bagged unrefined and transported to the stockpiles. The salt ponds are approximately 60 to 80 m long and from 7 to 9 m wide; they are spaced about 20 m apart in order to facilitate piling, storage and access. The narrow width of the ponds enables the workers to collect the accumulated salt from the pond bottoms by shovels. The Otuma saltworks are approximately 45 km from the Pan-American Highway; it is connected to the highway at a point 5 km north of Pisco by 28 km of asphalt roads and 17 km of improved dirt roads.

The Salt Monopoly's Huacho saltworks

Sea salt is produced seasonally at the Huacho saltworks because the brine level fluctuates; it rises in winter because of seepage of rain water and falls in summer by evaporation during the dry season. The brine level in the ponds rises from January to March; the seepage of brine into the ponds is supplemented by the admission of brine through channels from adjacent lagoons.

Early in the season, the brine which has been diluted by rain seepage has low salinity. It is not possible to produce salt until evaporation has concentrated the brine to the saturation point and the precipitation of salt begins. As soon as evaporation reduces the brine level, the ponds are dry and the salt can be harvested. The salt is in a hard crust; its thickness varies depending on the period of seasonal evaporation. This crust is broken with picks and crowbars into crystals or small clods, piled into heaps and then loaded into skips from which it is emptied into stockpiles around the ponds or loaded into 750 kg mine trucks and transported over a Decauville narrow-gauge railway by diesel locomotive to the storage centre to be crushed. All the work of harvesting is done by contractual labour.

The salt ponds vary in shape and area; many of them are in scattered groups, and the possibility of modernizing these saltworks is limited at the moment to the two largest groups of ponds. It does not appear feasible to integrate the many separate ponds into a properly controlled and regulated system of solar-evaporation ponds where maximum output and purity could be obtained.

Production is not steady because there are periods when the ponds contain brine of low salinity and because of the fluctuation in the natural brine levels. The average production is only 50 per cent of the possible yield. The pumping of saturated brine from drilled brine wells to supply brine throughout the year should double the present production of salt. The salt is collected annually or in some areas bi-annually, depending on the depth of the deposits. The crystals of this granular salt are 2 cm in diameter.

The purest crude salt produced is marketed as domestic salt; salt with an appreciable contamination of sand is marketed as industrial salt. Approximately 3 per cent of the 54,871 tons produced at the Salt Monopoly's Huacho saltworks was industrial salt. A small section of the deepest deposits near the edge of the ponds is cut into square pieces and sold as block salt for livestock.

Most of the output of both industrial and domestic granular salt is bagged and packed for transport and distribution to the various stockpiles around the salt ponds. The central stockpiles supply the salt-milling plant where fine-grained ground salt is produced. Granular salt is sold in 80 kg jute sacks, while ground salt is sold in 50 kg calico sacks.

Alcalis Peruanos S.A. at the Huacho saltworks

The Alcalis Peruanos S.A. (Peruvian Alkalis) concessions at Huacho have a very well-designed system of twelve ponds laid out in four series of three ponds with channels for the movement of the brine and for filling and emptying the ponds. Salt wells and pumps provide a constant supply of brine, so that the brine level in the ponds is constant throughout the year. The ponds can be emptied to harvest the salt at any time. Transport is by lorries that drive between the ponds for easier loading with a minimum of manual labour. Mechanized harvesting and loading are now being considered. The 270 kg/m^2 output of the salt ponds is approximately double the average 150 kg/m^2 output of the adjacent ponds belonging to the Salt Monopoly. Work is at present being carried out to double the area of the ponds.

Harvesting of salt at the brine springs

The seven brine-spring saltworks at present in operation are at Pichu-Pichu, Department of Arequipa; Azángaro, Ñapo, Muni and Tiquillaca, Department of Puno; and those at Maras and San Sebastián, Department of Cuzco. They have been operated on the purchase system since the establishment of the Salt

Monopoly. In the purchase system, the holders of common land rights harvest the salt and sell it to the Salt Monopoly at a fixed price. The reason for this system is that the brine springs have been operated for many generations by the local people who owned them. Local conditions helped to maintain this system, for in all the saltworks except Pichu-Pichu, the salt is crystallized in small man-made ponds that are waterproofed with clay; in Pichu-Pichu, however, crystallization occurs in the bed of the completely dry lagoon. The crystallization of salt takes place at various times of the year, but generally from April to October in the dry season. The heavy rains destroy the ponds, and consequently new ones must be dug in the dry season.

The small ponds, some of which are not even 4 m^2 in area, are passed from father to son. There have been innumerable disputes and litigation between families over their ownership. At the Azángaro salt deposits, an individual or family holding common ground rights is assigned a strip of land which runs from the edge of the lagoon to a post in the centre of the salt producing area.

The direct operation of these saltworks by the Salt Monopoly on the basis of day labour would at present be extremely risky and could be ineffective. It would be necessary, first of all, to maintain the whole labour force throughout the year, and extremely strict supervision would be needed to obtain a good output of salt and to ensure the proper maintenance and preservation of the ponds. Moreover, salt production could not be mechanized sufficiently to reduce costs. At Maras, the small ponds are constructed on a slope where machinery cannot be used and large ponds cannot be built. At Azángaro and Pichu-Pichu, even though the lagoons are large and the former has a considerable output of salt, their irregular layout would permit neither the construction of permanent ponds nor the mechanization of salt harvesting. Therefore the purchase system is appropriate although archaic because at least it satisfies local demand and produces industrial salt.

The spring in the Maras saltworks with two outflow points is the only brine spring with any possibility for modernised salt production.

PRODUCTION AND MARKETING COSTS

Production

The over-all gross receipts from the operations of the Salt Monopoly in 1965 were 73,794,623 sol from the sale of 108,708 tons of domestic and industrial salt and jute sacks:

	Weight (tons)	Value (sol)
Domestic salt		
Granular	67,450	40,239,206
Ground	30,611	18,387,705
Iodized	1,617	1,206,325
Table salt	1,863	3,725,990
Industrial salt	7,167	1,435,030
Packing material (jute sacks and calico bags)		8,800,367
Total		73,794,623

The total expenses were 65,913,362 sol; the net profit was 7,881,263 sol.

It must be borne in mind that the figures for the consumption of industrial salt recorded by the Salt Monopoly do not reflect its actual national consumption since there are private companies which hold concessions to harvest salt for their own and other industries. It is estimated that these concessionaires, who are not under the control of the Salt Monopoly, have an output larger than 40,000 tons of salt per annum.

The production costs are computed by adding the wages, the cost of materials and tools and extra expenses such as social security payments. Table 4 shows the harvesting and total production costs for 100 kg of salt.

The transport and administrative costs must be added to the production costs to give the total costs of placing the salt on sale at a given depot. Such figures also show the high incidence of transport costs for each depot and the way in which the transport costs considerably exceed the value of the salt itself particularly for depots in the interior of the country; for example, for the depots of Rodriquez de Mendoza, Puerto Maldonado and Iberia, the percentages of the total costs accounted for by transport are 87.13, 89.80 and 92.46 per cent, respectively. The lowest transport costs are recorded at the Locumba depot, where only 5.16 per cent of the cost of the salt from Puite is transport costs due to the proximity of the saltworks to the depot. There is an enormous difference at many depots between the sales price and the total cost of the salt. To avoid a high sales price, the Salt Monopoly tries to subsidize the most expensive salt with the higher profits obtained from the saltworks with easy access, such as those on the coast. It has therefore been a social service of the Salt Monopoly to sell salt at less than actual cost in areas which are difficult to supply.

Table 4

Costs of harvesting salt from seawater and from brine springs (sol/100 kg)

	Harvesting cost	Total production cost
Sea salt		
Huacho	1.32	8.24
Cañacmac	4.77	8.15
Otuma	1.63	7.09
Grupo Sechura	5.10	8.69
Las Garzas	1.75	34.97
Colán	1.61	34.83
Casma	2.93	47.39
Grupo Negritos	7.76	35.89
Brine springs		
Pichu-Pichu	10.00	61.70
Maras	11.31	31.63
Ñapa	15.00	43.41
San Sebastían	10.00	46.79
Tiquillaca	11.38	37.95
Azángaro	15.00	21.68
Muni	10.00	53.21

The annual costs of production and marketing by the Salt Monopoly can be itemised:

	Per cent
Salaries and allowances of regular staff	30
Wages of day labourers	16
Materials and raw materials (purchases of salt)	17
Transport	30
Other expenses	7
	100

Marketing

The marketing of salt, which includes its transport, distribution and sale, is perhaps the most important work of the Salt Monopoly.

The production centres dispatch the salt to the main depots or stores which then send it to depots in the provinces and smaller towns. As the Salt Monopoly is now a part of the Department of Tax Collection of the National Bank, the operation of the saltworks and the sale of salt at the depots are supervised by each divisional office of the bank and the money received from sales is likewise paid into the cashier's department of each provincial or district branch of the Department of Tax Collection. Each saltwork and depot submits monthly accounts to the divisional office, which sends them to the Salt Monopoly's headquarters in Lima.

In 1966, salt was distributed through 141 depots and sold by more than 4,400 retail outlets or agents with special contracts which granted a commission of between 5 and 10 per cent of the sales. The costs of transporting the salt to the depots are paid by the Salt Monopoly.

Domestic salt is distributed in the following forms:

Granular salt in 60 to 80 kg jute sacks;

Ground salt in 50 kg packages or polyethylene-lined paper sacks (Polyclupack);

Table salt in 1 kg cartons.

Industrial salt is sold either in jute sacks or in bulk at the saltworks.

In 1966, the Salt Monopoly paid 17,373,695 sol for these shipment and reshipment operations using the following means of transport at an average cost of 13.75 sol/100 kg:

Means of transport	Transported salt (kg)	Transport cost/100 kg (sol)
Road	108,707,357	11.98
Rail	11,836,200	24.11
Beasts of burden	394,837	35.41
Water	2,078,059	36.44
Air	84,875	175.16
Total	123,101,328	Average 13.75

Although distances are considerable, unit transport costs are low because of the heavy movement of freight in areas where contractors can transport other freight from the place to which the salt is being dispatched. In other areas of lesser economic importance there is no return load; the transport costs are higher. Poor minor roads give difficult access to most salt production centres.

The weight of a consignment is increased by 1 to 5 per cent to allow for losses during transport and sales. If the salt is stored for more than one year, the weight is increased another 1 per cent; the storekeeper is usually responsible for losses above this figure.

Inadequate packaging is responsible for much of the loss during the sales process. There is also considerable loss during refining and also during transport because of inadequate loading systems.

The transportation services to the various depots is provided by contractors selected annually on the basis of tenders, except in special cases where transport is free.

The Salt Monopoly generally rents storage depots; many of them are small and inadequate. The premises at the saltworks, however, are built and owned by the Salt Monopoly. This system enables an annual stock to be maintained for initial supplies; on 31 December 1966 the saltworks and depots held stocks of 34,768 tons of domestic salt, 236 tons of industrial salt and 1,178,462 empty jute sacks. Salt stored at the depots in jute sacks or calico bags eliminates storage losses; but the sacks and bags are destroyed by humidity when the salt is stored for a considerable time. For the last few years, four-ply polyethylene-lined Polyclupack paper sacks have been used as containers for ground salt with marked success; these sacks are not returned by the consumer, and therefore their cost is included in the sales price of the salt.

The average sales price in 1966 in all of Peru was 0.63 sol/kg for domestic salt and 0.20 sol/kg for industrial salt. The maximum price was 2.50 sol/kg domestic salt at the depots at Iberia, Department of Madre de Dios and Rodriguez de Mendoza, Department of Amazonas and 0.50 sol/kg industrial salt at the depot at Cajamarca.

DEVELOPING AND MODERNIZING THE PERUVIAN SALT INDUSTRY

Large prospects exist in the north of the country for the production of large amounts of high-purity salt as a by-product in the extraction of phosphate and potash deposits. This production would satisfy not only current requirements and the estimates for 1972, but it would also supply a surplus for export. The 1,400-hectare natural dam of the Virrilla estuary retains enough brine for a salt production of 15 tons/m^2. The salt beds in the southern part of the

Virrillá estuary, which are even larger than those at the Cañacmac saltworks and which are in the same mineral deposits as the Sechura group, could be used either for immediate harvest or to saturate seawater and provide brine for crystallization ponds without the five- or six-year interval required under the normal system of salt production.

Various problems must be overcome in order to quickly develop this area economically. One of these problems is inadequate roads and consequently high transport costs; there is a considerable distance between these deposits and the consumption areas at Piura or Lambayeque. Another problem is contamination with sand. This difficulty is encountered in all the sea-salt production of the Salt Monopoly, but it is more apparent and more difficult to solve at the Sechura group and Cañacmac because of the strong winds from the desert. Perhaps the economic feasibility of covering the salt during production could be considered. Another unusual problem is the flooding of deposits located below sea level. The dilution of the concentrated brine in the estuary and the dissolving of the salt in the sedimentary deposits of Cañacmac would not represent a great loss but simply a delay in crystallization, because the underground reserves of salt would increase the salinity of the brine to the degree of saturation needed for salt production.

From the economic and commercial point of view, an important long-term problem is the lack of ports close to the saltworks. The solution to this problem is in the Government's projects for new ports and for the modernization of the port installations at Paita to permit bulk loading, which is at present only possible in the northern area at the port of Salavarry. The phosphates project of Compañia Bayovar also provides for the construction of a port in Bayovar Bay.

If the Virrillá projects for producing salt as a by-product of potassium chloride and phosphate extraction or for the production of salt by solar evaporation are not feasible, the future development there should be concentrated on harvesting the rock-salt deposits, which do not require a large investment either in digging ponds or in purchasing equipment.

The development of salt production in the central area must be limited at present to the saltworks at Huacho and Otuma, where the highly favourable climate and saturated brine are ideal for large-scale production. Transport is not difficult here where highways connect with the Pan-American Highway to Lima and other centres of consumption. There is sand in the crystallizing salt in the ponds and in the storage heaps, but this problem is less serious than at Sechura. Salt cannot be exported through the ports of Callao and Ilo at present, because they lack facilities to load large tonnages of salt at low cost. Implementation of the Government project to install the necessary equipment at Ilo for loading minerals would remove this difficulty.

The only possibility in the Department of Cuzco for expansion and industrialization is the Maras saltworks, where refined salt could be obtained by feeding the brine into a vacuum evaporation plant. There are no major transport or climatic problems here. The output would be sufficient to supply the local demand of the Departments of Apurímac, Cuzco and Puno, which is estimated to be 12,000 tons/year.

The projects for the development and modernization of the Peruvian salt industry should be put into effect immediately without prejudice to any subsequent decision to develop rock-salt deposits or other brine springs.

Each saltwork has its specific priority; however, studies, technical assistance, advice and instructions from persons and organizations with special experience in the salt industry provided through the co-operation of UNIDO could help to solve the technical and economic problems mentioned in this report, which can be summarized as follows.

Production of solar salt

A review of the solar-salt industry must be limited to the solar evaporation of sea salt, the harvesting of rock salt from existing sedimentary beds, or both operations together, particularly in the saltworks of the Sechura group and Cañacmac.

The brines in the northern saltworks and in the southern saltworks of Huacho and Otuma differ from the sea brine used for washing to produce highly purified salt. The salt from Sechura, Huacho and Otuma has an approximate sodium chloride content of 90 to 97 per cent, which is much lower than the 99.2 to 99.5 per cent content of the salt produced by primary washing. Experiments are therefore necessary to determine the best extraction processes, the selection of brines, the construction of ponds, the crystallization process, and improved materials and equipment.

To help in the drafting of such projects as the determination of methods for improving operations at Huacho and Otuma, it must be borne in mind that the brines from these saltworks and indeed those from the Peruvian coastal saltworks in general contain a higher percentage of sulphates and carbonates than natural marine brine. They therefore not only produce a salt which is less pure, but there is also a tendency for the formation of deposits of crystalline gypsum which are harder, more permeable and more difficult to break and to separate from the individual natural salt crystals than the deposits on sea salt. Such deposits of salt are formed at the Huacho and Otuma saltworks when an annual or semi-annual salt harvest allows the deposits of hard salt to thicken. This is probably the reason for monthly harvesting at Otuma. The harvesting of these deposits would be difficult with the standard machinery used in small marine saltworks; and the heavier and more costly equipment would be too heavy for the bottoms of the ponds and would necessitate the construction and maintenance of a permanent floor of salt in the pond bottoms, which would, in turn, require very deep ponds. All these factors indicate that salt can most economically be harvested by the present manual methods. Economies can only be achieved after analysis of particular operations, because scale is important.

Mechanical loading into trucks by light equipment in the bed of the salt ponds would be quite feasible and less costly than the present system with wheelbarrows or skips and light railways. The greater flexibility and speed of mechanical loading would permit more evaporation time and hence greater output. The use of a conveyer and lorries also might pay dividends because of the small investment required.

Crushing and initial washing are essential to produce good salt; they must be done as soon as the salt is extracted because the impurities from the brine residues adhere to hard salt crystals. The present manual crushing methods are strenuous, laborious and do not break the crystal conglomerate sufficiently to give good results in the washing process.

Modernization of harvesting, transport, loading and packing

The salt harvesting, transport and loading methods should be the subject of an economic and engineering study in connexion both with the expansion of salt production at existing works and with the possible development of new saltworks. This study should determine the appropriate methods and equipment for the conditions of each saltwork.

For the northern saltworks such as those in the Sechura group and at Cañacmac, 20- to 40-cm thick rock-salt deposits covered with a layer of sand require rakes or scarifiers to break and harvest the salt. The methods now used by the Salt Monopoly there are not only laborious and unhealthy for the workers, who must work in brine through most of the salt harvest, but they also are expensive. The use of suitable machinery could give a saving greater than 25 per cent on these operations and much more if there were large exports of salt. Mechanical harvesting with light equipment in the bed of the salt ponds would be perfectly feasible, especially in Central Peru at Huacho and Otuma; it would cost less than the present method of the Salt Monopoly, in which wheelbarrows or mining skips are filled manually with shovels. The investments for loading machines and adequate transport would soon be repaid, because these machines would permit a substantial reduction in the labour force. In harvesting approximately 55,000 tons/year, the Salt Monopoly employs an average of 100 men on a permanent basis. The Alcalis Peruanos S.A. has mechanized harvesting and employs no more than ten men for an average salt production of 40,000 tons/year.

Hoppers or another type of storage which would permit automatic packing would produce additional savings in handling operations. The salt is now packed in the open air from the stockpiles; jute sacks are filled with salt and weighed on small platform scales.

It is important in mechanization projects to take into account the materials used, for the high corrosiveness of the salt and the humid climate make it necessary to renew components continually, thus adding to expenses.

Processing of the salt

Apart from the very small production of refined salt at the thermo-compression plant in Lima which has already been described, the Salt Monopoly does not process salt to improve its quality except by straightforward crushing of crude salt without drying or screening. The increase in sales of ground salt indicates that if the present salt was washed, screened and dried, a better quality salt would result which would be adequate for the industrial and domestic markets. Very few chemical or food products need refined salt of high purity, but crude salt which has simply been crushed can only be used in a few of them. Peru has no experience in operating plants for washing, screening and drying crude salt. A slight acquaintance with the literature of the subject suggests that the relatively small investment capital needed for plants producing 10,000 to 30,000 tons of washed salt per annum could easily increase profits. The potential market is large for a product of better quality and smaller grain size than the crude granular or milled salt now marketed.

It may be added that if the equipment chosen were neither complex nor specialized, and if it were similar to the same kind of equipment used in other industries and made in Peru, it would give the advantages of more economic flexibility in the expansion and diversification of the product specifications of the salt industry than would be possible in the more complex installations used in large salt refineries. The consumption of fuel, power, water etc. should of course be low.

Because of the special conditions at each saltwork including fundamental differences between the northern saltworks and those at Huacho and Otuma, a complete study of the proposed washing process is necessary to determine, for example, if it is feasible to eliminate the encrusted or superficial sand from the salt crystals in order to obtain 99 per cent sodium chloride content or to determine the maximum purity which could be obtained. The use of local brine for washing should be studied for the concentration varies, and sulphate and carbonate impurities are frequent in the brines of the Peruvian coast. It must be determined whether this washing process can best function in conjunction with a refining plant or if it should be completely independent. Finally, it is important to determine the most convenient and least expensive methods of primary washing to be carried out at the time of harvesting and the most appropriate types of mills, screens, dryers etc.

The design of a washing, milling and drying plant of 30,000 tons annual capacity in the northern area and another of 75,000 tons capacity in the central area would be a first step in the modernization of salt processing. Such plants must also fulfil the fundamental requirement of suitable location. They must naturally be adapted to the climate and other conditions, including transport, water and electric power. If these factors do not ensure smooth functioning and low operating costs, the plants should perhaps be located in cities, where many disadvantages can be eliminated. These include lack of drinking or fresh water, proper power plants, suitable staff facilities etc.

For the Huacho saltworks in the central area, the plant could probably be erected on the actual saltworks, thus preserving the desired continuity of operations. The very short distance to centres of population is an important, positive factor. Consideration could however, also be given to the possibility of establishing the plant in the town of Huacho Pueblo, which is only 17 km from the saltworks, and connected to them by a good road.

Consumption forecasts indicate that the demand for refined table salt would be subject to competition from low-priced salt that was simply washed, ground and dried; therefore its quality and the marketing methods used for refined table salt would determine the sales prospects. There is now a potential market for not less than 20,000 tons of refined table salt in the Lima and Callao area and 15,000 tons in the northern and southern areas: i.e. a total of 35,000 tons/year for the whole country. Thus, when this potential consumption is projected for a five-year period and added to the increased consumption for other uses connected with the food industry, any plants to be installed in the near future should have a production capacity of 50,000 tons/year.

The outputs from the three processing projects which have total capacities of 30,000 tons for the northern area (Piura and Lambayeque), 75,000 tons for the central area (Huacho) and 9,000 tons for the southern area (Maras) should be 10,000 tons of refined salt and 20,000 tons of washed salt per annum from the northern area; 30,000 tons of refined salt and 45,000 tons of washed salt from the central area (Huacho); and 9,000 tons of refined salt from the southern project at Maras and additional washed salt from the Azángaro saltworks.

In addition, the washing plants should include a section provided with appropriate equipment for the manufacture of salt bricks containing suitable additives for the various kinds of livestock. The proportion or quantity of such bricks to be manufactured could be determined later by a simple study.

The usual vacuum evaporation systems with one or more thermo-compression or vacuum pan stages could be used in the proposed refining plants, but some automation equipment and instrumentation should be eliminated where possible to reduce investment costs and also depreciation and operating expenses. Local manufacture of some parts of the equipment might be possible. It is naturally very important to study the power supply or the possibility of installing a steam plant, which would itself need a supply of fresh water in the saltworks.

An important factor in the marketing of refined table salt is packing and packaging equipment. One of the reasons for the low output of the Salt Monopoly's present refining plant is the difficulty of maintaining the packaging machines and processing equipment. They suffer premature wear and require expensive maintenance and upkeep because of the corrosive effect of salt. The infiltration of the dust produced in the packaging rooms and around conveyers and elevators is particularly serious because of the damage it causes to electric circuits, motors, pipes etc. The use of suitable equipment to eliminate this dust and the corrosive action of the salt is therefore very important.

The Salt Monopoly's refining plant at present packs refined salt in 1 kg duplex packets, which are placed in corrugated cardboard boxes containing 25 cartons. But both the duplex packets and the corrugated cardboard boxes in which they are packed are expensive in Peru, and their manufacture is uneconomical; each 1-kg packet at present costs 0.80 sol which is more than 30 per cent of the retail price of 2.00 sol. When the other packing costs of labour and materials are added to the cost of this packet, it can be seen that packaging is a determining factor in the marketing cost of the salt. Experiments have been made in the use of polyethylene bags packed on a triangle L-2P Hesser machine, which gives an approximate cost of 0.18 sol per bag with less use of additional materials and less consumption of labour, but the automatic mechanism of this electronically controlled machine requires very careful operation and constant maintenance, which militates against the continuous operation of the machine to obtain satisfactory output. Moreover, the polyethylene sheet used is not of the uniform quality essential for the smooth operation of the packing and sealing machine.

It would appear that there is at present no type of packing on the national market which costs less than polyethylene or some similar product. Polyethylene is also very suitable in that it protects the salt packed in it from humidity. Duplex packets or other thicker packings are not only more costly but also fail to protect the salt from humidity, particularly in the climate of the Peruvian coast. Therefore, an appropriate sealing machine for polyethylene bags must resist the adverse effects of the salt on its operation and also be relatively simple to operate.

Consideration must however be given to the use, although to a lesser extent, of other types of retail packing such as plastic, tin or cardboard in different shapes and sizes to hold quantities from 250 g to 1 kg and wholesale packagings from 5 to 50 kg. Packing would have to be automatic or semi-automatic, because the planned projects require an average of 100 tons/day to be packaged in a single plant (Huacho). It must also be kept in mind that the entire packing system and equipment from the conveyer belts and railway tracks to the packaging machines and stores must be continuous and involve the least possible use of labour.

The above considerations could benefit from the more advanced knowledge of countries where the salt industry has already advanced beyond the stage which Peru wishes to reach. Recommendations and actual experiments on the spot would therefore constitute most valuable assistance.

2. MACHINERY, EQUIPMENT AND COMPONENTS USED FOR MAKING SOLAR SALT IN THE UNITED STATES OF AMERICA

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Introduction

A solar-salt plant with a production capacity of 500,000 short tons/year is used as a model in this report. Data for this plant size are more readily available than for other sizes.

The planning and construction of concentrating and crystallizing ponds are first discussed and then the appropriate machinery. The total cost estimate for equipment of the model plant is given at the end of this paper.

DIKES, PONDS AND GATES

The area required for the concentrating and crystallizing ponds will vary with the net evaporation rate. The ratio of the areas of the concentrating and crystallizing ponds will vary with seepage.

The annual yield from crystallizing ponds can vary from 650 short tons/acre where the net evaporation rate is 36 inches/year to considerably more than 1,000 short tons/acre where the net evaporation rate is 96 inches/year. A reasonable yield of 1,000 short tons/acre from the crystallizing ponds has been selected for the model plant. Therefore, the area required for the crystalling ponds would be 500 acres.

A 15 to 1 ratio between the areas of concentrating and crystallizing ponds has been selected as typical. Therefore, the area of the concentrating ponds should be 7,500 acres and the total area of the concentrating and crystallizing ponds should be 8,000 acres.

The Garrett Research and Development Company, LaVerne, California, found it unprofitable to develop an area for solar operations if the cost for the initial survey and for building pond walls and gates exceeds $500/acre. The initial survey usually requires a test hole every half mile to determine whether the area contains sedimentary clay deposits within 10 feet of the surface. Each test hole costs approximately $50. If the initial survey shows a break in this sedimentary deposit due to ancient channels etc., additional test holes must be drilled nearby on quarter-mile centres to define the area of the break in order that it can be avoided. Some soils without continuous underlying clay may nevertheless be acceptable as determined by seepage tests.

Walls are prepared from clay or other suitable soil dug from outside the plant area and mixed with overburden. The clay must be taken from a depth of several feet into the clay deposit. Earthen walls should be built at approximately a 45° angle. Usually there are ten concentrating ponds; they are normally irregular in shape and are walled off according to elevation. The average size of a concentrating pond is approximately 500 acres.

The crystallizing ponds, on the other hand, are normally rectangular with a maximum area of approximately 50 acres. They frequently have fences or sidewalls made from horizontal pine, fir or cedar boards nailed to vertical stakes with galvanized nails. The crystallizing ponds should have at least two smoothly graded areas by which harvesting machines and rubber-tired vehicles or narrow-gauge railway trains can have easy access during the harvest. One plant in Utah which uses rubber-tired vehicles has graded all four dikes with drift salt.

Gates can be fabricated either from wood or from a combination of wood and concrete. Wooden gates are built of 2-inch tongued and grooved timbers for the frame etc. and 1-inch plywood for the gate itself. Pine, fir and cedar are acceptable timber to be used with galvanized nails.

A variation uses concrete winged sluice-ways, which are essentially U-shaped troughs with wings on both ends; they are slotted in the side walls and in the bottom to guide the gates. A 1-inch plywood gate is again used with a rack and pinion or other means of lifting the gate. Armco Steel Corporation and Rodney Hunt Machine Co. also make gate lifts. The gate opening is determined from a knowledge of the desired flow rate by applying standard weir formulas. The rational formula for rectangular weirs is:

$$Q = 5.35\ C_d\ Lh^{1.5}$$

where the discharge Q is in ft^3/sec; the coefficient of discharge $C_d = 0.597$ for a weir 5 ft wide and with a 1.2 ft head; the width of the weir L is in ft; the head or height of water above the bottom opening h is in ft. The coefficient C_d will vary with the width of the weir and head; the value is about 0.6. Handbooks of chemical engineering should be consulted for the exact value.

PUMPS

Pumps will be required at any point where the preceding pond or body of water is at a lower elevation than the pond under consideration. In many solar plants, the first pond is at the highest elevation and pumping is required only from the body of water to the first pond. The water will then flow by gravity from the first pond to the succeeding crystallizing ponds and thence to the concentrating ponds and exit with the bittern discharge. However, the pond elevations may be different; then pumps are necessary.

For the model plant, consider that pumping is only required between the source and the first pond. Assuming that the incoming brine has a density of 3.5° Baumé or a specific gravity of 1.025, then each US gallon of brine will weigh 8.55 lb. If it contains 2.7 per cent NaCl, then every gallon of brine will contain 0.231 lb NaCl. However, 12 per cent or 0.028 lb of salt are lost in the bittern, therefore each gallon of brine contains 0.203 lb of recoverable salt. In order to produce 500,000 short tons of solar salt, the model plant will need 4,930 billion US gallons of fresh brine.

If the plant were to operate 365 days/year and 24 hours/day, then the intake pump should be designed to handle 9,400 US gal/minute. However, intake pumps are normally designed to fill a given area for a maximum of one third of the operating season. Therefore, the pump capacity should be 40,000 US gal/minute. However, it is good practice to use pumps in pairs so that they may readily be repaired; two pumps that each deliver 20,000 US gal/minute would be feasible.

The pumps used in solar operations are axial-flow pumps. Cast-iron pumps with open Ni-resist impellers are in use at some plants, but the wetted parts should be coated where possible with bitumastic material. As a sacrificial anode, a zinc bar which measures approximately 4 x 4 x 2 inches should be held to the pump suction with a galvanized steel rod passed through it. The rod should be bolted with stainless steel bolts to the pump suction. The preferred material for saltwater contact is 316 L stainless steel.

These pumps can be obtained from the following manufacturers:

Couch Manufacturing Company
110 Richards Street
Grant, Florida 32949, USA

Byron Jackson Pumps, Inc.
P.O. Box 2017, Terminal Annex
Los Angeles, California 90054, USA

Fairbanks Morris Pump Division
Colt Industries Incorporated
3601 Kansas Avenue
Kansas City, Kansas 66110, USA

Harvesting machines

Harvesting machines are available from the following manufacturers:

Caldwell, Richards, Sorensen, Inc.
118 First Avenue
Salt Lake City 3, Utah, USA

Salins du Midi
53, Rue des Mathurins
Paris 8^{e}, France

Barber-Greene Company
402 North Highland Avenue
Aurora, Illinois 60507, USA

Assuming that the 500,000 short tons of salt are harvested in 7 months at the rate of 45 hours/week, then the harvesting rate would be 370 short tons/hour. All of these manufacturers produce a unit with this capacity. Therefore, only one unit would be required.

HAULAGE EQUIPMENT

The United States west coast plants use narrow-gauge railways with diesel locomotives and bottom-dump mine cars for transporting the salt from the harvesting machines to the plant for further processing. This type of equipment is available from:

Sanford Day Company
P.O. Box 1511
Knoxville, Kentucky 37901, USA

Rubber-tired equipment is more popular at the newer plants. Manufacturers of this type of equipment are the following:

Caterpillar Traotor Company
100 N. E. Adams
Peoria, Illinois 61602, USA

International Harvester
2701 Bueter Road
Fort Wayne, Indiana 46803, USA

White Trucks
Division of White Motor Company
415 Madison Avenue
New York City, New York 10017, USA

The Caterpillar Tractor Company makes an off-highway lorry with a capacity of 35 tons. At one installation it is planned to use a 20-ton trailer with this lorry; the lorry and trailer both have aluminium type bodies. These trailers can be obtained from the following manufacturers:

Challenge-Cook Brothers, Inc.
15421 E. Gale Avenue
Industry, California 91745, USA

Easton Car and Construction Company
36 Holley Street
Easton, Pennsylvania, USA

The proper transport capacity is dependent on loading time, distance from the harvesting machine to the plant, unloading time and distance from the plant back to the harvesting machine. Three units are specified in the model plant.

WASHING EQUIPMENT

Many solar plants in the Utah area discharge the salt direotly from the transport equipment through a chute and onto a de-watering drag conveyer. This operation is possible because the scant rainfall during the winter permits operations on salt floors.

The de-watering drag conveyer is essentially a rectangular box approximately 100 ft long and 6 ft wide which is open at the top and equipped with a stainless steel belt. The belt is first sprayed with concentrated brine and then fresh water at a rate of approximately 300 US gal/minute in the model plant. It is difficult to estimate the cost of these conveyers as they are normally made in the plant. The salt then passes to a second belt from which it is removed by a stacker whioh carries it to a storage pile. The solids are passed through classifiers and then oentrifuged. The salt from the centrifuge oontains approximately 2 to 4 per cent moisture; therefore it then passes through rotary dryers before it is soreened and packaged.

All of this equipment is available from:

Arthur G. McKee and Company
Process Machinery Division
Manufacturers of WMCO Equipment
P.O. Box 15619
Sacramento, California 94813, USA

Classifiers are available in addition from:

Eagle Iron Works
129 Holcomb Avenue
P.O. Box 934
Des Moines, Iowa 50304, USA

The United States west coast plants normally use a dumping pit filled with brine into which the salt is dumped by mine cars from the harvesting machine. The bottoms of these pits are equipped with submerged pit screw conveyers or drag conveyers which deliver the material to the salt slurry pump. This discharges to the screw washer which in turn discharges to the de-watering drag conveyer. Drag conveyers can be obtained from:

Link Belt - Speeder Company
Division, FMC Corporation
1201 Sixth Street, S.W.
Cedar Rapids, Iowa 52406, USA

Engineering advice on washing plants can be obtained from:

J. Frank Bonell Engineering Associates, Inc.
2330 South Main Street
Salt Lake City, Utah, USA

DOUBLE-WING STACKERS

The discharge from the de-watering drag conveyer in the Salt Lake City, Utah, and west coast solar-salt plants can be placed on a belt which feeds a rail-mounted double-wing stacking conveyer which in turn places the material on the storage pile. Each wing has a self-contained electrical power unit with electricity generated by a diesel engine. The wings are 115 ft long with a trailing edge of 126 ft and are not used simultaneously. The secondary steelwork is epoxy-painted tubing. Suppliers of this equipment are:

Stevens, Adamson Manufacturing Company
Ridgeway Avenue
Aurora, Illinois 60507, USA

Barber-Greene Company
402 North Highland Avenue
Aurora, Illinois 60507, USA

Hewitt-Robins, Inc.
Division of Litton Industries
664 Glenbrook Road
Stamford, Connecticut 06906, USA

All conveyer equipment should be supported by either wood or concrete.

RUBBER-TIRED LOADERS, BULLDOZERS AND HOPPERS

Several methods of recovering salt from the storage pile have been devised. One of the most satisfactory is use of a rubber-tired loader with a 7 to 8 yd^3 bucket which can be obtained from:

Caterpillar Tractor Company
100 N. E. Adams
Peoria, Illinois 61602, USA

Michigan Division
Clark Equipment
324 E. Dewey Avenue
Buchanan, Michigan 49107, USA

International Harvester
2701 Bueter Road
Fort Wayne, Indiana 46803, USA

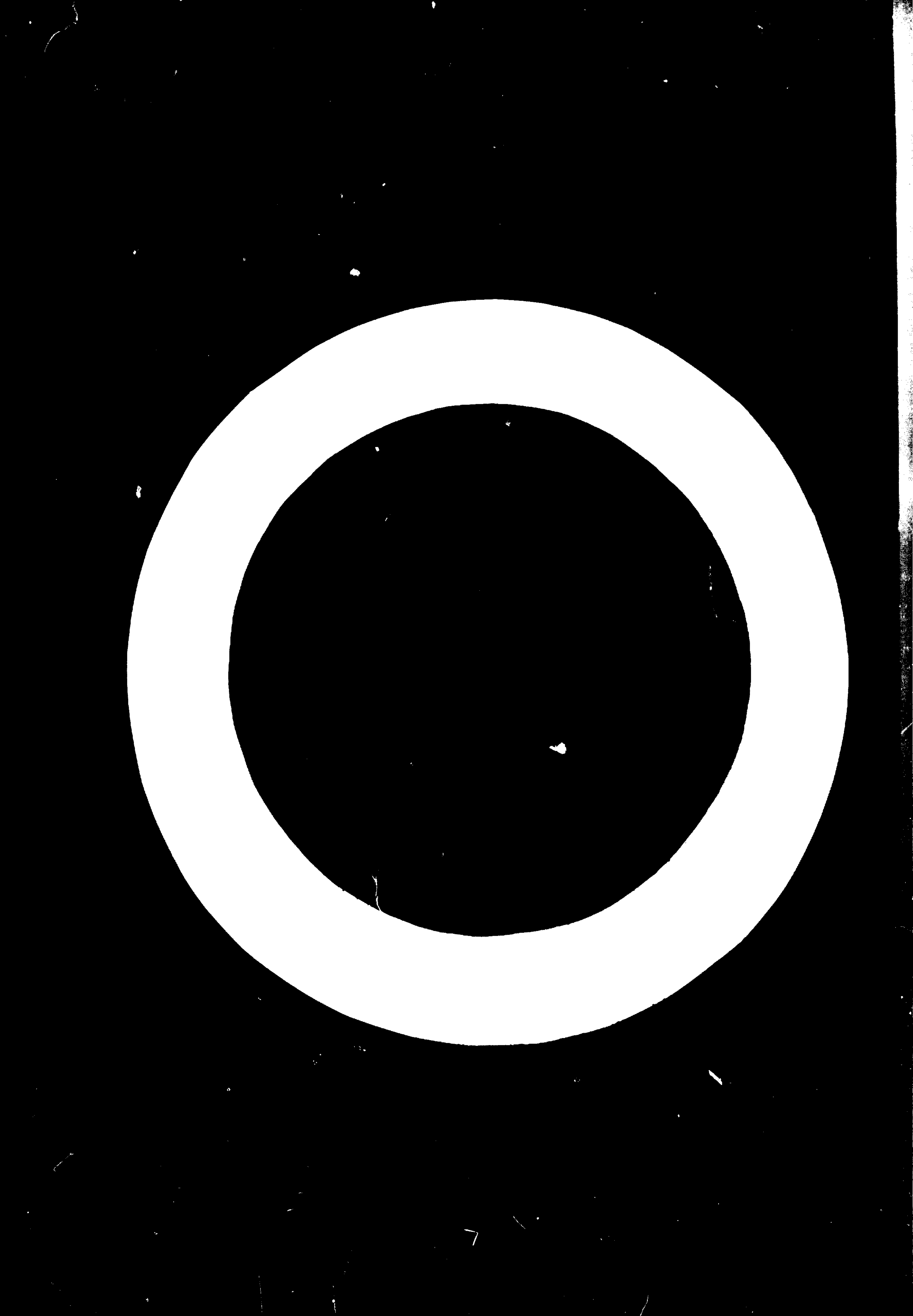
These companies also supply crawler tractors which are useful to shape the storage pile.

Rubber-tired loaders can return material to a reclaiming hopper. This hopper should fit over the conveyer belt used to supply the double-wing stacker and travel on the same track as the double-wing stacker. One supplier of this equipment is:

L. B. Smith Company
1946 Mayer Road
Sykesville, Pennsylvania 15865, USA

Cost estimates for establishing a 500,000 short tons/year solar plant
(thousands of US dollars)

Quantity	Equipment, construction, etc.	Cost Per unit	Cost Total
	Soil survey, construction of pond walls and gates for 8,000 acres	0.5/acre	4,000
2	Stainless-steel, electric, axial-flow pumps (20,000 US gal/min)	13	26
1	Harvesting machine (400 tons/hr)	40	40
3	Off-high way lorries (35-ton rear-dump body)	73	219
3	20-ton trailers	15	45
2	66-in classifiers (280 tons/hr)	19	38
3	Centrifuges (150 tons/hr)	20	60
3	Pumps (1,500 US gal/min of slurry)	3.5	10.5
3	Cyclones (1,500 US gal/min of slurry)	1.8	5.4
1	Double-wing stacker (per wing 370 tons/hr)	250	250
4	Rubber-tired loaders	72	288
1	Crawler tractor model fitted with bulldozer blade, rear-mounted counterweight, hydraulic tilt cylinder and controls	60	60
1	Reclaiming hopper	20	20
1	48-in conveyer belt to carry material from centrifuge to double-wing stackers (370 tons/hr)	120	120
	General maintenance equipment		300
	Total		5,481.9



3. KUWAITI EXPERIENCE

Mahmud A. Mardi */

*/ Plants Director, Ministry of Electricity and Salt, Kuwait.

BACKGROUND

Desalination of seawater by the multi-flash evaporator process is now established in many parts of the world. The largest group of seawater distillation plants is in Kuwait on the Arabian Gulf; the present total capacity of 17 million imperial gal/day will increase to 42 million gal/day by 1971. The principle of the flash evaporator is the evaporation of seawater to produce concentrated brine.

Such concentrated brine has been used in a forced-circulation evaporator plant to produce pure sodium chloride. The Kuwaiti experience is an example of the practicability of the process. The author believes that when the industrial demand for salt increases in Kuwait, the present process or modifications of it will be applied on a much larger scale. This will reduce the manufacturing cost of salt considerably and, possibly, foster the development of ancillary industries to recover valuable by-products from the bittern. The recovery of salts from effluents of seawater evaporation plants is of particular appeal to both contractor and client. On one hand, it will contribute to a reduction in the cost of water conversion, and on the other, a new industry would be established in an arid developing country.

It is the object of this paper to describe the process for production of common salt which has been applied in Kuwait for the last six years and to indicate the solutions to some of the operational problems.

Early in 1960, it was decided to install a chlorine-caustic soda plant in Kuwait to meet the continually increasing demand for chlorine necessary for the chlorination of seawater used in cooling systems of the expanding power and water-production installations. Salt of relatively pure grade was obviously necessary for such a small industry, but it was not available locally. Discussions and inquiries were initiated by the Ministry of Electricity and Water, Kuwait, on the possibility of installing a small salt plant based on concentrated seawater from seawater distillation plants. Due consideration was clearly given to production of sea salt by solar evaporation, but it was decided not to pursue this proposal because of space limitations, severe weather conditions and lack of construction data. Also such a small demand for pure salt would not justify a thorough investigation of solar-salt production and the subsequent purification by thermal evaporation.

As a result of these inquiries, specifications were drawn up for a conventional plant with calender-type evaporators and incorporating a calcium sulphate separator, as is normal in evaporators fed with solar-salt brines containing this impurity. Only three contractors submitted tenders. The contract to set up the plant and begin the production was awarded to Standard-Messo Gesellschaft für Chemietechnik, Duisburg, Federal Republic of Germany. Other interested contractors were cautious because of the problems entailed in evaporating such a solution.

DESCRIPTION OF THE PROCESS

The Kuwaiti salt plant uses the triple-effect, forced-circulation evaporator process. Concentrated seawater from a distillation plant working on the flash principle is fed into a storage tank from where it is pumped to the first-effect evaporator. The feed-brine composition is compared with the Kuwait Bay seawater in table 1.

Table 1

Composition of feed brine and of Kuwait Bay seawater (in per cent)

	Kuwait Bay seawater weight	Concentrated feed-brine weight
$NaCl$	3.165	8.157
$MgCl_2$	0.490	1.149
$MgSO_4$	0.244	0.555
$CaSO_4$	0.183	0.465
KCl	0.081	0.205
$Ca(HCO_3)_2$	0.023	nil
$MgBr_2$	0.009	0.023

Brine in the first-effect evaporator is heated by low-pressure live steam which is piped from the boilers of the adjacent power station. The brine discharge from the first evaporator is fed into a similar second evaporator which is heated by the vapour resulting from the brine in the first effect. At this stage, there is precipitation of $CaSO_4$, which is the least soluble and most troublesome of the constituents. Therefore, the discharge from the

second effect is led to a cone-bottom settler or gypsum separator, from which $CaSO_4$ slurry can be withdrawn at the bottom. The overflow is passed to the third and last effect.

The salt crystallizes in the third effect, from which the slurry is pumped to a stirred slurry tank or thickener where salt crystals collect at the bottom and a solution of the more soluble impurities collects at the top of the thickener. The solution is withdrawn, and the salt slurry is led to a centrifuge which reduces the moisture content to less than 3 per cent. The wet salt is then dried, cooled, screened and conveyed to sacking and polyethylene packaging machines. Magnesium carbonate is added to the packaged salt to act as a free-flowing agent.

The Kuwaiti salt plant started production early in 1963 and has a capacity of 20 tons/day. More than half of it is used to make chlorine; the remainder is marketed as table salt or as industrial salt. The salt is fine grained; a typical screen analysis is given in table 2. A typical chemical analysis of the final product is given in table 3; it compares well with vacuum-pan salt except for the contents of $MgCl_2$ and $MgSO_4$, which for the latter salt are 0.009 per cent (minimum) and 0.0 per cent, respectively (Kaufmann, 1960).

Table 2

Sieve analysis of Kuwaiti salt

Opening (mm)	Salt retained (%)
0.8	nil
0.6	2.0
0.5	12.0
0.4	45.0
0.3	40.0
0.2	1.0

Table 3

Typical chemical analysis of common salt produced in the Kuwaiti salt plant

	Weight (%)
NaCl	99.56
H_2O	0.10
Insolubles	0.001
$CaSO_4$	0.09
$MgCl_2$	0.15
$MgSO_4$	0.10

Since the process uses evaporation, distilled water is also produced at a rate of about 62,000 gal/day. This water is returned to the main product line of the seawater distillation plants which supply the feed brine to the salt plant.

Chemistry

For an understanding of this process, it is necessary to mention briefly the chemical changes which take place during seawater conversion by evaporation. Starting with seawater in a flash distillation plant, two factors, namely, heat and concentration, influence scale formation on heating surfaces. The chemical mechanisms involved have been quoted by many workers (Messing, 1965; Cadwallader, 1967):

$$2\ HCO_3^- \rightleftharpoons CO_2\uparrow + CO_3^{-2} + H_2O, \qquad (1)$$

$$CO_3^{-2} + Ca^{+2} \rightarrow CaCO_3\downarrow, \qquad (2)$$

$$H_2O + CO_3^{-2} \rightarrow 2\ OH^- + CO_2\uparrow, \qquad (3)$$

$$2\ OH^- + Mg^{+2} \rightarrow Mg(OH)_2\downarrow, \qquad (4)$$

$$Ca^{+2} + SO_4^{-2} \rightarrow CaSO_4\downarrow. \qquad (5)$$

The $CaCO_3$ in equation (2) results from the thermal breakdown of the CO_2 ion [equation (1)] present in seawater. On further heating, part of the carbonate ions decompose and hydroxyl ions are produced resulting in the formation of $Mg(OH)_2$ [equations (3) and (4)].

At the brine temperatures reached in the Kuwaiti flash distillation plants (194°F maximum) and with continuous dosing with a polyphosphate additive (PD.8) at the rate of 5 ppm, the scale in the distillation plant heater tubes has the oomposition shown in table 4. Both $CaCO_3$ and $Mg(OH)_2$ are deposited in the heater section of the distillation plants supplying concentrated seawater to the salt plant. Scaling by $CaSO_4$ is negligible at this stage of evaporation, but it becomes the predominant deposit in salt evaporators when more concentrated brine is used.

In practice, the evaporation of concentrated seawater to obtain salt follows the trend of the solubility curves obtained from seawater during solar evaporation. These curves of seawater brine composition against concentration are given by Kaufmann (1960, p.103). When using the curves, due allowance should be made for variations of constituent concentrations in different seawaters as well as for the temperature of evaporation.

Table 4

Analysis of scale deposit from heater tubes of the Kuwaiti salt plant

	Per cent
Organic matter	13.5
$Ca(PO_4)_2$	27.5
$CaSO_4$	4.3
$CaCO_3$	5.6
Fe_2O_3	trace
Fe_3O_4	nil
$Mg(OH)_2$	13.2
$Mg_3(PO_4)_2$	16.0
Basic magnesium carbonate	9.5
$MgSiO_3$	2.3
SiO_2	3.9

In accordance with these solubility curves, the $CaSO_4$ in the concentrated seawater fed to the salt evaporator precipitates to a great extent together with any remaining $CaCO_3$ and newly formed $Mg(OH)_2$ before NaCl crystallizes.

The precipitation of $CaSO_4$ takes place in the second-effect evaporator at about 1.180 s.p. and a NaCl content of about 16.5 per cent. The $CaSO_4$ crystals are withdrawn suspended in solution from the bottom of the gypsum separator. The underflow from the gypsum separator is partly discarded and partly returned to the first effect and mixed with the brine feed. The purpose of this latter stream is to provide $CaSO_4$ seed crystals on which new crystallization takes place in the first and second evaporators. The slurry containing $CaSO_4$ crystals is withdrawn at a point about 28 cm from the bottom of the separator. This procedure guarantees a suitable crystal size on which nucleation takes place. A continuous, controlled flow of $CaSO_4$ slurry from the bottom of the separator is drained; inaccurate control of this withdrawal could result in $CaSO_4$ stone filling the gypsum separator.

A discussion of calcium sulphates which may be formed in evaporating brine with or without crystal seeding is found in Messing (1965). Some useful curves may be derived from data on the solubility of constituents referred to in Kaufmann (1960).

The brine from the gypsum separator, which is as near as possible to the point of crystallization of sodium chloride, flows to the third effect where, with further evaporation, NaCl crystallization takes place. At this stage, the extent of evaporation or concentration in the third effect has to be controlled. If concentration is too high, a larger yield of salt is attained, but the magnesium impurity would crystallize and appear in the final salt product. Under the circumstances, a compromise is reached on the tolerable magnesium impurity.

From the author's experience in the operation of this plant for over five years, it has become apparent that, under the specified brine composition, a brine concentration of 30.4^{o}Be (s.p. 1.265) should not be exceeded. Otherwise the $MgCl_2$ impurity will be too high for the salt to be used for chlorine production in mercury electrolytic cells. Further, a $MgCl_2$ content greater than 0.25 per cent will result in relatively rapid caking of the stored salt.

Further crystallization of $CaSO_4$ takes place in the third effect together with NaCl. However, the quantity is small at this stage, and the fine, light crystals are conveniently removed from the thickener or preconcentrator. Part of the overflow from the thickener is recycled to the brine-storage tank and part is drained in a controlled manner to prevent build-up of other impurities in the system. The underflow from the preconcentrator passes to a centrifuge where the cake is washed with a spray of distilled water. The filtrate from the centrifuge is also returned to the feed-brine tank.

When the Kuwaiti salt plant was first operated at the beginning of 1963, no provisions were in existence for crystal seeding. The $CaSO_4$ encrustations were so heavy on the heating surfaces of preheaters, evaporators and interconnecting pipes that much of the operation time was spent in dislodging scale by mechanical means. Analysis of scale deposits in the first two stages of the evaporator showed that about 86 per cent of the deposit was $CaSO_4$, while alkaline scales ($CaCO_3$ and $Mg(OH)_2$) accounted for only 7 per cent. Treatment with 5 per cent inhibited hydrochloric acid in order that the reaction of alkaline scales would help to break the hard tenacious sulphate coating produced no results.

Following the initial period of difficult operation, Standard-Messo Gesellschaft für Chemietechnik introduced the seeding technique which satisfactorily eliminated scaling problems in the plant. Table 5 shows the composition of the most important streams in the three-effect evaporator plant.

Table 5

Analyses of brine at different stages in the Kuwaiti salt plant
(in per cent)

Dissolved impurities	Feed brine to first evap. at 122°F, s.g. 1.108, 1.8% solids	Crystal seed slurry at 155°F, s.g. 1.180, 9.9% solids	Slurry from third evap. at 128°F, s.g. 1.265, 29% solids
$CaSO_4$	0.377	0.035	0.021
$MgSO_4$	2.003	2.955	6.963
$MgCl_2$	3.005	4.551	12.392
KCl	0.652	1.008	2.488
NaCl	9.450	16.381	9.320
$MgBr_2$	nil	nil	0.250

It can be seen from table 5 that the actual feed brine to the evaporator contains about 1.8 per cent solids which are mostly $CaSO_4$ crystals. From a material balance on the evaporator, solid $CaSO_4$ returned to the feed-brine storage tank averages between 1.5 and 2.5 per cent. Since no provisions have been made for proper mixing of feed streams, some $CaSO_4$ unavoidably precipitates in the brine storage tank.

The efficiency of NaCl recovery varies between 75 and 85 per cent, depending on the concentration reached in the third-effect evaporator. Representative operating conditions in the Kuwaiti salt plant are given in table 6.

There was little scaling in the first two effects during more than five years of operation. The heating surfaces in the third effect always have a polished appearance. Any encrustations of scale or salt deposit that may appear are washed with seawater. Washing is normal practice in salt plants because of the "salting effect" in which lumps of salt are formed that could damage the impeller of the agitator in their fall. The first two stages of the evaporator were cleaned once in the last two years with 2 per cent HCl. It was found that all the scale dissolved in the acid, indicating that the 1 to 2 mm thick formations were largely alkaline.

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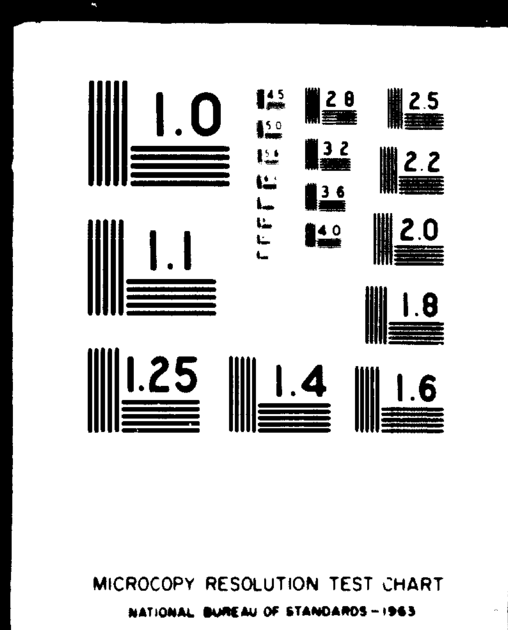
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1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

Table 6

Typical operating conditions in the Kuwaiti salt plant

First-effect evaporator, vapour space temperature	189°F (195°F max.)
Second-effect evaporator, vapour space temperature	163°F
Third-effect evaporator, vapour space temperature	134°F
Cooling seawater inlet temperature to main condenser	85°F
Cooling seawater outlet temperature from main condenser	102°F
Low-pressure steam temperature to first effect	215°F
Steam consumption, including steam needed for air ejector and dryer	5.9 tons/hour
Quantity of distilled water produced	2,580 gal/hour
Quantity of concentrated brine used (s.g. 1.065)	3,200 gal/hour
Purity of distilled water produced	80 ppm max.
Quantity of cooling seawater	55,000 gal/hour
Waste bittern	320 gal/hour
Power consumption for the whole plant	4,000 kWh/day
Production of dry salt	20 tons/day

Construction materials

The construction materials employed in the plant are somewhat sophisticated and expensive. The evaporator bodies are of mild steel lined with 2-mm thick welded Monel metal sheet. The tubes and tube plates are made of Monel. The shaft of the agitator is made of stainless steel, while the impeller is of Monel. The shaft at its lower end has a slide bearing lined with soft rubber and lubricated by a stream of brine. In the sixth year of operation, some rust appeared on the welds of the lining in the evaporators. Re-welding of the faulty sections was satisfactory.

The heat exchangers were intended to be used as brine preheaters and preheater-condenser respectively to recover the heat in condensates and in live steam from the ejectors. However, they are now used to cool the condensates with seawater as the cooling medium. This is satisfactory since the condensates are partly distributed in PVC pipes, which would fail if the water temperature were too high.

The three heat exchangers referred to above have tubes and tube plates made of Monel. Because the Monel has been attacked by seawater at the welds, the heaters are now being replaced by others with 70/30 cupro-nickel tubes.

The main condenser shell is made of steel and the tubes and tube plates, which are in contact with seawater, are made of 70/30 cupro-nickel. No trouble has been encountered in the condenser either from scale or corrosion.

Pumps for brine and slurries were originally made of bronze with Monel impellers. The bronze casings did not withstand the abrasive action of crystals in the streams, especially with $CaSO_4$ slurries. Regular cavities and grooves appeared after long operation, which resulted in many leaks in pump casings. The bronze casings of brine pumps were changed to Monel, which proved more successful but was also affected by solid particles.

Brine pipelines are mostly rubber lined. All other equipment on contact with wet or dry salt is made of stainless steel, for example the basket of the centrifuge, the dryer and salt bins.

Operating problems

Numerous mechanical and operational problems were encountered during the first year of operation. Mechanical troubles included the gear system driving the shaft of the propeller agitator and also the lower slide bearing of the shaft. These problems were recognized by the contractor who introduced a number of modifications. Rubber-lined bearings at the lower end of shafts proved very suitable for the conditions. The slide bearings are inspected fortnightly for wear when the plant is shut down for washing.

Purity of condensates

Foaming and consequent contamination of condensates occasionally occurs and could, sometimes, be attributed to high steam loads or high brine levels in any of the evaporators. Foaming and carry-over of brine were much more frequent at the start of operations when the feed to each evaporator was above the brine level, but this was modified by the contractor so that the feed is introduced in the lower part of the evaporator below the liquid level.

Foaming is now completely eliminated by injection of the anti-foaming agent NALCO 71-D5 to the first evaporator at the rate of 2 to 5 ppm. The anti-foaming additive is a liquid mixture of polyglycol and fatty-type surface-active materials with other self-emulsifying and emulsion-stabilizing agents. The anti-foaming agent is dosed whenever foaming is observed in any of the evaporators. The total dissolved solids in the condensates average 80 ppm and can be as low as 15 ppm.

Drying of salt

A drum dryer is employed for drying wet salt from the centrifuge. The steam-heated air and the salt originally entered in countercurrent flows. With this arrangement, the salt caked on the walls and baffles of the dryer near the feed end and on those extending to the middle of the drum. Lumps of salt were also formed and damaged baffles in their fall. The other half of the dryer nearer to the hot air inlet was practically free from caked salt. Many modifications were made on the dryer in an effort to avoid these formations since they involved frequent maintenance. The modifications included installation of scrapers instead of baffles over about one third of the dryer length from the salt-feed end and adjusting the hot air inlet, so that the air and salt flows are parallel. These changes reduced salt cake in the dryer but did not completely eliminate it. It is now part of the operating procedure to stop the dryer for inspection once every two days to remove the caked salt mechanically. The inlet and outlet temperatures of the steam-heated air are about 340^{o}F and 240^{o}F respectively.

Caking and flowing properties of final product

Within 24 hours of manufacture, the dry salt from the salt bins is either sacked in 60 kg polyethylene-lined jute sacks, piled for use in the chlorine plant or bagged in 1 kg polyethylene bags for table use. To improve the flowing properties of the material, $MgCO_3$ is added to table salt before packaging. When the relative humidity of the air is more than 70 per cent as is frequent in Kuwait, table salt is not made and the production is usually iverted to the stockpile.

Caking of sacked salt in the plant is not unusual; it may occur after one to three months in storage depending on variations in humidity, temperature, storage, superincumbent weight and other associated factors. Table salt with added $MgCO_3$ rarely cakes in small polyethylene bags, but its free-flowing property is poor.

Because of the limited production capacity of the plant, it was thought unjustifiable to install new equipment to prevent caking or to improve the flowing property of the salt. Inquiries have been made, however, about a process for prevention of caking by adding 1 to 2 ppm of potassium ferrocyanide.

The process[1] is now applied by a number of licensees in Europe. One well-known manufacturer and licensee offered the benefit of his experience, including toxicity aspects and process control, against a specified payment. It is intended to investigate this process further when a larger plant is constructed.

The poor-flowing property of the salt is largely attributed to the high content of $MgCl_2$ in the final product. Tests made in the laboratories of the contractor showed that the salt could not be made completely free-flowing merely by the usual additives. Washing of the salt with a brine of low $MgCl_2$ content could reduce the average amount of $MgCl_2$ to less than 0.02 per cent. Dry salt with 0.02 per cent $MgCl_2$ and mixed with 0.5 to 1.0 per cent $MgCO_3$ would result in a product which keeps its free-flowing property under humid conditions. Washing of salt by incorporation of a salt-wash tank after the thickener would probably solve caking as well as flowing troubles.

RECOVERY OF OTHER CHEMICALS FROM CONCENTRATED SEAWATER

Recovery of minerals other than sodium chloride from seawater is not a new process. Magnesium and bromine have been commercially extracted from seawater for many years. The blowdown or waste from seawater distillation plant offers a solution richer in minerals than the original seawater. Recent reviews (Tallmadge, 1964; Weinberger and De Lapp, 1964; Salutsky and Messina, 1965) outline methods by which recovery of minerals may be possible. One suggested scheme (Weinberger and De Lapp, 1964) to extract magnesia, salt and bromine entails treatment before and after water distillation. Another suggested scheme is to treat seawater with phosphoric acid and ammonia to obtain a phosphate fertilizer and thus eliminate the formation of scale (Salutsky and Messina, 1965).

The Kuwaiti salt plant is based on present-day operating conditions of flash distillation plants with concentration ratios of about 2:1. Chemical by-product recovery should be based on waste streams from a large salt plant using the process described in this paper. Calcium sulphate slurry drained from the gypsum separator can easily be processed by filtration, washing and drying to obtain gypsum. The material is not mined in Kuwait, and therefore

1/ Federal Republic of Germany patent 954,691 issued in 1956.

a large salt plant would produce sufficient quantities for the local market to justify installation of the required equipment.

The mother liquor drained from the salt plant contains magnesium salts, potassium chloride and bromine in concentrations about 29 times higher than the original seawater. This solution can be utilized for the recovery of these chemicals by existing processes. Magnesium, for example, could be precipitated by treatment with sodium hydroxide, which could, in turn, be obtained by electrolysis of brine from the plant. Bromides could be converted to bromine by chlorination and stripping. Potassium chloride may be obtained by precipitation or fractional crystallization.

A plant of this type recovering chemicals in the waste bittern from water distillation plants will use few chemicals other than those produced in the scheme. Equipment will also be small and not varied as compared with the equipment of the salt plant.

CONCLUSIONS

The salt plant in Kuwait demonstrates the practicability of using effluent brines from multi-stage flash evaporators for production of pure evaporated salt. Over 70 per cent of the water contained in the effluent is converted in the evaporation process to potable water. The sodium chloride produced in this manner has been used in Kuwait in the production of chlorine, sodium hydroxide, hydrogen, hydrochloric acid and sodium hypochlorite.

Production cost at $40/ton of salt may be considered high, but it has proved competitive under the conditions of the area. This cost could be halved with a three or four times larger plant.

The recovery of other minerals from waste bitterns by well-established processes is obviously attractive. Since such recovery units would be coupled with water distillation plants, they can contribute towards a reduction in the cost of potable water production as well as providing new industrial growth.

The economic recovery of minerals from wastes of seawater distillation plants will be one of the subjects to be investigated by the Water Resources Centre in Kuwait, which will start its programme of research shortly in co-operation with the United Nations Development Programme.

Acknowledgement

The author is indebted to His Excellency, The Minister of Electricity and Water, Kuwait, for his permission to use the information available on the Kuwait Salt Plant.

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4. FRENCH EXPERIENCE

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Introduction

Solar-salt production by ancient principles was common in France and many other countries until 50 years ago. An increase in consumption was dependent upon an increase in population. However, after the First World War, chlorine chemistry opened a new industrial market that required large quantities of salt every year. The quantity and quality of solar-salt production have completely changed in the last twenty years.

The available surfaces for solar evaporation were finite; therefore the output/unit area was increased. Costs were reduced to compete with the products of chlorine chemistry. The industrial consumers required a high-grade raw material. Improved working conditions and more regular employment were also results of the modernization of the solar-salt production.

VARIABLES IN SEA-SALT PRODUCTION

Increase of output and improvement of quality, productive capacity and working conditions were based on comprehension of all factors in the production of salt. Knowledge of the sea was absolutely necessary. A study of the reactions of seawater exposed to solar evaporation was required, as well as research into the impurities contained in salt, a survey of crystallization etc.

It was necessary to develop safe, accurate and rapid methods of chemical analysis. These analyses determined the contents of the chief anions: chlorine, sulphate, iodine, nitrate, nitrite, phosphorus and bromine; and the cations: sodium, calcium, magnesium, potassium, aluminium, chromium, iron, copper, manganese, nickel, lead, silicon, titanium, vanadium etc.

It was also necessary to standardize methods of measuring moisture and the insolubles in water and acid. Soil studies included:

Diagrams of soil strengths, permeability, liquidity and plasticity limits;

Determination of density, mechanical analysis, content of organic matter etc.

The basic practical investigations included measurements of:

Concentration and composition of seawater;

Evaporation rates of brines in relation to concentration, magnesium content and climate;

Crystallization of the salt;

Caking;

Speed of solution;

Density;

Size analysis;

Purity etc.

Lastly, quality control was important in marketing the salt and to comply with Board of Health regulations concerning additives to the salt, including anti-caking agents, carbonates, iodine, magnesia, nitrite and phosphate.

FROM THE SEA TO THE CRYSTALLIZING PONDS

Modernization reduced the effect of variables that had curtailed production or increased costs:

Occasional or periodical reduction of the salinity of the brine at the intake;

Irregularity of the concentration process on the evaporating surfaces;

Dimensions of concentrating ponds;

Intermediate pumping;

Lack of balance between the output of the concentrating ponds and the needs of the crystallizing ponds;

Dilution of the saturated brine by rain.

If the pumping is insufficient or the quality of the brine varies, a salt plant cannot operate at full capacity without a suitable seawater intake. It is therefore necessary to have an adequate pumping capacity and to store the brine. Therefore, a reserve pump should be located near the intake to feed the concentrating ponds regularly. The pond bottoms are levelled with the utmost care, so that large heads of brine do not impede the process of concentration at hollows in the bottom.

As the slope of the ground is usually unsuitable, it is necessary to install pumping stations between the intake and the final concentrating ponds to pump the brines to their level. In order to reduce investments, maintenance and control, the number of intermediate pumping stations must be as small as possible; one automatic pumping station in the centre of the plant would be ideal.

When the brines have been concentrated to the saturation point of sodium chloride, there is generally a lack of balance between the need for saturated brine of the crystallizing ponds and the quantities which can be supplied by the concentrating ponds; reserve ponds are, therefore, absolutely necessary to regularize the feed. They should be as deep as possible to reduce the effect of rainwater on the saturated brines stored in them. The depth and area of the storage ponds and, consequently, their volume vary with the climate.

FROM THE CRYSTALLIZING PONDS TO THE STOCKPILE

Efforts were concentrated on improving the output/unit area and the chemical quality to meet increasing industrial demand.

The preparation of the bottom of crystallizing ponds is one of the most delicate operations in a salt plant. It was often neglected before mechanical equipment was used. The ideal soil is not always available, but it is always possible to improve the composition and thus to strengthen it to permit the movement of the harvesting equipment and to provide the best possible conditions for salt crystallization. In fact, at the time of the first precipitation of salt, a reaction takes place between the soil and the salt. Both the size analysis of the salt and the impurities it contains can be affected by unsuitable soil. A permanent, thick salt floor in favourable climates circumvents this difficulty.

If the investment appears to be costly, the method has the advantage of reducing maintenance expenses of the crystallizing ponds and it ensures a good harvest. It may sometimes even be the only means to achieve mechanical harvesting.

The crystallized salt certainly varies with the quality of the soil, but the composition of the original brine is more important in determining its quality. The brine is under permanent control in order to obtain the thickest deposit of good-quality salt.

The magnesium content is critical because it is the chief impediment to evaporation. In very humid countries, crystallizing ponds should be fed in series; the magnesium content of the brines increases from one pond to the next. This may sometimes ensure salt production in an early pond whereas had the brines been mixed, there would have been no production of salt in these ponds.

Salt harvesting is a delicate operation, but its successful mechanization has saved labour and produced better salt. The harvesting equipment can be either towed or self-propelled; the latter should be separable from the vehicle for other uses outside the harvest season. Different blades are fitted to the harvesting equipment for use in sand, clay or salt, but the method of removal of the harvested salt is usually based on processes involving blade or bucket elevators, and belt conveyers. The salt is moved from the crystallizing ponds either by tractor-drawn trailers or on conveyer belts. The harvesting output of a machine ranges from 100 tons/hour to 1,500 tons/hour.

The total harvesting capacity depends mainly on economic and climatic factors. Depending on the climate, it is possible either to harvest the year round or during most of the year at a low rate; on the contrary, a very high rate can reduce the duration of the harvesting period to a minimum and provide the maximum advantage from the dry season.

Whether it is piled beside the crystallizing ponds or loaded at the time of harvesting, the salt is taken to the washing plant either by trailers with capacities of 20 tons or more or by hydraulic conveyers. Washing equipment is based on different processes that eliminate as much as possible of the physical and chemical impurities from the salt to satisfy the most stringent consumer requirements.

The washing plant uses an artificial saturated brine in which the salt losses by solution are minimized. As this brine becomes polluted, it is decanted and drained off. This loss is compensated by adding fresh water and fine salt recovered from the decanting pond to ensure that the impurities in the washing brine do not rise above permissible levels.

Different types of washing equipment are used: moving screw, fixed screw, vibrating or centrifuge drainers. The choice of one of these types depends on many factors which are connected not only with the function of the salt but also with the dispatch rate and especially with the harvesting system used; the salt can be dry or wet.

The salt is stored to permit subsequent mechanical handling. The design and size of the loading and handling equipment vary with the type of salt.

FROM STOCKPILE TO CONSUMER

As a result of national economic and industrial developments and increases in purchasing power, the consumers demand higher quality and use more salt, but they use it quite differently. Old packings, presentations, colours and designs became obsolete. Variations in salt grain size, blends etc. were absent or rare. It was, therefore, necessary to satisfy every customer who might require salt to "his own design". In the past, there were only about ten different varieties; in France now there are almost 150. It has therefore been necessary to investigate packing, storing and handling problems.

Since consumers use salt for different purposes, the shipping equipment must be designed both for bulk deliveries to chemical industries, which use an entire trainload of salt, and also to supply dried or wet salt to the packing equipment in smaller quantities which vary with sales. Special storage hoppers are equipped to dispatch the salt at any time from the stockpiles separately or simultaneously to these different destinations. Transport is usually by conveyer belts or hydraulically; the quantities delivered are measured by automatic weighing machines which are a guarantee to the buyer and an aid to book-keeping.

Undried salt is often crushed to the grain size requested by the buyer and automatically bagged, generally in sealed palletized polyethylene bags. Dried salt is packed by high-capacity automatic machines in bags ranging from 0.25 kg to 50 kg and in plastic or cardboard packages.

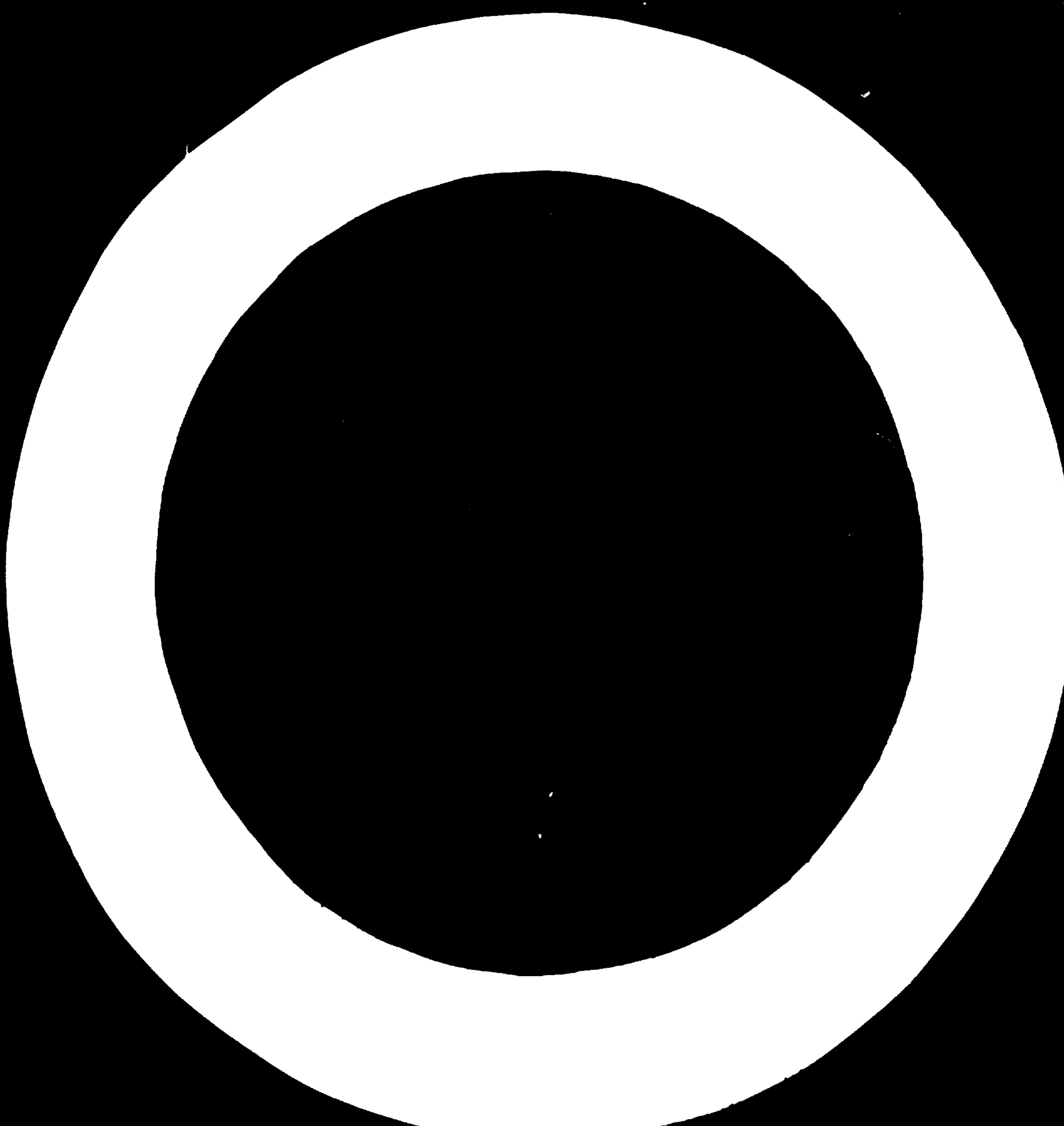
According to the use of the salt, it is treated with anti-caking agents and is blended with additives such as sodium iodide to prevent goitre or sodium carbonate and naphthalene to cure hides. The salt can also be moulded under high pressure to manufacture blocks of pure salt or mixtures containing food supplements for cattle feeding. The warehouses are provided with loading equipment for both road and rail transport.

ACTIVITIES OF FRENCH CONSULTANTS

Modernization and mechanization of the various operations at French salt plants have facilitated work which had been extremely arduous. They have also resulted in standardized production, reduced costs by increased production and secured a constant improvement in quality. Thanks to such developments, French solar-salt producers can meet domestic and international demands.

The system solved French problems, but it also proved valid for other countries in the past ten years in the modernization and mechanization of their own solar-salt plants or even building new modern plants. It must be emphasized that solar-salt production requires experts who can investigate thoroughly each individual aspect (climate, soil etc.). France had a contract extending several years with Brazil to increase the 300,000 tons annual production of a solar-salt plant, to supply the washing and harvesting equipment, to perform the engineering work and to build a plant to produce 40,000 tons/year of table salt. French consultants have worked on salt plants also in Australia, Ceylon, Ethiopia, India, Ivory Coast, Jordan, Madagascar, Senegal, Tunisia and Venezuela.

Finally, in a subject closely related to the production of salt from seawater, France is applying original techniques to produce fresh water at competitive prices. It is possible to combine some desalting methods with salt production, and thus lower the cost of both products.



5. PORTUGUESE EXPERIENCE

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Introduction

Sea salt was harvested in the Iberian Peninsula before the Roman conquest; it is still a leading industry. Trade and export of sea salt were very important factors in the Portuguese economy. In the fifteenth century, the output had reached 300,000 tons/year; two thirds of it was exported to other European countries. Early in the twentieth century, 150,000 tons were still exported annually, but the exports decreased quickly for various reasons, including the decline of the sailing ship in which salt was used as ballast and the competition of other Mediterranean areas using industrialized methods of production.

The loss of the export trade and the beginning of rock-salt production were not calamitous for the sea-salt producers because of the increase in the national consumption, the beginning of the chemical industry and increases in other uses of salt, for example, fish canning.

Therefore in contrast to the changes in other countries at the turn of the century, Portuguese producers felt neither the need to develop nor to change their working methods. Salt production therefore experienced only minor change and maintained its traditional manual character with little mechanization.

The good climate, especially in the south, has allowed sea-salt production to be profitable, although there have been occasional crises. But the progressive increase of wages, the development of the communications network and the competition of other industries and of imported salt (mainly Spanish) have created conditions which indicate that technical and economic change are extremely necessary. Technical investigations will be considered in relation to the various sea-salt areas.

CHANGES IN THE TRADITIONAL METHODS OF HARVESTING SEA SALT

Aveiro

The increase in the annual output from the Aveiro saltworks has averaged 2,600 tons since 1954 with the following average outputs over five-year periods:

	Average annual output (tons)
1952-1956	43,881
1957-1961	54,306
1962-1966	73,490

The salt ponds were not enlarged, but the significant increases in output were caused by technical improvements concerning salinity, replacement of earth walls by plank walls and the covering of salt piles with polyethylene film.

Salinity. All Portuguese saltworks, except Algarve, have been located on estuaries for historical reasons. The intake brine is therefore mixed with a percentage of fresh river water that varies with the tide and the conditions of the river mouth.

At Aveiro, an obstruction to the Vouga river was removed by dredging and coastal engineering work, so that the salinity of the intake brine was increased with a resulting higher production. The saltworks are in lagoons with small islands separated by narrow channels through which the water flows. The gates built in these channels exclude sweet water and allow the salt water to enter, thus maintaining the salinity of the intake water.

Plank walls. The Aveiro saltworks have a complex outline with evaporating ponds decreasing in size as the concentration of the brine increases; the crystallizing ponds measure about 4 x 14 m. Formerly the crystallizing ponds were separated by small walls of compacted soil, which had to be carefully rebuilt every year. These walls are now being replaced by plank walls, thus increasing the pond area and reducing the construction labour.

Covering the salt piles with polyethylene film. Since Aveiro is very rainy in winter, the salt piles were traditionally protected from the rain by matting made from the bajunca water plant and covered with clay. The more economical and practical polyethylene sheeting is now replacing this material.

Figueira da Foz

Annual production from this group of saltworks is nearly constant; it varies between 24,000 and 29,600 tons. From 1954 until 1965, the average annual increase was only 200 tons. Technically these saltworks resemble those at Aveiro.

Planks are being used but there is a tendency towards inferior workmanship either from carelessness or from the use of part-time workers. An investigation is now in progress to provide these small saltworks with brine directly from the sea through a collective pumping station.

Tejo

These saltworks are near Lisbon; they are in a declining phase. The annual output reached 86,000 tons in 1954, but since then the production has decreased at an average rate of 1,900 tons/year with the following average outputs over five-year periods:

	Average annual output (tons)
1952-1956	83,501
1957-1961	77,260
1962-1966	68,522

This decrease is caused by the halting of production at some saltworks because of urban and industrial development; also the brine salinity has been progressively reduced, especially by the effect of large dams which increase the stream flow without providing any protection for the saltworks. Nevertheless some technical improvements have taken place. Traditional hand pumping is still used in several smaller saltworks, but mechanical pumping is now common. Mechanical transport is also used. Traditionally the pond bottoms were covered with seaweed, but this method has been discarded.

Sado

An excellent climate favours these saltworks that are similar to Algarve. The estuary location is not harmful except to the upstream saltworks, because the seawater flows into the estuary.

The traditional method of the area is closer to modern methods with simpler, larger saltworks than those of Aveiro and Figueira da Foz. While in these two areas the water level rises 2 or 3 cm and the salt is harvested at intervals of three months, in the Sado ponds the water rises 10 cm and the salt is harvested only two or three times a year.

It might appear that the traditional Sado method would provide better conditions than the Aveiro method. Paradoxically, however, the Sado method has been replaced by the Aveiro method, which is more expensive and antiquated. Nevertheless, it has been recognized that Aveiro-type production is more uniform and less effected by bad weather; furthermore, employment is more frequent, and the administration is simpler.

Because of the technical change and for other reasons, there has been an average annual increase of 1,100 tons with the following average outputs over five-year periods:

	Average annual output (tons)
1952-1956	53,857
1957-1961	65,189
1962-1966	68,810

Algarve

Algarve is on the southernmost coast of Portugal. It has a remarkable Mediterranean climate that is favourable to salt harvesting. The conditions there and those at Aveiro are compared in table 1. Average temperatures at Algarve are 6.7°C higher than at Aveiro.

Table 1

Rainfall and evaporation at Aveiro and Algarve in mm

	Aveiro	Algarve
Annual rainfall	913.3	452.6
Total rainfall April to September	232.4	75.0
Total evaporation April to September	555.0	1,076.5
Total excess evaporation April to September	322.6	1,001.5
Daily evaporation April to September	3.1	6.0

Since this region is remote from the largest centres of consumption, the advantages of its climate were underestimated previously. Recent reduction in transport costs enabled production to expand from the fourth largest output to the largest production in the country.

In fact, from 1954 to 1965, the output increased from 40,000 to almost 70,000 tons; the 1968 output was expected to exceed 100,000 tons. The yearly outputs averaged over five-year periods are:

	Average annual output (tons)
1952-1956	35,625
1957-1961	56,025
1962-1966	66,405

The remarkable increased production in this group of saltworks in the last few years is especially due to the rebuilding of the ponds, and their rearrangement and mechanization.

New ponds. Marsh land usually submerged by tides is being used for new ponds, but the technique is not perfect. At a pilot plant the first evaporating ponds of 500,000 m^2 area and crystallizing ponds of 5,000 m^2 area are now being built. The harvesting is mechanical or semi-mechanical.

Ratio of areas of concentrating to crystallizing ponds. The area of the concentrating ponds in this area was traditionally too small in relation to the crystallizing area; 4:1 is now usually considered satisfactory.

Mechanization. Production costs in this area are now less than half those at saltworks in northern Portugal; they tend to decrease even further with the increasing mechanization of transport.

PRODUCERS' ASSOCIATIONS AND THE INFRASTRUCTURE

One of the conditions for survival of small producers is the existence of an infrastructure for collectively achieving the results that a single producer cannot achieve alone. This requires a well-organized association of producers.

Although most owners are strong individualists, the first attempts to form an association of Aveiro producers were made several decades ago. Rules were written, but this first co-operative association never functioned.

Later with the institution of corporativismo in Portugal, sea-salt producers were grouped in Gremios de Lavoura or agricultural guilds within which separate salt sections were created in Aveiro and Figueira da Foz. These sections formed the first effective associations of producers in the salt industry and have recently had a positive effect on production, sales control, statistics etc.

Recently the idea of the co-operative was re-activated since the agricultural guilds were not allowed to perform certain economic activities. A co-operative exists in Aveiro with about 300 producers and another one is being organized in Figueira da Foz.

In the national plan, the salt producers are represented in the Corporacao da Agricultura which has a working group on salt, and in the Comissao Reguladora dos Produtos Quimicos e Farmaceuticos (salt section) which is a centre for economic co-ordination. The State is represented and also industrial and commercial groups. Policy decisions about development and co-ordination are made by this department.

One important task for these organs is the creation of infrastructures for marketing, product improvement and transport from the saltworks to the consumer, including harbour equipment. Another task will be the establishment of co-operative salt washing plants because individual plants are not economic for small saltworks. Salt-storage methods also have to be evolved.

REPLACEMENT OF TRADITIONAL UNITS BY MODERN SALTWORKS

It has been thought advisable to replace small traditional saltworks by larger, technically advanced units. The preliminary investigation into this subject was made five years ago at the saltworks of Tejo in the Vasa-Sacos area. The matter is now again being studied. A favourable mental attitude of the owners is, however, needed, and the existing associations are helping to create such an attitude. The aim is to associate the traditional small saltworks with the larger ones.

Such a grouping could be achieved by establishing: co-operatives of producers, limited companies. Solutions used in agriculture, such as land grouping and group agriculture, should also be considered. All these aspects are under investigation, but the outlook is not optimistic. In fact the saltworks are sometimes located on small islands, which are crossed by channels and affected by tides; therefore engineering work is expensive and difficult.

These obstacles, the usual opposition by owners to association and the availability of land in southern Portugal indicate that new large industrial saltworks would be a more productive investment. The association of saltworks could be a later development. Meanwhile the smaller saltworks must be provided with the necessary means to compete with the new large units. This can be achieved by the improvement of infrastructures and by technical changes to reduce the labour required by the industry and to improve the low-quality salt of the small traditional saltworks.

The mechanization of small units, the strengthening of pond bottoms and the replacement of river transport by an efficient network of roads and small bridges are now being investigated. Also under investigation is the building in Aveiro of a saltwork of about 300,000 m^2 as an example for the association of the smaller saltworks in the area.

New saltworks

The new units are considered to be the growing point of Portuguese salt production. In a national survey of possible locations of large saltworks from 5 million to 7 million m^2 in area, two sites on the Algarvian coast were the best. The proposed mechanized saltworks should each produce about 50,000 tons/year and have plants for extracting the magnesium and potassium salts from the bittern and possibly a chemical plant.

To gather all the technical and economic information for such a large enterprise, it was decided to establish a pilot saltwork of about 500,000 m^2 in Algarve. This is now being built and will be a model both for the new large saltworks and for the associations of small and medium-sized saltworks.

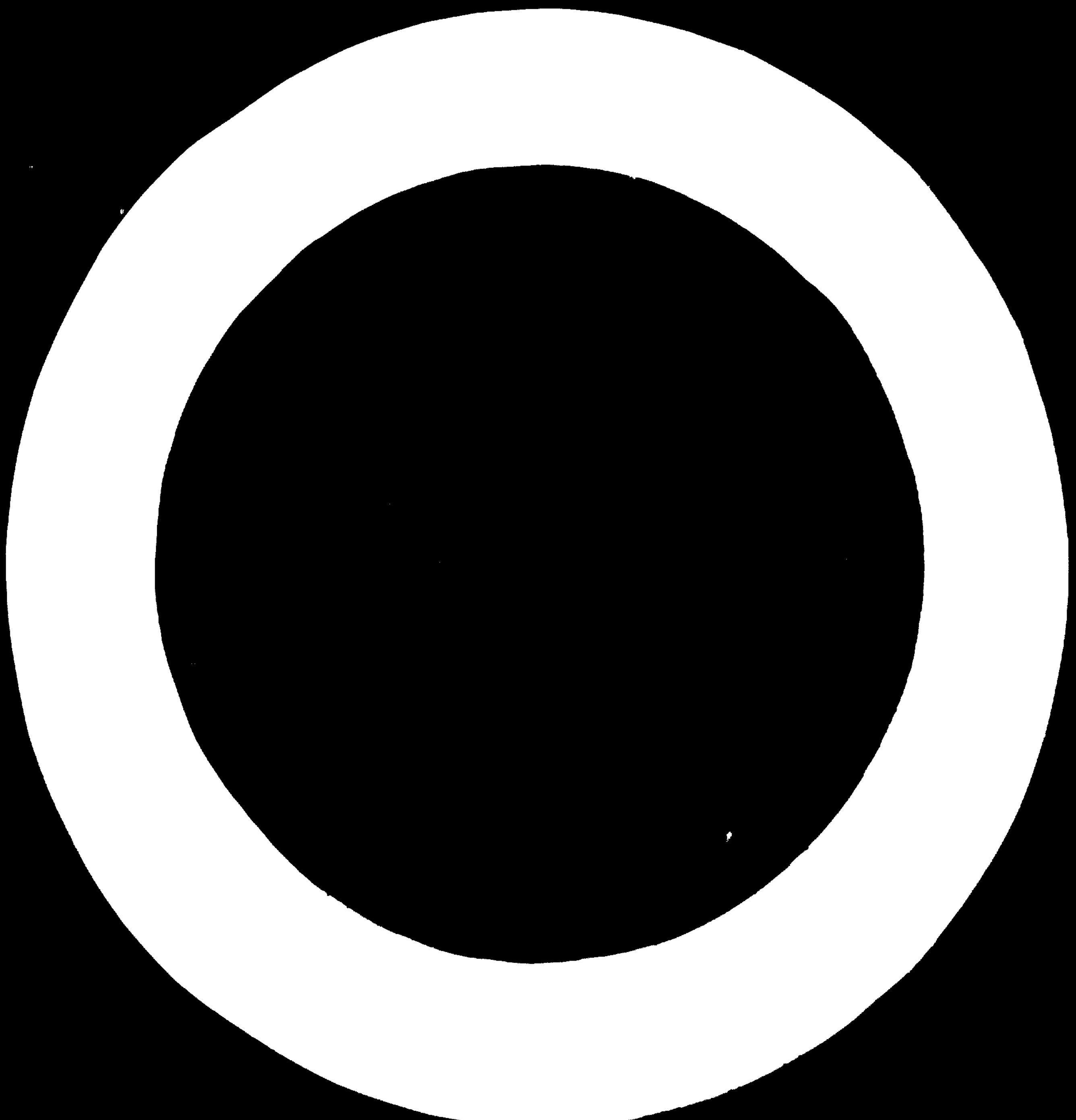
SALT QUALITY

Salt from traditional saltworks is usually of low quality because it contains large percentages of magnesium, other impurities and moisture. It is purified for food purposes in nine table-salt preparation plants and two refineries. Quality is also important for the chemical industry and for other consumers such as fish canneries.

A recent lowering of the quality of the salt has been observed in connection with the statutory marketing arrangements; the price of salt has been established for each area regardless of its quality. This difficulty will be quickly removed by establishing three new classifications of crude salt according to the percentages of sodium chloride, moisture and organic matter. Experience in the reinforcement of pond bottoms by impermeable material has shown that it enables the harvesting of high-quality salt.

Re-crystallization of rock salt in seawater

The re-crystallization of rock salt in seawater is being tested in Algarve because of its good climate and the proximity of a rock-salt mine. The rock salt is transported in lump form by lorry to the ponds where it is dissolved in seawater to separate most of the impurities by re-crystallization. This work, which started in 1967 in a small pond, was extended to four ponds in 1968.



6. ITALIAN EXPERIENCE

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Introduction

The favourable geographical position of the Italian peninsula and of the island of Sardinia in the centre of the Mediterranean as well as the suitable climate have undoubtedly been the main reasons for the production of salt from seawater in Italy since the beginning of civilization. Many of the saltworks have been improved in accordance with modern techniques and new political and economic conditions.

At the end of the Second World War, the main saltworks in Italy were:

Italian mainland	Margherita di Savoia and Bari Cervia near Ravenna
Sardinia	Cagliari la Palma, Cagliari Santa Gilla and Carloforte
Sicily	Trapani

These saltworks were organized on an industrial footing and their over-all production, which was approximately 1 million tons per annum, was used by Italian industries. A considerable tonnage was, however, exported.

The Italian saltworks have been gradually improved to quite a high qualitative and quantitative level both in techniques and in the product. The layout and work methods varied; but they all had used manpower. The saltworks were large, and many men were needed.

Particularly in the southern areas where most of the saltworks were located, unemployment was common and the saltworks offered good permanent employment as well as attractive seasonal work which supplemented the seasonal farm work. Furthermore, the work in the salt plants, though tiring and unpleasant, attracted labour because the wages were higher than those offered by agriculture.

TRADITIONAL HARVESTING OF SALT

The simple mechanical equipment and tools were shovels, picks, wheelbarrows, Decauville tilting wagons, horses and tractors, small conveyer-elevator chains or belts. Even the pumping and all other maintenance operations were manual.

In the harvesting of the salt, the hard salt surface of the dried ponds was broken with a pick, shovelled into small heaps and left to drain for a few days. These salt heaps were subsequently shovelled onto wheelbarrows or Decauville tilting wagons, and thus conveyed from the ponds to the collecting areas. The salt was rarely collected in one area; usually there were many small scattered stockpiles in the saltworks. These stockpiles were shaped by hand. Washing plants were virtually unknown, but the harvested salt was nevertheless immaculately white, thanks to the skill with which the workmen loosened it from the bottom of the ponds. Its purity was also satisfactory because of the long period of seasoning in the stockpiles. For special types of salt, small purification plants were occasionally used for crushing, washing and centrifuging. The final operations were also manual; workmen removed the dark crust which had formed on the stockpile and then shovelled the salt onto the traditional means of transport.

Long practice in these methods of harvesting resulted in a high degree of training and specialization in the skills needed and in the adaptation of equipment to the particular needs of the work. In the early 1950s, the Italian saltworks operated with traditional methods and did not urgently need a complete review of these methods.

Therefore, before examining the reasons for a fundamental revision of operating methods in the Italian saltworks, which eventually led to their complete modernization with a high degree of mechanization, it is essential to bear in mind the economic situation of Italy in the post-war period. After the paralysing stagnation and destruction of the war years, steps were taken to rebuild and re-activate Italian industries. The fruitful results fostered general industrial expansion.

In the salt industry, the progressive wage increases weighed more and more heavily on the cost of production. The high proportion of manpower in the salt industry caused it soon to suffer a much higher cost increase than the average of other industries.

Furthermore, the sudden intensive industrial development of the north of Italy caused a migration from the depressed south to the more prosperous north and foreign countries. Government efforts and investments to provide new jobs in the south for the remaining workers deprived the salt industry of additional labour. It was difficult for the Italian saltworks to meet the constant wage increases and even to recruit the labour required to harvest the salt.

The demand for industrial salt increased, but purer quality salt was required. The solutions of these new problems were difficult because they required changes in the established methods of harvesting salt.

The export market was also a problem. After a comparatively easy post-war period with a real dearth of salt, competition became much keener. Many new saltworks had been started; many of them were favourably located in relation to certain markets or in countries whose economic conditions permitted highly competitive costs of production. In addition, the considerable increase in freight charges as a consequence of international events completely excluded certain markets from the Italian salt industry.

Thus, in the 1950s, the Italian salt industry was faced with an increasing series of grave problems which could only be solved by producing a higher-grade salt than in the past at a lower cost. Therefore, it was imperative to review the industry completely.

MECHANIZATION AND MODERNIZATION

The first step was quite obviously to replace the prohibitively expensive labour by machinery as far as possible. But, the negative aspects of this reform could not be overlooked. These included the introduction of costly machinery into highly corrosive surroundings in areas situated far from industrial centres and into the hands of totally inexperienced workmen, who were unaccustomed to handling machinery of any kind.

It proved comparatively easy to replace men by machines for all the operations for which machines were then available, as long as due allowance was made for special local conditions. Thus, in the selection of more efficient pumps and the apparatus for their automatic control, it was essential to buy well-protected equipment which could endure the saline atmosphere and which was simple to operate. It proved also fairly easy to choose the right excavators, dumpers, tractors, wagons, lorries, conveyer belts, elevators etc. for conveying, stockpiling and loading. Here too, the local conditions were considered, especially the bearing capacity of the soil.

Salt-harvesting machines

The real difficulties arose in the mechanisation of harvesting, which must be a quick operation to avoid the autumn rains. Harvesting always required many workers.

Salt-harvesting machines had not been used previously. It was not feasible to adapt any available machines to this task in view of the many peculiarities, including the highly variable hardness of the top crust of salt; its thickness could also vary from a few cm to more than 20 cm; the looseness of the ground at the bottom of the ponds on which even a man's weight would often leave a deep imprint; the necessity to harvest the maximum amount of salt without disturbing the bottom of the pond; the need to load the harvested salt straight from the pond onto the conveyance which would take it to a central stockpile.

There was never a suitable span of time for testing the machine before it was put to use; once the harvesting had started, it was almost impossible to make any radical changes in the machines which had been built during the previous year.

Of all these points, the bearing capacity of the soil in the salt ponds determined the types of machines eventually built. In fact, different harvesting machines were designed suitable for the various bearing capacities in the ponds. Thus in compact soil, a self-propelling machine was built which could load directly from the ponds onto the trucks which took the salt to the stockpile. Special machines were designed for harvesting the salt in ponds with soft or loose bottoms; the trucks were loaded outside the ponds.

It took several years before these two types of machine were perfected. The output of both types is about 250 m^3/hour. Neither machine could be used without a complete rearrangement of the ponds. Indeed, for these machines to operate successfully, each pond had to be of a regular shape and cover a much larger area than the small ponds, which had been handed down through centuries of modifications and were irregular in shape.

Rearrangement of ponds

The mere rearrangement of the old salt ponds proved to be arduous, not only because it was extremely costly but also because of the technical difficulties of the levelling work. It was also impossible to interrupt the production process at any time. The rearrangement therefore had to be carried out in stages. Every year work was done on a proportion of the ponds during the winter in spite of the hardship of working on more or less marshy land. Another reason for proceeding in stages was to allow time for the soil in the new ponds to settle properly.

The rearrangement of the ponds was, without a doubt, the largest and the most costly part of the mechanization process. It did, however, have the further advantage of reducing the actual number of ponds, thereby also the number of dikes and thus affording savings on maintenance. Maintenance operations were also mechanized by the use of specially built levelling machines and rollers.

Lower production costs were a result of all these technical changes in the saltworks and the considerable decrease in wages. However, it was imperative to improve the appearance and quality of the salt, especially its chemical purity.

A washing and purifying plant therefore became necessary. It seemed best to perform this operation during harvesting and before stockpiling. Here too it proved necessary to design and test special machinery.

Some negative aspects of these profound transformations should be mentioned. Mechanical harvesting and washing of the salt undoubtedly waste more salt than the old methods. In order to maintain production at the old levels, it has therefore been necessary to enlarge the ponds.

Maintenance and amortization costs

The large-scale introduction of machines which are often used only a few weeks a year implies problems of maintenance and of amortization. Maintenance can no longer be limited to an annual coat of paint; this task must now be undertaken by preventive maintenance specialists. Furthermore, some of the machines must be covered during the winter months. Amortization costs are no longer negligible because of the high value of the equipment and the exceptionally corrosive atmosphere. Although the harvesting machines and the washing plant are actually in use only a few weeks in each year, it would be incorrect to calculate their depreciation over many years without bearing in mind that they may well become obsolete before the end of this period.

The salt industry must be a modern industry that is willing to adopt new methods and play its full part in the national economic development.

7. ENERGY REQUIREMENTS AND RELATED COSTS OF SELECTED DESALINATION PROCESSES IN THE UNITED STATES

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Introduction

The economics and prospects of making fresh water from seawater by desalination are of interest for a solar-salt industry. The most favourable conditions for solar-salt locations - consistently high evaporation rate, low precipitation and high solar insulation - are conditions of arid areas. Therefore, desalting of seawater to make fresh water at solar-salt locations can be expected in the future.

Although solar energy accounts for a very large proportion of the total energy required to produce salt by solar evaporation of seawater, the use of solar energy has generally not been found to be economical for desalting water except in small units. The majority of the present commercial seawater desalting plants are based on a distillation process. Freezing has thus far found very limited application, and the membrane processes are usually used for desalting brackish waters with up to 5,000 ppm of salt.

DESALINATION PROCESSES

Before discussing the energy requirements for desalination plants, a description of several processes will be given. With the distillation processes the brine effluent concentration may be raised from about twice seawater to perhaps four times seawater. If the brine is to be used in a solar-saltworks, an analysis of the combined operation for minimum total cost would be in order. Three distillation processes are of special interest: the multi-stage flash (MSF) process, the multiple-effect multi-stage flash (MEF) process and the multiple-effect vertical tube evaporator (VTE) process.

Multi-stage flash distillation

Figure 1 shows the flow of seawater, brine and condensate through a typical MSF process. Seawater enters the plant through a submarine pipeline and intake pit. The water passes through a screen to the seawater intake pump. Or it may be introduced directly from the intake pit to the heat-rejection section of the evaporator. Alternately, it may first be pumped to a settling tank and storage tank if these are provided. A booster pump is then necessary to introduce the seawater into the evaporator heat-rejection section. Seawater coolant and brine blowdown are returned to the ocean through separate outfall systems.

Figure 1

Multistage flash distillation

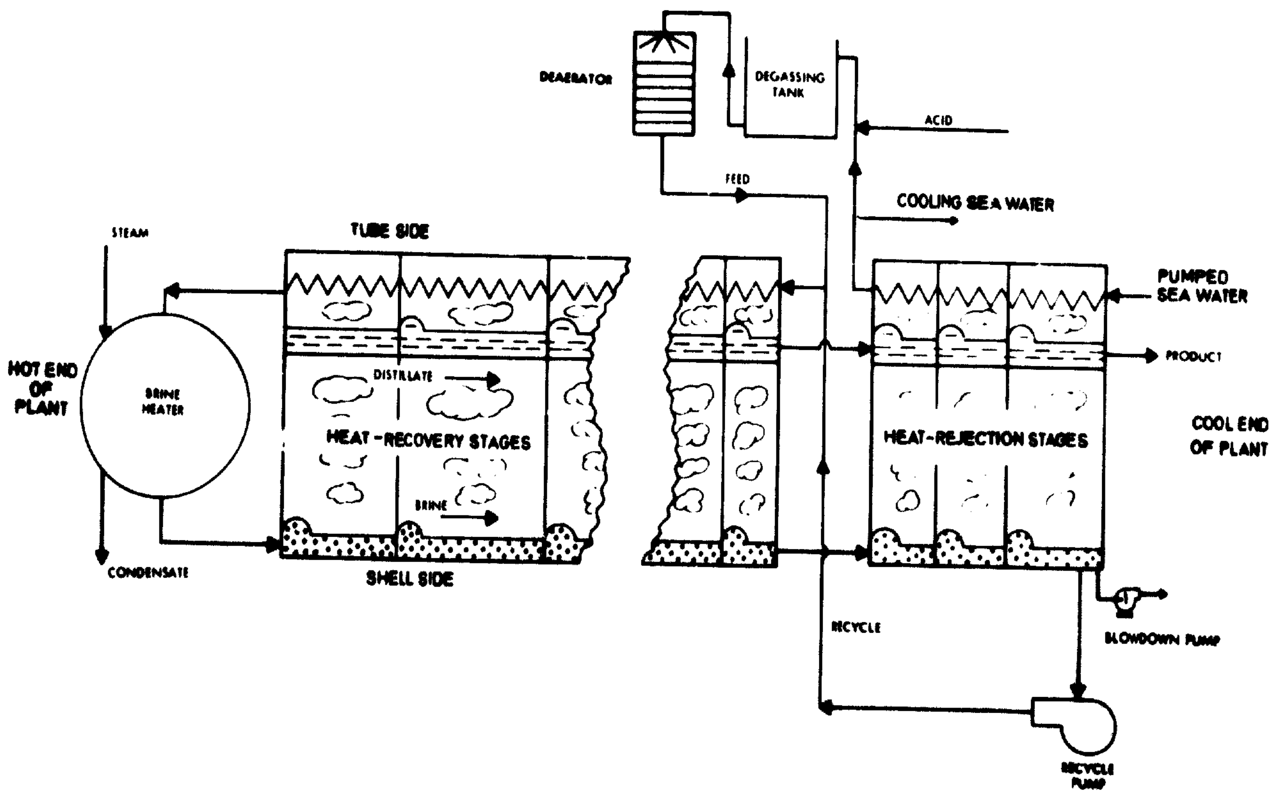
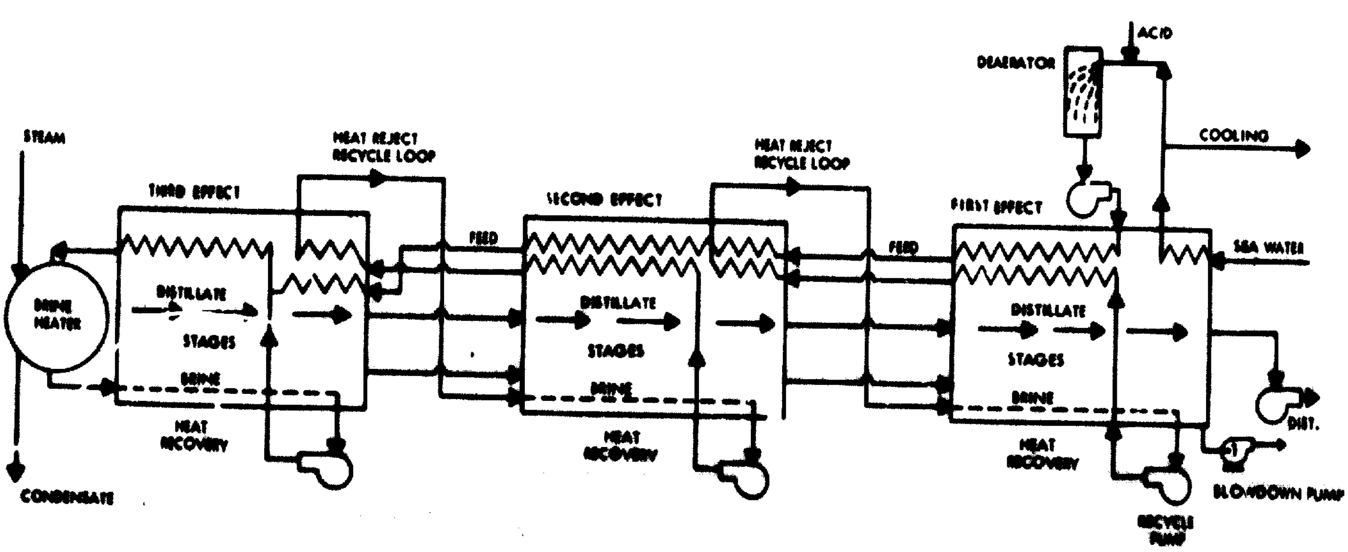


Figure 2

Multiple-effect multistage flash distillation



Dissolved carbon dioxide and air must be removed from the seawater to very low levels in order to mitigate scaling and corrosion, and to minimize the quantity of non-condensibles which would impair heat transfer. To remove carbon dioxide, sulphuric acid is injected into the seawater stream. The carbon dioxide thus released from the bicarbonates and carbonates is then stripped from the seawater.

Seawater is heated by passing through the tubes of the evaporator heat-rejection section. The coolant portion of this stream is then returned to the ocean through the outfall pipe. Acid is proportioned into the remainder as it flows to an atmospheric degassing tank. A series of overflow and submerged weirs assures thorough mixing of the acid with seawater and promotes evolution of the carbon dioxide from the water.

From the degassing tank, the seawater stream flows to a vacuum deaerator. This vessel is operated at the same absolute pressure as the coolest flash stage. In the deaerator, the remaining dissolved carbon dioxide and air are stripped from the seawater by the combined effect of the vacuum and stripping steam. A vacuum is maintained by a steam jet ejector. The deaerated seawater serves as the make-up to the plant and is mixed with the recycle stream. These two streams are now combined and pumped through the remaining tubes of the evaporators and the brine heater before being introduced into the shell side of the highest temperature stage. The shell-side brine then cascades from stage to stage. In each stage some of the water flashes from the brine solution is condensed on the tubes of the evaporator and caught in troughs positioned below the tubes. The distillate also cascades from stage to stage.

Finally, the shell-side brine and the cooled distillate reach the lowest pressure and temperature stage. At this point, the distillate is pumped from the system as product. The brine in excess of that required for recycle is pumped from the system and discharged to the ocean as blowdown. The remainder of the brine is mixed with the make-up and recycled through the system.

<u>Multiple-effect multi-stage flash distillation</u>

The multiple-effect multi-stage process shown in figure 2 utilizes several simple multi-stage flash systems or "effects" arranged in series. Each effect operates over a part of the total temperature range. Brine is recycled within each effect. Fresh seawater is added to the first effect as make-up. Each succeeding effect receives blowdown from the previous effect as its make-up. A steam-heated brine heater supplies the heat to the left-hand (first) temperature effect. Each succeeding effect makes use of the heat-rejection stages of the previous effect as its brine heater.

Seawater make-up is heated in separate bundles of condenser tubes to the first-effect blowdown temperature. At this point, it is mixed with the first-effect recycle brine before entry to the first-effect heat-recovery section.

In other respects, the plant is similar to the MSF plant. Seawater coolant is circulated through the heat-rejection stages of the last effect. Carbon dioxide, dissolved air and other gases are removed from the seawater make-up before entry to the cycle. Non-condensibles are vented from each flash stage to prevent blanketing of the heat-transfer surface.

In operation, the flash evaporators in this plant are identical to those in a standard multi-stage flash plant, except that the make-up and recycle brine flows are heated in separate condenser bundles until they reach the heat-recovery stages of the last temperature effect. At this point, they are combined to a single stream.

As in the MSF process, brine from the brine heater flashes into the first-stage flash chamber of the first temperature effect of the MEF. This brine flashes from stage to stage in the first effect. In the last stage of each effect, the flashing brine is divided into two streams. One stream is recycled and the other stream is blowdown to the next effect, where it serves as make-up to that effect. This is repeated in each effect until the flashing brine reaches the last stage in the last temperature effect where the blowdown is rejected to the ocean.

Distillate is collected beneath the condenser bundles and cascaded from stage to stage and from one effect to the next. Total distillate flow from the last stage of the last temperature effect is pumped from the system as product.

<u>Vertical-tube evaporator</u>

Figure 3 shows a forward-feed, multiple-effect, falling-film, vertical-tube evaporator (VTE) with a multi-stage flash evaporator for a feed heater. The vertical tube effects and the flash feed heater constitute parallel streams for the flow of brine and heat. About three fourths of the total heat supplied to the first effect are used to vaporize a portion of the seawater feed passing through this first effect. This heat is passed as latent heat from effect to effect as the vapour from each effect condenses in the succeeding effect, creating an equivalent amount of vapour from the brine flowing isothermally through the tubes of that effect. In this fashion, the effects create over 80 per cent of the product. The remainder of the total heat supplied to the first effect completes the sensible heating of the seawater feed to its maximum temperature. The flash feed heater accomplishes the regenerative heating of the feed, supplies brine at the appropriate temperature to each effect, cools the cumulative distillate and produces the remainder of the total distillate.

In a typical case, after the incoming seawater has been screened, a part of it is acidulated and pumped to the deaerator where it becomes part of the feed. Another part of the incoming seawater goes into the tubes of the final heat-rejection condenser where it is partially heated, and a substantial portion of the seawater from the final condenser is returned directly to the ocean as a heat-rejection stream. The remainder of the seawater from the final condenser is acidulated and pumped to the deaerator to provide the remainder of the feed.

The two streams of acidulated seawater are now at different temperatures and are sprayed into the deaerator in countercurrent to the stripping steam. The deaerated stream is pumped into the condenser-tube bundles of the multi-stage flash evaporator at the coolest stage. The seawater feed passes through all of the stages as its temperature is increased by the heat from condensing vapour in each stage.

The entire feed brine then goes to the brine chest of the first effect, passes through individual spray nozzles into the vertical tubes where steam from an outside source raises the feed to its maximum temperature and vaporizes several per cent of it. The brine then flows into a distribution chamber from which it passes through an orifice into the first flash-evaporator stage where flashing occurs; it cools the brine to the saturation temperature of that stage. The vapour passes through the entrainment separator, condenses on the feed-heater bundle and falls into the distillate tray. The brine and distillate then flow separately through orifices into the next lower temperature and pressure where both streams flash down to the saturation temperature of that stage. The vapour from both streams condenses on the condenser-tube bundle and falls down to join the distillate stream. This process continues until the coolest stage, at which point the distillate is pumped to the

Figure 3

Vertical-tube evaporator with multistage flash feed heater

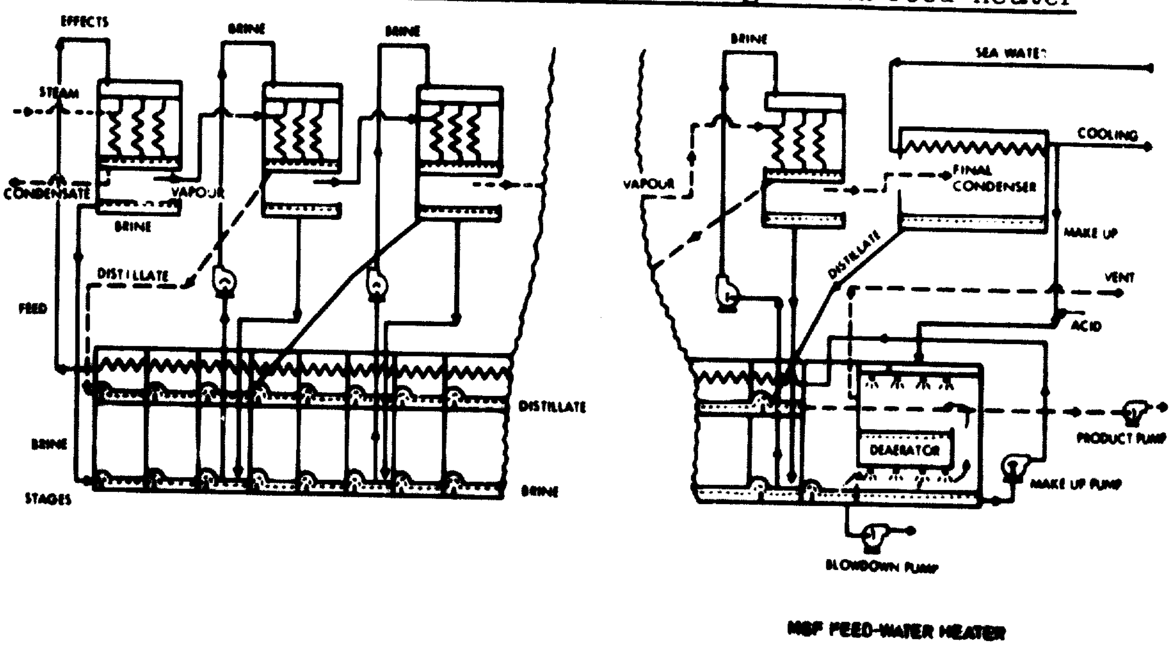
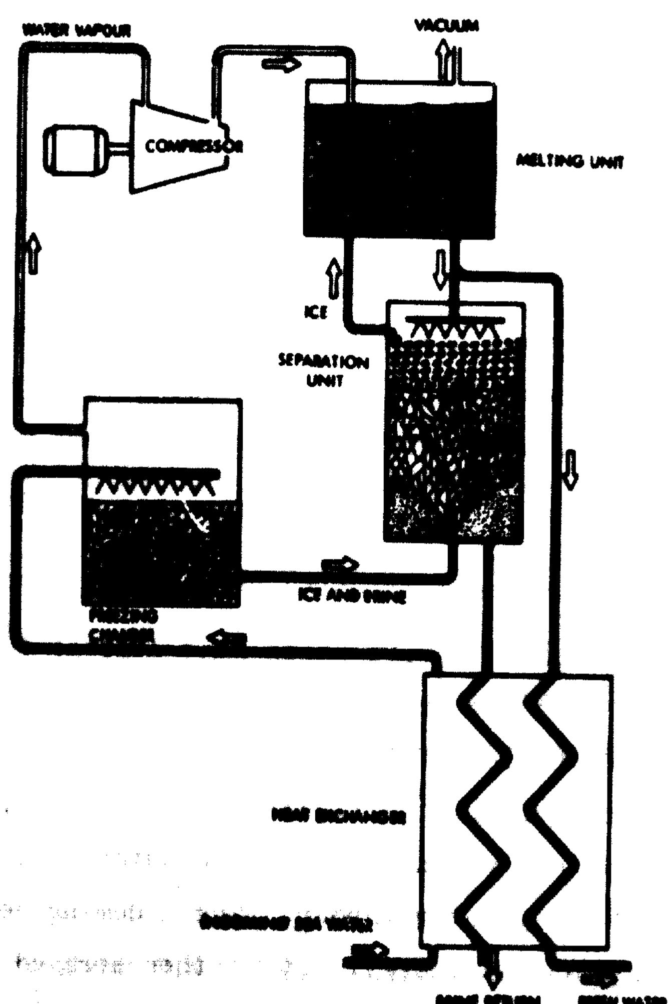


Figure 4

Vacuum freeze-vapour compression process



product water system. The brine from the lowest temperature stage is flashed to provide the stripping steam for the deaerator before it is pumped back into the ocean.

The vapour that is generated in the first effect disengages from the brine at the tube exit, passes to the next lower temperature effect, condenses on the tubes and is collected and combined with the distillate stream in the first flashing stage. For each succeeding vertical tube effect, brine is pumped to the brine chest from a flash stage at the same temperature as the VTE effect. Vapour is generated as the brine flows down the vertical tubes and the vapour flows downward with the brine. The brine, which is still at the same temperature as the flash stage from which it was pumped, returns to the stage. The vapour disengages from the brine after emerging from the lower end of the vertical tube, passes through the entrainment separator, condenses in the next effect and is sent to the distillate stream in the flash stage at the same temperature. This process continues through all of the effects and in the last effect the vapour released is condensed in the final condenser and the distillate sent to the distillate stream in the last flash stage. In this fashion, all of the heat of vaporization supplied to the first effect is passed as latent heat to the final condenser. Each effect has the same heat duty; there is virtually no gain or loss of heat between the vertical tube evaporator and the multi-stage feed heater. Vapour equalization passages between associated effects and stages are provided to accommodate design uncertainties and operational problems.

This process requires that there be a flash-evaporator stage at the same saturation temperature as each vertical tube effect. This means that the intereffect temperature decrement must be spanned by some whole number of flash-evaporator stages.

Freeze desalting

Most of the freeze-separation processes have similar functional components. This is due to the fact that the freezing processes utilize similar mechanisms for ice formation and separation of ice from brine. The vacuum freeze-vapour compression method shown in figure 4 illustrates this point. This scheme is a direct refrigeration method which utilises the water as a refrigerant and then compresses the resulting water vapour. The incoming seawater is cooled in a heat exchanger to conserve energy. It is then sprayed into a freezer maintained under sufficient vacuum to cause ice to form. A slurry is led to a separator with the ice going to a melter. Cold is recovered from the melted ice as it leaves the system. The water vapour formed in the freezer is compressed and led to the melter, there by exchange of heat, the ice is melted and the vapour condensed; both become product water.

ENERGY REQUIREMENTS FOR DESALTING

All of the desalting processes require a considerable expenditure of energy to separate the water from the salt. The vapour pressure of seawater at any given temperature is less than the pressure necessary for recondensation of the vapour to liquid. Thus, the water must not only evaporate from the seawater, but the vapour must either be cooled or compressed to effect recondensation. The compression energy is the energy required to separate water molecules from the ions in the seawater. This amount of energy or work of separation represents the absolute minimum for separation of water from the saline solution regardless of the desalting process used. It can be used as a yardstick to compare actual processes with the minimum energy. In any event, it is unlikely in practical cases, that the actual energy required will ever be less than, say, ten times the minimum.

The minimum work of separation is the thermodynamically reversible work at zero recovery; that is, with zero product. This work may be represented by the equation:

$$-W = \Delta F = RT \ln a,$$

where W = Minimum work of separation;
ΔF = Change in free energy
R = Universal gas constant;
T = Absolute temperature;
a = Activity of water in salt solution;
$\ln$ = Logarithm to the base e.

Fabuss and Korosi (1966) have calculated water activities for a standard seawater and for its concentrates based on experimental measurements of vapour pressure of several binary and ternary solutions representing the major seawater components. At 25°C, the activity of water in standard seawater is 0.982. The minimum work of separation is, therefore:

$$-W = RT \ln a,$$
$$W = -(1.9872)\ (298.2)\ (\ln 0.982),$$
$$W = 10.77 \text{ cal/gram mol.}$$

This is equivalent to about 0.695 kWh/m^3, which is in good agreement with the value of 0.706 kWh/m^3 calculated by Stoughton and Lietzke (1965) from osmotic

Figure 5

Minimum energy requirements for desalting seawater at various temperatures

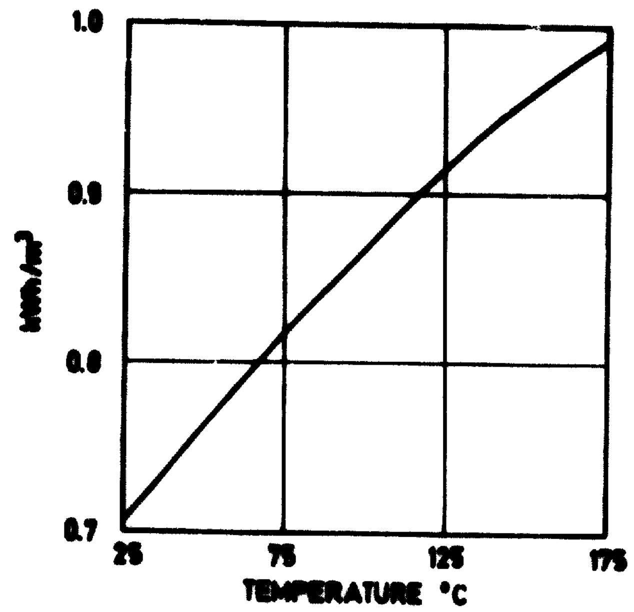


Figure 6

Minimum energy requirements for recovery of water from NaCl solutions as a function of per cent recovery

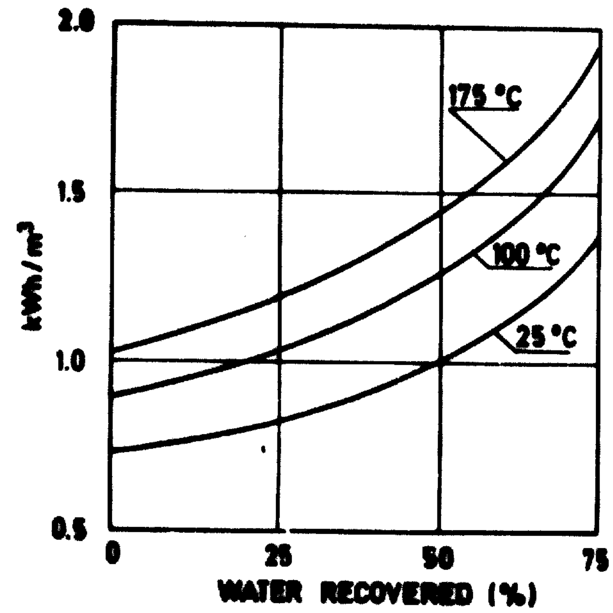


Figure 7

Activity of water in seawater and seawater concentrates as a function of temperature

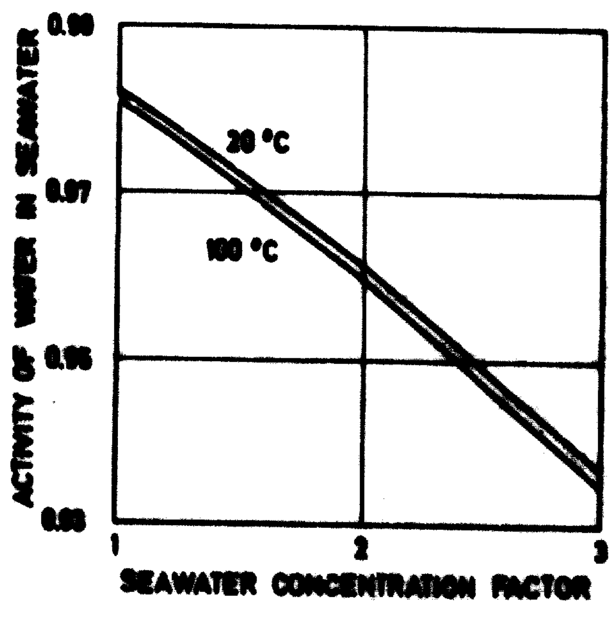
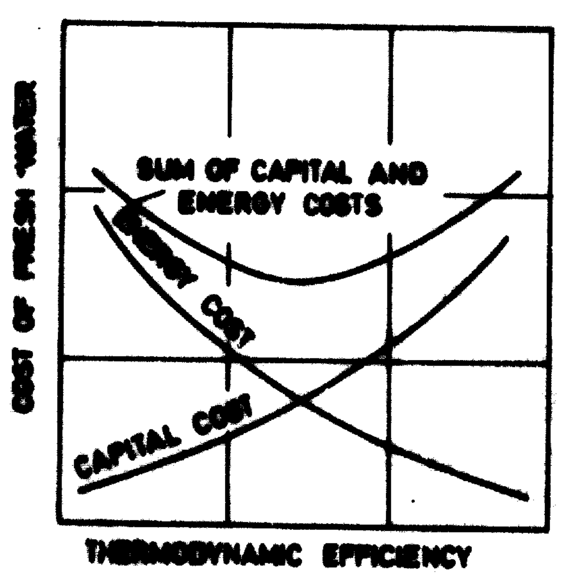


Figure 8

Variation in water cost with plant efficiency



coefficients and neglecting any precipitation of calcium sulphate. To concentrate to twice seawater at isothermal conditions of 25°C in a completely reversible manner, the minimum energy (Spiegler, 1966) is about 1.0 kWh/m^3. Figure 5 is a plot of the minimum energy of separation of water from seawater as a function of temperature; figure 6 shows it as a function of the per cent recovery of water (Stoughton and Lietzke). The minimum energy of separation can also be calculated for selected conditions from the activity data (Fabuss and Korosi, 1966) presented in figure 7.

For practical processes in which energy expenditure or efficiency must be balanced against the capital cost of the apparatus necessary to obtain a certain thermodynamic efficiency, many irreversible effects must be considered. These include fluid friction, pressure losses, temperature differences necessary in heat exchangers, heat losses, fluid mixing when there is a temperature or concentration difference and mass transfer with a finite concentration gradient.

In an optimization for minimum cost, the primary consideration is the cost of energy and capital investment. The two items normally represent 80 per cent or more of the total water cost. This can be illustrated as shown in figure 8 by plotting water cost against plant thermodynamic efficiency for the energy and capital components. For any given energy cost as the plant efficiency is increased, less energy is required for a specified plant output. Hence, per unit of output, the energy cost component of the water cost decreases with an increase in plant efficiency.

In order to make the plant more efficient, for example with the distillation processes, more heat-transfer condenser surface is required. In order to accommodate more condenser surface, other items must also be increased. This results in a higher capital cost as the plant efficiency is increased. Hence, per unit of output, the capital cost component of the water cost increases with an increase in plant efficiency. If these two curves are added, a curve with a minimum is obtained as shown on figure 8.

The minimum point on the curve is the least costly desalted water that can be obtained for the conditions assumed. The plant would then be built to operate at the efficiency determined from figure 8.

Mechanical or electrical energy is the type of input energy required in a freezing process. It is used to operate the pumps, compressor and other process equipment. It is sometimes mistakenly pointed out that a freezing process has a potentially higher efficiency than a distillation process based on the fact that the latent heat of fusion of water is only about one seventh of its latent heat of evaporation. However, for realistic values of the controlling parameters, there is very little difference between the freezing and distillation processes in the energy required.

Wiegandt (1960, p.82) has given the minimum work of separation for freezing in the following equation:

$$W = \frac{(\Delta H_f)\ (\Delta T_{fpd})}{T}$$

where ΔH_f = change in enthalpy,
ΔT_{fpd} = freezing point depression,
T = absolute temperature.

Since the minimum work of separation is independent of the process, the values of figure 6 apply to the freezing process. When one takes into account the irreversible effects in any practical system, one can compute a realistic energy target for freezing processes (Spiegler 1966, p.299) in the order of 10.5 kWh/m^3.

For the demonstration plant of the US Office of Saline Water, Point Loma, San Diego, California, on a typical operating day in February 1964, the thermal input to the plant was about 320,000 kWh/day (US Office of Saline Water, 1964). For the plant output of 1,028,000 US gal/day of desalted water, this is equivalent to about 320 kWh/1,000 US gallons, which is more than 80 times the normal energy of separation for a seawater concentration of twice the normal salinity. Since in this plant the major pumps were steam-turbine driven, most of the energy input to the desalter was in the form of steam. Main pumps and their powers are listed in table 1.

Table 1

Power requirements for major pumps in the 3,785 m^3/day multi-stage flash plant at Point Loma

Type of pump	Number	Connected (hp)	Total (hp)	
Seawater	1	60	60	
Product	1	30	30	(turbine)
Blowdown	1	30	30	(turbine)
Recycle	2	325	650	(turbine)
Condensate	2	5	10	
Boiler feed water	2	40	80	
Boiler make-up	1	5	5	
		Total	865	(645 kW)

By contrast the Clair Engle plant, also of the US Office of Saline Water, San Diego Saline Water Test Facility, Chula Vista, California, which uses the multiple-effect multi-stage process, is considerably more efficient (Mulford, 1968). This plant uses about 145 kWh/1,000 US gallons, which is less than 40 times the minimum energy of separation for a seawater concentration of twice normal salinity. As previously discussed, the selection of any given efficiency must be based on an optimization of all costs to give the lowest total cost. The major pumping energy requirements for the Clair Engle plant are shown in table 2.

Table 2

Power requirements for major pumps in the 3,785 m^3/day multiple-effect multi-stage flash plant at Clair Engle

Type of pump		Connected (hp)
Recycle:	1st effect	125
	2nd effect	125
	3rd effect	100
Blowdown		20
Product		40
Seawater		125
Make-up		250
Condensate		7.5
	Total	792.5 (591 kW)

Two very important design variables to minimize energy requirements by developing an efficient flash evaporator system are the cross-section of the flashing brine flow path and the devices incorporated to provide stage-to-stage brine flow. These design problems become more acute as the brine enters the cooler areas of the evaporator train where the pressure drop available for brine flow from one stage to the next diminishes rapidly. Consequently, the brine flow width should be selected to produce low superficial velocities through the stages.

The condensing efficiencies of condensers in large-capacity plants can be materially affected by the design of the tube bundle cross-section. Of necessity, the tube bundles in large-capacity plants would be very large in the vertical direction, and thus the effect of condensate flowing downward through these bundles could possibly affect the over-all condensing coefficient. Suitable bafflings or vent channelling must be provided. If proper consideration is not given to these items, plant efficiency will be low and much energy will be required for each unit output of desalted water.

To provide one m^3/day of desalted water with an energy expenditure of 50 times the minimum work of separation in which 50 per cent of the water is recovered from the seawater would require the expenditure of about 43,000 kcal/m^3 or 15.7 million kcal annually. This amount of thermal energy consumed by an electrical generating plant operating at 33 per cent efficiency is equivalent to the production of about 60,000 kWh annually. Obviously, the cost of energy is a very significant component of the water cost. A substantial reduction in the cost of desalted water could be realized if a relatively inexpensive source of energy were available. It is for this reason that nuclear energy offers hope for large-capacity desalting.

SOLAR-SALT PRODUCTION

About 85 per cent of the salt produced in California is from solar evaporation. The largest production is in the San Francisco area. The second area is near San Diego. The area of concentrating ponds to crystallizing ponds is about 15 to 1. At one of the Leslie Salt Company facilities on San Francisco Bay, 5,696 hectares of concentrating ponds are required for 358 hectares of crystallizing ponds.

The Western Salt Company has 567 hectares of concentrating ponds and 41 hectares of crystallizing ponds. For the past few months, the Western Salt plant has been receiving brine from the Claire Engle plant. The brine concentration is slightly less than twice that of normal seawater. While it is too early to judge the results, the chief advantage is expected to be a reduction in evaporation time.

The Leslie Salt Company plant utilizes San Francisco Bay water with an average concentration of 3^{o}Be. For normal seawater, the concentration ponds would be reduced from 5,696 hectares to 4,856 hectares. If a distillation plant were to be integrated with a solar-salt plant, the area of concentrating ponds would be reduced about in proportion to the increase in salinity. For a brine of three times seawater concentration, the area of concentrating ponds would be divided by three. The primary advantage of the reduction of land required would depend on land value. A minor amount of energy may be saved by reducing the brine pumping requirements.

Another consideration in combining solar-salt production and desalting is to balance the output of desalted water and salt. Assume a desalter has an output of 4,000 m^3/day and discharges a brine of 7° Be from a seawater of 3.5° Be; the quantity of brine discharged is also 4,000 m^3/day. If the <u>per capita</u> water consumption is 0.25 m^3/day and the <u>per capita</u> salt used in 3 kg <u>per annum</u>, then 16,000 people would consume all of the water but only 48,000 kg of salt <u>per annum</u>. The 4,000 m^3/day of brine contains 205,000 kg of salt. Since in an average solar-salt process only 40,000 x 3.5 = 140,000 kg about 70 per cent of the salt is recovered, the salt production would amount to about 144,000 kg/day. Clearly, industrial use of salt must be high if advantage is to be taken of concentrated brine from a desalting plant. Caustic soda, chlorine and other industrial uses would be necessary to develop a sufficient market to make the use of the brine attractive.

<u>Table 3</u>

<u>Power requirements for major pumps and compressors for a 946 m^3/day freezing plant</u>

	Number	Connected (hp)	Total (hp)
Seawater pump	1	25	25
Prefreezer slurry pump	1	15	15
Module slurry pump	4	7.5	30
Brine recirculation pump	4	3	12
Product pump	4	5	20
Brine discharge pump	4	7.5	30
Coolant pump	1	5	5
Prefreezer compressor	1	120	120
Refrigerant compressor	1	100	100
Vacuum pump	5	3	15
Blower	5	7.5	37.5
Slurry agitator	5	7.5	37.5
Main compressor	4	75	300
		Total	747.0 (557 kW)

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8. INDIAN EXPERIENCE

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HISTORY, LAW AND GEOGRAPHY

Background

Until recently, salt was used in India essentially for edible purposes, and its recovery by solar evaporation of seawater has been practised for centuries. Even now seawater represents the major source of salt in the country.

The salt industry has a chequered history before India attained independence in 1947. Before the First World War, salt from the princely states in India was forbidden entry into the rest of the country with the result that salt from the Cheshire England mines was imported into West Bengal. Even when the restrictions were removed, salt continued to be imported until 1947 from Aden, which was under the jurisdiction of the Government of India at that time. There was also a tax on salt equal in value to several times the cost of salt. The salt tax was criticized vehemently for many years; resistance to payment of the salt tax was an important part of the national movement for independence.

Since 1947, many steps have been taken by the Government of India to encourage increased production of good-quality salt. The duty on salt was abolished in 1947 and a directive principle was incorporated in the Constitution of India that salt should remain free of duty. However, a cess is levied under the Salt Cess Act at a maximum rate of $0.47/ton, which is roughly a quarter of the production cost of salt, to obtain funds for improving the industry and for labour welfare activities. Cess is charged at half the rate if the saltworks have a total area between 10 and 100 acres; those below ten acres are exempted from payment of cess altogether to encourage self employment in the industry. Co-operative society saltworks pay cess at rates applicable to the holdings of individual members. Three special committees were appointed by Government in 1948, 1950 and 1958 to review the progress of the industry and to suggest measures for its expansion etc. A Central Salt Advisory Board and regional committees consisting of officials as well as representatives of different interests in the industry meet regularly to discuss the problems of the industry. The Salt Commissioner and his officers located in all parts of the country are responsible for ensuring improvement in the quality of salt as well as for maintaining regular distribution of salt throughout the country. This concerted action has enabled the country to become self-sufficient within a few years and to export salt since 1951. The distribution of production between the various sized saltworks is shown in table 1.

Table 1

1967 output of Indian licensed saltworks according to plant capacity

Plant capacity (1,000 tons)	No. of plants	Annual output (1,000 tons)
>100	3	653
50 to 100	21	1,462
10 to 50	30	645
<10	5,022	1,513
Total	5,076	4,273

Regulation of the industry

Saltworks larger than ten acres have to obtain a licence from the Office of the Salt Commissioner under the Ministry of Industrial Development. Further, as many of the saltworks are situated on Central or State Government lands, they have to obtain the land on renewable leases that are now granted for twenty years at a time. Unsatisfactory performance or non-observance of the directives of the Salt Commissioner for improvement in the quality of salt is cause for termination of the lease. This clause has been most effective in ensuring improvement in the quality of salt as well as in achieving the targets of production. The two Government saltworks at Kharagoda in Gujarat and at Sambhar Lake in Rajasthan accounted for nearly a third of all salt produced in the country 30 years ago. With the growth of very large privately owned saltworks since 1948, Kharagoda and Sambhar only produced 5 per cent in 1968. These saltworks are managed now by the two public-sector undertakings Hindustan Salts Ltd. and Sambhar Salts Ltd.

The annual production of salt by the organized sector since 1958 is listed in table 2:

Table 2

Salt production by licensed saltworks
(thousand tons)

Year	Sea brine	Brine springs	Lake brine	Rock salt	Iodised salt	Total
1958	2,670	809	359	5.2	0.6	3,843.8
1959	1,965	671	280	3.7	0.7	2,920.4
1960	2,314	556	278	4.3	0.6	3,152.9
1961	2,290	650	211	4.3	0.6	3,155.9
1962	2,473	697	325	4.5	0.7	3,500.2
1963	2,984	827	314	3.4	4.6	4,133.0
1964	3,206	778	240	2.9	21.8	4,248.7
1965	3,325	782	279	2.9	48.6	4,437.5
1966	3,175	870	226	4.1	47.3	4,322.4
1967	3,259	735	220	3.6	55.6	4,273.2

The figures for the production of iodized salt (one part of potassium iodate in 40,000 parts of salt) are also included, as its distribution represents a rapidly expanding and successful campaign for the control of goitre that was introduced with the assistance of UNICEF. Precise figures for production from saltworks smaller than 10 acres are not available, but at present it is estimated to be 300,000 tons.

Geographical location of saltworks in India

A dry hot climate, a short season of moderate rainfall, high winds and large flat tracts of land along the sea coast that are unsuitable for crops are ideal conditions for solar-salt production. Such conditions are available in the extreme west of India in Gujarat, and therefore this area is responsible for more than half of all salt production in the country. However, as the cost of transport of salt over long distances is high in comparison with its cost of production, medium-size and small saltworks have been set up along the entire coastline of India. The most adverse circumstances are in West Bengal where the seawater is rather dilute because of the inflow of fresh water from large rivers, and the evaporating season is short because of two rainy seasons in a year. For this reason, very little salt is produced in West Bengal. Saltworks also exist inland where lake or pit brine is available in adequate amounts. Rock salt is available only at one place in northern India in Himachal Pradesh, but its production is almost negligible because mining is difficult in the highly disturbed sedimentary strata.

The saltworks are organized to ensure that the salt crystallizes in the hottest months of the year with minimum interference from rains. By a systematic study of the climate, each saltwork determines when the rains are expected and evaporates the brine with the maximum benefit; the storage of salt is completed before the next rains. In the Gujarat region, particularly, in Kutch, a longer period for salt production is available because of the very scanty rainfall there; it ranges from 15 to 50 cm/year. There are 300 to 320 sunny days with strong hot winds every year. Hence, the yearly salt production of 100 to 120 tons/acre is the highest. On the south-east coast at Tuticorin, there are about 200 to 250 days of clear sunny weather. Here the annual production of salt is between 40 and 80 tons/acre. In the many small saltworks on the coastal regions of Andhra Pradesh, it is possible to have about 200 sunshine days.

Size and distribution of saltworks

There are three saltworks with annual production greater than 100,000 tons. The largest sea-saltwork produces almost 350,000 tons/year for use in the manufacture of soda ash and caustic soda. The second largest saltwork is owned by the Government and produces 190,000 to 200,000 tons of salt from brine springs; nearly 100,000 tons of this salt are marketed to industrial consumers. The third largest saltwork produces about 120,000 tons/year; part of it is exported and the rest is marketed in Calcutta.

There are 22 saltworks with annual production of 50,000 to 100,000 tons. Four of them produce salt from brine springs; one of these is in Didwana, Rajasthan and three in the Rann of Kutch. One of the latter is owned by the Government and has a production capacity of 150,000 tons of table salt. In the other 18 saltworks of this size on the Gujarat coast, two saltworks in Madras and one in Bombay, sea salt is harvested.

Most of the industrial and export demands for salt are met by 24 that produce 2 million tons/year which is 40 per cent of the total annual production.

Out of the 4.27 million tons of salt produced by organized saltworks, 76 per cent are from sea brine, 17 per cent from brine springs, about 5.5 per cent from lake brine and only a very small percentage from salt mines. The present pattern of consumption is:

60 per cent for edible purposes;

30 per cent for industrial requirements;

10 per cent for export.

The salt produced in the Gujarat region from sea brine is exported to Japan, East Africa and South-east Asia, while that produced on the south-east coast near Tuticorin port is exported from Madras to Ceylon. The inland saltworks in Rajasthan and Rann of Kutch export salt to Nepal.

The three soda ash factories in Gujarat have their own sea-saltworks. The fourth factory in Uttar Pradesh depends on the saltworks in Rajasthan. Of the 28 caustic soda factories, two are attached to the soda ash factories in Gujarat; two factories have sea-saltworks, viz., those in the south at Mettur Dam and Tuticorin.

The acreage licensed for harvesting of salt is capable of producing 8.5 million tons of salt if fully worked. Because of the low demand, however, only 4.8 million tons were produced in 1967. It is expected that by 1974 the demand will increase to 7.5 million tons. The revised demand pattern in million tons/year is expected to be:

	1967	1974
Table salt	2.85	3.80
Industrial salt	1.47	2.70
Exports	0.48	1.00
Total	4.80	7.50

In the salt industry, where production depends on climate, it is desirable to provide for surplus capacity in suitable areas. For example in 1966 during the drought, there was a bumper production of salt. This necessitated reduction in actual production in a few saltworks in 1967 to clear the accumulated stock. But in 1968, the monsoon was heavy, many saltworks were flooded and stocks were washed away. It may be necessary to increase production to meet the demand and to create a buffer stock to stabilize the price.

RECOMMENDATIONS BY SALT EXPERTS COMMITTEE

In April, 1948, the Government set up a committee to advise the measures necessary to place the salt industry in India on a sound footing, examine the existing methods of salt production and recommend steps to increase production and quality and reduce the cost. Other functions were also assigned to the Committee because when India gained independence, it was found that the country had to import salt from England or Aden to meet its internal requirements. Industrialization, particularly in the heavy chemical industries, could not take place without an increased production of salt. After detailed study and visits to the various saltworks, the committee made certain basic recommendations as well as several suggestions for improvement of individual saltworks. The basic recommendations were as follows:

Where rainfall is high and sea brine is diluted, the alternative method of tapping subterranean brine by tube wells should be investigated.

Bitterns should be prevented from draining into reservoirs used for the storage of brine.

The relative areas of crystallizing ponds and evaporating or concentrating ponds (reservoirs or condensers) should be fixed with due regard to the density of the initial brine.

In marine saltworks, the crystallizing ponds should be located together to facilitate easy harvesting and storage of salt and should be so placed as to have the benefit of the land breeze. It is advisable to have a small area of evaporating ponds intercepting the land breeze before it reaches the crystallizing ponds.

The crystallizing ponds should, so far as possible, be large, but where the single irrigation system is followed, the width may be fixed at 35 to 40 ft so that all parts of them may be within reach of the wooden scrapers. A gentle gradient should be provided in the beds of the crystallizing ponds so that the bitterns can be drained effectively into the bittern channels and puddles of mother liquor do not remain.

The partitions in the crystallizing area should be given a proper slope to the beds of the pans. In large crystallizing ponds, they should also be surfaced with stone so that the wave action of the brine does not continually wash away the edges and damage the earth walls.

Separate channels should be provided for the incoming brine and the outgoing bitterns.

Bitterns should be discharged before each crop is harvested.

Even where the single-irrigation system is followed, an attempt should be made to allow the crust to grow by accretion during the fair weather.

The sale of salt by volume should be banned by law.

Artificial evaporation in open, direct-fired pans should be discouraged. All table and a good proportion of industrial salt should be manufactured economically by solar evaporation only. When salt of high purity is required and is not directly obtainable by solar evaporation, vacuum evaporation is recommended.

This report formed the basis for a beginning of modernization in salt-manufacturing techniques, and the office of the Salt Commissioner was strengthened to implement it. Soon the country became self-sufficient in its requirements both of table and industrial salt. The first salt was exported in 1951.

In 1957, when production reached 3.6 million tons from the 1948 level of 2.3 million tons, Government appointed another committee to consider certain problems of the salt industry, particularly the steps to be taken to prevent haphazard growth and to help co-ordination between small and large salt producers. In its report presented in 1958, the committee recommended:

Production of larger quantities at lower cost;

Greater use of salt for industrial purposes and diversification of production;

Intensive export efforts;

Improvement in quality or standard of purity;

Greater emphasis on co-operatives, which are the proper agency for working numerous small areas throughout the country and for developing their production and employment potentialities;

Scientific and systematic development of small-scale production of salt which requires small capital investment but provides large employment opportunities;

Increasing attention to wages and welfare of workers in the salt industry.

It was recommended that all manufacturers of salt should henceforth be licensed regardless of the area worked. The only exceptions were those who manufactured salt for domestic or local use and not for regular trading purposes as contemplated in the Gandhi-Irwin Pact of 1931.

For smaller saltworks with an area of 10 acres or less, it was recommended that they should be registered with the Salt Department after complying with the conditions for registration. Existing small saltworks might register, but new small saltworks should be permitted to start manufacture only after registration. While registering such saltworks and granting them permission to manufacture salt, the Salt Department should control that all salt-producing units located in a particular area have full scope for growth and development and not be subjected to unhealthy internal competition resulting from limitations of brine supply or markets or the unavailability of labour or transport.

The registered saltworks should receive help and guidance from the Salt Department which should have complete information regarding the area: a map of the area, the quality and quantity of salt produced, the number of persons engaged in salt manufacture, the wages paid to hired labour etc. All existing unlicensed manufacturers of salt were to come under the proposed registration system. They would either be licensed or registered with the Salt Department. Saltworks with a total area of more than 10 acres required a licence from the Salt Department; those with a total area not exceeding 10 acres required a certificate of registration from the Salt Department.

Proper regulation by the Salt Commissioner of India has brought discipline into the industry. It has modernized its techniques and adapted them to local conditions to provide maximum employment in regions where alternative employment throughout the year is not possible. Railway transport is organized and regulated by the Salt Department to ensure the availability of salt at a uniform price throughout the country.

LAYOUT OF SALTWORKS

The fundamental principle has been to trap the sea brine during high tides by building a number of reservoirs and evaporating ponds to store sufficient brine for the production of salt by evaporation. The natural slope of the ground is effectively used to help the brine flow from one compartment to another in the reservoir and evaporating ponds. Necessary lift pumps and

Figure 1

General layout of Sumandi saltworks of the Industrial Development Corporation in Orissa

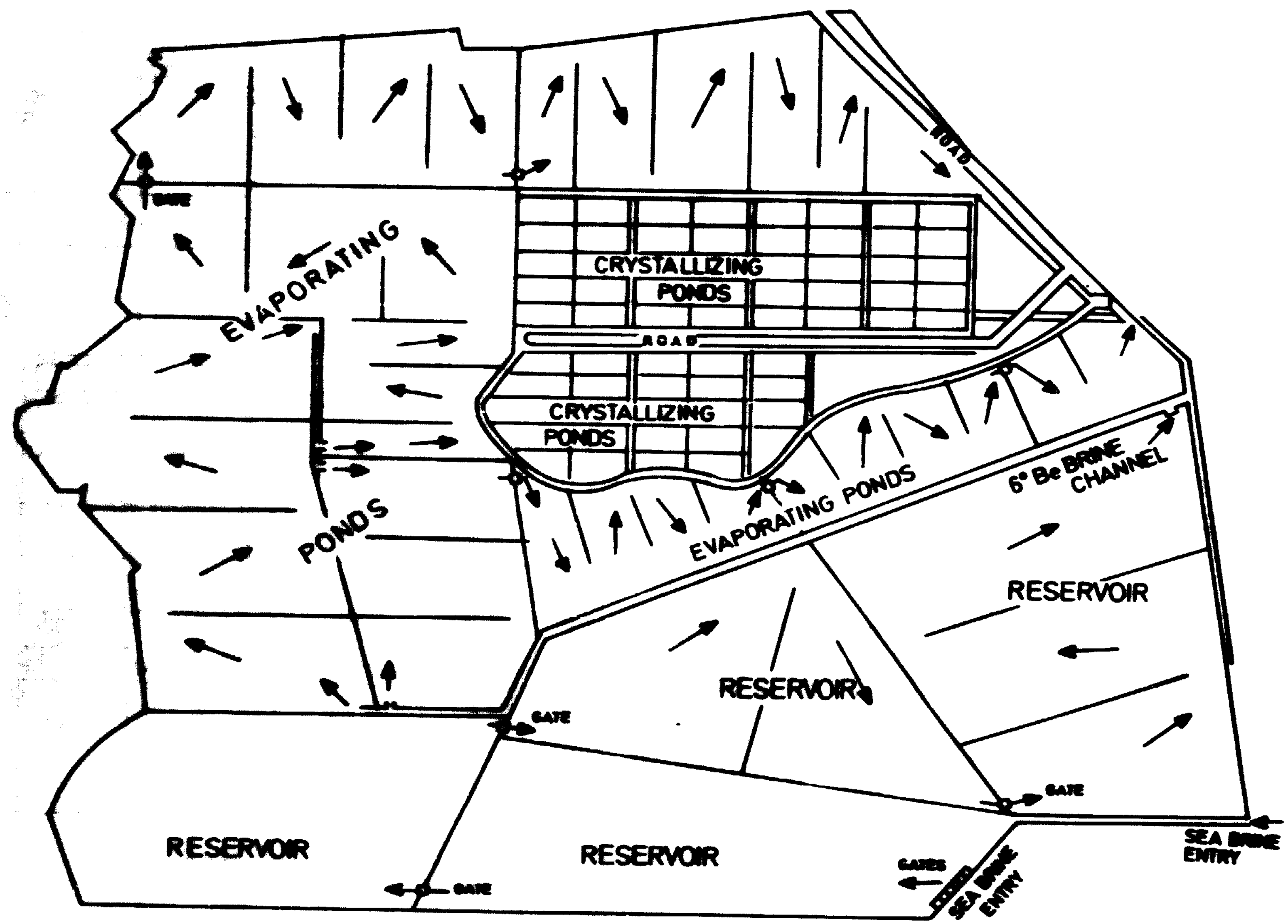
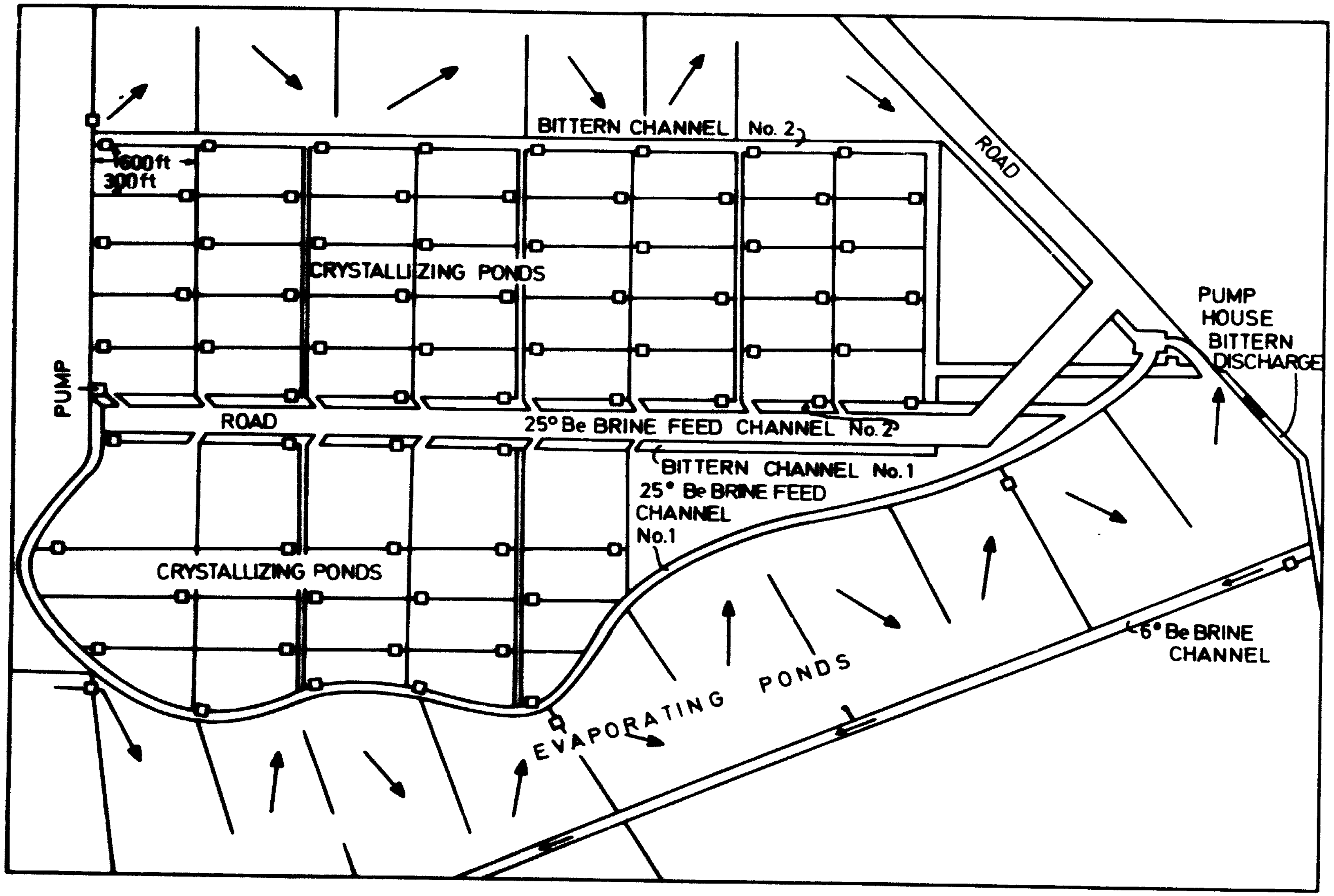


Figure 2

Layout of the crystallizing ponds in the Sumandi saltworks



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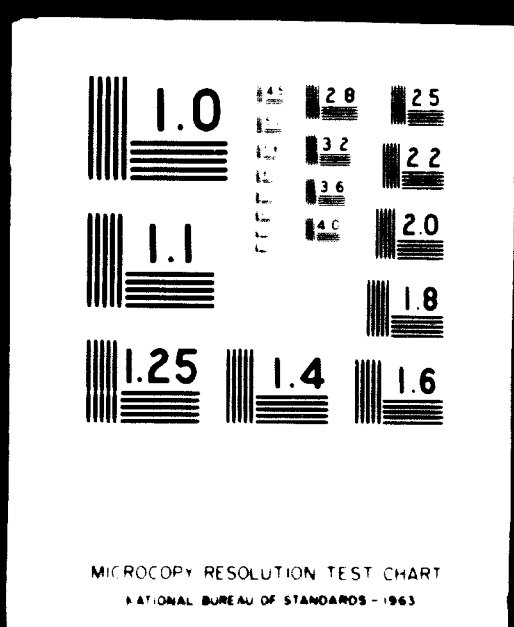
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

earth walls are installed for this movement. Finally, the concentrated brine is fed to the crystallizing ponds where salt is produced. The residual liquors or bitterns are allowed to flow through separate channels from this area without polluting the condenser reservoir and the intakes. The salt is transported to storage, washed if necessary and then transported by railway or ship to the consumers.

Figures 1 and 2 show the layout of a saltwork in Orissa. The reservoirs cover 1,100 acres, and the evaporating ponds 1,300 acres. The crystallizing ponds cover 400 acres and measure 600 by 300 ft each; they are laid out in rows of five. The crystallizing area is elevated; the evaporating ponds are below it. The ponds are laid out according to the ground level with two intake streams taking advantage of the tides. There is one pump for the two streams.

The crystallizing ponds are provided with by-pass channels and with a facility for series flow; they are planned for the future adoption of harvesters.

Series flow in the crystallizing ponds has the following advantages:

- Continuous flow from the higher level to the bittern stage;
- It avoids mixing poor and good brines;
- A 10 per cent increase in yield can be expected because of a 20 to 30 per cent higher evaporation rate;
- Separate harvesting of graded salt for industrial and table use.

It is proposed to use a mobile harvester of tractors and trailers to break the crust. The proposed washing plant will be a hydroclone with centrifuge and belt conveyers. Annual production is being increased to 30,000 tons. The saltworks has been operated since 1966 by the State Government.

Details of the manufacturing process, the techniques and procedures adopted for the various operations from the intake of brine to the transport to the consumer are described in succeeding paragraphs.

INTAKE, TREATMENT AND STORAGE OF SEAWATER

According to the source of brine, Indian saltworks can be classified as inland (using brine springs or lake brine) or marine. In the inland saltworks rich brine is obtained either from the salt lakes such as those in Rajasthan or subsoil sources as in the Rann of Kutch from shallow wells, deep tube-wells, pits and percolation canals. The brine for marine saltworks is obtained from the sea and has an initial density of 3^{0}Be, though it varies slightly from place to place depending on the inflow of fresh water from rivers. The composition of dissolved solids in seawater is practically uniform. The quality of salt produced in the marine works therefore does not vary much with a scientific layout and proper control.

The seawater is admitted by sluice gates at high tides through creeks or man-made canals to low-level reservoirs or small creeks and lagoons that store the brine. The reservoir has a fairly large capacity and generally is capable of holding at least a substantial portion of the whole season's requirements. Natural depressions near the seacoast are often used as reservoirs; the arm of an estuary or a silted basin is banked off and isolated to form a reservoir in some places. Artificial reservoirs have to be aligned and protected with due regard to the contours of the land. A contour survey of the licensed area is essential to the initial planning of a saltwork.

It is occasionally possible to locate the storage reservoir at a higher elevation than the rest of the saltwork; brine is then pumped from the creek or canals to the elevated reservoir; from there it flows by gravity through long winding channels into the evaporating ponds. The cost of lifting the brine is an important item in the manufacturing cost of salt. The reservoirs are indispensable features of modern saltworks. Some evaporation inevitably takes place in the reservoir. The concentration of brine rises even though the main function of the reservoir is to store brine between high tides; it also helps to settle the impurities suspended in the brine.

The sea brine is led to the reservoir through canals, trenches, natural estuaries or depressions. The inlets to the reservoirs are either through sluice valves or butterfly valves. They are also fitted with cast-iron axial flow pumps (figure 3). These pumps are operated by diesel engines where steam and electricity are not available. The tendency now is to convert to electrically driven pumps wherever possible. The brine from the reservoir is pumped into evaporating ponds as necessary.

No special treatment is given to the soil of the reservoir because natural environments are used as much as possible. Special care is, however, taken to ensure that brine is not lost by percolation in areas where the soil is very loose. The elevated areas are levelled, and the earth is transferred to low-lying areas to fill the surface. However, with the settling of silt and clay in the course of time, the pores in the ground are closed and the reservoirs become fairly impervious. In view of the large areas involved, it will not be economically possible to treat the soil or excavate the reservoir area. The earthen walls or dams are strengthened periodically to ensure that during heavy winds, tide and monsoon, they do not break or lose brine. Embankments are built as necessary to help the brine travel long distances in the reservoir and evaporating ponds.

BRINE MOVEMENT AND EVAPORATION

Evaporating ponds

They are an integral part of solar saltworks and serve two purposes: (a) to raise the concentration of brine; and (b) to precipitate and settle the impurities. The undissolved impurities are mainly mud and organic matter in suspension. When the brine is allowed to settle, the solids separate out as a slushy slime mixed with small quantities of calcium carbonate which also precipitates in the early stage of evaporation. When the brine is concentrated sufficently (between 10^{o} and 14^{o} Be) to permit crystallization of gypsum, steps are taken to prevent loss of this useful material in the slush. Some brine also contains considerable quantities of algae which separate out as the concentration increases. In view of this, the general tendency is a series of evaporating ponds. The extent of removal of suspended impurities is judged by visual examination because a properly settled brine is clear and transparent.

The early stages of concentration up to 14^{o} Be are carried out in the reservoir and evaporating ponds. The solids separating out at this stage are of no value and are not recoverable. The usual practice is to effect this concentration in a large number of evaporating ponds. In typical marine saltworks, the seawater is evaporated in four stages. In the first stage, seawater flows into a large reservoir at high tide and is trapped there when the tide recedes. It is concentrated to 37 per cent of its original volume. Then it either flows or is pumped from the reservoir to the evaporating area where it is kept moving until the volume is further reduced to 20 per cent. The third stage is similar to the second. The brine volume is reduced even further to 12.5 per cent of the original volume by flow through additional evaporating ponds. It is at this stage that the calcium sulphate precipitates

Figure 3

Tractor power take-off used for driving axial-flow pump

Figure 4

Compacting soil by pressing the salt into the clay with a sheepsfoot roller

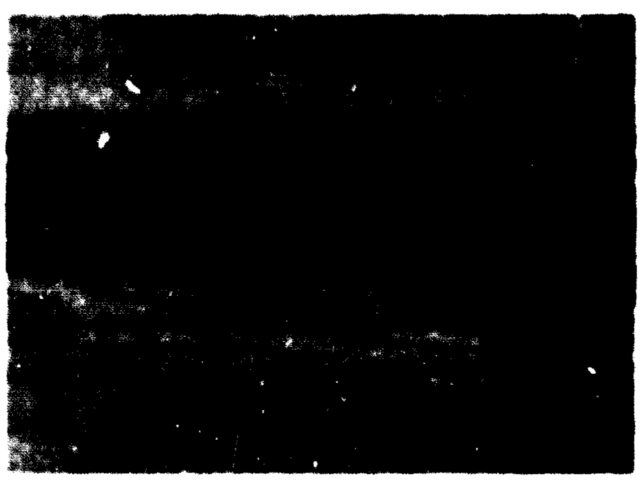


Figure 5

Sheepsfoot roller

and collects as gypsum at the bottom of the pond. This is removed once in three years and is marketed at a good price.

The layout and preparation of the last series of evaporating ponds in which the brine density is raised from 14°Be to 22°Be are important and need special attention. In large saltworks, the brine leaves the last evaporating pond at about 22° to 24°Be. This means that the brine is evaporated to a tenth of its original volume. The relative areas of evaporating and crystallizing ponds are important in improving the quality of the salt. In earlier years, brine of density higher than 20°Be was fed to crystallizing ponds. Many saltworks provided an equal area for evaporating and crystallizing ponds. Thus impurities which could be removed normally in the evaporating area passed into crystallizing ponds, and the salt was low grade. By careful control of evaporation of the brine and properly designed evaporating ponds, gypsum which separates out between 14°Be and 22°Be is now collected as a profitable by-product. In most of the modern saltworks, only concentrated brine at a strength of 22° to 24°Be is led to crystallization after separation of gypsum.

In the preparation of the bottoms of evaporating ponds, the gypsum formed is tamped into the soil; the bottoms are hardened as much as possible to avoid losses of valuable concentrated brine by percolation. The earthen walls of evaporating ponds are also strengthened with stone pitching so that no brine will be lost by walls breaking during cyclones and heavy winds.

To accelerate evaporation, the brine in the evaporating ponds is channelled to circulate in a zigzag manner by walls, embankments, barriers and sluices. In some of the saltworks these internal walls are also stone pitched to withstand erosion and provide for good circulation of brine within the evaporating area itself. The layout in most saltworks also allows the brine to travel a long distance around the crystallizing area. Pumps are used as required in intermediate stages in the evaporating area.

The size of evaporating ponds varies depending on the total evaporating area, climatic conditions, humidity, wind velocity, slope of the land etc., because the density of the brine is 20° to 24°Be before it is fed to the crystallizing ponds.

Crystallising ponds

Normally the area of the evaporating ponds determines the area of the crystallizing ponds since the function of the latter is to separate the salt in the concentrated brine from the evaporating ponds. The seawater is reduced to a tenth of its volume during concentration in the reservoir and evaporating ponds with a rise in density from 3° to 24° Be; if there were no loss of brine due to percolation, the area of the crystallizing ponds should be normally one tenth of the area of the reservoir and evaporating ponds. However, as the rate of evaporation falls appreciably with the increase in density it has become necessary to provide more than one tenth of the total reservoir and evaporating area for the crystallizing ponds. Evaporation also depends upon the season, the duration of hot days, the wind velocity, relative humidity, the rate of evaporation, absence of rainless days etc. The ratio of crystallizing area to total evaporation area therefore varies between 1:2 and 1:5 in old small saltworks. An unnecessarily large crystallizing area was provided under the mistaken notion that the output of salt depends upon the area with the result that low-density brine led to formation of salt largely contaminated with gypsum. As the crystallizing ponds need special attention both in their layout and maintenance, this also led to unnecessary expenditure. They are lined with a bed of prepared clay which is consolidated by puddling and tamping. In new saltworks, the original clay has been removed and good fresh clay with sand as required is introduced to provide a hard surface. As this operation has been considerably improved in recent years, it is described in detail.

At the start of each season, crystallizing ponds are given the following treatment, which may be repeated in mid-season if the bottom becomes pitted by rain. The clay is first loosened and brine is admitted to form a salt mud. It is puddled by treading till it is so hard that a foot ceases to make an impression in it. It is then allowed to dry and harden, but when the surface shows signs of crackling, fresh brine is admitted and the bed is again puddled till it is firm and again allowed to dry and harden. It is then tamped with wooden ramps or mallets; sand is sprinkled if necessary to prevent the clay from sticking to the ramp.

The pond bottoms must be at proper levels; otherwise, there will be difficulties in harvesting the salt and in drainage of the mother liquor. Crabs and insects must be removed from the ponds because they bore holes. Flushing with concentrated brine kills most of them. Rollers made of stone, wood or steel pulled manually or by tractor are now used to consolidate the bed. (See figures 4 and 5.)

Normally the crystallizing ponds are situated below the evaporating ponds to allow a natural flow of brine into them wherever possible, but occasionally it has been necessary to pump the evaporating brine into the crystallizing pond. The crystallizing ponds are also located in an area suitable for easy harvesting, storage and transport of salt. The location of the crystallizing ponds with respect to the direction of the land wind is also an important factor. Winds that blow directly from the land carry a good deal of dust which may fall into the ponds and contaminate the salt. It is therefore necessary to have a small area of evaporating ponds intercepting the land breeze before it reaches the crystallizing ponds. Winds that blow over an expanse of water become humid and do not allow rapid evaporation of the brine in the crystallizing ponds; hence the crystallizing ponds are sited away from the major evaporating area. Facilities for by-passing the feed of reservoir brine around the crystallizing ponds to provide washing brine are also available in a few saltworks.

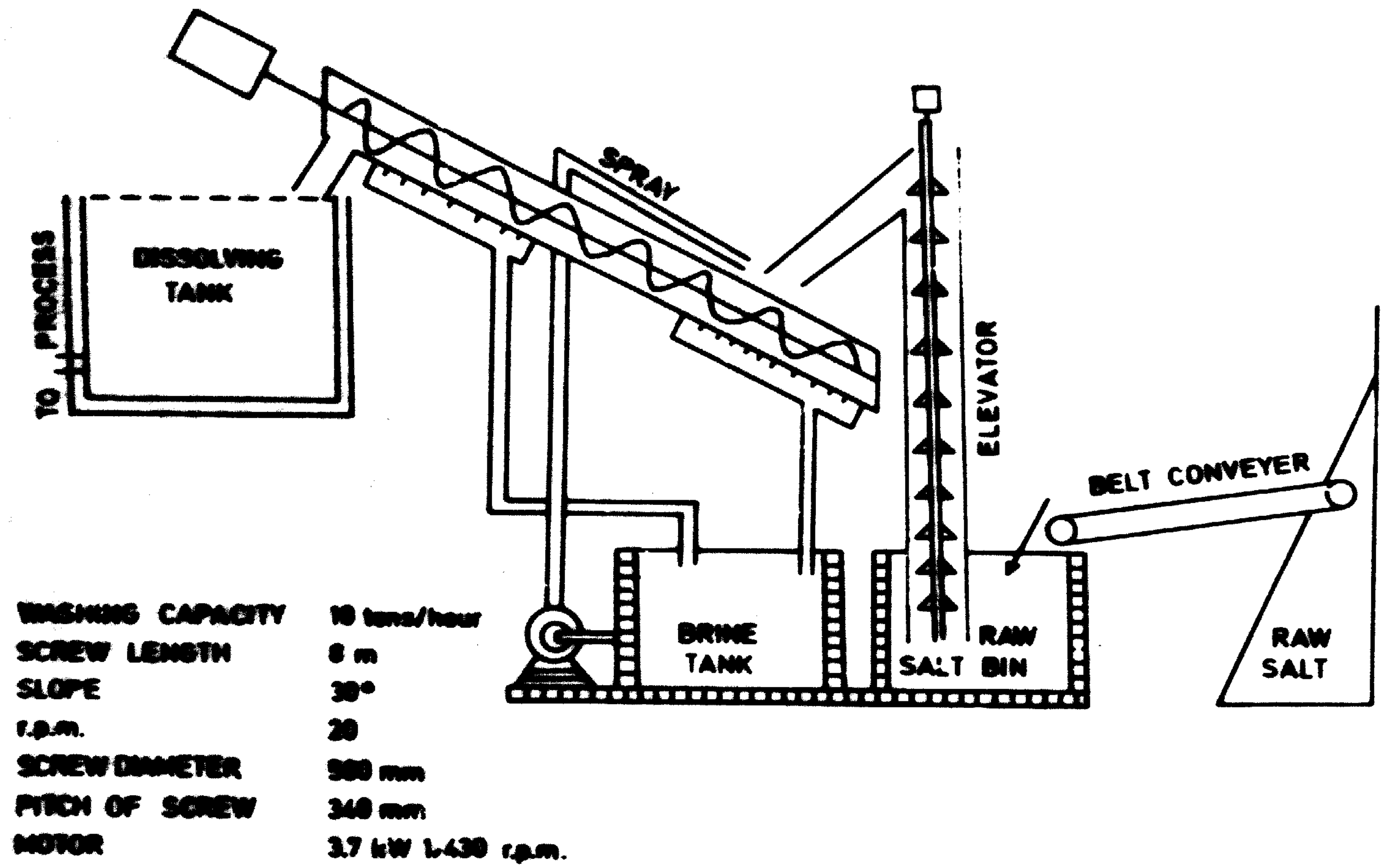
Though from time immemorial crystallizing ponds have been made with manual skill and simple tools like puddling pads, tampers and wooden or stone rollers, in some of the new saltworks mechanical equipment such as tractors, bulldozers (provided with wooden shoe plates to reduce the ground pressure), stone rollers and sheepsfoot rollers have been used to run over the crust, consolidate the soil and harden the surface.

As the salt is now harvested manually in all the saltworks, the size of the individual crystallizing ponds is of great importance (see figure 6). The optimum size depends upon the ease with which the crop is harvested from the pathway without the labourers having to step into the beds or walk inside them. Apart from discomfort to the man who works in the concentrated bittern, frequent treading loosens the bed and renders it pervious. The loose clay also tends to find its way into the crystals and makes the salt dirty.

Where rain showers are likely during the crystallizing season, the crop of salt is not allowed to accumulate in the ponds. It is removed to the storage yard as soon as a sufficient thickness is formed. The crystallizing ponds also are very small. In Bombay and Madras States, the size has been 20 x 20 ft. However, producers have now become conscious of the necessity to prepare crystallizing ponds with larger area in order to improve the quality uniformly as well as to reduce the area occupied by the walls. Where the mother liquor in the ponds is not drained sufficiently before the salt crop is harvested, the result is inferior salt. Now, because quality standards of salt are required,

Figure 6

Salt washing plant at Amlai, Madya Pradesh, for th caustic soda plant of the Hukumchand jute mills



the crystallizing ponds have a gentle gradient so that no puddles of mother liquor remain; the mother liquor is periodically drained completely.

Recently an effort has been made to enlarge the crystallizing ponds when they are relaid. In saltworks producing less than 20,000 tons/year, the crystallizing pond size varies from 20 x 20 ft to 20 x 80 ft. But in saltworks where annual production exceeds 50,000 tons, the size has been increased to 100 x 300 ft. Larger ponds are now laid out in some new units also for the purpose of introducing mechanical harvesting of salt.

IRRIGATION AND REMOVAL OF BITTERN

In marine saltworks where there is a threat of interruption by showers of rain in the harvesting season, the crystallizing ponds are charged with brine to a depth of 2 to 5 cm and the crop of salt is scraped periodically when the density is 29° to 30°Be. This is known as the single-irrigation system. After the first salt harvest, more concentrated brine is admitted and the density of brine is increased to force a quick deposition of salt in the second and subsequent chargings. In large saltworks, the bitterns are withdrawn periodically while in others the bitterns are discharged only at the end of the season.

In the multiple-irrigation or accretion system, concentrated brine is charged into crystallizing ponds and periodically replenished to make up for evaporation and to allow the crust of salt to grow into a layer varying in thickness from 6 to 20 cm. Care is taken that at no stage does the concentration of brine on the bed rise above a stipulated maximum density which is generally below 29°Be. Brine is charged to a greater depth than in the single-irrigation system; the crystals of salt are well developed and compact and yield a heavy type of salt. In this manner, two to four crops of salt are harvested annually depending on the length of the harvesting season and other local conditions. The mother liquors are drained frequently at a specific density and thus all the successive crops of salt are clean and of uniformly good purity as they are crystallized from a solution of similar composition.

Single irrigation is popular; multiple irrigation is adopted only in the large saltworks in Gujarat. But where the crystallization season is long, many saltworks are adopting multiple irrigation. The Gujarat saltworks are able to operate from October to June. There are two distinct rainy periods in the

Madras region viz. November to December and April to May. But there is strong pit brine in the Tuticorin area. The saltworks can therefore change from single to multiple irrigation and produce salt of a uniformly high quality for export and industrial use.

Earthen walls

The walls around the crystallizing area are used for storage of the salt before transport and are prepared with care. They are used as both a pathway and a heaping ground for the salt after it is recovered from the ponds. After draining the bittern, the salt is removed to storage. Usually the salt is heaped in the pond itself for a day or two to drain further and is removed to the wall after washing with fresh concentrated brine. After sun drying in this area, the salt is removed to the main storage yard.

The width of the wall may vary with the size of the crystallizing ponds from 1 to 2 m wide, and the height in most of the old saltworks is about 15 to 25 cm above the bed level. Some of the walls did not even have proper slopes in early periods. Their slope and width have become important as the size of the pond increases. They are now properly strengthened and pitched at the angle of repose so that the wave action of the brine does not wash them away continuously. In large crystallizing ponds, some of the walls are used for laying out rail tracks for haulage of salt in manual wagons or trolleys or by small diesel locomotives. They may also be used as a haulage road by lorries and tractor-drawn trailers. In view of this, most of the main walls in modern saltworks are 5 to 10 m wide with a camber falling 3 to 4 cm towards the bed. Broad walls are used for the main mechanical transport, while the small ones are used for intermediate transport by manual labour.

Channels

Normally, there are parallel flows of brine in and out of the crystallizing ponds in most of the saltworks. There are two channels on either side of the ponds - one for the inflow of concentrated brine and the other for the outflow of the bitterns. Wherever the layout permits, the brine channels also help to raise the concentration of the brine. It is fed either by gravity or by pumping through channels from the reservoirs to the evaporating ponds and then to the crystallizing ponds. The bittern left in the crystallizing ponds is diverted into the bittern channels. The sides e frequently washed into the channels by erosion and the channels become silted; the flow is impeded and the brine becomes muddy. To ease the flow through the channels, they are made with hardened soil and are pitched with stone. This also prevents leakage and loss of the concentrated brine. In an ideal layout, evaporating and crystallizing ponds are now laid continuously to avoid long channels. Considerable attention is given to achieve a compact design for the saltworks, particularly with reference to the location of evaporating ponds, crystallizing ponds, walls and channels as can be seen from the layouts in figures 1 and 2.

Bittern channels to remove the mother liquor are laid out to avoid the incoming brine from the evaporating ponds and reservoirs. In some saltworks, since evaporating and crystallizing ponds are arranged in all kinds of juxtaposition, the bitterns from the channels find their way by leakage or seepage into them, thus spoiling the quality of the salt. In some saltworks, the bittern is not completely drained from the channels and is allowed to stagnate; it pollutes the salt later. A scientific layout of bittern channels, evaporating ponds and bittern pumps is now gaining acceptance with a view to recovery of magnesium and potassium salts from the bittern.

Removal of bitterns

As by-products from the bittern are not recovered in most of the saltworks, the salt was formerly allowed to crystallize till the brine reached 30°Be to recover the maximum salt. Consequently a considerable amount of magnesium sulphate and chloride precipitated with the salt, and the NaCl content was as low as 90 per cent. After considerable persuasion by the Salt Department, bittern is now led out at densities between 29° and 30°Be and in a few cases even at 28°Be to produce industrial salt of low magnesium content. Due to these and other recent steps, the salt harvested in crystallizing ponds now contains up to 98 per cent NaCl.

In table salt, 2 to 2.5 per cent calcium and magnesium salts are tolerated, while in industrial salt usually less than 0.5 per cent each of sulphate and magnesium contents is demanded; a bonus-penalty clause is applied. The Gujarat factories which export salt in bulk and market also in the Calcutta region produce good salt by crystallizing it from concentrated brine of 28° to 29°Be density.

HARVESTING, WASHING, DRYING AND TRANSPORT OF SALT

Harvesting of salt

At present, the harvest of salt from crystallizing ponds involves several steps. Once the bitterns have been drained from the ponds, labourers break the salt layer with metal hoes and shovel it into piles about 4 ft high. The piles are left for one day to permit the remaining bittern and its numerous impurities to drain from the pile. On the second day, the pond is filled with fresh brine from the second evaporating pond. The labourers wash the salt with this fresh brine one shovelful at a time. When the washing is completed, the salt is again piled and allowed to drain off. This improves the purity and colour of the salt. Finally it is loaded into split bamboo or wicker baskets and carried to the wall of the pond and stacked. The salt is then transported to the central storage yard by trolley wagons, lorries or trailers. It is stored in piles nearly 30 ft high. The salt is allowed to dry on the heap by exposure to wind and the sun's heat. In a few places the salt is dumped in a thin layer in a yard before it is stocked in a pile by stacking conveyers.

No mechanical equipment is used at present for harvesting salt from the crystallizing area. The largest saltwork in Gujarat operated an experimental, rail-mounted harvester with a boom, designed and made in the saltwork with a capacity of 20 to 40 tons/hour. Experience has shown the need to standardize the operation and improve its design. The Central Salt and Marine Chemicals Research Institute, Bhavnagar, has designed and fabricated a small mobile harvester and also modified an agricultural tractor to operate as a harvester; both are in an experimental stage.

The advantage of the harvester is not so much the saving in manpower, but the quick removal of the crop to enable another crop of salt to be harvested before the hot season ends. This increases the production of the limited crystallizing area.

Salt washing plants

It is possible to harvest 96 to 98 per cent NaCl by the conventional methods used for centuries; this purity is satisfactory for table salt. However, industrial consumers need a purer salt with low magnesium and sulphate contents and are willing to pay higher prices for it. Salt washing plants were then worthwhile. The largest soda ash factory was the first to install a salt washing plant with screws, classifiers and vibrating screens.

It was in operation for about five years, but the maintenance and operation costs became high. It was possible to make better salt by rigid control of the brine evaporation. The objectionable calcium, magnesium and sulphate impurities could be removed easily during the preparation of brine for soda ash by adding sodium carbonate and calcium hydroxide solutions to precipitate the sulphates and chlorides of magnesium and calcium. The washing plant is therefore no longer in use.

Another soda ash factory installed two stages of inclined screw conveyer washing plants (30 ft each) with vibrating screens for washing the incoming salt before it was made into brine for production of soda ash. The wash water could be fed to the condenser of their own saltwork. Later a Sharples cone ejector of capacity 20 tons/hour was installed at a cost of about $3,500. This installation coupled with the screw washing plant was able to produce crushed, washed and dried salt; the purity was increased from 96 per cent to 99.2 per cent NaCl with 6 to 7 per cent salt loss in washing and dewatering. The moisture content of the dry salt was between 0.5 and 0.8 per cent. Since the incoming salt contained grit, the centrifuge screen was damaged. A minor modification to screen the salt before feeding is being installed.

A caustic soda factory has installed an inclined screw washing plant for salt not only to remove the insoluble impurities but also to reduce the calcium and magnesium sulphates before the salt was dissolved. All caustic soda plants have a built-in brine purification section to make pure brine for electrolysis.

One saltwork in Madras State has installed a hydroclone washing plant. The crude salt is dumped into a saturated brine pit and pumped by a slurry pump to an elevated cylindrical tank with a conical bottom discharge for intimate mixing. The slurry is discharged into an inclined screw conveyer for dewatering. A wash with fresh brine is also given. The washed salt is taken by trolleys to the open yard for drying. The wash brine flows back to the brine pit. A constant-level overflow maintains the level and the excess brine is led to the reservoirs.

Another factory in Madras State has a simple, batch system. Salt is heaped on a wooden bin with a perforated bottom. Saturated brine solution is sprayed on the top of the heap. The brine percolating through the perforations is drained and recycled with fresh saturated brine.

All salt marketed in Calcutta and for export is crushed by roller crushers. But, to avoid loss in handling, industrial salt and salt marketed in inland regions is not crushed.

Figure 7

Slurry of salt and brine being prepared for pumping

Figure 8

Front-end loader pushing raw salt onto belt conveyer

Figure 9

Rail-covered pit into which the raw salt is dumped

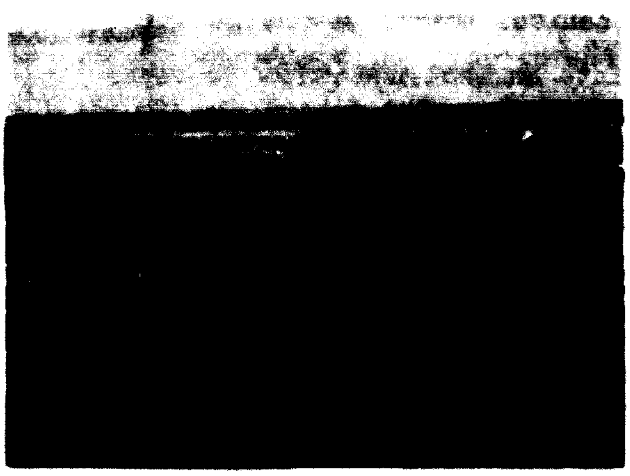


Figure 10

Washing plant with stacker conveyers at left and centre

Transport

Salt may be moved in many ways; two of them are illustrated in figures 7 and 8. Often when salt is pumped in brine, it must first be dumped by lorries or other land transport into a rail-covered pit (figure 9). From the crystallizing area to the main storage yard, the salt is usually transported by lorries or trailers; or if by rail, on platform wagons or tipping wagons. Stacking is either manual or with inclined conveyers (figure 10). In the Sambhar and Kharagoda saltworks the railway wagons are pulled to an elevation, the sides of the wagons opened outwards and salt discharged to form heaps on either side of the platform. Where rail trolleys are used, they are laid on sleepers over the salt heaps for stacking as high as possible. By employing these techniques it is normal in each saltworks to transport 100,000 tons of salt for storage during a season of five months.

The stocks are stored for one season because rain-washed salt is purer than freshly stacked salt. Then the piles are cut at one end with pick axes, and the salt is shovelled onto lorries, wagons or conveyers.

Salt is transported inland mainly in jute bags. The railway has, however, agreed to allow open wagons for movement of bulk salt provided a bamboo mat is spread on the floor and the top is covered by tarpaulin. These wagons are used for regular point-to-point transport from a saltwork to a consumer factory - for soda ash factories such as Kuda to Dhrangadhra (50 miles) or Jamnagar to Porbunder (100 miles); or for caustic soda factories from Kharagoda to Ahmedabad (40 miles) or from Adirampattinam to Mettur Dam (80 miles).

Salt is now sold to the general trade under the metric system. Salt is sent by the producer to the consumer in wagons specially allotted on a priority basis by the railway on the recommendation of the Office of the Salt Commissioner.

A substantial quantity of bulk salt is moved from Gujarat and Tuticorin ports to Calcutta by ocean-going vessels. In Calcutta, salt is stored in warehouses and marketed in jute bags.

MECHANIZATION IN THE INDIAN SALT INDUSTRY

The salt industry in India has developed because of a favourable climate with hot sunny days, dry winds and low rainfall in an extensive coastal region.

Its economical production is nearly 5 million tons of table and industrial salt and salt exports (nearly 10 per cent of the production). Employment is provided to nearly 500,000 people in both east and west coast regions in rural areas where no alternative employment is available. Under the guidance of well-trained officers of the Salt Department, since 1943, the industry has developed tools and techniques for production of salt on modern lines.

Recently, when electricity and modern facilities were available at some of the large saltworks, it has been found profitable to mechanize transport, stacking and issue of salt for industrial requirements and export. The two Government-owned inland saltworks (Kharagoda and Sambhar) have nearly 40 miles of broad-gauge and metre-gauge railway track connected to the national rail system so that salt from these factories can be sent directly to consumers. Some Gujarat factories use diesel locomotives for haulage. Many use belt conveyers for transport and stacking. No saltwork uses cutting conveyers for de-stacking and issue. Conveyers and dump trucks fill flat-bottomed barges drawn by tugs to load ocean-going vessels at the rate of 2,000 tons/day.

In India large-scale mechanization has not gained popularity everywhere mainly because of the high cost of imported equipment and maintenance, and the need to provide power and fuel for operation in remote coastal areas. In addition mechanization would create unemployment for many men who work all around the year in preparing the crystallizing ponds, repairing walls and channels, irrigating, harvesting and stacking the salt, and finally loading it into wagons in bulk or in jute bags and on barges. All this work is done by permanent trained labourers; for many of them it is a family tradition.

Some other factors preclude the need for full mechanization of harvesting in most saltworks. Series of crystallizing ponds are usually worked on a lease system; payment is based on the output that is strictly supervised for quality control. This has resulted in better upkeep and high productivity. In inland salt areas, labourers have long-term contracts to dig the wells, pump the brine with manual or animal-drawn lifts, prepare the evaporating and crystallising ponds, maintain walls and channels as well as to harvest and stack the salt at transport yards. There is a minimum wage level; but the rates of payments are negotiated annually and depend on the price of salt. Many other saltworks operate on a co-operative basis.

However, in industrially developed areas where not only are wage rates high but labour is scarce, mechanized harvesting may be necessary to maintain the low salt price. For this purpose, light mobile harvesters should be developed to harvest a salt crop between 10 and 15 cm thick in ponds of dimensions ranging from 100 to 250 ft wide and 250 to 500 ft long.

Salt washing plants are gaining popularity in coastal saltworks. One of the large inland saltworks purposes to install a screw washing plant with vibrating screens. In Sambhar it is proposed to separate the sodium sulphate impurity by refrigeration and to recycle the brine.

The economics, local conditions of employment and availability of labour are factors to be considered prior to mechanization. In India, the salt industry is labour-intensive with completely Indian technical know-how, equipment and facilities. Any attempt to mechanize to save labour will not be appreciated as this will lead to unemployment among people who cannot be given other work. However when coastal saltworks with a production of more than 500,000 tons are developed, the need for mechanization of all operations including harvesting will be obvious.

CHEMICAL BY-PRODUCTS

When 1,000 tons of salt are produced from sea brine, the following by-product chemicals in approximately the proportions given will be contained in the bitterns discharged:

	tons/100 tons NaCl
Magnesium sulphate	92
Magnesium chloride	145
Potassium chloride and sulphate	23
Bromine	2.5

But unfortunately not all of these chemicals are recovered because it is not possible to collect all the bitterns from the large number of saltworks in a central area as they are discharged or because there is no incentive for this additional investment due to lack of demand for the products. The processes for recovery of these products are well known.

During the evaporation of seawater, gypsum is deposited at densities between 14°Be and 20°Be. The gypsum crystals become well defined and are removed from the evaporating ponds every three years. About 15,000 to 20,000 tons of marine gypsum are marketed to the cement industry in Gujarat and Tuticorin by large saltworks.

Magnesium sulphate, magnesium chloride, magnesium carbonate and calcium chloride have been recovered since 1920 from the concentrated bitterns obtained at a saltwork producing salt from subsoil brine in the Gujarat region. But now it is able to market only magnesium chloride for the textile industry and calcium chloride as a cooling medium for refrigeration. Current annual production is about 4,500 tons of magnesium chloride and 850 tons of calcium chloride. Figures 11 and 12 are flowsheets of by-product recovery.

In another saltwork bromine, magnesium sulphate, magnesium chloride and potassium chloride have been recovered from sea-salt bittern since 1942. The processes adopted are well-known unit operations using completely Indian machinery. Bittern discharged from the ponds at 29° to 30°Be is pumped to a set of bittern crystallizing ponds and concentrated to 32° to 34°Be by solar evaporation. A crop of crude salt is harvested and washed. Bromine is recovered from it by passing the concentrated bittern through a granite-packed tower countercurrent to steam and chlorine gas in the bottom. The liberated bromine vapour is cooled on a tantalum condenser and bromine liquid is separated and stored in stoneware vessels. Bromine is marketed as a chemical or used there to manufacture potassium, sodium, iron and ammonium bromides as medicines and also the fumigant ethylene dibromide. The production in the last five years has met the entire demands of the country. The maximum amount of bromine recovered in a year has been 200 tons. It has not been possible to recover all the bromine in the bitterns mainly because of lack of storage and sometimes because of dilution of the bitterns.

Debrominated bitterns (figure 12) are used in the manufacture of Epsom salts; these bitterns are cooled on chilling rolls to crystallize crude magnesium sulphate, which is separated by centrifuge. The crude $MgSO_4$ is further dissolved and re-crystallized by cooling; its purity is 98 to 99 per cent. It is also made into grades to the standard of the British Pharmacopoeia.

The residual bittern is evaporated in a triple-effect evaporator to separate kieserite. The clear liquor is chilled to separate carnallite and centrifuged out. Potassium chloride is separated by selective crystallisation, and further purified to 96 per cent KCl. The final residual liquor is heated in iron kettles, and the hot molten liquor is filled into drums and allowed to solidify as $MgCl_2 \cdot 6H_2O$.

Figure 11

Bittern densities and flow sheet for recovery of by-products from sea salt

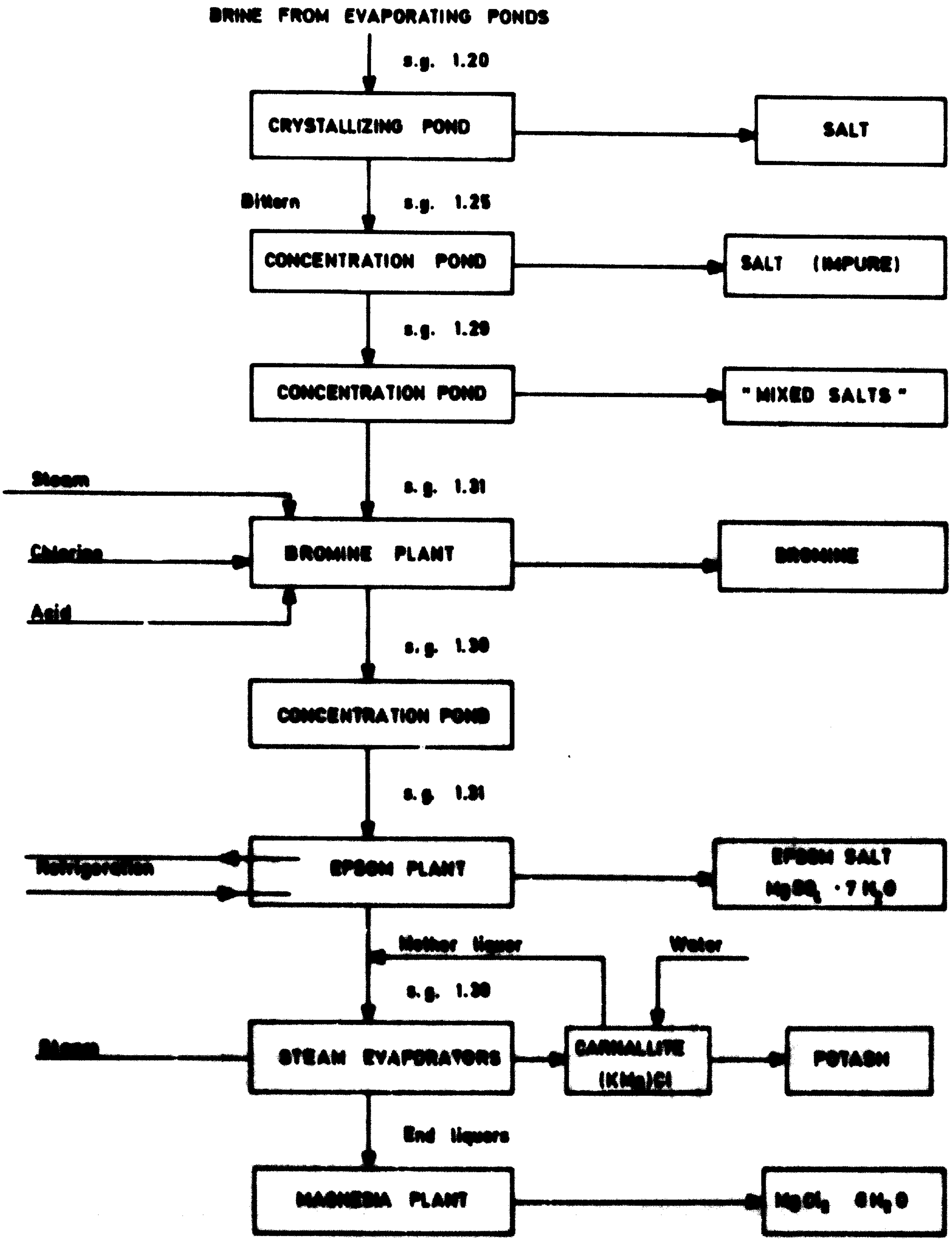
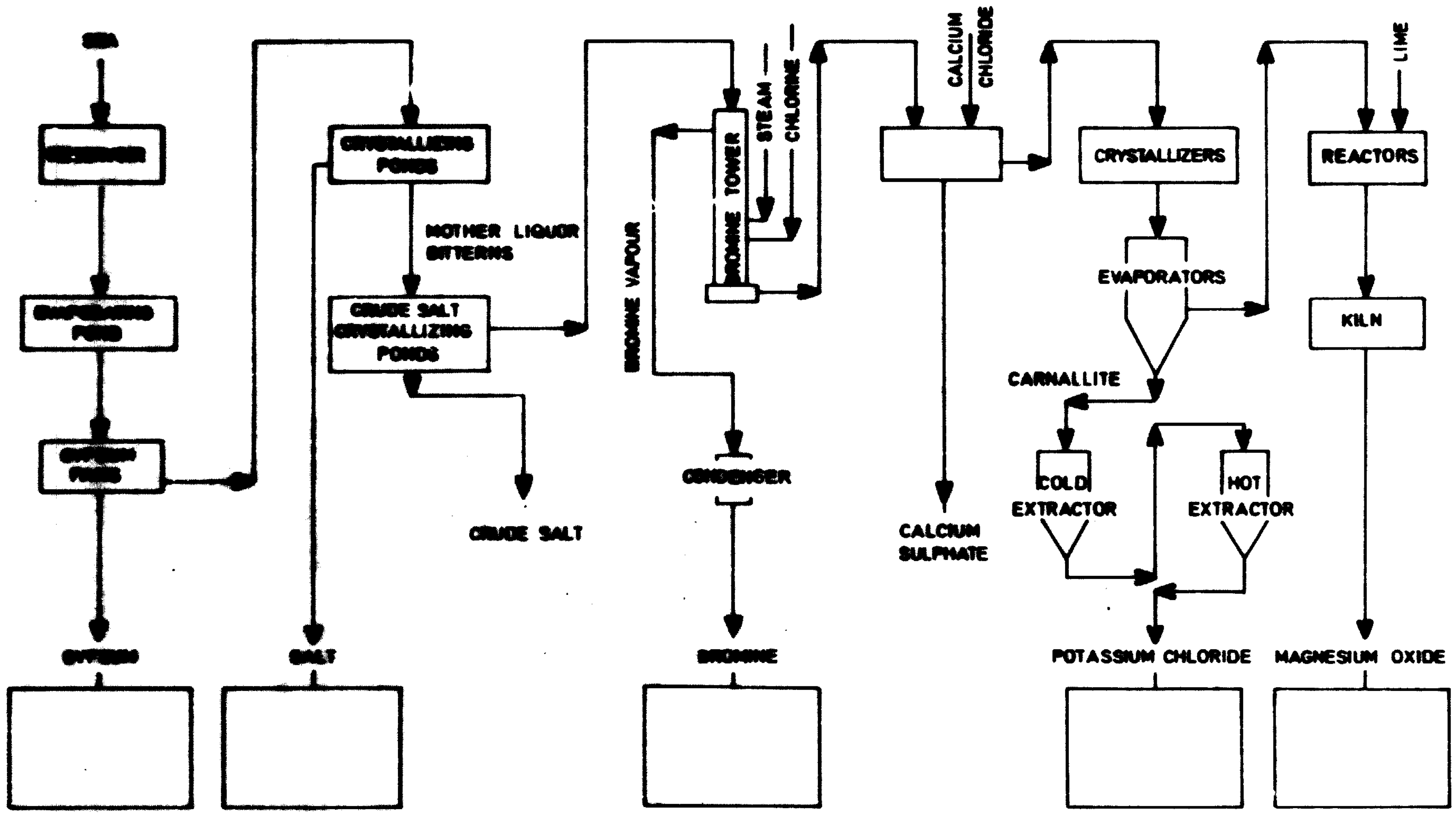


Figure 12

Flow sheet for recovery of by-products from sea salt patented by G. P. Kane and B. K. Kamat



Unfortunately the export demand for Epsom salts and magnesium chloride declined sharply. The plant is now idle. An installation for making periclase by precipitating magnesium oxide from magnesium chloride by adding calcium hydroxide was also commissioned, but it has not been possible to operate it economically for various reasons.

An Indian patent by G. P. Kane and B. K. Kamat describes a process (figure 12) for the recovery of potassium chloride by desulphurization of the bittern using soda ash distillery effluent containing calcium chloride; this converts magnesium sulphate to magnesium chloride and separates out the sulphate as gypsum. The remaining solution is evaporated to carnallite either by solar evaporation or in evaporators. From the carnallite the potassium chloride can be easily separated. Two factories have proposals for recovery of potassium chloride and magnesium oxide by this process using calcium chloride made from lime and magnesium chloride from bitterns.

The Central Salt and Marine Chemicals Research Institute at Bhavnagar has been testing several processes to make potassium salts from the bittern crust, i.e. mixed salts containing 16 to 18 per cent KCl. For every 1,000 tons of salt produced, 80 tons of mixed salt can be obtained by solar evaporation. Pilot-plant studies have been made for the manufacture of potassium chloride, potassium sulphate, magnesium sulphate, sodium sulphate, magnesium carbonate, potassium schoenite ($K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$) and syngenite ($K_2SO_4 \cdot CaSO_4 \cdot H_2O$).

At Kandla a trial plant was set up to produce 3 tons/day of KCl and at the company's Bhavnagar laboratory another plan to produce 0.5 ton/day of schoenite. Commercial exploitation is not yet organized.

Since bitterns from saltworks are an intermittent source of raw material, the key to the recovery of their potash would be an organization to collect mixed salts containing 16 to 18 per cent of KCl produced by the evaporation of bitterns beyond 30°Be from different saltworks and to process them centrally.

In India this processing would be possible at Kandla, Jamnagar, Porbunder, Vedaranyam and Tuticorin. Apart from potassium salts and bromine, there is no large outlet for magnesium salts, because in India high-purity magnesite occurs naturally and is used for refractories etc. This situation has probably inhibited progress in the recovery of by-products from bitterns because magnesium salts are their main constituent.

A number of special varieties of salt are made, such as vacuum salt, refined salt, free-flowing table salt, dairy salt, iodised salt, medicated salt and salt licks for cattle. Only one saltwork uses vacuum evaporation; there the main object was to produce distilled water for the high-pressure boilers. This became necessary because of the shortage of fresh water to generate electricity to run the alkali complex. The quadruple-effect evaporator is designed to produce 340,000 m^3 of distilled water and 45,000 tons of vacuum salt per annum. The vacuum salt is sold in bags of 50 and 100 kg to several industrial consumers.

The other varieties of salt are produced in Rajasthan and at Mandi because of the higher purity of salt made there. The iodized salt from Sambhar is supplied to the hill regions of Kashmir, Himachal Pradesh, Nepal, Assam, the North East Frontier Area, Bhutan and Sikkim for goitre control under a programme sponsored by UNICEF which supplies the potassium iodate. The sea salt marketed in the Assam region is iodized in Calcutta.

At Mandi, Himachal Pradesh, a salt refinery of 3 tons/day capacity is operating. Here saturated brine is pumped from a mine to an overhead tank, preheated in a rectangular steel pan and allowed to crystallize in a boiling pan. The pure salt is scooped out and either centrifuged or dried on a hot plate as required. If the brine is weak it is saturated with salt by mixing and agitation with impure rock salt containing 75 per cent NaCl. The only impurities present in the rock salt are insolubles, like sand, therefore purification of the brine is unnecessary.

Similar refineries are also operating based on low-grade salt obtained from inland saltworks. Here the impurities, mainly sulphates, are precipitated by adding settled or filtered milk of lime, soda ash etc. The brine is then concentrated by heating in open pans for crystallizing. About 0.8 ton of coal is used as fuel for each ton of salt refined. This process produces good quality table salt which is made free flowing either by heating again on a hot plate or by a magnesium carbonate additive.

INDUSTRIAL COMPLEXES BASED ON SEA SALT

Salt is an essential raw material for large-scale production of soda ash, caustic soda and chlorine, which are essential raw materials in several manufacturing processes. In India soda ash is familiarly known as washing soda and still is an essential chemical for washing clothes and textiles.

It is used in several industries as a mild alkali to neutralize acid and for the manufacture of basic products like glass, enamels, silicate and bichromate for textile processing. Domestic production of soda ash in 1969-1970 is expected to approach 470,000 tons; the estimated pattern of consumption is:

	Tons
Glass and glassware	75,000
Glass bangles	5,000
Sodium silicate	60,000
Sodium bichromate	8,000
Photographic chemicals	4,000
Chemical caustic soda	34,000
Dye-stuffs, soap, rayon, petroleum fertilizers	3,000
Sodium bicarbonate	18,000
Metal refining	2,000
Textile processing	17,000
Pulp and paper	30,000
Miscellaneous demands	30,000
Laundry	180,000
Total	466,000

Soda ash or sodium carbonate is made in India in three factories by the standard Solvay process and in another by the modified Solvay process which also makes soda ash for the chemical industry and ammonium chloride for fertilizer. About 60 tons/day of caustic soda are made by the reaction of soda ash with lime. The country is self-sufficient and about 350,000 tons of caustic soda are expected to be produced during 1969-1970. Caustic soda is an essential raw material for making pulp, paper, rayon, aluminium, soap, hydrogenated oils, dye-stuffs and several miscellaneous chemicals.

The pattern of distribution of caustic soda is expected to be as follows by 1970:

	Tons
Viscose rayon, staple fibre and cellophane	86,000
Paper, pulp and newsprint	76,400
Miscellaneous chemical factories, fertiliser, drugs, electroplating salts etc.	50,000
Textile processing	50,000
Soap and detergents	44,500
Alumina and aluminium	37,000
Hydrogenated oils and refined vegetable oils	5,000
Photographic chemicals, sodium aluminate, sodium phosphates, borates, bleach liquor, rare-earth chlorides etc.	5,000
Dye-stuffs and organic intermediates	3,000
Total	356,900

The co-product chlorine is in demand for production of polyvinyl chloride, insecticides, chlorine-based bleaching agents, chlorinated solvents, refrigerants, drugs, dyes and several inorganic and organic chlorine compounds.

It is economical for each alkali factory to integrate either in its own plant or with other industries in the neighbourhood for full utilization of its products. Caustic soda is transported either as a 50 per cent solution or as a fused solid packed in steel drums. Liquid chlorine is transported in cylinders or in tank cars. Industrial complexes that require chlorine or caustic soda in large amounts are now installing saltworks in their complexes for production of these raw materials.

In India there are ten alkali complexes to manufacture a variety of products. The largest alkali complex in Mithapur produces annually about 350,000 tons of salt, which are used entirely for making alkalis; the recovered by-products are magnesium sulphate, magnesium chloride and bromine. The production includes about 180,000 tons of soda ash and about 20,000 tons of industrial and British Pharmacopoeia grades of sodium bicarbonate. Facilities for conversion of 20,000 tons of soda ash to caustic soda by reaction with milk of lime were also set up. They are not in use at present because of the high demand for soda ash.

A production of 10,000 tons of caustic soda by diaphragm cells has been established, and most of it is sold to the textile and soap industries. To utilize the chlorine, a facility to produce bleaching powder was set up in 1948, but it has been closed down since 1955. The chlorine is converted in part to hydrochloric acid and in part liquefied. The hydrochlorio acid is used to produce zinc chloride for galvanising and dry-cell manufacture. The liquid chlorine is used to produce the insecticide benzene hexachloride. Part of the liquid chlorine is also sold to neighbouring waterworks. This factory also produces chlorinated rubber and bromides of potassium, sodium, iron and ammonium as well as ethylene dibromide. Several glass and silicate or bichromate factories throughout India depend on its soda ash. The total investment in this project exceeds $15 million; it employs about 2,000 workers.

In Bombay four producers of caustic soda and chlorine with a total production of 250 tons/day purchase 150,000 tons/year of salt mostly from the Gujarat area and supply the needs of those extensive chemical complexes:

Two rayon and tire-cord factories,
Two petroleum refineries,
Two complex fertilizer factories,
Two petrochemical complexes,
Two units producing polyvinyl chloride,
Two units producing carbon tetrachloride and dichloro-difluoro-methane gas refrigerant,
Two dye-stuff factories,
An insecticide factory producing benzene hexachloride,
Two factories producing paper and paper products,
Two factories producing phosphates, pigments and copper oxychloride,
A factory producing chlorosulphonic acid,
A factory producing barium chloride,
A unit producing potassium chlorate,
A unit producing anhydrous aluminium chloride,
A factory for tri- and perchloro-ethylene solvents,
A factory for ethyl chloride, phosphorus trichloride, zinc chloride etc.

Other factories produce drugs, dyes and miscellaneous chemicals, textile auxiliary chemicals and organic and inorganic chlorides. Several large and small waterworks, textile mills and soap factories also purchase their requirements of caustic soda and chlorine from these factories.

In an alkali complex in Mettur, Madras State, 120 tons/day of caustic soda and the corresponding amount of chlorine are produced. The following products are made in the factory itself:

Hydrochloric acid and liquid chlorine,
Stable bleaching powder and bleach liquor,
Chloromethanes (methyl chloride, methylene chloride and carbon tetrachloride from methanol),
Ferric chloride,
Potassium chlorate,
Chlorinated paraffin, hydrogenated oils and soaps.

The complex supplies caustic soda and chlorine to the following local factories:

Alumina and aluminium,
Polyvinyl and barium chloride,
Viscose rayon,
Pulp and paper products,
Textile,
Waterworks.

Caustic soda is marketed in three forms: liquid (50 per cent lye), solid and flakes. Chlorine is marketed as bleach liquor; liquid chlorine is shipped to the consumer in cylinders and tank cars. Jars, carboys and tank cars of HCl are shipped by road and railway. A benzene hexachloride factory is under construction; bromine manufacture has also been proposed.

Another alkali complex near Cochin (Kerala State) produces sodium hydro-sulphite and iron-free sodium sulphide for sale to sugar and dye-stuff factories and tanneries. It also supplies caustic soda and chlorine to the following local factories:

Aluminium,
Paper pulp, viscose rayon and cellophane,
DDT and benzene hexachloride,
Rare-earth chlorides, trisodium phosphate and thorium salts,
Pure ammonium chloride and fertilizers,
Petroleum refinery,
Rayon-grade bamboo pulp,
Paper products,
Sodium aluminate, potassium chlorate and copper oxychloride.

Another factory is Tuticorin (Madras State) produces 150 tons/day of caustic soda. The bulk of the salt required is produced in the saltworks. The factory is now producing tri- and perchloro-ethylene solvents and has started construction to produce rutile from ilmenite and hydrochloric acid. It proposes to make polyvinyl chloride from naphtha as feed stock. Solid and flaked caustic soda is supplied to consumers all over India.

There are similar integrated producers in Calcutta, Rajasthan, Uttar Pradesh, Andhra Pradesh and Delhi. They all follow more or less the same pattern, viz., market the bulk of their production of caustic soda and chlorine to other factories producing a variety of products and themselves develop chlorine-based industries such as plastics, insecticides and solvents.

The formation of industrial complexes based on salt, whether produced in the factory or elsewhere, has been a profitable industrial activity in recent years. Each complex requires large capital investment and employs hundreds of skilled and semi-skilled personnel. This has saved much foreign exchange. The economic value of these industrial complexes can be judged by a typical example. One complex in Madras State based exclusively on salt made by the company has a sales turnover of $10 million; the value of salt delivered to the works is less than $0.5 million. The value of the products made from the alkali and chlorine may reach a figure possibly 100 times the price of salt at the saltworks.

Industries based on salt can be conveniently added to existing complexes. The following are typical examples of such activity in India. A pulp and paper mill with a capacity of 200 to 300 tons/day has a caustic soda factory with a capacity of 30 tons/day located near it. A rayon and tire-cord factory produces 80 tons/day and has a caustic soda factory of similar capacity; 100 tons/day of chlorine is supplied to a paper mill. A caustic soda factory of a textile mill produces 100 tons/day for a petrochemical complex producing PVC from ethylene. Another caustic soda unit owned by a textile mill produces 50 tons/day; it supplies a soap factory with caustic soda and some textile mills with caustic soda and bleach liquor. They use the chlorine to produce polyvinyl chloride and perchloro-ethylene using calcium carbide as a source of acetylene. In another unit in Uttar Pradesh the caustic soda is supplied to factories making aluminium, rayon and paper; part of the chlorine is used to produce bleaching powder using nearby limestone. This unit is also erecting a benzene hexachloride (BHC) factory using benzene from the coke ovens of steel mills. Another unit in Calcutta uses the chlorine to make BHC insecticide with benzene obtained from coke ovens and also supplies several paper mills. DDT insecticide using benzene from the coke ovens of a steel mill and alcohol made from molasses from a sugar factory; fuller's earth, bleaching powder and bleach liquor are made with chlorine from a caustic soda plant attached to a textile mill in Delhi. In Rajasthan a caustic-soda-chlorine unit meets the full requirement in caustic soda of a viscose and tire-cord factory and a staple fibre factory; it converts the chlorine to PVC with acetylene from calcium carbide. It proposes to expand PVC production and also to make diammonium phosphate fertilizer using hydrochloric acid in its fertilizer complex under erection.

Thus the caustic soda and chlorine products of electrolysis of salt are so versatile that they can be attached to several industrial complexes that are already operating in different regions of the country, even if new ones cannot be formed.

The pattern of consumption of salt in India is changing rapidly. The annual table salt requirement is estimated at 5.5 kg *per capita* or 5,500 tons for a population of 1 million. If the rate of growth of population remains at 13 million/year until 1975, the consumption of table salt will increase by 572,000 tons in the next eight years. In industry, manufacturers of soda ash and caustic soda are the main consumers of salt at about 2 tons for each ton of alkali product. The present combined production of 600,000 tons of these two alkalis is likely to be doubled by 1975. A provision of 25 per cent more salt than the tonnage consumed by the alkali industries would cover the requirements of other industries, including food products, tanning and cattle licks. The estimated figures for consumption of salt in India during 1975 are listed in table 3. The requirement up to 1975 can be met without difficulty by the present method of production.

Table 3

Estimated distribution of salt consumption in India in 1975, compared with actual 1967 consumption

Salt consumption (million tons)		1967	1975
Table		2.85	3.42
Industrial		1.50	3.00
Export		0.45	1.00
	Total	4.80	7.42

Exports of salt from India commenced in 1951, and the annual total exports since 1958 are listed in table 4.

Table 4

Salt exports from India 1958 to 1967

Year	Total (1,000 tons)	Year	Total (1,000 tons)
1958	297	1963	268
1959	345	1964	358
1960	449	1965	331
1961	158	1966	387
1962	165	1967	450

There was a sharp decline in exports during 1961 and 1962, but the situation improved again in subsequent years with the result that the tonnage for 1967 is almost identical with that for 1960. Exports in 1968 were expected to increase to 550,000 tons. A substantial proportion of the total is exported in bulk to Japan. As the annual imports of salt into Japan from various sources exceed 4 million tons, India has to compete on the basis of a delivered price, and therefore the realization free alongside ship (f.a.s.) at Indian ports is $2.50/ton. There is a small margin of profit even at this low price, because there are favourable circumstances including the availability of low-cost, seasonal labour for salt production near ports. A bonus-penalty clause for purity of salt is included in every contract for export; the quality has improved in recent years, and salt producers have invariably earned a bonus. Ceylon and Nepal usually buy salt packed in jute bags at an f.a.s. price of about $5 including the cost of bags.

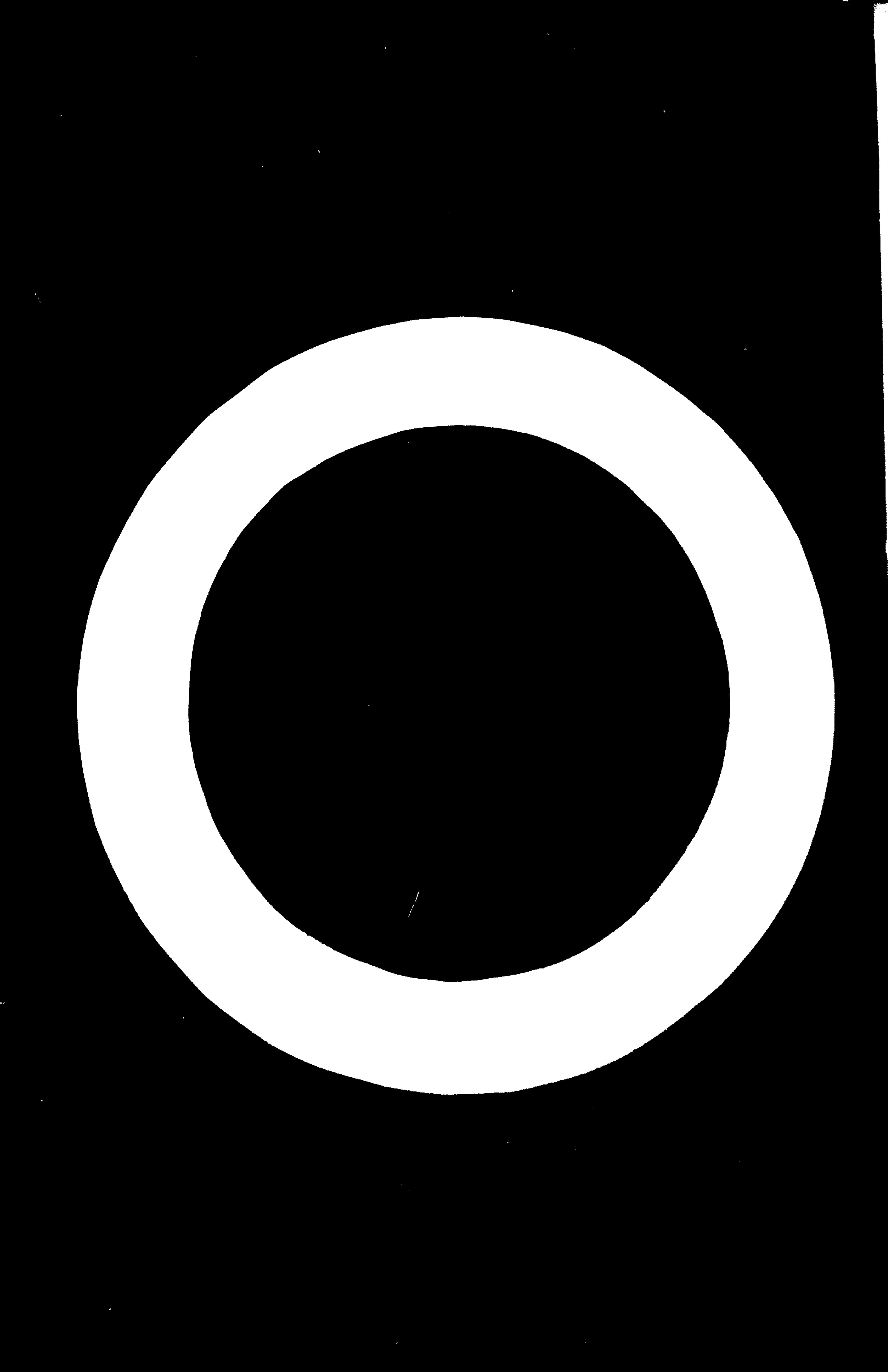
CONCLUSIONS

The progress of the Indian salt industry demonstrates how the rising demands for table and industrial salt in a developing country can be met from domestic production. The harvesting of salt can be organized as a capital-intensive or labour-intensive industry according to local circumstances. If it is labour-intensive, the industry can sustain itself with local materials, domestic finance and the experience of other developing countries. A capital-intensive industry, on the other hand, would need overseas know-how and machinery, and perhaps also some capital. The salt industry therefore provides considerable scope for international co-operation.

The industries and complexes based on salt have contributed to the increased production of high-quality salt in India. Half of the 4.5 million tons of salt is expected to be used for industrial purposes. A salt industry that produces table salt only is not likely to develop rapidly. In technically advanced countries the industrial demand is several times as large as the demand for table salt. There is also the export of industrial salt to countries which do not meet their domestic industrial requirements. The salt industry in India is being developed on these principles.

Acknowledgements

The reports of expert committees set up by the Government of India in 1950 and 1958 and those of the Office of the Salt Commissioner of India have provided valuable data. Discussions with M. L. Gambhir, Salt Commissioner of India, S. K. Vakil, Saurashtra Chemicals, Porbunder, R. V. Ramani, Mettur Chemicals, Mettur Dam, M. Venugopal, West India Match Company, Vedaranyam, and officers of the Hindustan Salts Ltd. were also very helpful. Some of their sketches and technical data are reproduced in the figures and text.



9. VENEZUELAN EXPERIENCE

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Introduction

All the salt produced in Venezuela comes from seawater; rock salt is unknown. The only saltworks in the country that have been modernized and mechanized are those on the Araya Peninsula, Estado Sucre in eastern Venezuela.

The Araya saltworks were first worked in 1499 by two Spaniards, Alonso Niño and Cristobal Guerra. Since the colony was founded, they have been owned by the Spanish Crown. A fortress was built on the peninsula to protect them from the pirates of the Caribbean Sea.

No real modernization took place before 1939 but a system of crystallizing ponds was then built next to the Laguna Madre with a view to using the Laguna Madre as an evaporating pond. The installation of a pier, an electricity plant, a factory and a drying plant was also considered.

From 1940 to 1952 no improvements were made, but in 1953, the Administración General de la Renta de Salinas consulted some excellent Italian, French and Spanish experts with a view to improve the Araya Peninsula saltworks.

The main reasons for mechanizing the Araya saltworks were:

Excellent natural conditions,

Salt has been harvested there for many years,

The convenient location for workers.

In accordance with the consultants' recommendations, a project to form a salt complex was elaborated as follows:

Use of the existing natural lake;

Mechanization at this lake;

Construction of crystallizing ponds and a mechanized plant at Punta Araya;

Construction of a plant for making table salt;

Reconstruction of the plant for making veterinary salt;

Construction of complementary plants.

The production centres, washing plant and salt dispatching equipment are favourably located and take full advantage of the possibilities of the Araya Peninsula. But some related services are too expensive for an industry of this type.

THE ARAYA PENINSULA COMPLEX

The installations on Araya Peninsula (figure 1) form a complete industrial centre based on sea salt; they are adapted to the shape of the ground and are located in an arid, windy zone that ensures high productivity.

The two production areas for bulk salt are Laguna Madre (Unit 1) and the artificial ponds of Punta Araya (Unit 2). They are on the only land that is really good for producing salt. They have fully mechanized systems for harvesting, washing, piling and dispatching the sea salt.

The salt factory and dispatch plant are on the coast at approximately the same distance from the two production centres. For bulk transport of salt between production areas and factory, there is a narrow-gauge track with diesel locomotives and mechanized loading and unloading of wagons.

The factory includes the following plant:

Salt refinery (Unit 3) with washing. milling, drying, classifying and packing plants for fine salt with additives;

Plant for making veterinary salt (Unit 4) equipped with washing, crushing, drying and classifying plants. It can also manufacture either compressed salt blocks or bagged salt with additives;

A 10,000 ton bunder silo for bulk salt;

A 6,000 ton bunder silo for refined salt in boxes or bags;

A 400-m pier accessible to boats up to 10-m draught and equipped for mechanized loading simultaneously two ships with 150 tons/hour of bulk salt and 1,200 bundles of boxes and bags/hour;

A platform pier for boats of any type including launches or ferry boats up to 10 m draught;

Complete mechanical shop with forging shop, foundry, electric, carpentry, structural steelwork and precision mechanical shops;

A 240 kVA auxiliary power plant for emergency use;

Minor buildings, including warehouses and offices for general services;

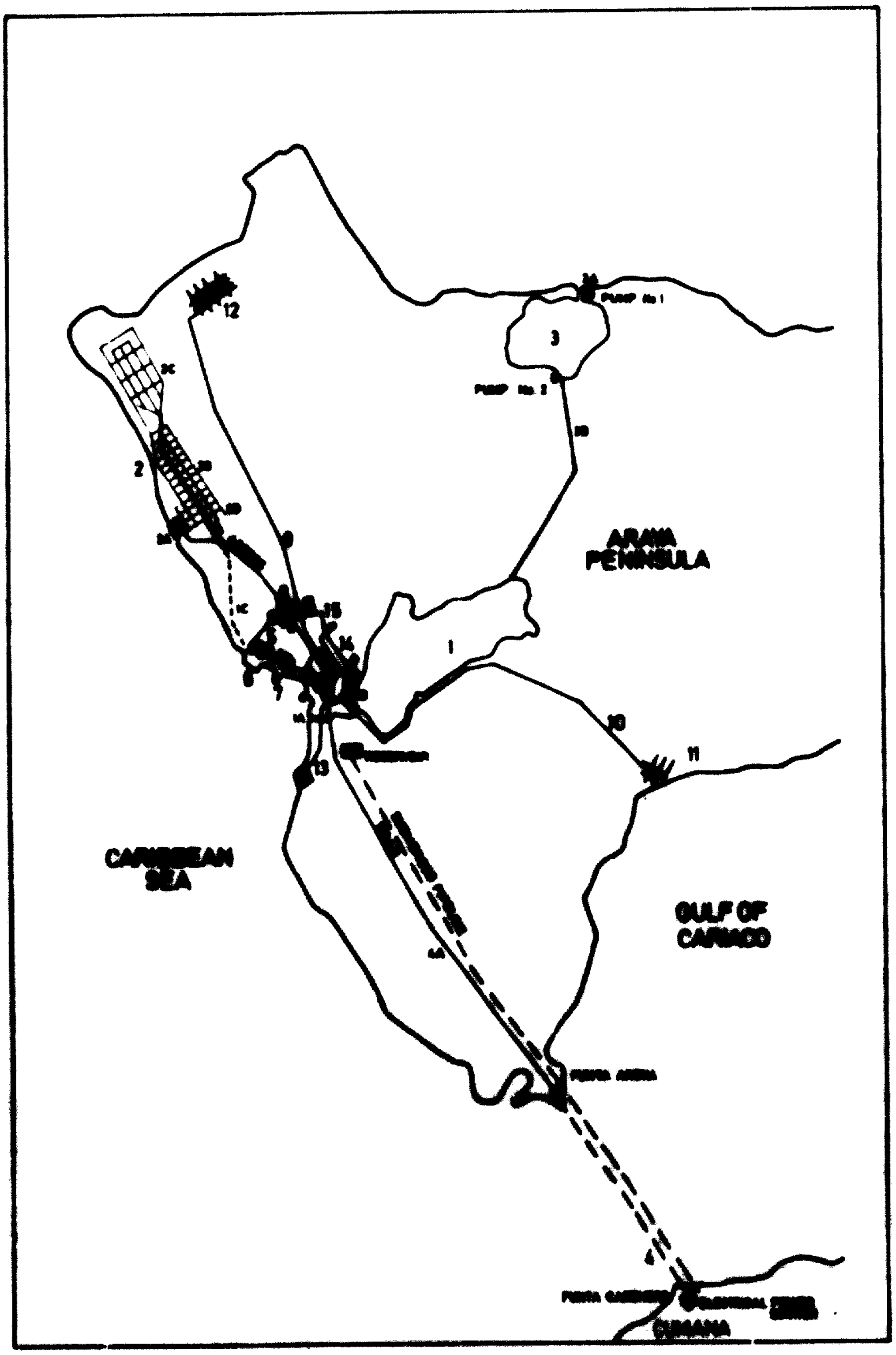
A submarine electric power line and a submerged pipeline for fresh water to supply the industrial complex and neighbouring villages.

The power line is supplied by 33,000 V from the Estado Sucre power grid at Cumana where there is a 5,000 kVA transformer station. The power is stepped down to 13,800 V at a distribution station in Araya.

The fresh water line is supplied from a treatment and pumping station also at Cumana of 75 m^3/hour capacity. On a hill near Araya there is a reservoir with 2,000 m^3 capacity.

Figure 1

Map of the Araya Peninsula and the saltworks



Explanation of the layout of Araya Peninsula Salt Works

1	Laguna Madre natural lake
1A	Intake channel
1B	Mechanical plant for unloading, receiving, washing, stacking and unstacking salt
1C	Railroad to factory and shipping area
2	Punta Araya artificial ponds
2A	Intake channel
2B	Crystallizing ponds
2C	Evaporating ponds
2D	Mechanical plant for unloading, receiving, washing, stacking and unstacking salt
3	Guaranache salt pond
3A	Intake channel
3B	Connecting channel
4	Underground submarine electric power cable from Cumana
4A	High voltage line
5	Industrial area: refining factory plant, veterinary salt, refined salt store, store for bulk salt and ship loading facilities
6	New pier
7	Old industrial sector
8	Salaraya settlement
9	Road to Punta Araya village
10	Road to Manicuare
11	Manicuare village
12	Punta Araya village
13	Araya castle
14	Ring road
15	Hospital

Figure 2

Harvesting salt by the dry, manual method in Laguna Madre

Figure 3

Conveyer of salt-harvesting machine in Laguna Madre

Apart from these industrial structures, the salt complex possesses other buildings in Araya village: administrative offices, a warehouse, barracks, restaurant and houses for employees and labourers, a school, a hospital, police station and beach bathing resort.

LAGUNA MADRE (UNIT 1)

Salt lake

The two main sides of this natural lake are bounded by hills from 100 to 200 m high. For many years the working area has been steadily diminishing because of silt brought by rain and wind. A detailed study of this important problem was published in August 1953 by the Ministry of Agriculture (Ministerio de Agricultura y Cria). On the basis of this report, some soil conservation work was initiated, including building small dikes and channels for water control in ravines, creeks and elsewhere to hold back rainwater; trees were planted in some areas.

The seawater flows in naturally, the pond surface being 2.5 m below sea level. The intake channel has been laid out so that the prevailing wind aids the inflow of brine. The bittern is not returned to the sea. Contrary to expectation, its content of unwanted salt does not increase but remains steady, perhaps because of seepage between the lake and the sea. The extent of seepage is unknown but must be appreciable.

The main lake is connected by a channel and fed by pumps to the new salt pond at Guaranache, which is intended to be used only as an evaporating pond.

Harvesting

The salt is deposited over the bottom of the pond in a 5- to 6-cm thick deposit at the beginning of the harvest; the thickness is 15 to 18 cm at the end of harvesting (figure 2).

The harvesting machine is a semi-floating machine equipped with three main floats supporting a metal frame carrying a tractor similar to a conventional farm tractor; it is driven by a 40 hp diesel engine with five forward gears and one reverse gear (figures 3 and 4).

A pronged shovel of adjustable height and 1.50 m wide lifts the salt cake onto a steel pan conveyer sloping upwards at 20° to a belt conveyer at right

Figure 4

Hopper of salt-harvesting machine in Laguna Madre

Figure 5

Loading barges by the old, manual method in Laguna Madre

angles to it. The belt feeds a hopper for loading the small barges. The smallest float at the rear helps to maintain direction.

The height of the floats relative to the tractor is adjustable so as to vary the pressure on the salt cake and to enable work to be possible in water of variable depth. The pan conveyer, belt conveyer and the tractor's lifting equipment are driven by the same engine through chains from the gear-box.

The harvester loads more than 150 tons/hour. Its efficiency depends on the condition of the salt cake (thickness and uniformity), the climate (wind) and the organization of transport.

Transport

The harvested salt is transported from the harvest area to the washing plant in small wooden barges hauled by a flat-bottomed wooden tug (figures 5 and 6). Its four paddle wheels (two on each side) are driven by a 25 hp air-cooled diesel engine with a differential gear coupled to it. One tug pulls ten barges each containing 3 tons of bulk salt.

Washing plant

A canal system has been dug from the lake shore to float the strings of barges to the washing unloading plant (figures 7 and 8). The barges are released from the tug and are pushed singly onto a submerged metal frame. The salt is thus unloaded (figure 10) into a concrete hopper. The boats are then pushed to the end of the channel and the tug brings them back to the harvest area.

The conventional washing plant consists of a first wash in a screw-ribbon conveyer (figure 9) by concentrated brine. The salt is brought first to the spiral from the hopper after passing through a crusher. The salt passes up the spiral against the flow of the clean brine. At the top of the spiral the salt is drained before passing into a Reedler conveyer where it is again washed with less concentrated clean brine and transported by a belt conveyer to the storage point.

The washing plant is provided with pumps, mixing tanks and settling tanks in order to handle and clean the wash brines. It produces 150 tons/hour of clean salt. Its output is recorded by a continuous weighing machine.

Figure 6

Salt barges leaving the harvest area of Laguna Madre

Figure 7

Salt barges approaching the washing plant of Laguna Madre

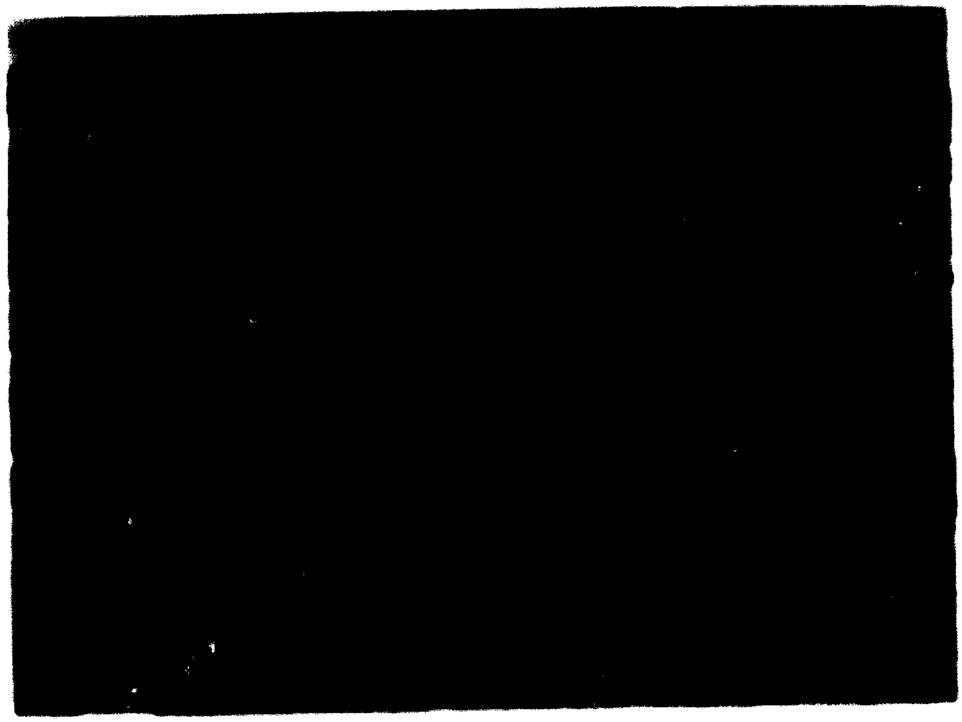


Figure 8

Salt barges at the washing plant of Laguna Madre

Figure 9

Screw ribbon conveyer for washing salt in Punta Araya

Figure 10

Salt barge being unloaded at Laguna Madre

Storage and dispatch

The salt from the washing plant arrives at a central concrete tower with a slewing stacker. This makes small piles in the main stacking area which is semicircular and has a 125 m radius. Outside the semicircle are two mobile metal towers on rails which can move the salt radially by rope-hauled scrapers either from centre to periphery (storage) or from any point towards the centre (dispatch).

The tower that supports the stacker carries a central hopper below which an apron feeder removes the salt to a concrete bunker from which the salt can be dispatched either in bulk on rail wagons or in polyethylene bags of 50 kg each.

Operation

The operating cycle is annual; the harvest starts in June and normally lasts five months. During the harvest, some seawater is admitted to keep the brine level high enough to allow the harvesting machine and barges to float.

After the harvest, seawater from the Guaranache pond is introduced to dissolve the remaining salt. Only twenty additional workers are hired at harvest time.

REVIEW OF THE SALT COMPLEX

Bulk salt

Laguna Madre (Unit 1)

The recent annual productions of washed salt were:

	Tons
1964	106,100
1965	87,200
1966	55,100 1/
1967	91,300

The average yearly output is 90,000 tons. In an area of 360 hectares, the annual productivity is 250 tons/hectare, which is a satisfactory figure.

1/ Low production year due to organisational difficulties.

The brine from the pond is of good quality and contributes to the excellent productivity of the saltworks; productivity cannot be increased by improving the quality of the brine. It can be increased only by connecting with Guaranache pond (140 hectares). This work is now in progress and will increase the area to 500 hectares and the annual capacity to 120,000 tons.

Typical analyses of the salt in table 1 show the high proportion of insolubles and sulphates. The salt colour is slightly yellow from clay incrustation.

The washing plant is in good mechanical condition and is well kept; but it is obsolete for making pure salt for the chemical industry. Not only is it antiquated, but it is too large for the output of 120 to 150 tons/hour. The storage system also is too large and expensive for this production. The harvesting and transport systems are well adapted to local conditions.

Punta Araya (Unit 2)

The recent annual productions of washed salt were:

	Tons
1964	41,500
1965	47,500
1966	60,000
1967	37,700 2/

It can be assumed that the saltworks will produce an average of 50,000 tons of salt from an area of 230 hectares that includes evaporating and crystallising ponds. The annual productivity is therefore 217 tons/hectare, which is an acceptable figure.

The crystallising ponds are always filled with brine except during the harvest period; the density never exceeds 28.5° Be, which guarantees satisfactory evaporation.

There are no means to increase the evaporating area. Productivity might be raised by a slight improvement in the quality control of the brine in the crystallising ponds.

2/ Production difficulties due to plankton in the brine.

Table 1

Salt and brine analyses

Origin of sample	Density	Degrees Baumé	H_2O (%)	Insolubles (%)	Ca (%)	Mg (%)	SO_4 (%)	Cl (ppm)
Laguna Salina (Unit 1)								
Unwashed salt			3.3	0.34	0.38	0.38	1.11	
Brine for washing	1.2	22.2			0.36	24.02	27.45	134.9
Washed salt			2.2	0.06	0.09	0.19	0.32	
1966 harvest			1.5	0.12	0.11	0.06	0.27	
Punta Araya (Unit 2)								
Bitterns from crystallizers	1.2	27.1			0.36	21.26	29.18	187
Salt from crystallizers			8.1	0.06	0.13	0.73	0.88	
Washed salt			4.5	0.20	0.07	0.33	0.43	
1966 harvest			2.6	0.09	0.07	0.08	0.20	

Figure 11

Salt-harvesting machine at Punta Araya

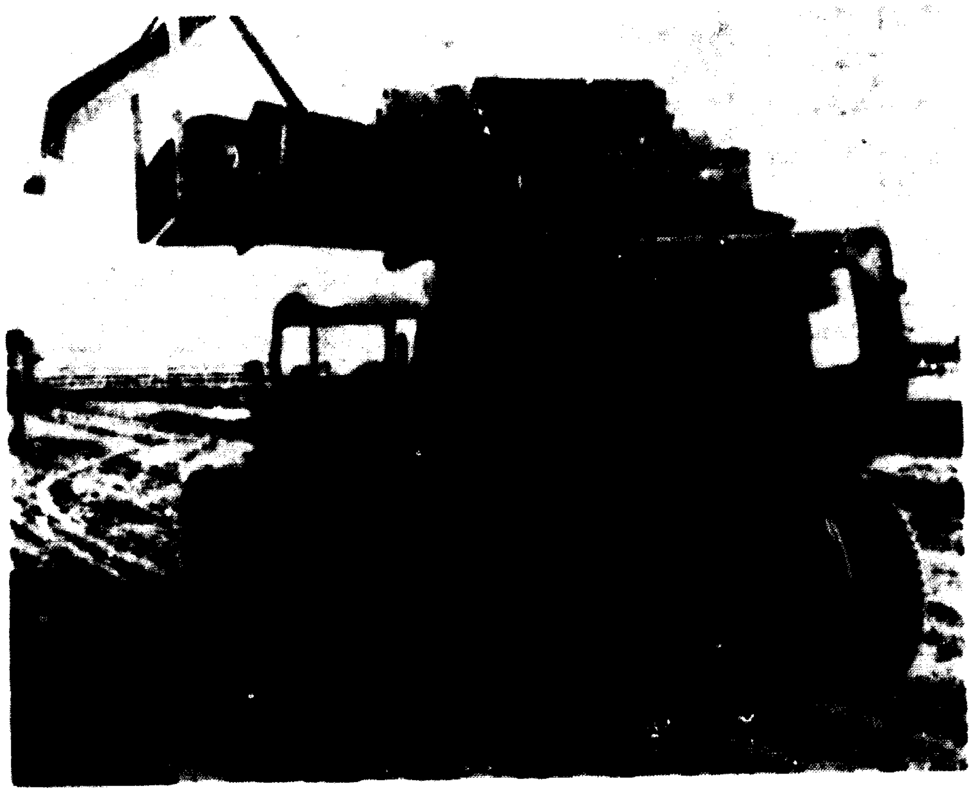


Figure 12

Stockpiling salt at Punta Araya

The washing plant is old and has too large a capacity for the output similar to the washing plant of Unit 1. It does not produce high-quality salt for industrial demands. The harvesting system is flexible; the high output of 150 tons/hour is reasonable (figure 11). The stacking system (figure 12) is acceptable and well maintained; its capacity and hourly output are in balance with the harvesting machine.

Factory (Unit 3)

The washing plant is located in a large building with an area of 8,500 m^2, including settling tanks for brine recovery. There are two duplicate production lines to crush, wash and dry 3 tons/hour each.

The refined salt contains additives and is filled in the following packaging:

Paper bags containing 50 or 25 kg,
Paper bags of 1 kg,
Cardboard packets of 0.5 or 0.25 kg.

The washing system involves crushing in saturated brine and two further washings to reduce the contents of insolubles and other salts. Centrifuging and drying in a rotary dryer reduce the humidity.

The quantities produced during the only operating years were as follows:

	Tons
1964	3,035
1965	3,163

Production was stopped for political reasons. These small outputs therefore are not technically significant.

The fine salt is too coarse; its appearance is unsatisfactory because it is a light yellow without lustre. The packaging is too expensive and too unattractive. Taking into consideration the short operating period, it is difficult to judge the results.

Veterinary salt (Unit 4)

This installation is a 30-year old plant which has been improved by rebuilding. It consists of a modest building of 700 m^2 with a large, old crushing plant for washing and drying salt, an additive mixing-dosing system, a press for making compressed salt blocks and a bagging silo.

The salt-processing equipment has a capacity over 7 tons/hour, while the press can only make 1.6 tons of blocks/hour; the remaining output is packed into 25 or 50 kg bags. Since its reconstruction, however, the plant has not operated regularly.

The quality of the salt obtained during test operations was satisfactory. The final compositions of the blends have not yet been determined.

Although the plant has not operated regularly, some theoretical statements can be made because it is large, old and lacks space. The equipment for washing, milling and drying of salt represents a useless duplication of the excess capacity at Unit 3.

Handling of salt

Unit 1

The salt is recovered, as already mentioned, by rope-hauled scrapers. The system seems too powerful in proportion to the tonnage handled. The salt is sent to a concrete bunker before being dispatched in wagons. The bunker is too large to act merely as surge capacity so it is largely unused. The salt is transported to the industrial area on a narrow-gauge rail track. On the whole, the system seems too sophisticated, inflexible and expensive.

Unit 2

The salt is loaded by hand because there is neither a crane nor a railway. From a theoretical point of view, the same comments could be made as on Unit 1.

Unit 3

Salt from Unit 1 or 2 is unloaded into an underground concrete hopper with an apron feeder to a horizontal belt conveyer installed on a heavy metal structure. This belt conveyer can either make a stockpile at the factory (Unit 3) entrance or discharge under the parabolic concrete roof of the store. This store is expensive and not very useful considering the low rainfall. With the small loading capacity of the port (150 tons/hour) the store is not useful as surge capacity and will not be until the port loading capacity reaches 300 tons/hour.

Bulk salt can be loaded at 150 tons/hour and salt packages can be loaded at 1,200 boxes or bags/hour, as already mentioned (figure 13). The systems are obsolete because of ships draught and loading rate. The bulk system is very restrictive for boats used for this type of merchandise; it is difficult to obtain competitive export freight rates.

Figure 13

Conveyers loading salt into a ship in the industrial area

Services and costs

Electric power supply through a submarine cable is perhaps a little risky considering that the industry depends wholly on this link; the emergency generator has very low capacity.

The shops have equipment that is too expensive, delicate and large for the maintenance work they have to perform. Therefore, a way must be found to use this equipment permanently by enlarging the field of activity, otherwise it will remain uneconomic.

The needs for drinking water by the industry itself are very low, therefore any trouble from failure of the pipeline is unlikely to be serious.

Some costs are given in tables 2, 3 and 4; table 2 lists the labour required and the rates of payment, table 3 the production expenses and table 4 the capital investments.

Table 2

Labour requirements

	Unit 1	Unit 2	Unit 3	Unit 4	Services	Administration	Totals	Monthly salary (US$) a/
Managers	1	1	1	1	1	2	7	800
Technicians	-	-	3	-	6	-	9	400
Clerical staff	3	3	6	3	4	9	28	250
Others	6	6	5	1	3	5	26	150
Labourers	67	39	62	19	40	-	227	150
Total	77	49	77	24	54	16	297	

a/ Excluding social contributions.

Table 3

Manufacturing expenses

		Thousands of dollars/year	
Raw materials			
Unit 3		340	
Unit 4		200	
Sub-total			540
Direct labour cost			
Washed salt			
Unit 1 (120,000 tons/year)	148		
Unit 2 (50,000 tons/year)	118		
Refined salt			
Unit 3 (25,000 tons/year; 2 shifts)	168		
Unit 4 (10,000 tons/year; 1 shift)	50		
Unit 5 (services)		88	
Sub-total			572
Indirect manufacturing cost			
Unit 1		81	
Unit 2		83	
Unit 3		146	
Unit 4		44	
Unit 5 (services)		92	
Sub-total			446
Management		141	
			141
Grand total			1,699

Table 4

Investments in the Araya Peninsula Complex
(in thousands of dollars)

	Production		Refining		Services and utilities		
	Unit 1	Unit 2	Unit 3	Unit 4	Workshop	Pier	General and administrative
Land	24	2	15	-	-	-	20
Civil works	2,850 a/	2,600	36	-	-	1,595	44 b/
Buildings	200	280	1,460	34	184	365 c/	556 d/
Heavy equipment	500	285	1,080	285	40	780	-
Medium equipment	520	270	340	40	156	7	146 e/
Light equipment	25	130	144	11	3	-	12
Short-life equipment	16	11	21	1	-	6	106 f/
Various	10	10	23	1	4	-	21
Total	4,145	3,588	3,119	372	387	2,753	905

Note: An additional $2,400,000 were invested in electric power and water supply to Araya village and salt complex.

a/ Includes $1,940,000 for dikes, channels etc.

b/ Pier for general use.

c/ Covered salt store.

d/ Residential zone for employees and other properties in Araya village.

e/ Equipment for earth moving and ships.

f/ Value of vehicles and tracks.

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