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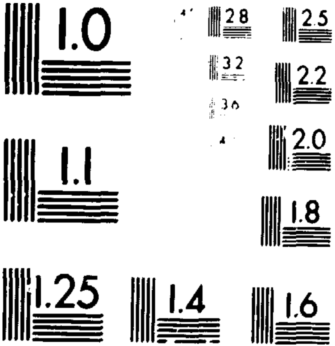

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GUIDELINES FOR THE ESTABLISHMENT OF SOLAR SALT FACILITIES FROM SEAWATER, UNDERGROUND BRINES AND SALTED LAKES *

by

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Industrial and Technological Information Bank (INTIB)

Industrial Information Section

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FOREWORD

The Industrial and Technological Information Bank (INTIB) came into existence in 1977 as a UNIDO pilot operation in four industrial sectors. Since its successful inception, INTIB has become a permanent activity of UNIDO covering, at the moment, 20 industrial sectors. Its main objective is to facilitate the choice of technology for decision makers in developing countries.

In view of the importance of salt for human and animal consumption and of the availability of this natural resource in most developing countries, this document has been prepared under the INTIB programme of UNIDO.

It is hoped that this document will be of assistance to planners and promoters in developing countries in identifying the most suitable technology for solar salt production according to their local conditions.

CONTENTS

CHAPTER - I

IMPORTANCE OF SALT

The story of salt is the story of mankind. Salt has played a predominant part in the development of man's activities, trade, politics and culture from prehistoric times. One reason for its overwhelming influence is that it is the source for Sodium and Chlorine, two of the twelve dominant elements in the human body. These two elements have important functions in the metabolism of the body. Lack of these elements leads to decay and death. The other reason is that the science of chemistry has used this inexpensive and abundantly available commodity as an important raw material in today's industry. Directly or in the form of derivatives, salt finds application in more than 14,000 ways. The word salt has become synonymous with Sodium Chloride and will be considered equivalent in this publication.

Salt for human consumption:

Salt is a principal constituent of extracellular body fluids i.e. fluids outside the cells as in the tissues, blood serum and saliva. Its concentration varies with the type of fluid being almost the same in blood serum, cerebral and spinal fluids, but less in tissue fluids, sweat and gastric juices. It becomes part of the human body even in the embryo stage since the foetus floats in a saline solution. The amount of salt increases during the period of growth and reaches 230 grams in the body of an adult.

In the physiological system, salt functions as sodium ion and chloride ion. Sodium controls muscular movement including that of the heart muscles, the peristallic movement of the digestive tract and the transmission of messages by nerve cells. The chloride ion produces hydrochloric acid required for digestion. A principal function of salt is to regulate pressure and the exchange of fluids between the intra cellular fluid and the extra-cellular fluid.

For normal health, the salt concentration in the body can vary only within narrow limits. Salt that goes out of the system has to be replaced. Salt is lost mainly through sweating. It is also passed out through urine but the amount is so regulated by the kidneys that the salt remaining in the system is maintained at the necessary level. Salt in the gastric juices and the digested food is mostly reabsorbed in the intestines, except in cases of frequent loose motions which result in salt depletion. Salt loss is high in the tropical summer under conditions of heavy manual work when excessive sweating takes place. Such loss of salt through sweating and other processes has to be made good by intake of fresh salt with food. The early man who subsisted on a meat diet had no need to add salt to his food as meat contains an adequate amount. Even today, certain Eskimo tribes living on seal meat or the Masai tribesmen of Kenya who drink the blood of cattle, do not need salt. When man took to agriculture, cereals became his staple food. These contain more potassium salts than sodium salts and hence addition of salt to the diet became important. The rice eating population of the world requires more salt than others because rice is very deficient in salt. In the tropics, where most of the population is rice eating, the condition is further aggravated by sweating. In temperate climate the annual human requirement of salt is about 5 kg/year. In the tropics this is higher.

Chronic inadequacy of salt produces loss of weight, loss of appetite, inertia, nausea and muscular cramps. Acute salt depletion as in gastroenterites, results in dehydration and reduction of blood volume, interfering with the supply of oxygen and other elements to the tissues. When this happens, the body, in an attempt to maintain the normal balance in the fluids, releases vital substances from within the cells, causing damage to health and hazard to life. Excessive heat, like the summer in deserts, results in salt depletion and causes heat strokes especially among children.

On the other hand, excess of sodium in salt and in other foods, can contribute to hypertension, heart, liver and kidney diseases. In such conditions, water (required to maintain sodium at the preper concentration in blood) accumulates in the tissues leading to oedema. Patients are then advised to be on a low sodium diet.

Salt for animal consumption:

Salt is as important for the health of animals as for that of human beings. It is a part of an animal's body fluid in almost the same concentration as in humans. Experiments indicate that insufficient salt stunts the growth of young animals and in the case of fully grown ones produces lassitude, lowered production of milk, loss of weight and nervous diseases leading at times to death. Since fodder and plant life have little salt, domestic animals have to be given salt with their feed. Herbivorous animals in the wild get their salt from salt licks. The carnivorous animals get it from the flesh and blood of the herbivorous ones. In today's modern farms, salt is also used as a vehicle for mineral supplements that are essential for good health of livestock.

History and culture of salt:

The primary use of salt for man, ever since he took to agriculture, is as an essential item of diet both for him and his cattle. Salt has also been used from prehistoric times for flavouring, pickling, preserving, curing meat and fish, and in tanning. In view of such widespread importance, it has become part of our culture and civilisation. As one writer points out 'From cells in our brains and bones to customs that spice our languages, salt penetrates every aspect of our existence'. 'Worth his salt', 'above salt', 'old salt', 'loyal to one's salt', 'the salt of life', 'salary', are expressions and words used every day which originate from salt. Salt has been held as a symbol of divinity, of purity, of welcome and hospitality, of wit and wisdom in different cultures. In Sanskrit the word 'lavanya' expressing grace, beauty and charm, is derived from the word for salt 'lavana'.

Salt has been equally important in trade and politics. It was used as currency in many earlier cultures. Some primitive tribes gave gold, weight for weight, to purchase salt. The Hanseatic league developed initially on the salt trade. Salt trade was a monopoly of the state in many countries. The salt tax, among other things, provoked the French into revolution. The same salt tax was a principal issue in Mahatma Gandhi's civil disobedience movement against British control of India.

Salt for industrial consumption:

With the advent of industrial civilisation, the uses and importance of salt have multiplied. Today only 6% of the world's annual salt production is directly used for human consumption, the balance being consumed mainly by chemical industries. It is one of the Big Five among the chemicals which form the base of the chemical industry, the other four being sulphur, coal, limestone and petroleum.

The chlor-alkali industry is the largest industrial consumer of salt. Chlor-alkalis consist of chlorine, caustic soda (sodium hydroxide) and soda ash (sodium carbonate). Chlorine is used in the production of vinyl chloride resins which form the base for a variety of plastic products, in the paper industry, for water and sewage treatment, in laundry and textile bleaching, in the synthesis of numerous organic and inorganic chemicals including hydrochloric acid and in the manufacture of insecticides. Caustic soda and hydrogen gas are the co-products formed during manufacture of chlorine. Caustic soda is used in the manufacture of chemicals, paper & pulp, soaps and detergents and in vegetable oil refining, rubber reclaiming and petroleum refining. It is also used to digest bauxite in the manufacture of aluminium metal. Caustic soda is so important that its consumption is taken as an index of the industrial activity of a country. Hydrogen is used mainly in the manufacture of ammonia. Soda ash (sodium carbonate) is used in glass making, in the manufacture of chemicals, soaps and detergents. In recent years the discovery of very large resources of trona (naturally occuring soda ash) has led to a decreased demand of salt manufacture of soda ash.

A small quantity of salt is used in the production of other chemicals such as metallic sodium, sodium sulphate, sodium nitrite and nitrate, sodium chlorate, sodium cyanide and sodium bisulphate.

Salt finds application in food industries such as canning, baking, processing of flour and other foods, meat packing, fish curing, dairying and food flavouring. Salt is used in animal nutrition as a vehicle for supplementary minerals which are added in controlled doses.

The leather industry consumes salt for tanning. Salt is used in de-icing of roads & highways. Salt is used as a flux in the production of high purity aluminium alloys, as a flotation agent in ore enrichment and in soil stabilisers and pond sealants. Salt is also used directly in the manufacture of pulp and paper. Salt, alum and acetic acid are used to separate emulsified latex in the production of synthetic rubber. The petroleum industry uses salt in drilling mud when underground salt formations are anticipated. In the textile and dyeing industry it is used to salt out the dyestuff. Salt is used to regenerate cation exchange water softeners for domestic and municipal purposes. Figure 1.1 indicates the various uses of salt.

As the frontiers of the chemical industry grow, new applications for salt and its derivatives are constantly being discovered. Salt will be playing an even more important role in the future.

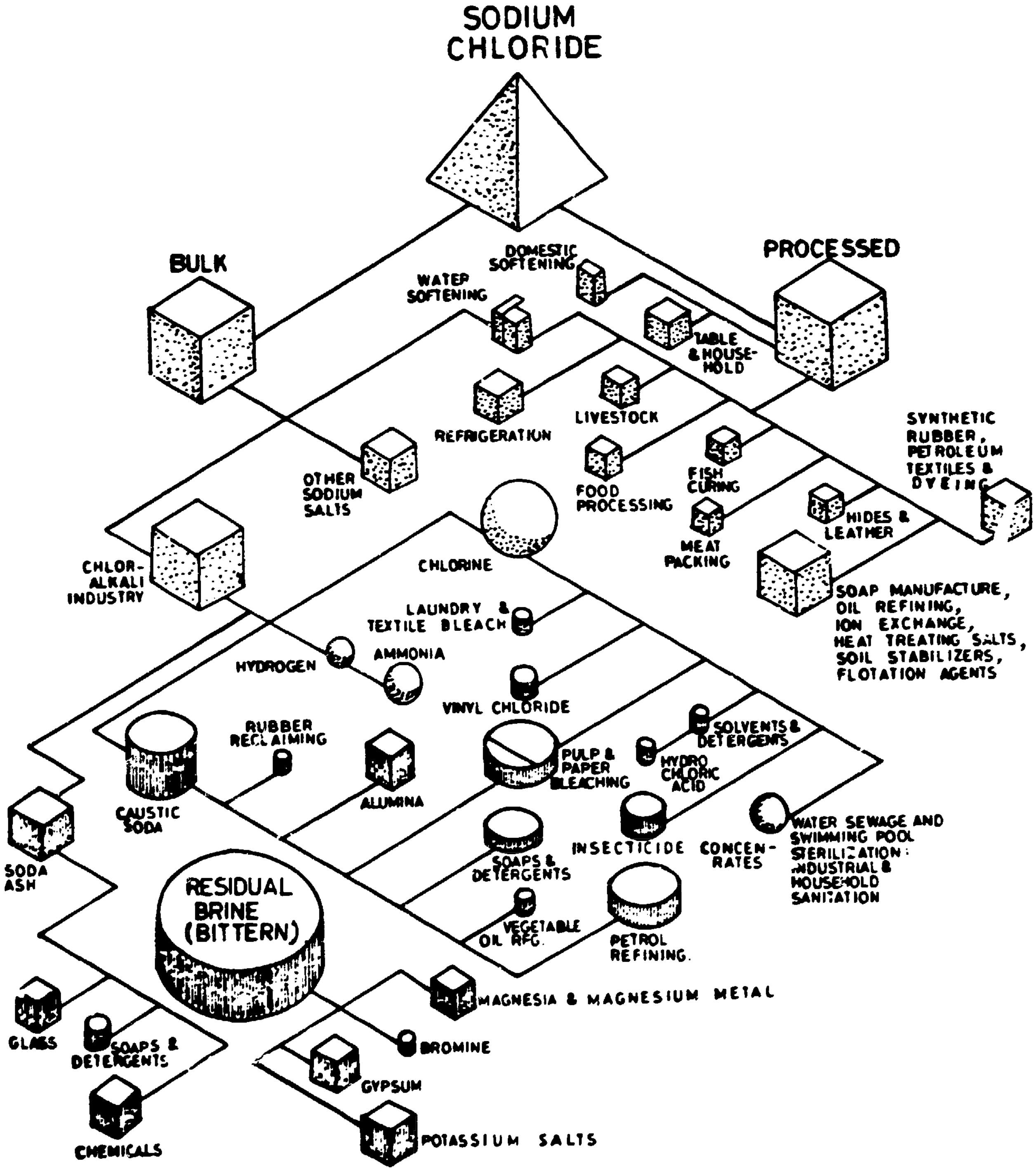

FIG.1.1. USES OF SODIUM CHLORIDE.

CHAPTER - II

STATUS OF THE SOLAR SALT INDUSTRY IN THE WORLD

The production of common salt is one of the most ancient and widely distributed industries in the world. Salt is produced by mining of solid rock deposits and by the evaporation of sea water, lake, playa and underground brines. The latter method accounts for over 50% of world salt production today. The distribution of world salt production in 1980 was as follows:

Name of Continent	Total salt production (all types (million tonnes)
Europe	73.6
North America	56.2
Asia	36.5
South America	6.0
Oceania	5.9
Africa	3.3
	181.5

Country-wise production during the years 1978-80 is given in Table 2.1. Some countries depend entirely on rock salt, some on solar salt. There are a few countries where both forms are produced. Figure 2.1 gives the location of solar salt operations in the world. While the process for solar evaporation of brines is the same the world over, manufacturing techniques and product quality vary considerably.

The demand for salt increases with growth of population as well as the development of industries. Apart from consumption for human use, heavy chemical industries chiefly chlorine, caustic soda and soda ash require salt as raw material. In the developed countries, industrial requirements of salt are several times the edible consumption. In the USA for instance, over 95% of the total production of approximately 41 million tonnes is used for non-edible purposes. In the developing countries the trend towards increased industrial demand for salt has become apparent only during the past decade.

A brief review of the status of the salt industry in the world is presented below:

EUROPE:

Poland, East & West Germany, Czechoslovakia, Hungary and Holland mine rock salt. France & Italy have facilities for both rock and solar salt production. As is to be expected in these developed countries, the solar salt operations are large and are run on a completely mechanised basis incorporating scientific techniques of layout design, brine density and biological control. Countries like the USSR, Bulgaria and Rumania have a relatively small proportion of solar salt operations. Solar salt is produced in the USSR from the waters of the Black Sea and the Sea of Azov. Greece, Spain & depend almost entirely on solar salt making although they have rock salt deposits also. The size of salt works in these countries ranges from large mechanised works to small units. In the hinterland of Spain, there are salt springs where salt is produced on almost a cottage scale by boiling of brine. Saline lagoons are also a source of brine in Spain. Portugal produces rock salt and solar salt in almost equal amounts.

NORTH AMERICA:

Canada does not produce any solar salt. Even in the USA, only 5% of the production is accounted for by solar salt. Indeed, most of the salt obtained by evaporation of brine from the Great Salt Lake (to recover potassium and magnesium salts) is flushed back into the lake. Solar salt is manufactured mostly along the California Coast by about a dozen operations and around the Great Salt Lake in Utah. Production in the USA has been almost static during the last decade because of a reduction in demand owing to the closure of several synthetic soda ash plants following the discovery of natural deposits. American salt works are noteworthy for the large number of varieties produced for different applications.

CENTRAL & SOUTH AMERICA:

In Mexico, solar salt operations play an important role although there are rock salt deposits. The 6 million tonnes per year operation of Exportadora de Sal in the Baja California desert is considered the largest solar salt operation in the world today. There also exist in Mexico several small and medium sized solar operations managed by individuals or co-operatives. Small quantities of solar salt are produced in the central American countries like Costa Rica, Nicaragua and Panama bordering the sea. In south America, Brazil is the largest producer of salt, the major portion of which is solar. Venezuela is building a very large solar salt works which is expected to become the world's second largest salt producer. In Uruguay, solar salt production has been attempted but abandoned. Chile has no solar salt industry. In Argentina and Peru, all the solar salt is produced from brine wells. In Cuba, salt is produced almost entirely by solar evaporation of sea water. In this country there is potential for increasing production because of favourable climatic conditions and availability of land. Bahamas & Netherlands Antilles have lately emerged as large scale producers of solar salt from sea water. However, in recent years the Bahamian operations have suffered production set backs due to heavy rainfall.

ASIA:

In Asia, the Middle Eastern countries like Syria, Iraq and Iran depend mostly upon rock & playa salt. Turkey is an exception and concentrates on solar salt making. Production methods are traditional. However, a few modern solar salt operations are now being developed in Turkey, Iraq and Iran. Israel produces a small quantity of solar salt from the Dead Sea. In the Indian subcontinent, Pakistan has extensive deposits of rock salt but also produces some solar salt. In India, almost all the salt is produced by solar evaporation of sea water, underground springs and inland lake brines. Here salt works range from very small to large sized operations. Salt works are operated by private and government owned companies, co-operatives and individuals. Solar salt is the only form of salt produced in Sri Lanka, Bangladesh and Thailand where the size of salt works is mostly small. In Indonesia, the government has a monopoly on salt production and the state owned salt company produces salt in half a dozen locations. The production methods adopted in Kampuchea and other south east Asian countries where small holdings predominate, are primitive and the salt is not very pure. Salt making has had a very important role in China from ancient times. In spite of rock salt resources, about 75% of the production is solar salt from sea water. Salt farms are worked in every coastal province of China. In the Philipines and Taiwan salt is produced entirely by solar evaporation of sea water in small and medium sized operations. In Japan, the pressure on availability of land has encouraged the development of sophisticated ion exchange technique for recovery of salt directly from sea water. Direct evaporation methods using a combination of solar and artificial evaporation are also employed. However, the production by these methods is small and Japan today is the world's largest importer of salt.

OCCEANIA:

Australia has enormous reserves of rock salt as well as facilities for solar salt manufacture. The main locations where solar salt is manufactured are the South Australian and West Australian coasts. Five companies operating along the West Australian coast together produce nearly 8 million tonnes in highly mechanised operations. Most of this production is exported to Japan. In terms of design and layout the Australian salt works can be considered to be the most modern, producing an exceedingly pure product. However, their profitability has been low owing to low price realisation. New Zealand produces a small quantity of solar salt to meet domestic requirements despite unfavourable weather conditions. Recently rock salt deposits have been discovered in the Antartic region.

AFRICA:

In contrast to Australia, the techniques in the African countries are conventional and in some areas, ancient. Solar salt is produced only in certain countries while others depend on rock salt and other salt sources. In the former category are Egypt, Libya and Ethiopia. In Egypt, there exist small and medium sized salt pans. In Libya and Ethiopia there are several small operations. Ethiopia produces salt along the Red Sea coast and exports it. There is very good potential for improvement of production in this country if modern techniques are adopted and transport and port facilities are improved. In general the Red Sea area is well suited for solar salt production from the point of view of salinity, climate and topography and deserves detailed investigation. Mozambique is a country with a long coastline but very little salt is produced as climatic conditions are not favourable. In Tanzania conditions of humidity and rainfall are not conducive for solar salt manufacture. Nevertheless, a small quantity of salt is manufactured from sea water and the major portion by solar evaporation of playa and lake brines In Somalia small quantities of solar salt are being produced for local consumption. In Mauritius small shallow paved ponds are used for solar salt production. Niger produces playa salt by solar evaporation almost as a cottage industry. This forms the mainstay of its economy. In Zambia plants growing in brine marshes are out and squeezed in water to get a weak brine solution which is heated in pots to recover salt. In

Mauritania salt is made by solar evaporation of brine from inland lakes. Although South Africa has a long coastline and has a solar evaporation plant, the major portion is from solar evaporation of playa salt brine after the rains. In Namibia there is natural solar evaporation of sea water which gets trapped in tidal basins. In most of West Africa conditions for solar salt production are unsatisfactory because of the humid climate and low salt concentration of sea water owing to dilution by large rivers. However, in countries such as Ghana, Guinea, Senegal and Togo solar salt production is feasible. The North African countries have by far the most favourable conditions in Africa for solar salt manufacture. These include Algeria, Morrocco, Tunisia and Egypt. In Algeria most of the salt is produced from salt lakes although there is good potential for sea salt production also.

There is tremendous potential for increasing output and improving the quality of the salt produced in the African, Asian and South American countries. In several countries, simple machines for the harvesting and handling of salt could be introduced. Improved techniques can be adopted for designing the concentrating and crystallising ponds and quality control procedures introduced for production of high purity salt. The recovery of chemicals like Bromine, Magnesium and Potassium salts from bittern could be the next step.

A major portion of the world output of salt (more than 80%) is consumed in the country in which it is produced. Since bulk salt for industrial use has a relatively low value, transportation costs usually form a large part of the delivered cost. This is a disadvantage in international trade. Japan is a major industrial country that depends largely on salt imports of nearly 10 million tonnes per year from Australia, Mexico and mainland China to meet the requirements of its chemical industry. Other salt importing countries are Australia, Bahamas, Canada, Mainland China, Mexico, Netherlands and Spain. There is however, fairly widespread international trade in refined grades of salt for table use.

The U.S.Department of Mines had made the following forecasts for growth in world demand for salt:

Production in 1980	165 million tonnes
2000 Forecast range	
Low	282.8 million tonnes
High	452.1 million tonnes
Probable Demand	
1990	253.6 million tonnes
2000	364.5 million tonnes
Probable average annual growth rate 1980 - 2000	3.7 %

In the developing countries the demand growth rate is expected to be faster (4.2%) than in countries like the USA (2.0%). This is because many countries in various stages of economic development are expanding industries that consume salt as raw material. Most countries produce salt only at 70 - 80% of the full rated capacity since the production of salt by solar evaporation is subject to weather fluctuations. To meet anticipated increases in demand, salt producers in many countries will have to increase productivity of existing operations, increase the capacity of existing plants or construct new facilities. Today production economics and quality considerations indicate that the size of solar salt operations has to be progressively increased from a cottage level of 500 tonnes/year to atleast a small scale level of 2000 to 3000 tonnes/year. The fact that solar salt production utilises the abundant and inexhaustable resources of the sun and the sea should encourage such a growth.

TABLE - 2.1

COUNTRYWISE PRODUCTION OF SALT[*]

(Thousand metric tons)

Country[2]	1978	1979[p]	1980[e]
North America:			
Bahamas	[e]1636	441	[3]685
Canada	6465	6895	[3] 7044
Costa Rica	35	46	40
Dominican Republic	38	38	38
El Salvador[e]	27	27	27
Guatemala	11	15	[3]10
Honduras	[e]32	[e]32	[e] 32
Leeward and Windward Islands[e]	50	50	50
Mexico	5647	[e]5636	6000
Netherlands Antilles[e]	400	400	400
Nicaragua	[e]18	[e] 18	20
Panama	15	19	19
United States including Puerto Rico:			
Rock salt	13352	13537	10734
Other salt:			
United States	25619	28092	25949
Puerto Rico[e]	25	25	25
South America:			
Argentina:			
Rock salt	1	1	[3]1
Other salt	701	563	[3]627

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[*] Source: US Bureau of Mines Minerals Year Book (short tonnes have been converted into metric tonnes

(thousand metric tonnes)

Country[2]	1978	1979[p]	1980[e]
Brazil	2733	2806	3000
Chile	395	591	500
Colombia:			
Rock salt	178	176	173
Other salt	575	459	445
Peru	493	451	500
Venezuela	158	[e]155	[3]244
Europe:			
Albania[e]	50	64	68
Austria:			
Rock salt	1	1	[3]1
Evaporated salt	322	381	[3]411
Salt in brine	156	208	200
Bulgaria	87	86	[3]122
Czechoslovakia	258	272	273
Denmark	325	381	382
France:			
Rock salt	459	574	[3]301
Brine salt	1105	1191	[3]1115
Marine salt	865	1805	[3]1277
Salt in solution	3867	4504	[3]4424
German Democratic Republic:			
Rock salt	2694	3004	3091
Marine salt	53	55	56

(thousand metric tonnes)

Country[2]	1978	1979[p]	1980[e]
Germany, Federal Republic of:			
Marketable:			
Rock salt	6860	8978	7909
Marine salt & other salt	5824	6143	6091
Greece	134	155	155
Iceland	[e](4)	[e](4)	[3](4)
Italy:			
Rock salt & brine salt	3729	4499	[3]4005
Marine salt	1213	1181	1273
Malta	1	[e]1	1
Netherlands	2945	3959	[3]3471
Poland:			
Rock salt	1438	1461	1091
Other salt	2964	2977	2273
Portugal:			
Rock salt	327	408	409
Marine salt	149	[e]150	127
Romania:			
Rock salt	1661	1654	1655
Other salt	3088	3076	3073
Spain:			
Rock salt	1418	1420	1455
Marine salt & other evaporated salt[5]	1280	1263	1355
Switzerland	392	392	[3]369
U.S.S.R.[e]	14527	[r]14327	14527

(thousand metric tonnes)

Country[2]	1978	1979[p]	1980[e]
United Kingdom:			
Rock salt	1314	1593	1600
Brine salt[6]	1764	1919	2000
Other salt[6]	4248	4324	3000
Yugoslavia:			
Rock salt	85	137	--
Marine salt	21	21	[3]378
Salt from brine	193	193	--
Africa:			
Algeria	172	165	173
Angola[e]	50	50	50
Benin	[e](4)	[e](4)	(4)
Egypt	756	617	700
Ethiopia[7]:			
Rock salt	10	[r]15	[r]15
Marine salt	[e]50	93	91
Ghana	50	50	50
Kenya:			
Crude	20	[e]20	20
Refined	[e]12	[e]12	12
Libya	15	10	10
Madagascar	30	[e]30	30
Mali[e]	5	5	5
Mauritania[e]	1	1	1
Marutius	6	6	6
Morocco	35	102	105
Mozambique[e]	28	28	28
Namibia (marine salt)[e]	227	227	227
Niger[e]	1	- [r]3	3
Senegal	140	[e]140	140
Sierra Leone[e]	182	182	182

(thousand metric tonnes)

	Country[2]	1978	1979[p]	1980[e]
	Somalia	[re]27	30	[3]30
	South Africa Republic of:	491	540	[3]568
	Sudan	72	82	82
	Tanzania	20	37	36
	Togo	1	[e]1	1
	Tunisia	426	440	[3]437
	Uganda[e]	1	1	1
Asia:				
	Afghanistan	81	20	5
	Bangaladesh	787	675	700
	Burma	305	258	[3]269
	China:			
	Mainland	19571	14801	[3]17316
	Taiwan	341	367	[3]724
	Cyprus	--	6	[3]7
	India:			
	Rock salt	5	5	[3]5
	Marine salt	6710	7046	7273
	Indonesia	235	708	656
	Iran[e] [s]	[r]700	[r]700	600
	Iraq[e]	82	[r]100	91
	Israel	122	107	110
	Japan[9]	1075	1093	1091
	Jordan	30	25	30
	Kampuchea[e]	12	[r]26	30
	Korea, North[e]	545	545	573
	Kuwait	19	19	20

(thousand metric tonnes)

Country[2]	1978	1979[p]	1980[e]
Laos[e]	15	18	20
Lebanon[e]	12	[r]10	12
Mongolia[e]	15	15	15
Pakistan:			
Rock salt[7]	414	513	500
Other salt	227	193	205
Philippines	226	339	354
Sri Lanka	150	122	127
Syria	[re]109	75	82
Thailand:			
Rock salt	12	11	12
Other salt[e]	164	164	164
Turkey	931	1133	1091
Vietnam[e]	[r]532	[r]527	518
Yemen Arab Republic	27	64	65
Yemen, People's Democratic Republic of[e]	75	75	80
Oceania:			
Australia (marine salt and brine salt)	5778	5812	[3]5326
New Zealand	65	70	73
TOTAL	[r]167279	172214	165098

[e]Estimated [p]Preliminary [r]Revised

[1] Table includes data available through June 17, 1981

[2] Salt is produced in many other countries, but quantities are relatively insignificant and reliable production data are not available

[3] Reported figure

[4] Less than 1/2 unit

[5] Includes production the Canary Islands (Spain's provinces of Las Palmes and Santa Cruz de Tenerife) totalling 17,434 short tons in 1977, 15,766 short tons in 1978, 8,685 short tons in 1979 (1976 and 1980 not available)

[6] Data captioned 'Brine salt' for the United Kingdom are the quantities of salt obtained from the evaporation of brines; that captioned 'Other salt' are the salt content of brines used for purposes other than production of salt by evaporation.

[7] Year ending June 30 of that stated

[8] Year beginning March 31 of that stated

[9] Includes Ryukhy Islands

FIG. 2.1

● LOCATION OF SOLAR SALT OPERATIONS
). IN THE WORLD.

CHAPTER - III

THE CHEMISTRY OF SOLAR SALT MANUFACTURE

Salt from the sea:

The oceans are the most prolific source of sodium chloride accounting for over 50% of world production today. The reserves in the seas are estimated at 50 million billion tonnes. Apart from Sodium Chloride, the seas are an important source for Potassium, Magnesium and Bromine. 65% of Magnesium Metal and 68% of Bromine produced in the world are from seawater. Almost every element including gold and uranium is found in traces in seawater. Table 3.1 lists 60 elements found in seawater giving their concentration and the amounts present. Of these the more important ones are:

ELEMENT	CONCENTRATIONS (PARTS PER MILLION)
Chlorine	19000
Sodium	10500
Magnesium	1360
Sulphur	885
Calcium	400
Potassium	380
Bromine	65

These elements exist in the ionic states. Five ions - Sodium, Magnesium, Potassium, Chlorine and Sulphate -

TABLE - 3.1

CONCENTRATION AND AMOUNTS OF THE ELEMENTS IN SEA WATER

ELEMENT	Concentration mg/litre	Amount of element in seawater (tonnes/ cubic mile)	Total amount in the oceans (tonnes)
Chlorine	19,000.0	89.5 10^6	29.3 x 10^{15}
Sodium	10,500.0	49.5 10^6	16.3 x 10^{15}
Magnesium	1,360.0	6.4 10^6	2.1 x 10^{15}
Sulphur	885.0	4.2 10^6	1.4 x 10^{15}
Calcium	400.0	1.9 10^6	0.6 x 10^{15}
Potassium	380.0	1.8 10^6	0.6 x 10^{15}
Bromine	65.0	306,000	0.1 x 10^{15}
Carbon	28.0	132,000	0.04 x 10^{15}
Strontium	8.0	38,000	12,000 x 10^9
Boron	4.6	23,000	7,100 x 10^9
Silicon	3.0	14,000	4,700 x 10^9
Fluorine	1.3	6,100	2,000 x 10^9
Argon	0.6	2,800	930 x 10^9
Nitrogen	0.5	2,400	780 x 10^9
Lithium	0.17	800	260 x 10^9
Rubidium	0.12	570	190 x 10^9
Phosphorous	0.07	330	110 x 10^9
Iodine	0.06	280	93 x 10^9
Barium	0.03	140	47 x 10^9
Indium	0.02	94	31 x 10^9
Zinc	0.01	47	16 x 10^9
Iron	0.01	47	16 x 10^9
Aluminium	0.01	47	16 x 10^9
Molybdenum	0.01	47	16 x 10^9
Selenium	0.004	19	6 x 10^9
Tin	0.003	14	5 x 10^9
Copper	0.003	14	5 x 10^9
Arsenic	0.003	14	5 x 10^9
Uranium	0.003	14	5 x 10^9
Nickel	0.002	9	3 x 10^9
Vanadium	0.002	9	3 x 10^9

Manganese	.002	9	3×10^9
Titanium	0.001	5	1.5×10^9
Antimony	0.0005	2	0.8×10^9
Cobalt	0.0005	2	0.8×10^9
Caesium	0.0005	2	0.8×10^9
Cerium	0.0004	2	0.6×10^9
Yttrium	0.0003	1	5×10^8
Silver	0.0003	1	5×10^8
Lanthanum	0.0003	1	5×10^8
Krypton	0.0003	1	5×10^8
Neon	0.0001	0.5	150×10^6
Cadmium	0.0001	0.5	150×10^6
Tungsten	0.0001	0.5	150×10^6
Xenon	0.0001	0.5	150×10^6
Germanium	0.00007	0.3	110×10^6
Chromium	0.00005	0.2	78×10^6
Thorium	0.00005	0.2	78×10^6
Scandium	0.00004	0.2	62×10^6
Lead	0.00003	0.1	46×10^6
Mercury	0.00003	0.1	46×10^6
Gallium	0.00003	0.1	46×10^6
Bismuth	0.00002	0.1	31×10^6
Niobium	0.00001	0.05	15×10^6
Thallium	0.00001	0.05	15×10^6
Helium	0.000005	0.03	8×10^6
Gold	0.000004	0.02	6×10^6
Protactinium	2×10^{-9}	1×10^{-5}	3000
Radium	1×10^{-10}	5×10^{-7}	150
Radon	0.6×10^{-15}	3×10^{-12}	1×10^{-3}

dominate to such an extent that seawater is sometimes considered as a quinary system. It is convenient to study the solutes as salts. The major chemicals found in one litre of seawater are

Dissolved salts (in order of precipitation)	Concentration (gm/litre)	Percentage of total wt. of dissolved salts
Calcium Carbonate ($CaCo_3$)	0.12	0.34
Calcium Sulphate ($CaSo_4$)	1.26	3.61
Sodium Chloride ($NaCl$)	27.21	77.74
Magnesium Sulphate ($MgSo_4$)	1.66	4.74
Potassium Chloride (KCl)	0.86	2.46
Magnesium Chloride ($MgCl_2$)	3.81	10.88
Magnesium Bromide ($MgBr_2$)	0.08	0.23

Sodium Chloride also called Halite, dominates, constituting 80% by weight of the total salts dissolved in seawater. One litre of seawater contains 35 gms of dissolved salts giving it a specific gravity of 1.034. This value is variable within a small range.

The salinity of seawater depends upon a number of factors including location, season, temperature and dilution by river discharges. It is lower at seashores and estuaries than in the mid sea. Geographical features like the partly stratified surface layers in bays with constricted outlets as in the south Australian coast result in higher salinity. A remarkable fact about seawater is that though salinity may vary, the relative proportion of the dissolved elements is consistently the same everywhere in the world, in all seasons and, geologists believe, through all times.

For the manufacture of salt and its byproducts by the solar evaporation of seawater, a knowledge of both the composition of seawater and its phase chemistry is necessary. Considerable research has been done in this connection by the Italian scientist, Usiglio. His experiments on the separation of salts by the evaporation of sea brine have been performed at 25°C which is normal for a temperate climate. The ruling temperatures over salt pans in the tropics are generally between 30°C and 35°C. Some work has been done at these higher temperatures by Borschart (1940). The conclusions are broadly the same because the pattern of phase relationship remains the same. The actual values depend upon local conditions and results will not be absolutely identical at any two locations.

In studying the phase chemistry, brine concentration is given on the Baume scale which is defined as

$$°\text{Be (Degree Baume)} = 145 - \frac{145}{\text{specific gravity of the brine at } 15.6°\text{C}}$$

Table 3.2 gives the conversion figures from °Be to density (gms/ml). Table 3.3 gives the temperature corrections for solutions whose density is measured at different temperatures.

The order of separation of the dissolved salts depends on their relative solubility which is given below. Calcium Carbonate being the least soluble, separates out first. The highly soluble magnesium salts are separated last.

Salt	Solubility at 30°C (gm in 100 gm of water)
$CaCo_3$	--
$CaSO_4.2H_2O$	0.2
NaCl	36.3
KCl	37.0
$MgSo_4.7H_2O$	40.8
$MgCl_2$	56.0
$MgBr_2$	104.0

TABLE - 3.2

RELATION BETWEEN BRINE DENSITY IN GMS/ML AND DEGREES BAUME

Density gm/litre	°Be	Density gm/litre	°Be
1.020	2.8	1.061	8.4
1.021	3.0	1.062	8.5
1.022	3.1	1.063	8.7
1.023	3.3	1.064	8.8
1.024	3.4	1.065	8.9
1.025	3.6	1.066	9.0
1.026	3.7	1.067	9.2
1.027	3.8	1.068	9.3
1.028	4.0	1.069	9.4
1.029	4.1	1.070	9.5
1.030	4.2	1.071	9.6
1.031	4.4	1.072	9.7
1.032	4.5	1.073	9.9
1.033	4.7	1.074	10.0
1.034	4.8	1.075	10.1
1.035	4.9	1.076	10.2
1.036	5.0	1.077	10.3
1.037	5.1	1.078	10.5
1.038	5.3	1.079	10.6
1.039	5.4	1.080	10.7
1.040	5.5	1.081	10.8
1.041	5.7	1.082	11.0
1.042	5.8	1.083	11.1
1.043	6.0	1.084	11.2
1.044	6.1	1.085	11.3
1.045	6.2	1.086	11.5
1.046	6.4	1.087	11.6
1.047	6.5	1.088	11.7
1.048	6.7	1.089	11.8
1.049	6.8	1.090	11.9
1.050	6.9	1.091	12.0
1.051	7.0	1.092	12.1
1.052	7.2	1.093	12.3
1.053	7.3	1.094	12.4
1.054	7.5	1.095	12.5
1.055	7.6	1.096	12.6
1.056	7.7	1.097	12.7
1.057	7.9	1.098	12.8
1.058	8.0	1.099	13.0
1.059	8.1	1.100	13.1
1.060	8.2	1.101	13.2

TABLE - 3.2 (CONTD)

RELATION BETWEEN BRINE DENSITY IN GMS/ML AND DEGREES BAUME

Density gm/litre	°Be	Density gm/litre	°Be
1.102	13.4	1.141	17.8
1.103	13.5	1.142	17.9
1.104	13.6	1.143	18.0
1.105	13.7	1.144	18.1
1.106	13.8	1.145	18.2
1.107	14.0	1.146	18.3
1.108	14.2	1.147	18.5
1.109	14.3	1.148	18.6
1.110	14.4	1.149	18.7
1.111	14.5	1.150	18.8
1.112	14.6	1.151	19.0
1.113	14.7	1.152	19.1
1.114	14.9	1.153	19.2
1.115	15.0	1.154	19.3
1.116	15.1	1.155	19.4
1.117	15.2	1.156	19.5
1.118	15.3	1.157	19.6
1.119	15.4	1.158	19.7
1.120	15.5	1.159	19.8
1.121	15.6	1.160	19.9
1.122	15.7	1.161	20.0
1.123	15.8	1.162	20.2
1.124	15.9	1.163	20.3
1.125	16.0	1.164	20.4
1.126	16.2	1.165	20.5
1.127	16.3	1.166	20.6
1.128	16.4	1.167	20.7
1.129	16.5	1.168	20.8
1.130	16.6	1.169	20.9
1.131	16.7	1.170	21.0
1.132	16.8	1.171	21.1
1.133	16.9	1.172	21.2
1.134	17.0	1.173	21.3
1.135	17.1	1.174	21.4
1.136	17.3	1.175	21.5
1.137	17.4	1.176	21.6
1.138	17.5	1.177	21.7
1.139	17.6	1.178	21.8
1.140	17.7		

TABLE - 3.3

DENSITY OF CONCENTRATED SEA WATER - CORRECTION FOR TEMPERATURE

TOTAL CORRECTION TO 20°C, DENSITY IN GM/ML

Temp °C		Density range, gm/ml at 20°C					
		1.00 - 1.05	1.05 - 1.10	1.10 - 1.15	1.15 - 1.20	1.20 - 1.25	1.25 1.30
10		.002	.002	.003	.003	.003	.003
11	Subtract correction from measured density	.002	.002	.003	.003	.003	.003
12		.001	.002	.002	.003	.003	.002
13		.001	.002	.002	.003	.002	.002
14		.001	.001	.002	.002	.002	.002
15		.001	.001	.002	.002	.002	.002
16		.001	.001	.001	.002	.002	.001
17		.001	.001	.001	.001	.001	.001
18		--	.001	.001	.001	.001	.001
19		--	--	.001	.001	--	--
20		--	--	--	--	--	--
21		--	--	.001	.001	.001	--
22	Add correction to measured density	.001	.001	.001	.001	.001	.001
23		.001	.001	.001	.002	.002	.001
24		.001	.002	.002	.002	.002	.002
25		.002	.002	.003	.003	.003	.002
26		.002	.002	.003	.003	.003	.003

TABLE - 3.3 (CONTD)

DENSITY OF CONCENTRATED SEA WATER - CORRECTION FOR TEMPERATURE

TOTAL CORRECTION TO 20°C DENSITY IN GM/ML

Temp $^{\circ}$C	Density range, gm/ml at 20°C					
	1.00 - 1.05	1.05 - 1.10	1.10 - 1.15	1.15 1.20	1.20 - 1.25	1.25 1.30
27	.003	.003	.004	.004	.004	.004
28	.003	.003	.004	.005	.005	.004
29	.004	.004	.005	.005	.005	.005
30	.004	.004	.005	.006	.006	.006
31	.004	.005	.006	.006	.006	.006
32	.005	.006	.006	.007	.007	.007
33	.005	.007	.007	.007	.007	.007
34	.006	.007	.007	.008	.008	.008
35	.006	.007	.008	.008	.008	.008

The concentrations at which the more common of the salts precipitate are:

Original sea water remaining (percentage of weight)	Salt beginning to precipitate	Composition of salt
100.00	Calcite	$CaCo_3$
32.22	Gypsum	$CaSO_4.2H_2O$
12.13	Halite	$NaCl$
2.45	Astrakainite	$NaSo_4.MgSo_4.4H_2O$
2.18	Epsomite	$MgSo_4.7H_2O$
1.96	Kainite	$MgSo_4.KCl.3H_2O$
1.63	Hexahydrite	$MgSo_4.6H_2O$
1.22	Kieserite	$MgSo_4.H_2O$
1.18	Carnallite	$KCl.MgCl_2 .6H_2O$
0.93	Bischofite	$MgCl_2.6H_2O$

Table 3.4 gives the amounts of precipitation of the various salts at different concentrations. Figure 3.1 represents graphically the deposition of salts during concentration of sea water. Here the extent of deposition of different salts is plotted against the brine concentration expressed in °Be.

TABLE - 3.4

SEPARATION OF SALTS ON PROGRESSIVE EVAPORATION OF SEA WATER

^{o}Be at 21^{o}C	Volume on evaporation in litres	Iron Oxide Fe_2O_3	Calcium Carbonate $CaCO_3$	Gypsum $CaSo_4$	Common Salt	Magnesium sulphate
3.5	1.000	..	..	..	..	..
7.1	0.5330	0.003	0.0642	..	..	..
11.5	0.3160	..	Traces	..	..	..
14.00	0.2450	..	Traces	..	..	..
16.75	0.1900	..	0.0530	0.5600	..	..
20.60	0.1445	..	..	0.5620	..	..
22.00	0.1310	..	..	0.1840	..	..
25.00	0.1120	..	..	0.1600	..	..
26.25	0.0950	..	..	0.0508	3.2614	0.0049
27.00	0.0640	..	..	0.1476	9.6500	0.0130
28.25	0. 0990	..	..	0.0700	7.8960	0.0262
30.10	0.0302	..	..	0.0144	2.6240	0.0174
32.40	0.0230	..	..	..	2.2720	0.0254
35.00	0.0162	..	..	..	1.4040	0.5382
Total separated		0.0030	0.1172	1.7488	27.1074	0.6242
Remainder in solution i.e., 0.0162 litres		..	..	..	2.5885	1.8545
Total content in one litre		0.0030	0.1172	1.7488	29.6959	2.4787

TABLE - 3.4 (CONTD)

SEPARATION OF SALTS ON PROGRESSIVE EVAPORATION OF SEA WATER

°Be at 21°C	Magnesium Chloride $MgCl_2$	Sodium Bromide NaB_2	Potassium Chloride KCL	Total separated	Cumulative Total	
					Separated	In solution
3.5	..	..	..	..	0.000	38.4472
7.1	..	..	..	0.0672	0.0672	38.3800
11.5	..	..	..	Traces	0.0672	38.3800
14.00	..	..	..	Traces	0.0672	38.3800
16.75	..	..	..	0.6130	0.6802	37.7670
20.60	..	..	..	0.5620	1.2422	37.0060
22.00	..	..	..	0.1840	1.4262	37.0210
25.00	..	..	..	0.1600	1.5862	36.9610
26.25	0.0078	..	..	3.3240	4.9102	33.5370
27.00	0.0356	..	..	9.8462	14.7564	23.6903
28.25	0.0434	0.0728	..	8.1084	22.8648	15.7624
30.10	0.0156	0.0358	..	2.7066	25.5714	12.8756
32.40	0.0240	0.0518	..	2.3722	27.9446	10.5026
35.00	0.0274	0.0620	..	2.0316	29.9762	8.4709
Total separated	0.1532	0.2224	..	29.9762		
Remainder in soln. i.e. 0.0162 litres	3.1640	0.3300	0.5339	8.4709		
Total content in one litre	3.3172	0.8524	0.5339	38.4471		

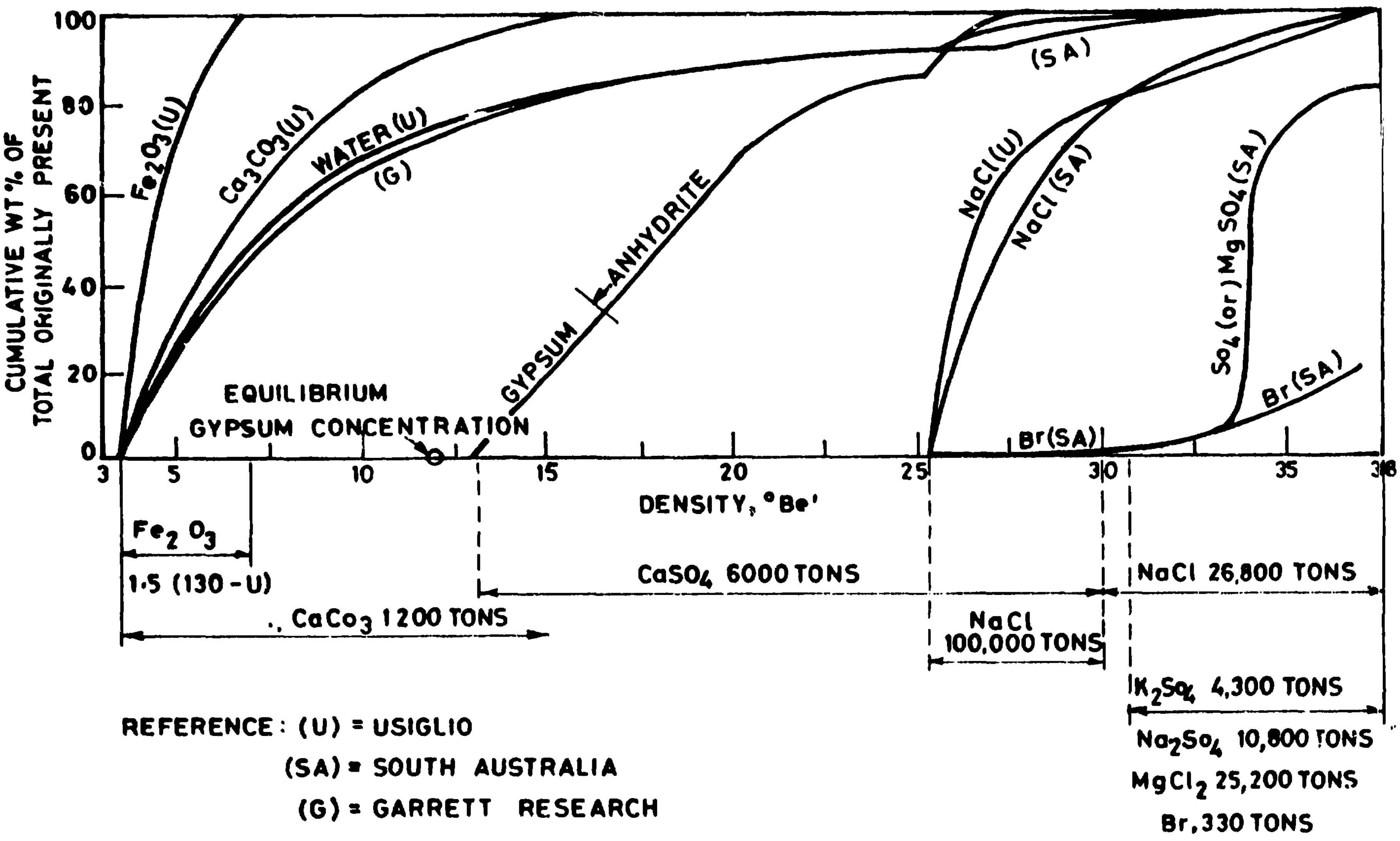


FIG. 3.1. DEPOSITION OF SALTS DURING CONCENTRATION OF SEA WATER.

As indicated by this graph, the evaporation process is conveniently divided into four distinct phases. The first phase is from 3° Be to 13° Be when most of the carbonates precipitate as salts of iron, magnesium and calcium. While iron carbonate and magnesium carbonate crystallise completely by 13° Be, calcium carbonate crystallises up to 90%, the remaining 10% precipitating by 15° Be in the next phase. These carbonates have little practical value.

The second phase, extending from 13° Be to 25.4° Be, centres round gypsum. This crystallises as needle shaped crystals of $CaSo_4.2H_2O$ from 13° Be to 16.4° Be and thereafter as anhydrite $CaSo_4$. 85% of the calcium sulphate present is precipitated in this phase. The precipitation of the remaining 15% is spread over the third and fourth phases in decreasing amounts, right until evaporation is complete. Gypsum is used in the production of cement and plaster of paris. It is also of immediate value in a solar salt works since its crystals are used to pave the pond floors thus preventing leakage of brine into the soil.

The third phase extends between 25.6° Be and 30° Be. Common salt (NaCl) precipitates out in this phase. Crystallisation starts at 25.6° Be and its rate rapidly increases in the initial stages. 72% of the total amount is precipitated by 29° Be and 79% by 30° Be. At higher levels of salinity the crystallisation slows down considerably and is complete only with the completion of evaporation. The concentration at which sodium chloride starts to crystallise is known as the salting point and the mother liquor at this point is called the pickle. At the end of the phase, when the concentration is 30° Be, the liquor is called bittern because of its characteristic bitter taste.

Sodium chloride is formed as cubic crystals. It is colorless, odourless and has a characteristic taste. It has a specific gravity of 2.165 and a molecular weight of 58.45. Its solubility in water varies only slightly with temperature.

Though salt is the predominant precipitate in the third phase it is not pure because gypsum is also precipitated, especially in the earlier stages. At the higher concentrations near 30° Be, some bromides, potassium chloride and magnesium sulphate from the fourth phase appear. The technique of salt manufacture involves fractional crystallisation of the salts to obtain sodium chloride in the purest form possible.

According to typical standards adopted in developing countries, the purity required is 99.5% for grade I industrial salt, 98.5% for grade II industrial salt, 96.0% for edible common salt, 99.6% for dairy salt, and 97.0% for table salt. In advanced countries the specifications are more stringent, the minimum purity prescribed for table salt being 99.5%.

Figure 3.2 shows the considerable shrinkage in the volume of brine that takes place during salt manufacture. The volume is 19% of the original at the beginning of phase I when gypsum starts crystallising, 9% at the salting point when salt crystallises and 3% when phase III ends and bittern is formed.

The relation of vapor pressure of brine vs vapor pressure of fresh water is dependent upon fresh water temperature and Mg^{++} concentration. The relative rate of brine evaporation is dependent upon this vapour pressure of brine vs vapour pressure of water and the percent relative humidity. Figure 3.3 is nomogram for calculating evaporation rate ratio between brine and evaporation of fresh water in evaporation pan given fresh water temperature, Be of brine and ambient hygrometry. This phenomenon is discussed in detail in Chapter IV. Figure 3.4 plots relationship of Mg^{++} with Be of normal sea water brine. Figure 3.5 shows the results of measurements in reduction of evaporation rate with increase in brine density at different locations. If the rate is taken as 1 at salting point, it drops down to 0.6 or lower at the end of phase III. The evaporation of bittern to produce byproducts is known to salt makers to be a tediously slow process.

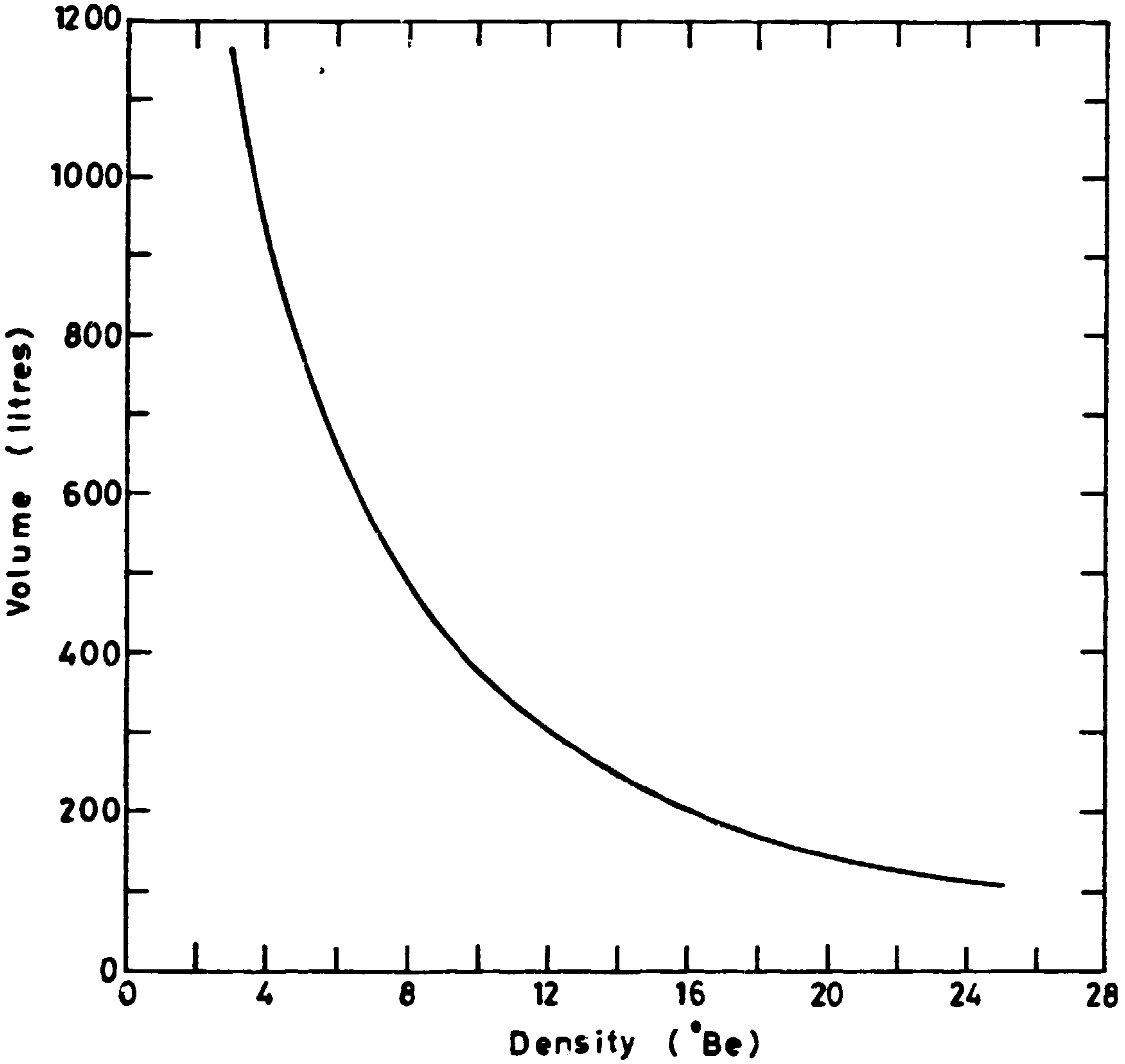
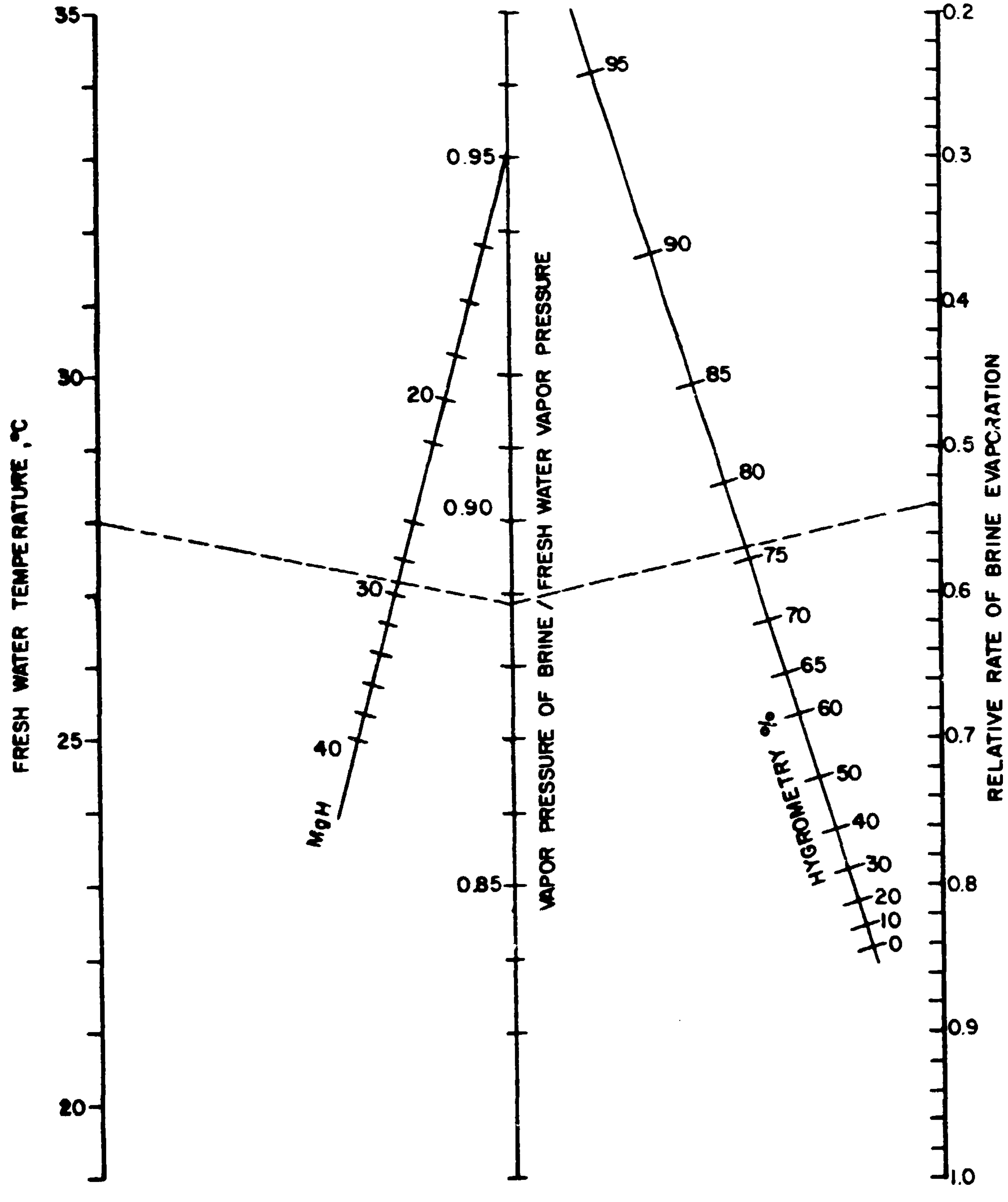


FIG.3.2. REDUCTION IN THE VOLUME OF BRINE WITH INCREASE IN DENSITY.



(SOURCES : FLERS et al.,1969,KMSE,D.W.,1983)

FIG. 3.3. EVAPORATION RATIO OF BRINE REFERRED TO FRESH WATER FROM FRESH WATER TEMPERATURE AND AMBIENT HYGROMETRY.

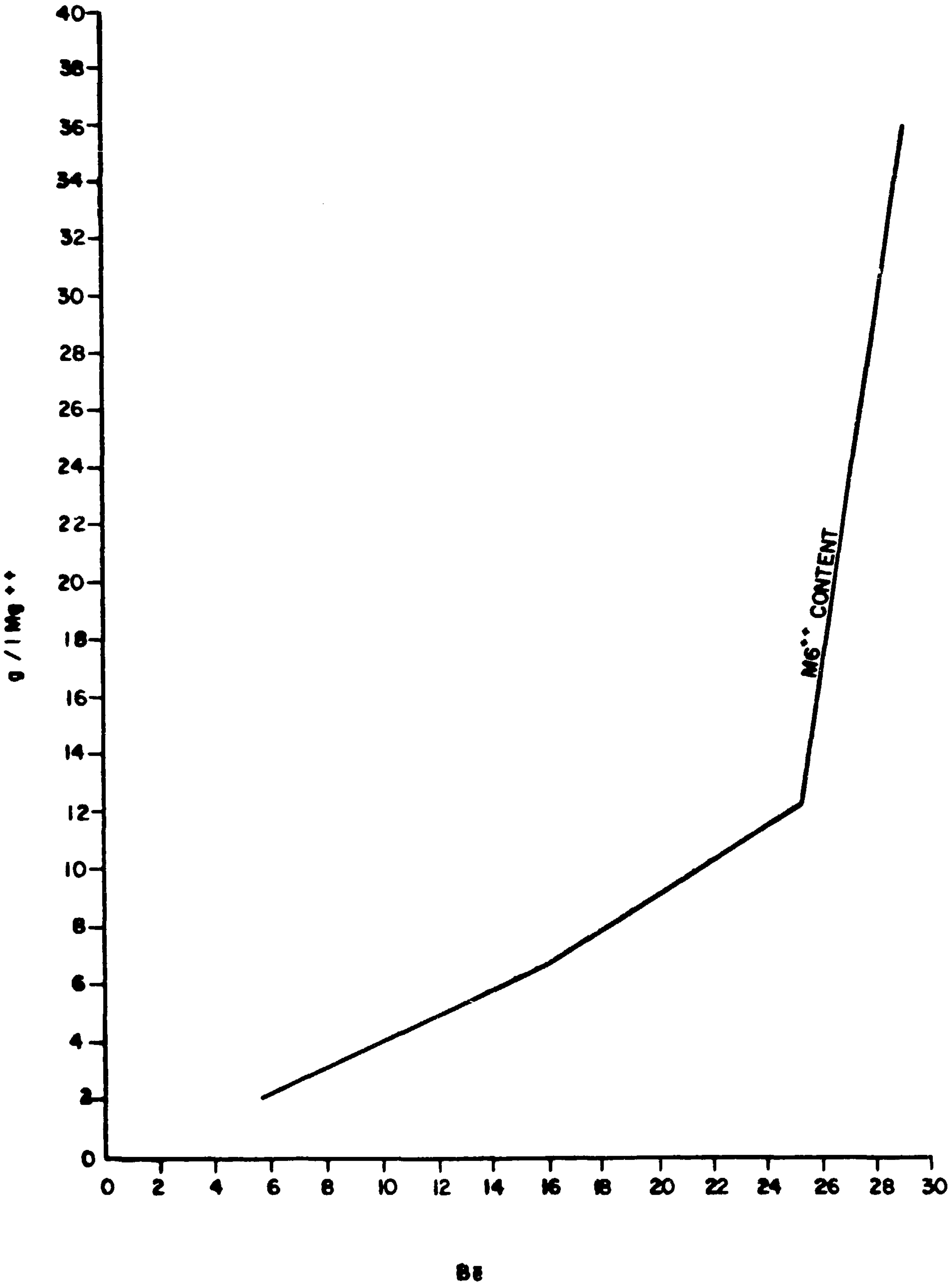


FIG. 3.4. PLOT Mg++ VS. BAUME (SOURCE: H.L. BRADLEY, 1983)

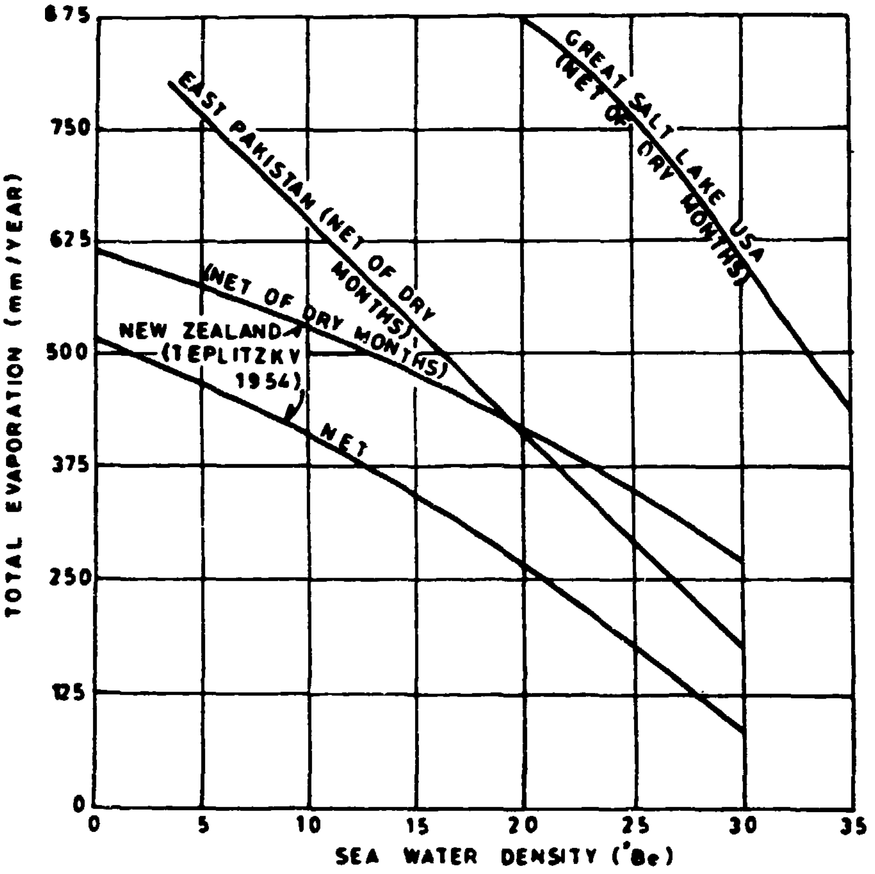


FIG.35. EFFECT OF DENSITY UPON EVAPORATION RATE.

Figure 3.6 demonstrates the percent of salt deposited in crystallisers vs Be drained as bittern from the crystalliser in relation to the original content of salt in brine. This will be used in Chapter IV.

For a given saline area a rough approximation can be determined of the Be of brine at any given pond by use of Figure 3.7. See Figure 3.8 for composition of seawater brine.

The chemistry of phase IV relating to the evaporation of the bittern is complex. A number of sulphates of potassium and magnesium and potassium chloride separate out either singly or as double crystals in equilibrium or in metastable conditions. The phase chemistry is also affected by weather conditions. Normally bitterns are not utilised [illegible] under certain conditions, recovery of byproducts of potassium, magnesium and bromine becomes economical. These conditions are that there should be an adequate market nearby and the solar salt operations must be on a large scale, producing more than 100,000 tonnes of salt per year. The recovery processes are complex. A brief account of the chemistry is now given:

If the bittern is concentrated by evaporation without precipitating potassium salts, a mixture of the remanent sodium chloride and magnesium sulphate separates out. This

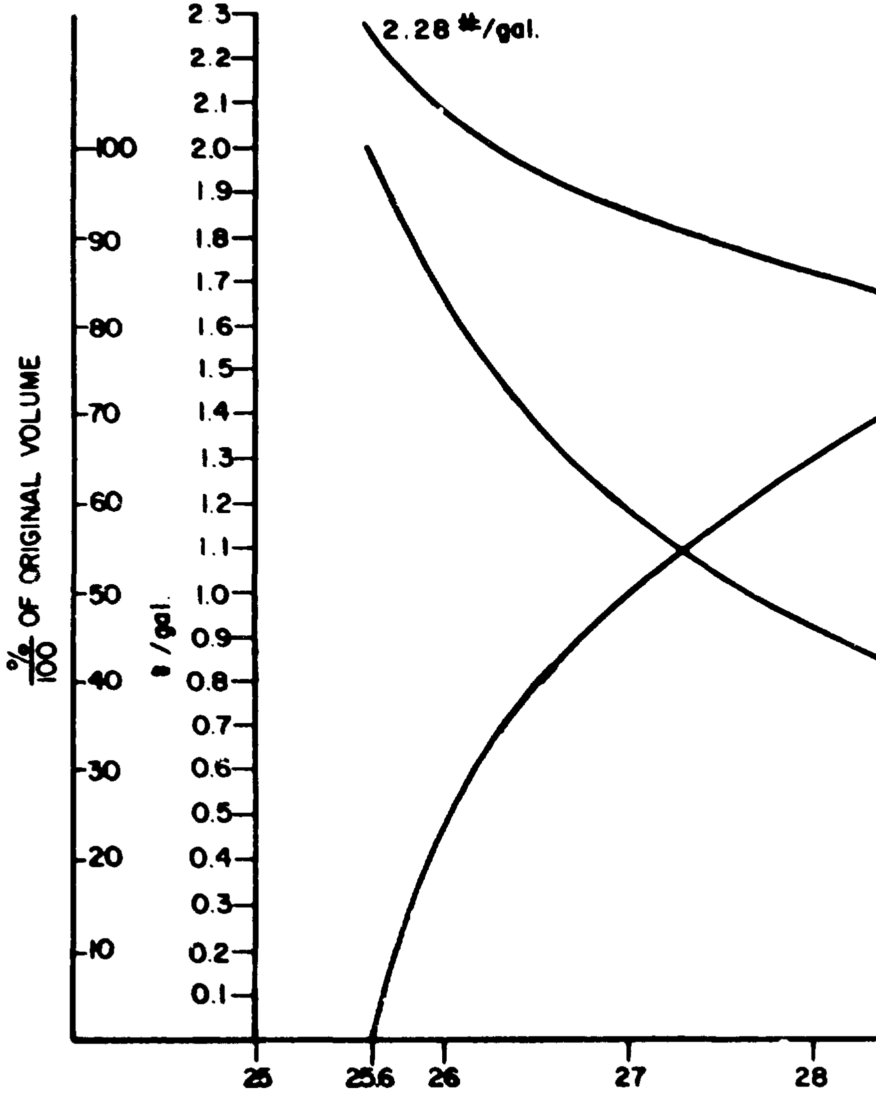
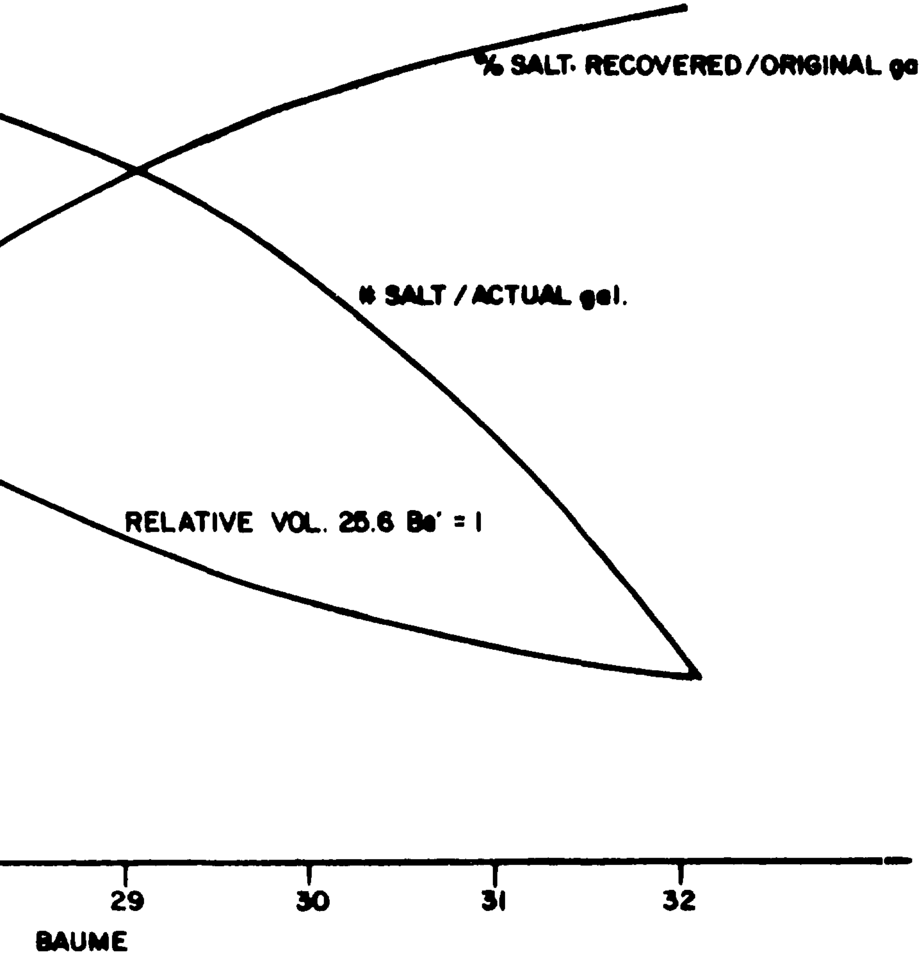


FIG. 3.6. BRINE RECOVERY FROM CRYSTALLISERS



(SOURCE: L. FOOT, 1954)

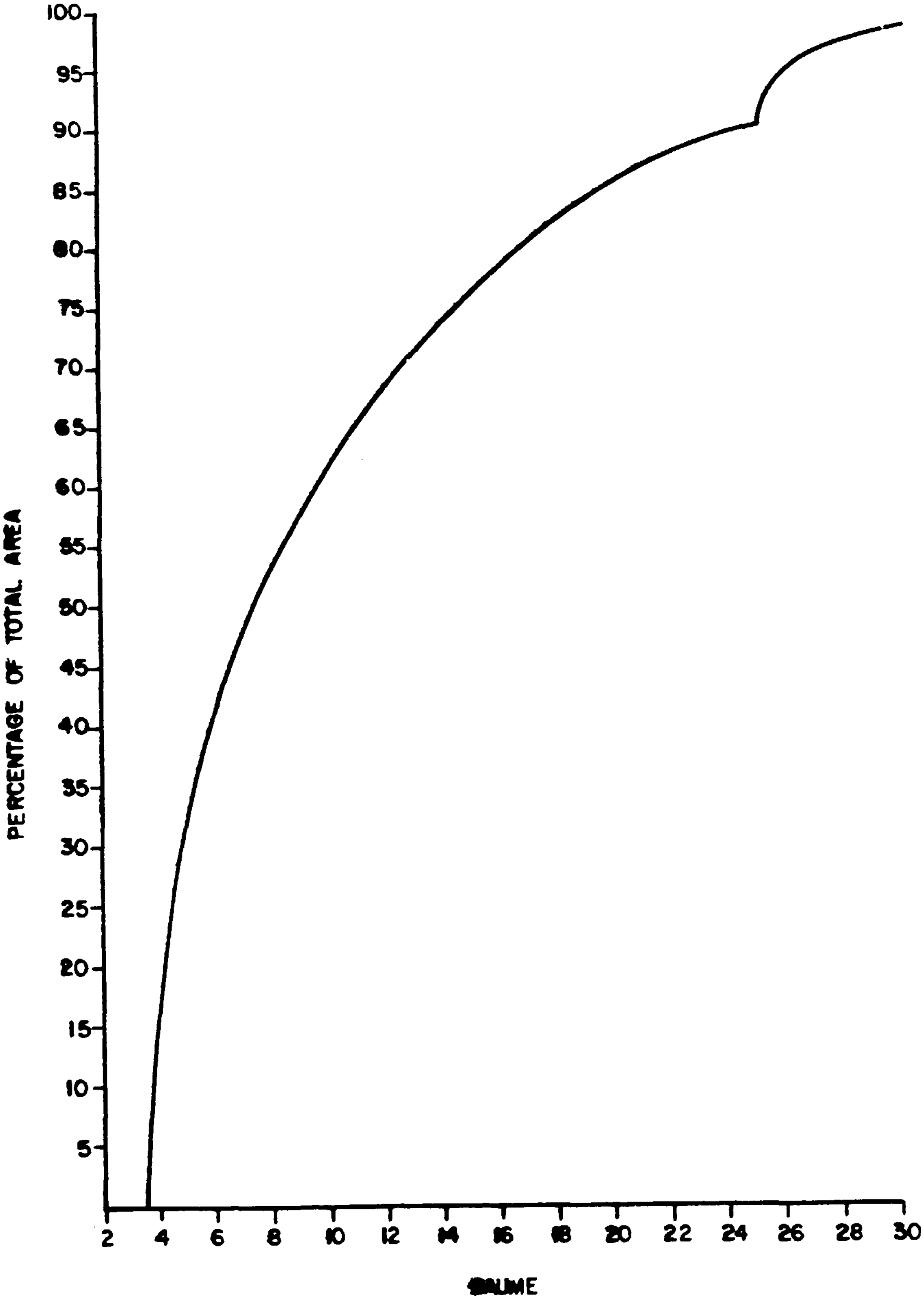


FIG. 3.7 ESTIMATING BAUME RELATED TO POND AREA (SOURCE: GARRETT RESEARCH, 1969)

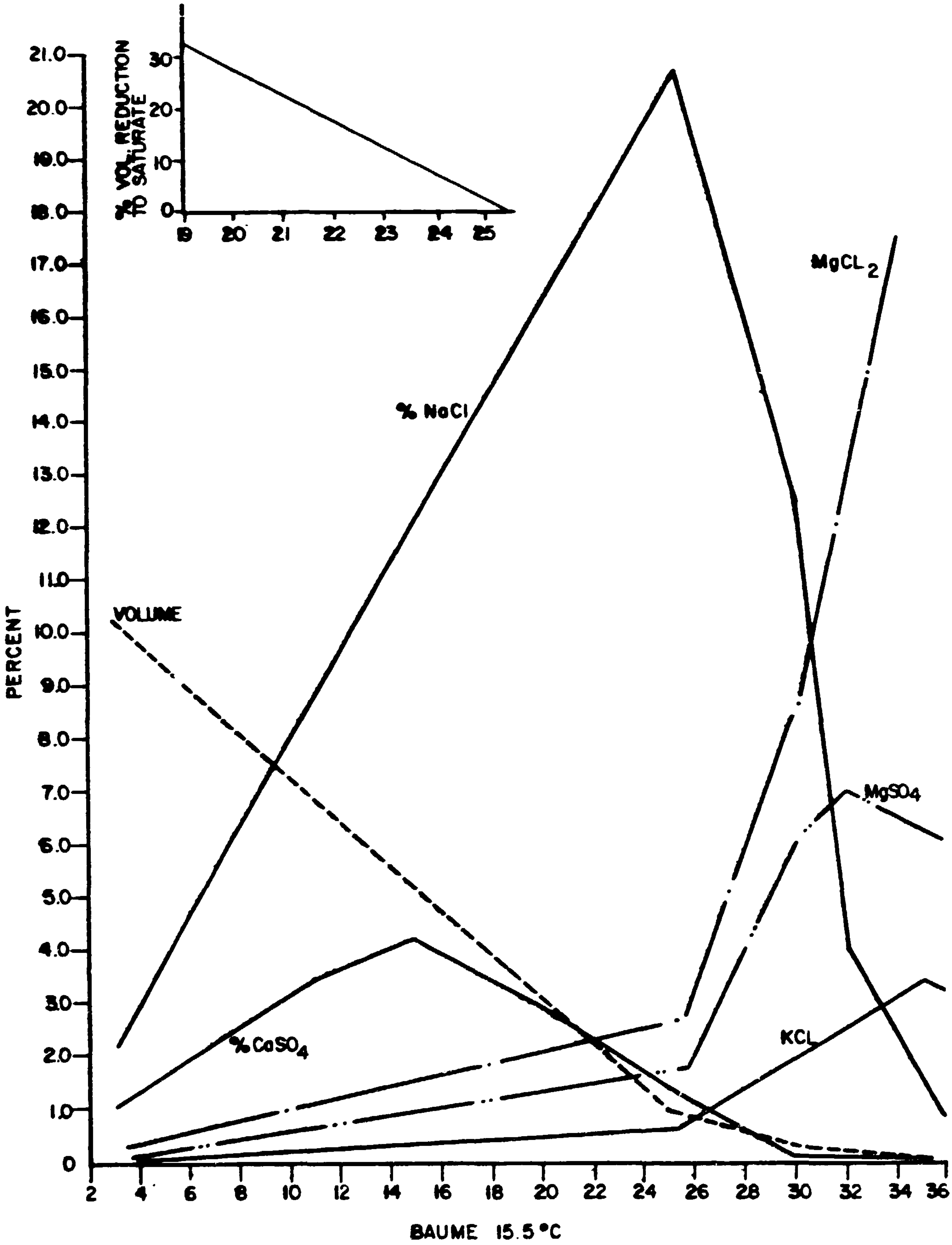


FIG. 3.8 COMPOSITION OF SEAWATER BRINES (SOURCE: PLANCK, 1958)

fraction is known as mixed salt I. The mother liquor is further evaporated when a mixture of sodium chloride, potassium chloride and carnallite called mixed salt II is obtained. Other potassium salts precipitating between 36° Be and 38° Be are kainite, schoenite, glasserite, sulphate and langbeinite. Beyond 38° Be, the mother liquor consists predominantly of magnesium chloride with a small proportion of bromides. This is crystallised as bischofite.

Underground brines:

The salinity of underground brines is much higher than that of seawater sometimes as much as eight times. Underground brine is considered to be seawater cut off from oceans by early geological changes and concentrated by periods of sunlight before being covered by further geological deposits. There are also brines formed by the flow of underground water amongst weak salt deposits.

The composition of underground brines varies widely. The composition of brines close to sea coasts is similar to seawater evaporated to the same concentration with minor variations. Sometimes the calcium sulphate content is higher. In other cases the KCl:NaCl ratio is higher than that of seawater. In certain inland underground brines, potassium and magnesium salts are totally absent and sodium sulphate is the only constituent other than sodium chloride.

Underground brines occur at varying depths from very shallow levels of 3 metres to depths of more than 200 metres. Underground sources are tapped by sinking borewells and pumping the brine to the surface and subjecting it to an evaporation process similar to sea brine.

Salt from inland lakes:

As in the case of underground brines the composition of salt lakes depends upon the history of formation of the lake. Salt lakes are found particularly in semi arid areas of the earth with low rainfall and high evaporation. The salts of such lakes may have been derived by a portion of sea being cut off from the ocean by geological upheavals in the past and their being subject to concentration by solar heat. In such cases, the waters are characterised by the presence of calcium and magnesium. An alternative method of formation is said to be from water collected in a depression over rock salt deposits of an earlier era. Salt lakes could also derive their salinity from sedimentary or igneous rock of the surrounding drainage areas. In such cases, neither the composition nor the phase chemistry will be similar to sea water.

Salt lakes can be broadly classified as

1) sulphate type
2) carbonate type
3) bittern type
4) sodium chloride type

In all types sodium chloride is present. Sulphate type lakes have derived their salts from surrounding rocks and contain sodium sulphate. Sambhar Lake in India is an example of this type. Carbonate type lakes are alkaline lakes which contain sodium carbonate in addition to sodium chloride and sodium sulphate. Searle's Lake in the USA is a carbonate lake. Bittern type lakes contain more magnesium than sodium. They are often sulphate free but contain calcium. The Dead Sea is one such lake. The Great Salt Lake of the USA is a sodium chloride lake similar in composition to sea brine of an identical density. Table 3.5 gives the composition of different lakes.

Lake brines may also form over playas which are the sandy, salty or mud caked floors of desert basins.

TABLE - 3.5

COMPOSITION OF DIFFERENT LAKE BRINES (% BY WEIGHT)

ELEMENT	Great Salt Lake USA	Searles Lake USA (dry lake)	Dead Sea Israel	Andhoqi Lake Afghanistan	Sea Water
Sodium (Na)	7.00	10.9	3.13	11.76	1.07
Potassium (K)	0.50	1.93	0.52	Trace	0.04
Magnesium (Mg)	0.70	--	2.93	0.90	0.13
Calcium (Ca)	0.03	--	1.13	0.02	0.04
Chloride (Cl_2)	14.20	12.26	15.43	18.56	1.93
Bromine (Br)	--	--	0.38	--	0.007
Lithum (Li)	0.003	--	--	--	Trace
Boron (B)	0.003	0.01	--	--	Trace
Sulphate (So_4)	1.75	5.12	0.07	2.96	0.26
Carbonate (Co_3)	--	2.39	--	0.007	Trace

CHAPTER - IV

EVALUATION OF POTENTIAL SOLAR SALT SITES

Although a country may have a long coastline or inland lake shore line, not all locations along the coast or lake shore become automatically suitable for manufacture of solar salt. There are a number of factors to be considered before setting up a solar salt plant. The effects of these factors may have to be studied for periods ranging from three months to a few years. Sometimes any one of the factors may turn out to be critical. However, for a solar salt works to be technically and economically viable, all the important factors must be at least reasonably favourable.

(i) Availability of low cost land and its topography

(ii) Use of Landsat imagery to evaluate potential sites

(iii) Accessibility to the market and competitive factors

(iv) Soil conditions

(v) Procedure for determining solar salt making capability of a site

(vi) Availability of seawater/brine and its salinity

(vii) Susceptibility of the area to storms, flooding, and runoff

(viii) Availability of infrastructure facilities such as electric power, fresh water, and labour.

Ideally, the location should be a flat or gently sloping block of impervious clay land unfit for agriculture, with access to abundant quantities of undiluted seawater/subsoil or lake brine, with provision for tidal intake during high tides in the case of seawater, with little or no rainfall, with a hot dry breeze blowing all year round, with a railhead or deep seaport nearby. However, such ideal locations are rare. The coast of West Australia and of the Baja California desert in Mexico, where salt is manufactured all the year round and exported by ship to Japan, come closest to these ideal conditions. Usually some compromises have to be made in the above factors and a decision taken based on the overall techno-economic feasibility of the specific site.

(i) Availability of Land and its Topography

Flat land closest to the sea, lake, or underground sources of brine, unfit for agricultural or other purposes is preferred for locating a salt works. Land that can be used for agricultural or other purposes is generally too expensive to make a salt project economically viable. The land chosen should be flat or very gently sloping (not greater than 30 to 40 cms per kilometre) in one direction so that it is possible to hold the brine in ponds at different stages and obtain an even cover with shallow depths and at the same time allow the brine to flow from one pond to another with the minimum of pump stations. To determine the area available, a traverse survey is conducted starting from one point on the boundary and proceeding along the boundary measuring distances and angles until the starting point is reached again. The area within the traverse is planimetered. Simultaneously, the levels within the area are determined within a specified grid of say 60 M x 60 M. This grid will vary depending on variations in topography, existing lake or pond areas, etc. Points of equal levels are joined to form contour lines. The contour map will then determine the brine holding capacity of the land at different levels and will yield the data required to design the brine circuit. Photogrammetric elevations are often taken from aerial photographs at a grid of 60 M x 120 M that are suitable for site evaluation purposes.

If insufficient flat lands are available, consideration can be given to practicality and cost of constructing ponds on elevation contours (terraced).

(ii) Use of Landsat Imagery to Evaluate Potential Sites

Satellite imagery is an invaluable tool to select and evaluate sites for solar salt production. Large scale images covering thousands of square miles can be reviewed in a matter of minutes to select and compare sites for further study. Magnified and processed images in black and white and false color provide more detailed data on site conditions for evaluating the feasibility of pond construction at selected locations.

Solar evaporation pond site selection is usually carried out on a regional or country-wide basis to determine the location of suitable land areas in proximity to transportation and shipping facilities. After initial site selection, evaluations to obtain detailed data on geological and hydrological factors affecting pond design and engineering are made from field inspection.

<u>Image processing</u>

Images obtained by Landsat remote sensing are extremely useful for both studies. The unprocessed image area for a single frame covers about 13,000 square miles. An image is obtainable in usable form for site selection procedures with a scale of about 1:250,000. The image can be rapidly scanned to locate sizeable areas with tonal variations signifying flat ground or low lying swampy areas potentially suitable for solar pond construction. Landsat sensors obtain images in four or more separate bands or wave lengths. Site screening and selection studies can be based on tonal variations for a single band that provides indications of soil moisture and surrounding terrain characteristics. A band 5 image generally gives the best display of geological features, soil moisture, and the location of the land-water interface.

Bands 4, 5, and 7 are composited to yield an image in false color for detailed site evaluation prior to field studies. The variations in color and tone on the image show the health and distribution of vegetation, moisture content of the soil, depth of water adjacent to the area, and site geomorphology. It is often helpful to enlarge or magnify the image by photographic processing to a scale of either

1:20,000 or 1:50,000 for detailed site evaluations. Single bands can be used jointly or separately with multi-spectral false color to provide data on soil moisture and geomorphology. The 4, 5, and 7 band combination provides usable data at the least cost for both site selection and evaluation.

The enlarged imagery scales recommended for site evaluation studies are commonly used as a base for topographic mapping. If topographic maps are available for a selected site, a clear overlay of the map should be prepared to match the scale of the image enlargement. When field investigations are implemented, features on the image can be directly referred to topographic map features and elevations. It is helpful to obtain images for a particular site during the wet and the dry season. Our efforts to obtain useful seasonal data depend on not having local or seasonal cloud cover in the area of interest at the times the satellite image sensors are turned on.

Sensor description and comparisons

As previously noted, Landsat images are available in four separate bands. The four bands designated 4, 5, 6, and 7 occur in two visible and two invisible portions of the spectrum, ranging from green through red to near infrared. The various sensing bands and their wave lengths are as follows for Landsat 1 through 3:

Band Number	Wave Length in Micrometers
4	0.5 to 0.6 visible - green
5	0.6 to 0.7 visible - red
6	0.7 to 0.8 invisible - near infrared
7	0.8 to 1.1 invisible - near infrared

Sub-scene images of each individual wave length from a Landsat Multispectral Scanner (MSS) range in tonal variation from white through grey to black, depending upon the wave length reflected from the object. As stated succinctly in Petroleum Engineer International, "these images are invaluable to the geologist because of their synoptic aspects--a single scene surveys a wide variety of terrain, geology and landform types under near optimum viewing conditions that enhance or emphasize the relationships of surface features." Vegetation shows up best in the near infrared and water is best indicated in the green band. On false color composites, using bands 4, 5, and 7, healthy vegetation appears in red and clear deep water in black. In a sparsely covered area typically selected for additional study, false color variations, appearing as red, green, and black, are used to identify or infer geological and hydrological features impacting on pond construction and operation. Interpretations of favorable and unfavorable siting characteristics are all subject to field confirmation.

Table 4.1 following is revised from a publication by David J. Barr to illustrate the possible use of Landsat imagery for interpreting technical and environmental solar evaporation siting factors.

Application to site interpretation

Landsat imagery have been used for siting studies in a number of countries with varying terrains. A suitable site was located for solar ponds near a proposed petrochemical

TABLE 4.1

SITING FACTORS AND SENSOR USE

Siting Factor	Imagery Satellite
Topography	I-F
Site Size	M
Existing Land Use	D
Existing Bodies of Water	D
Extent of Vegetative Cover	D
Diseased (affected) Vegetation	I-F
Regional Geology	I-F
Local Geology and Soils	I-F
Local Erosion	I-F
Deposition-Siltation	I-F
Soil Moisture Condition	I-F
Regional Hydrology	I
Local Hydrology	I-F
Pollutional Discharges	I
Lagoon Leaks	I-F
Discharge Dispersion	I-F
Flooding Potential	I-F

Key:
M = Measure
I = Infer with high confidence
I-F = Infer subject to field check
D = Detect

complex on the Arabian Gulf in Saudi Arabia. Standard aerial photography was not available due to government regulations. A Landsat image was readily available in band 5 and three flat sabkha or swamp areas were identified about 15 miles from the proposed complex. The satellite image was taken during the wet season, which assured that the areas were not normally subject to flooding by Arabian Gulf storm tides or seasonal surface water discharge. One of the areas selected for soil borings and permeability tests had variations similar to the tonal signature at two saline deposits about 60 miles away. The available literature indicated that this salt deposit was both limited in size and thin. Field investigations confirmed the image interpretation, revealing a large 20 square mile salt deposit. Later drilling showed the mineable salt thickness exceeded 25 feet. At the other two Saudi Arabian sites, testing showed permeability coefficients ranging from poor to fair and a recommendation was tendered to exploit the sabkha salt deposit.

Selection and evaluation was made of sites in Haiti and the Dominican Republic. A number of band 5 images for coastal areas in both countries were obtained and examined. Some of the preferred locations were too small to provide the requisite salt tonnage. Other areas had excessive water depths behind barrier beaches with drainage patterns indicating high surface water runoff. A total of three sites were selected for further investigation and magnified false color images were obtained for detailed studies. Inspection of false color image at one of the three sites selected for detailed evaluation revealed an extensive drainage system that was not apparent on the band 5 image or topographic map. Through a subsequent inquiry, we found that an agricultural land reclamation program would eventually incorporate part of the area needed for solar ponds. This consideration nullified the need for additional evaluations.

Standard aerial photography and topographic maps were available for the remaining two sites. At the only Haitian site, imagery studies confirmed with a field check indicated a potential for inundation of proposed concentration and crystallizer pond locations from storm tides and the possibility of breaching the landward side of the crystallizer dikes from flash flooding due to seasonal precipitation in the mountainous interior.

Problems at the third site located in the Dominican Republic differed significantly. Comparison of the Landsat imagery and air photos with available geologic maps showed that the mapped boundary of a water bearing karstic limestone was not correctly located. After adjustment of the land area, the facility was downsized by about 40 percent. A further interpretation of vegetation patterns and tonal variations suggestive of soil moisture indicated the karstic limestone dipped gently seaward below the site with groundwater rising near the surface through the overlying soil and rock. This local hydrologic condition was confirmed by field observations of underwater springs offshore and seeps and springs along the beach bordering one side of the site.

(iii) Accessibility to Market

Salt is a low value commodity. In transportation to the market the freight element becomes an important factor. Therefore in order to be competitive, the salt works should be located close to the market or to a large seaport or railhead that will enable the salt to be shipped in bulk quantities. In some cases, this becomes the overriding factor in determining the location of the salt works. Potential long term freight rate and fuel cost changes must be evaluated.

(iv) Soil Conditions

Brine in a salt works is held in large ponds with earth bottoms and allowed to concentrate by solar evaporation. The characteristics of the top one metre layer of the soil determine the capacity of the land to hold and evaporate brine at different stages of concentration. A prime indicator of the nature of the soil is its composition expressed in terms of percentages of gravel, sand, silt, and clay. This composition is determined by mechanical analysis. Obviously, a gravelly or sandy soil through which water seeps through quickly is not suitable whereas a clay soil which is impervious is suitable. It is recommended that insitu percolation tests be made where perçolation rates are questionable. However, too clayey a soil will be weak under wet conditions and will impede proper harvesting of the salt. Also clay soil tends to crack under dry conditions. In such a soil the presence of fine sand imparts a desirable characteristic viz., increased bearing strength. Ideally the soil should comprise of a good mixture of sand, silt, and clay with sand content not exceeding about 40 percent (as fine sand) and the balance being accounted for by silt and clay, clay being more than silt. In order of preference, clayey soils, clay loam, and silty clay are suitable for establishment of a salt works. Such a soil would fall under the groups ML, CL, MH, CH of the Unified Soil Classification.

In addition to the mechanical analysis, certain index properties of the soil are to be measured:

Name of Property	Desirable Range
1) Proctor compaction	
a) Max dry density	1.5 to 2 gm per cc
b) Optimum water content	16 to 25 percent
2) Void ratio	0.6 to 1
3) Permeability	3 cms to 7 cms per year
4) Compressibility	
a) at 1.5 kg per cm^2	1 to 2 percent
b) at 3 kg per cm^2	2 to 4 percent

The bearing capacity of the soil is to be determined from the point of view of assessing its strength and suitability for construction of roads and embankments. A bearing capacity of at least 1 kg per cm^2 is required. If lower, it should be improved by addition of sand and gravel on the top of transport roads and by addition of sand during the preparation of crystalliser floors.

The consistency limits of the soil should also be determined as these data are useful in the compaction of crystalliser floors and in the construction of embankments to achieve the desired strength. These consist of the liquid limit, plastic limit, plasticity index, and shrinkage limits. These limits are easily determined by simple laboratory tests. The procedures are described in any standard book on soil mechanics. The ideal ranges for these consistency limits are 40 percent to 60 percent for liquid limit, 15 to 30 percent for plastic limit, and 15 percent to 40 percent for plasticity index. In such soils the plasticity limit is generally much greater than the shrinkage limit which shows that the soils are mostly fine grained plastic soils.

Field inspection

Thorough site inspections are required for many purposes:

1) Signs of sub-surface fresh water flow
2) Potholes or sinkholes
3) Location of seepage areas
4) Consistence of soil conditions
5) Evaluate vegetation for potential seepage or infiltration
6) Geological classification and evaluation
7) Areas suitable and unsuitable for dike and crystalliser pump station construction,etc.

(v) Procedure for Determining Solar Salt Making Capability of a Site

Meteorological studies

The meteorological measurements recorded at the area serve to measure the factors affecting the salt making capability of the area. If the data is not readily available, the following meteorological instruments are set up and recorded for at least one year and more if highly fluctuating:

Parameter	Instrument
Wet and dry bulb temperature and humidity	7 day relative humidity recorder
Maximum and minimum air temperature	Maximum and minimum air thermometer
Wind direction	Wind vane
Wind speed	Anemometer - totalizing
Rainfall	Rain gauge
Evaporation	Open pan evaporimeter (1)(2)
Radiation	Solarimeter

(1) This includes floating min - max water temperature, stilling well, and hook gauge.

(2) This is a 10" x 48" diameter galvanized class "A" weather pan.

Procedures are well established and documented for recording pertinent weather data. Good judgement is required when extrapolating historical data from a weather station to apply to a prospective solar salt site. The weather can vary drastically within a few miles and serious mistakes have been made in attempting to extrapolate data from one area to another.

Evaporation

The starting point for determining salt production begins with the measurement of fresh water that evaporates per 24 hour period measured in millimeters from a 48" diameter, 10" high galvanized pan placed on 2" x 4" supports at ground level called a standard U.S. Class "A" evaporation pan. There are also other standard pans.

In most cases evaporation data for a site being evaluated does not exist. Until a weather station can be provided and at least a year of recordings made, an approximation can be calculated from wind speed by use of one of several formulas. A plot of the findings of 6 different authors of evaporation per day, versus wind speed in M/sec was assembled by Salin du Midi. From experience the Penman B formula $E = 0.14 (1 + 0.88V) D$[1] or Sutton's formula correlates pond evaporation of fresh water and wind speed. Wind records more frequently are available than evaporation records, i.e., airports and large farming operations (see Figure 4.1).

Penman confirmed that in areas having wind movement in excess of 1.34 M/S fresh water lake evaporation was approximately equal to fresh water pan evaporation. Below 1.34 M/S an appreciably lower ratio existed between ponds and evaporation pans.

Evaporation factor

The evaporation factor is necessary to establish the ratio of the evaporation of brine to fresh water for a site. It is greatly affected by the vapour pressure (which in

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[1] E = evaporation fresh water in mm/day, V = wind speed average/24 hours as meters/sec., D = difference in vapour pressure between air and fresh water.

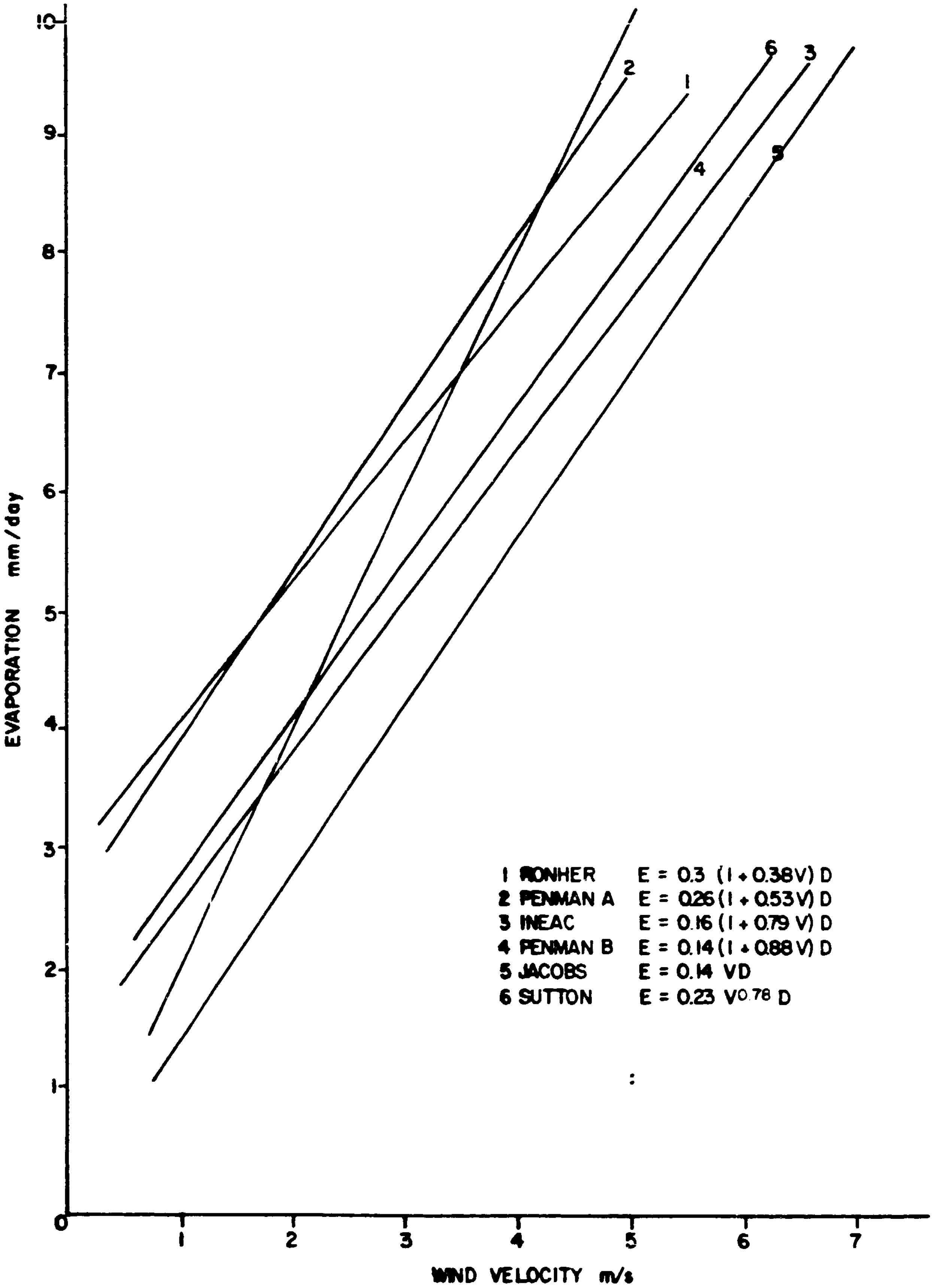


FIG.4.1. EVAPORATION ON FRESH WATER (SOURCE: SALIN DU MIDI, 1969)

turn is influenced by Mg^{++} content of the brine, Fig. 3.4) therefore, the higher the salinity (Mg^{++} content) the lower the evaporation factor.

Salin du Midi published data that they had gathered to demonstrate the relationship between temperature of fresh water, relative humidity, and of vapour pressure of brine (vapour pressure of fresh water vs. temperature is known) and presented a formula for calculating the evaporation factor using a derivation of Sutton's formula. These data have been plotted into a nomograph, Fig. 3.3 , for ease of use and accuracy by Dale Krmse, Ph.D., P.E., University of Florida.

Relative humidity

Relative humidity data taken over a one year period will provide fairly reliable data but should be recorded on a 24 hour basis. Very seldom such data exists at a new site, however, there may be readings taken at a nearby airport at 7 A.M., 1 P.M., and 3 P.M. The daily mean relative humidity will approximate the average of the 7 A.M. and 1 P.M. readings. The 3 P.M. reading should be discarded in determining the mean. This relationship should be verified for a site by using a recording relative humidity meter over a period of several weeks. Caution is needed in using published relative humidity data as the observer may not have realized the importance of taking relative humidity at the specified time of day and in his accuracy of measurements. The average of the 7 A.M. and 1 P.M. readings, at Palisadoes Airport, Kingston, and the mean of the average monthly 24 hour relative humidity between 1955-1971 was 74 percent and the average of the 7 A.M. and 1 P.M. readings was 73 percent which is reasonable agreement.

By use of the nomograph, Fig. 3.3, the evaporation factor for a site having 28°C fresh water evaporating pan temperature, relative humidity of 76 percent, and average brine Be' of 28.2 (28.5 g/l mg^{++}) is read at 0.55 percent. With 3.391 meters evaporation fresh water the brine evaporation becomes 1.87 meters (3.391 x 0.55).

Rainfall

Excessive rainfall makes solar salt production in many sites impractical. In calculating the net evaporation it must be remembered that rainfall evaporates at a rate equal to brine, i.e., (gross evaporation x evaporation factor) minus rainfall = net evaporation. Errors have been made at times of deducting rainfall from gross evaporation and then multiplying by the evaporation factor, i.e., (gross evaporation minus rainfall) x evaporation factor. This calculates to an erroneously high net brine evaporation.

Careful study of rainfall patterns for the site is essential, i.e.,

1) Average monthly rainfall
2) Maximum 1 day and 2 day rainfall per month
3) Variations in rainfall per month

4) Determine if there is a pattern of wind direction and velocity during and after rainfall, (evaluate suitability of using automatic floating decants in crystallisers and saturated brine ponds to remove top surface weak brine)

5) Determine frequency and period to harvest

6) Evaluate chances for catastrophic rainfall reducing or eliminating salt harvest

7) Determine if salt floors are possible in crystallisers.

At Araya, Venezuela net evaporation becomes (3.391 M x 0.55) - 0.188 M rainfall = 1.678 M. Then deduct for time crystalliser will be drained, harvested, and refilled ($1.678 \times \frac{350}{365} = 1.609$) net brine evaporation.

Brine recovery in crystallisers

Figure 3.6 illustrates salt recovery from original brine fed to crystallisers. When dumping brine from crystallisers at 29.0 Be' (bittern) 76 percent of the NaCl is recovered. Saturated brine contains 271 g/l NaCl so that if 76 percent of the salt in brine is recovered 206 g/l is deposited. Salt deposited then becomes 3,314 M ton/ha in parallel operation. $[10{,}000\ M^2 \times 1.609\ \frac{M \times 206 \times 10^3}{10^6}]$.

At this point losses in harvesting, washing, stockpile shrinkage, and scale losses are then applied to arrive at the salt saleable.

Series operation

Tests have been recorded indicating that approximately 10 percent more salt is produced in crystallisers by operating them in series of 3 ponds to maintain a lower average Baume of 27.6 Be' brine (lower mg^{++}) compared to operating in parallel of 28.2 Be'. The evaporation factor is improved from 0.55 to 0.60 or 9 percent greater in series.

(vi) Brine Availability and Salinity

The salinity of the intake brine and its availability in adequate quantities throughout the manufacturing season is an important factor. In the case of sea salt works, this involves a study of the salinity variation and tidal variation and a chemical analysis of seawater along the coast at different times during the year. Sometimes seawater is diluted at locations close to estuaries due to influx of fresh water. Generally the concentration of undiluted seawater is 3 to 3.5° Be (NaCl content 2.7 percent to 3 percent). If there is appreciable dilution below these values, it calls for serious investigation. The output of the salt works is dependent upon Baume of brine entering the system. Its past history has to be studied through local inquiries to determine the behaviour of the sea mouth and whether dredging operations will become necessary and to what extent and at what cost. This has a bearing on the economic viability of the project.

(vii) Susceptibility of the Area to Storms, Flooding, and Runoff

The area may become flooded due to accumulation of storm water discharging into it from the usually large catchment area surrounding it especially during rainy months. The extent of flooding will determine the type of boundary embankment protection required. Inundation of the area due to storm water from the adjoining areas should be avoided since this completely removes the salinity in the salt works year after year. For this purpose, the extent of catchment area must be approximately determined and co-related to the corresponding rise in level of water in the area. With this data a suitable boundary channel can be designed to divert the storm water directly into the sea or lake or an adjoining river without passing through the area.

(viii) Other Factors

There may be several other factors and ecological considerations that may influence the location of a solar salt works. In certain cases, marshy lands identified as ideal for production of solar salt and chemicals based on bitterns, have been found to be winter homes for rare birds. Therefore, the development of salt works in these areas is being objected to by ecologists. Availability of skilled labour in sufficient numbers, power for pumping, and fresh water and basic township facilities for the workers are other factors to be considered in locating a salt works.

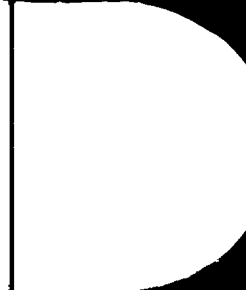
From these observations, it will be appreciated that the factors affecting the location of a solar salt plant are quite demanding. However, by careful analysis their restrictive effects can be considerably reduced and salt works set up in locations previously considered unfavourable.

CHAPTER - V

SMALL AND MEDIUM SCALE PRODUCTION OF SALT

Design and layout of the salt works:

Today salt is manufactured by solar evaporation of seawater and other types of brines by adopting a range of techniques from the most primitive to the most advanced. At one end of the scale salt is manufactured in cottage units using labour intensive methods with no quality control. At the other end there are very large solar salt plants employing modern methods of production and quality control and fully mechanised so that the material is produced and handled completely by machines. The aim of the guide is to outline design and manufacturing practices for small to medium sized operations that will produce a high quality product at minimum cost, adopt scientific methods of quality control and a selective mechanisation without displacing labour. The degree of mechanisation must be carefully considered not only from the financial but from an employment view point. In many developing countries solar salt manufacture is a traditional agriculture-type operation and mechanisation is likely to raise social and economic problems. Often in these countries employment in solar salt works is complementary with



agriculture. Nevertheless with the growing demand for larger quantities and a higher purity of salt for industrial and table applications in all developing countries, there has to be a gradual shift in size of operation from cottage scale to small scale. Also, existing solar salt works can frequently be made more productive by the application of new techniques of evaporation control and harvesting.

The size of a salt works could be considered in terms of its output and its area. Production yields vary considerably, depending upon the several factors outlined in Chapter IV and could be anywhere between 10 tonnes/hectare of total evaporation and and 250 tonnes/hectare. In certain exceptional cases, where the feed brine is almost saturated with salt, the yield could be even higher.

Yield potential of the area:

The yield potential of the area depends upon the net brine evaporation rate, intake brine salinity and seepage. See Chapter IV for calculation procedure.

Ratio of crystallisers to evaporating ponds:

The ratio of crystalliser ponds to concentrating ponds is determined as follows:

Integrated average evaporation rate of brine in the density range of 3° Be to 25.5° Be	600 mm/year
Integrated average evaporation rate of brine in the density range 25.5° Be to 30° Be	400 mm/year
Weight percentage of water evaporated between 3° Be and 25.5° Be	90
Weight percentage of water evaporated between 25.5° Be and 30° Be	6.7

If A_1 is the concentrating area and A_2 the crystalliser area then the area ratio is given by

$$\frac{A_1 \times 600}{A_2 \times 400} = \frac{90}{6.7}$$

$$\frac{A_1}{A_2} = \frac{90 \times 400}{6.7 \times 600} = \frac{60}{6.7} \quad \frac{9}{1}$$

Pond layout design guidelines:

The layout of ponds and brine flow circuit are based largely on the elevation contours and topography of the area. The concentrating ponds are made as large as is consistent with maintaining the desired pond depth and preventing the formation of dead areas or short circuiting. These are normally worked in series. To build up a graded density, weirs and gates must be provided to enable control of flow between ponds. In the case of seawater the division of the reservoir area may be restricted to only 2 or 3 parts to take maximum advantage of tidal inflow. The compartments in the concentrating area are smaller than those in the reservoir area. The brine entering the concentrating area (including the gypsum ponds) is at about 6° Be and the concentration is to be raised to 24° Be. This is achieved by spreading the brine in a number of compartments which prevents mixing of brine of different densities, thus helping the progressive increase in density. The flow path of the brine in the concentrating ponds is arranged so that is is made to travel over a longer distance, as brine in motion evaporates more quickly than in stagnant condition. In deciding on the size of the reservoirs and concentrating ponds, a balance has to be struck between the expenditure to be incurred for constructing the partition bunds and the advantage accruing in zig zagging the brine. Concentrating ponds containing brines of widely different densities are not normally located adjacent to each other because of possible infiltration of the weaker brine into the pond containing the concentrated brine. However, when the topography of the land does not permit this, they are separated from each other by strong, well compacted embankments. Figures 5.1, 5.2 and 5.3 give several layouts of several solar salt works.

In the case of small and medium sized salt works it is sufficient to restrict depth to about 60 cms in the reservoirs, about 30 cms in the concentrating ponds and to 20-40 cms in the crystallisers. However, reservoirs should be deep since their main function is to store and maintain a steady brine supply to the concentrating ponds. Large depths slow down the buildup of salinity and shallow depths may result in drying up. These are only thumb rules based on working experience.

Other general guidelines are

a) The brine flow should take maximum advantage of gravity.

b) The brine flow should be in the direction of the prevailing wind during the operating season as far as possible.

c) Where dust storms occur, the crystallisers must be flanked on the landward side by concentrating ponds to absorb and settle the dust.

d) The crystallisers and salt stackyard must be located at as high an elevation as possible to facilitate quick drainage. The crystallisers must not adjoin a weak brine area.

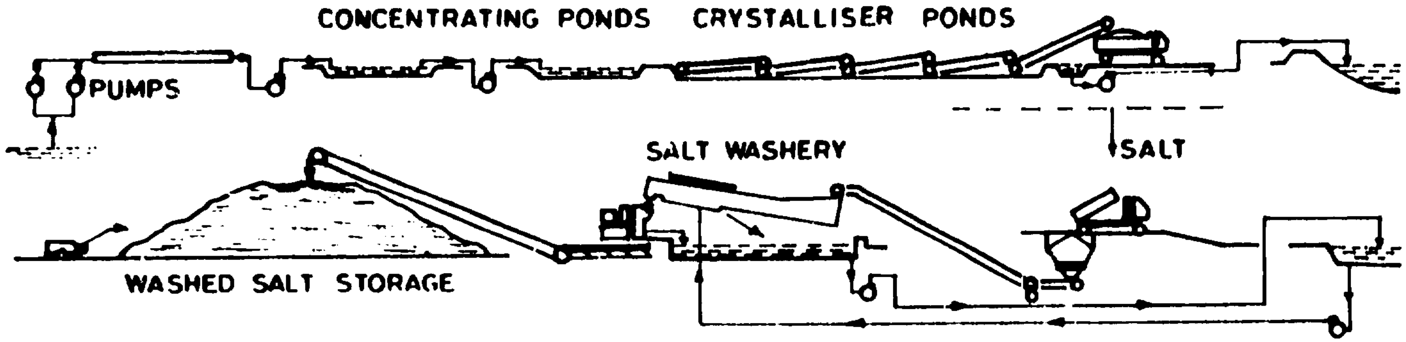


FIG. 5.1. PROCESS FLOW SHEET FOR A SOLAR SALT WORKS.

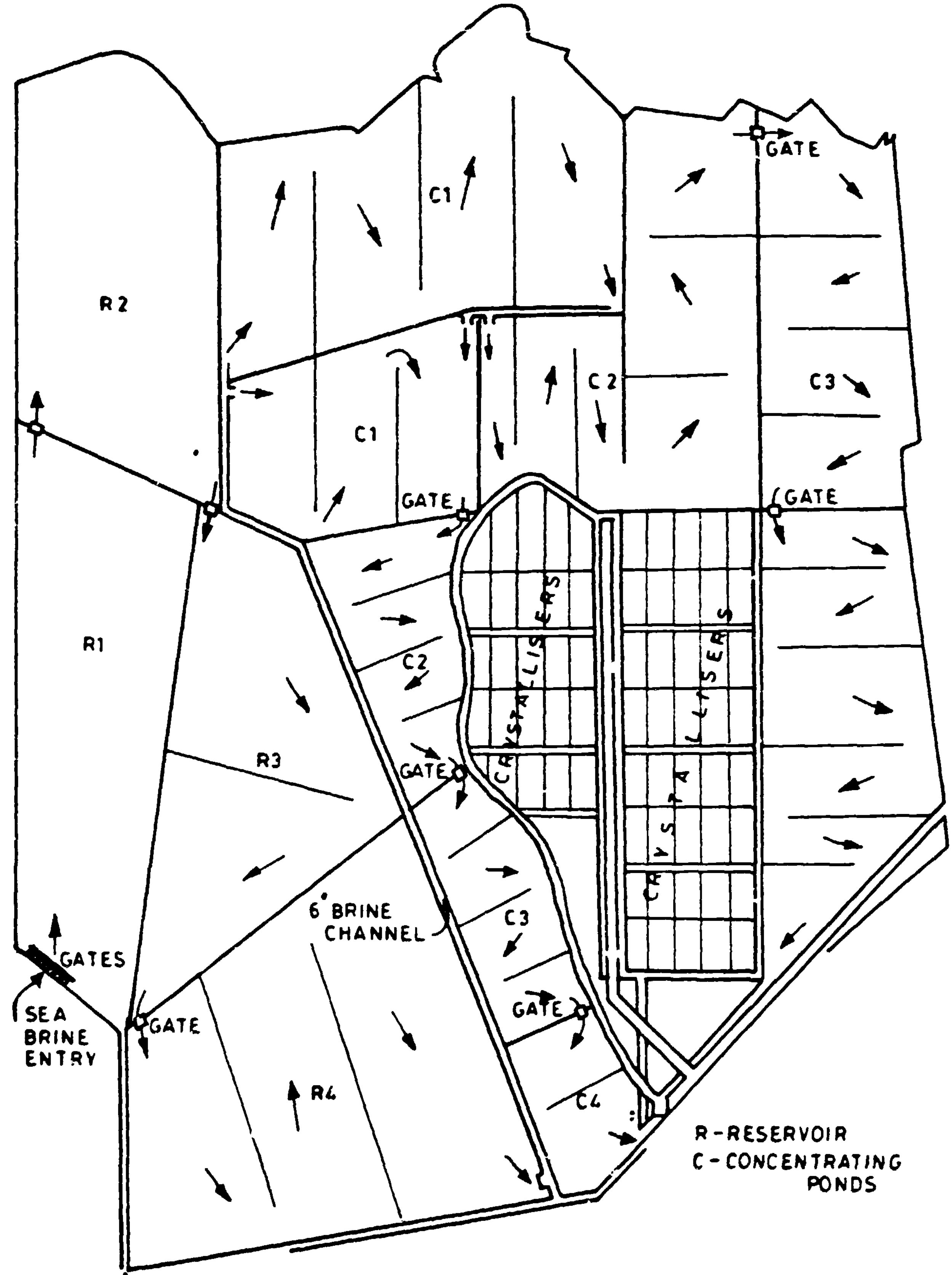
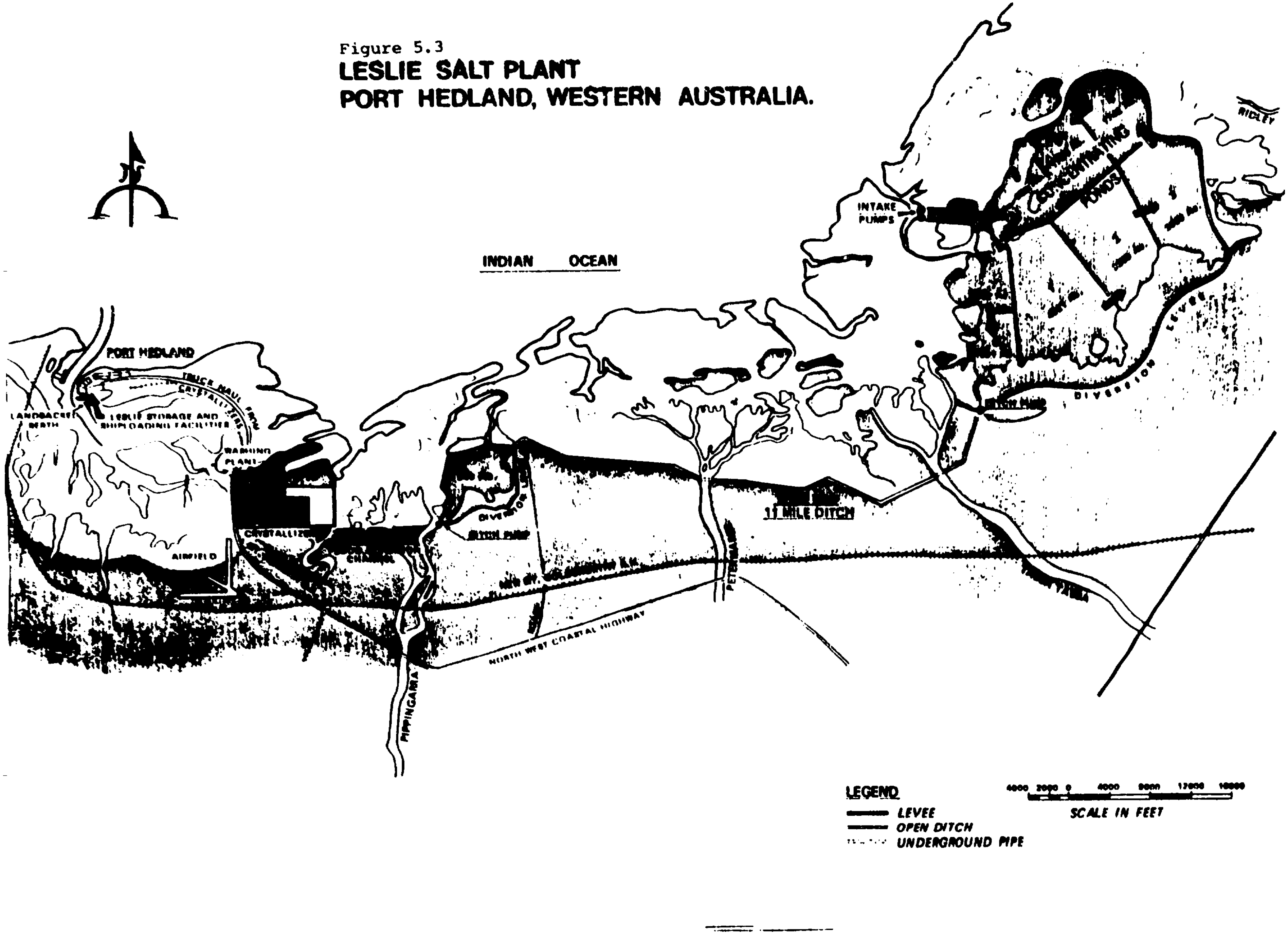


FIG. 5.2. TYPICAL LAYOUT OF A SOLAR SALT WORKS.

Figure 5.3

LESLIE SALT PLANT PORT HEDLAND, WESTERN AUSTRALIA.



e) In all ponds the orientation must be such as to have the shortest dimensions in the direction of the prevailing wind.

f) The orientation must route the weakest brines through the most porous or low lying area.

g) The crystallisers must be as close to the stackyard and despatch point as possible.

In an ideal layout the reservoirs are located on the lowest available land, close to the brine intake point and the crystallisers at the other extreme end. The concentrating ponds are located in between. This ensures smooth flow of brine from one end to the other avoiding the possibility of intermixing of brines at different concentrations.

Sluice gates:

Where tidal conditions permit intake of brine by gravity, sluice gates are to be provided. Normally automatic sluice gates that allow tidal water to enter during tide but prevent water from the reservoirs from returning during low tide are preferred (see Figure 5.4). The gates should be located on the main creek feeding brine to the salt works, so that maximum intake of tidal water is possible. The size and number of gates is fixed based on the height of the normal

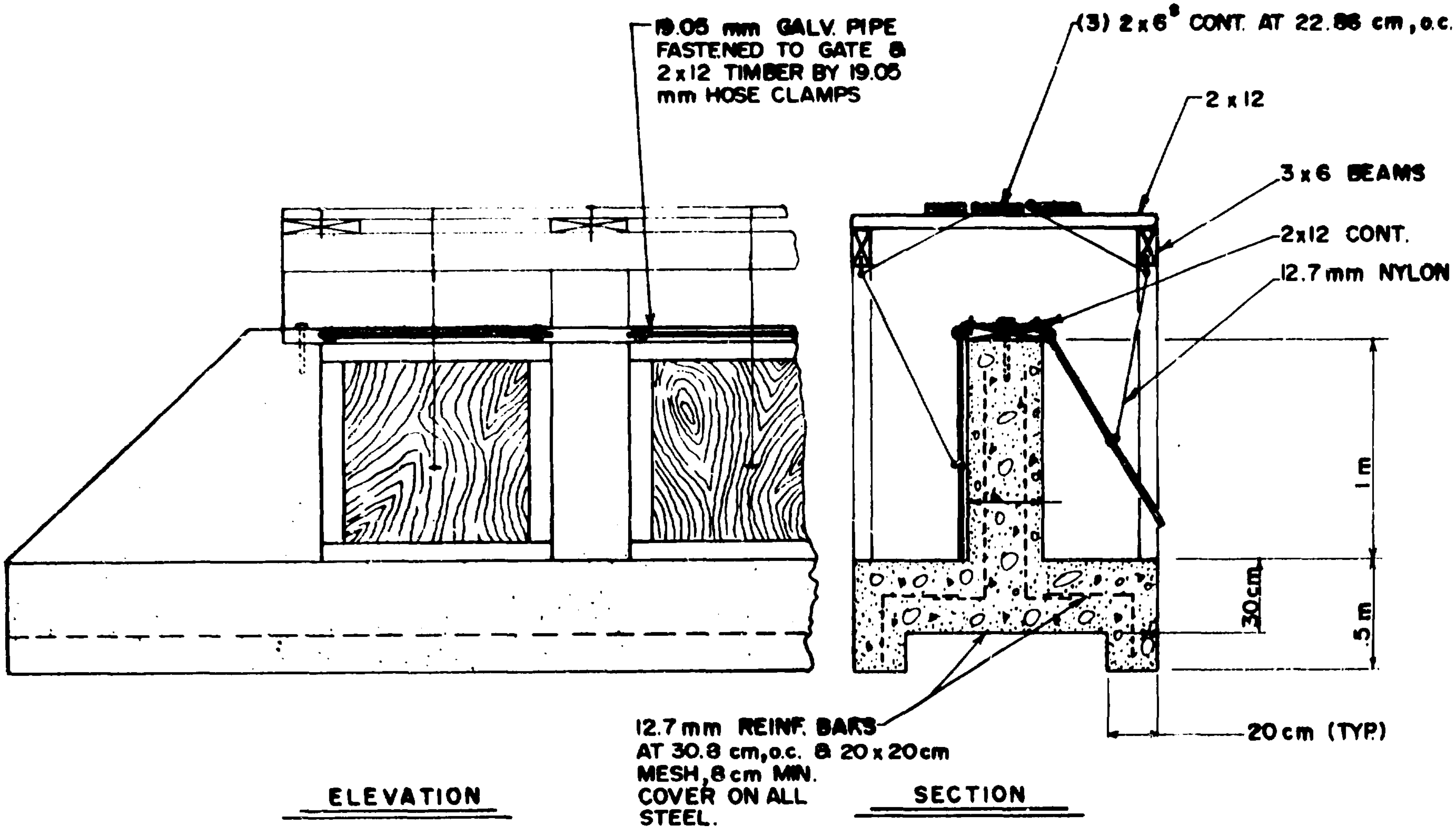


FIG 5.4 TYPICAL TWO WAY CONTROL GATES

tide, bed level of the reservoirs and pressure and period of high tides. The objective is to obtain the maximum level in the reservoirs as close to the high tide as possible. Provision can be made to operate the gates on both sides of their supports so that during the rains, these gates may operate as flood gates discharging rainwater accumulated in the reservoirs and preventing tidal water from entering the reservoirs. Care must be taken to determine the monthly or seasonal variations in tidal action as they can vary drastically because of local conditions.

Estimation of pumping capacity required and pump specifications:

In several sea salt plants the design must permit maximum intake of brine by tide. But even in such areas it is rare that the brine can travel through the system and reach the crystallisers by gravity alone. Pumps are therefore required to supplement or take the place of tidal gates.

Suppose the expected output of a sea salt works is only 10,000 tonnes per year. The volume of 3° Be brine required to produce one tonne of salt is 60 cubic metres. Providing for seepage and recovery losses the.actual requirement varies from 100-150 cubic metres. Assuming the higher figure, the annual requi-ement of seawater is 1.5 million cubic metres. If this quantity has to be pumped in 100 days the daily pumping requirement is 15,000 cubic metres. Assuming that the pumps operate for 15 hours a day, the pumping capacity is 20 cubic metres/minute. Two pumps of 10,000 litres/min are required.

Even though provision is made for pumping of brine during a comparatively short season the reservoirs should be designed to provide a steady supply of seawater to the salt works in the event of failure of pumps or fluctuation in sea water inflow due to tides.

In the concentrating area, advantage should be taken of the contours of the land available to minimise additional relift pumping within the brine circuit.

While permanent type pumping stations should be provided for brine intake and transfer ponds, a few portable pumps with diesel engines on trolleys are recommended to be available for temporary transfer operations between ponds or for drainage of ponds.

Low head high volume centrifugal pumps are recommended. Axial flow or centrifugal mixed flow pumps of cast iron construction are commonly used. A typical elevation of a pumping station is shown in Figure 5.5. Axial flow pumps do not need priming. Mixed flow and other centrifugal pumps

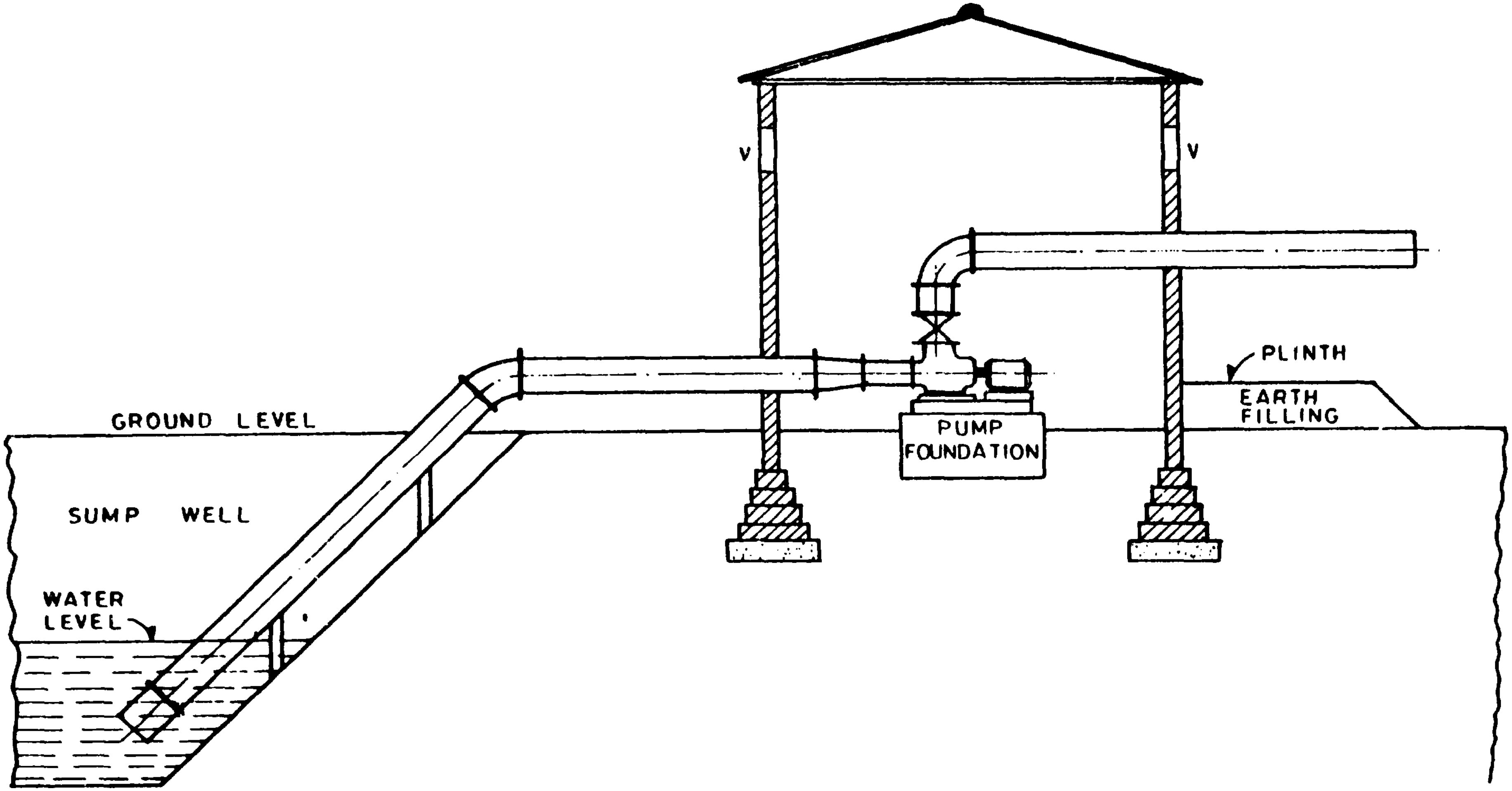
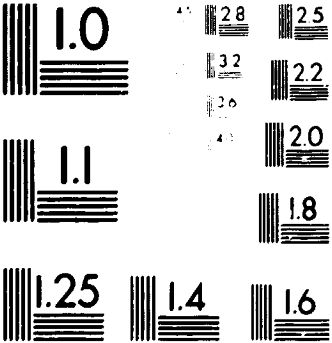


Figure 5.5 **ELEVATION OF A PUMPING STATION**



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

need priming. Priming can be done by fitting footvalves on the pump suctions or by using vacuum priming pumps. Figure 5.6 shows an intake brine pump installation. For permanent stations where power supply is available, pumps can be directly coupled with totally enclosed fan cooled squirrel cage motors. The impellers should be of open or semi-open construction to prevent clogging caused by salting. Pumps are usually made of cast iron with a 2% nickel cast iron casing and suction flare.

While lifting concentrated brines above 20° Be, salting is frequently a problem. Pumps for such applications must have provision for periodical flushing of the casing and impeller to clean out the salt. For these pumps the impeller should preferably be made of bronze with stainless steel shaft.

Design of crystalliser area:

The crystallisers where the deposition of salt takes place are the most productive and therefore the most important part of the salt works. They constitute not less than 8% of the salt works area for sea salt works and a higher proportion in the case of salt works based on richer underground or lake brines. An approximate estimate of crystalliser area required for different feed brine salinities is given below:

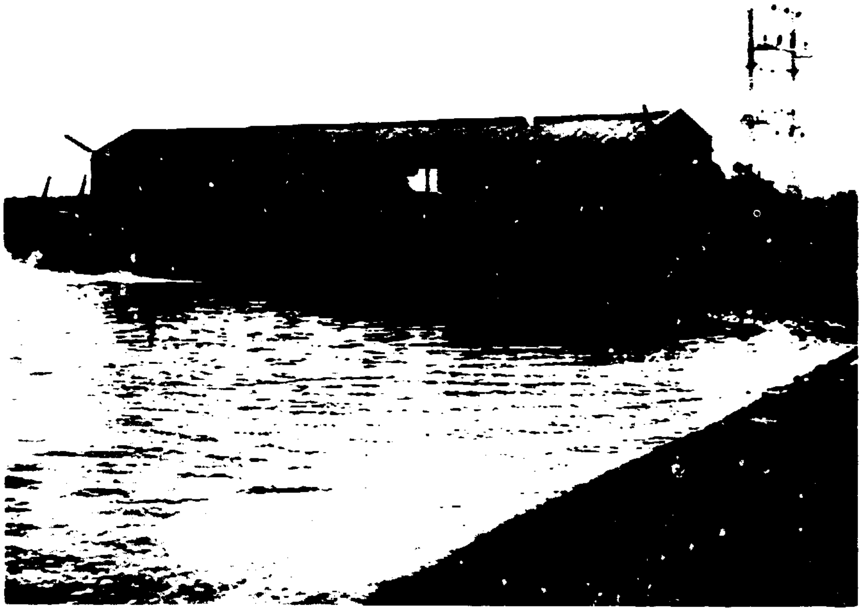


Fig. 5.6 (a) Intake brine pump installation - front view

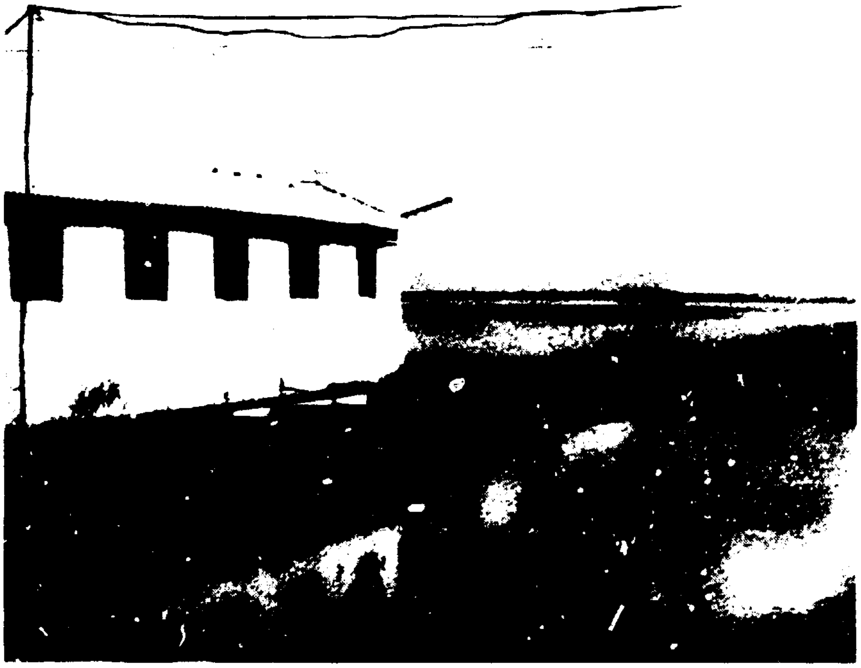


Fig. 5.6 (b) Intake brine pump installation - rear view

Salt content of feed brine (% NaCl)	Crystalliser area as as percentage of total area
3	8
6	16
10	24
15	40
20	70
25	90

Since the crystallisers are fed with the most concentrated brine in the salt works, soil in this area has to be impervious. The crystallisers are rectangular in shape, uniform in size and even in level. The beds are well consolidated and neatly maintained. The shorter dimension of the crystalliser is aligned in the direction of the wind to maximise evaporation. The size of the crystallisers depends upon the degree of mechanisation in harvesting and handling operations and the method of feeding followed which in turn depends on the incidence of rain during the manufacturing season. If the harvesting is done manually the crystallisers cannot be very large. A minimum size would be 30 M x 15 M and the upper limit would be about 100 M x 30 M. If the harvesting is done semi-mechanically or mechanically the crystallisers are larger, running sometimes to several hectares. Manual harvestiing involves removal of the salt with picks and shovels and conveying it to the nearest transport roads in baskets or sacks. The work is arduous and needs skill to collect the salt without mud adhering to it. However, in many countries it is a source of employment and should not be disrupted.

Normally a salt works has to be sufficiently large to justify investment in mechanical harvesting machines (about 40,000 tonnes per year). A variety of techniques exist for mechanical harvesting which consists of scooping the salt and transferring it to a truck/trailer through a conveyor.

Standard procedure for harvesting

Where weather conditions permit, a salt floor is preferred below the new crop salt. Salt floors thickness is widely different depending on many factors beside weather, i.e., ground support, harvest and hauling equipment where ground support is solid, as little as 1 to 2" salt floor has been used. Where rain melts the floor each rainy season a thin salt floor is deposited each year. Following is an outline of the procedure that most salinas have found from experience to be feasible and economical.

1. ALGAL SPLIT

Where rainfall does not permit maintaining a salt floor over the crystalliser bottom, a proven technique to prevent salt from adhering to the crystalliser bottom is to create an algal slime on top of the crystalliser bottom. This minimizes pickup of rock and dirt from the crystallisers. After harvest 20-30 cm of 10-12 Be brine is added and while filling add diammonium phosphate at the rate of about 0.7 P.P.M. to the brine. During the rainy season a slime of algae is created. When the rainy season is over this brine is returned to the salina and crystallisers are charged with saturated brine. This procedure has the advantage to plug off voids in subsurface and reduce seepage in newly constructed crystallisers.

2. SALT SPLIT

A salt split is made on the salt floor by adding unsaturated brine to the surface, and then dragging over the surface a 12" H beam by 3-meter wide pulled by a farm tractor. This breaks up sharp edges of crystals so that the new salt will not stick (bond) to the salt floor. After the first split has been made, then, on repeated harvests, the beam is not dragged over the surface until 1/2" or so of new salt has formed over the salt floor. No weak brine is needed for second, etc., splits.

3. DRAINAGE

When the salt depth has reached the desired depth, the crystalliser is drained. Before draining is complete, shallow drains are prepared using the blade of a grader (as a Cat 120 6). This is performed in several hours operation. The draining then proceeds and additional drainage provided near drain gate when fine drift salt has been deposited. Drainage time is usually 3 days on a 20 ha crystalliser to firm up salt cake so that equipment can travel on salt bed. During harvest, the grader is used to expedite drainage where needed.

To improve drainage, often a swale about 4 meters wide is excavated from end to end in a crystalliser bottom between gates.

4. SCARIFYING

In advance of the harvestor a Cat 120 6 or equal (with scarifying teeth, side shifting blade, and 16 x 24 wide tires) in one operation scarifies the salt to be harvested and at the same time the blade of the grader is angled to pick up salt left behind on the salt floor by the previous pass of the harvester and places it on top of the salt making a windrow. This operation assures that the harvester is always operating at full capacity. Scarifying (loosening) the salt drastically reduces the wear and tear on harvestors.

5. HARVESTING

It has been proven that it is not desirable to try to cut the new crop salt from the salt floor which requires pulling the harvestor with costly D-6 or equal. When salt is scarified, which loosens up the salt, a low cost 70 h.p. rubber tired farm tractor can pull the harvestor. Every effort should be made to utilize a harvestor mounted on rubber tires and avoid track mounted harvestors for maintenance cost and equipment life reasons. This cannot always be done where there is no salt floor and crystalliser bottom is soft such as clay.

Some guidelines for economical mechanical harvesting for small solar salt plants where amortization of equipment for low output is costly and for short period of operation each year (salt floor or firm earthen base)

1. Drain crystalliser.

2. Scarify salt with grader a path 10 - 12 meters wide the length of the crystalliser. This width will depend on size of front end loader to be used.

3. A rubber tire front end loader traveling at cross direction to path scarified picks up scarified salt and deposits it into a 6' - 8' windrow on top of new crop of salt the length of the crystalliser. This will require 2 or 3 passes depending on size of bucket. For a 344 M bucket (such as a Cat 966C) requires 2 passes and moves about 240 M/hr.

4. An equal or the same loader then loads out dump trucks or trailers from the windrow. These 10 - 15 ton payloader trailers are end or side dump trailers pulled by a farm tractor either singly or in tandem. Such trailers are simple and can be built in any country by local fabricators. Bronze axle bushings are recommended as suitable for low speed 15 - 20 KM/hr. and avoid the corrosion problems of ball or roller bearings.

Operations number 2, 3 and 4 can be performed on alternate shifts to minimize equipment requirements.

Loading and trucking is often feasible using contract trucks on a second shift when trucks are normally not used.

The rubber tire front end loader is basic all year salina equipment to move bulk salt, load hoppers, and in performing earth work, lifting, etc. - not just for harvesting. Conventional specialized harvestors are generally idle most of the time and the highly corrosive action of salt requires costly annual maintenance.

Construction of the salt works:

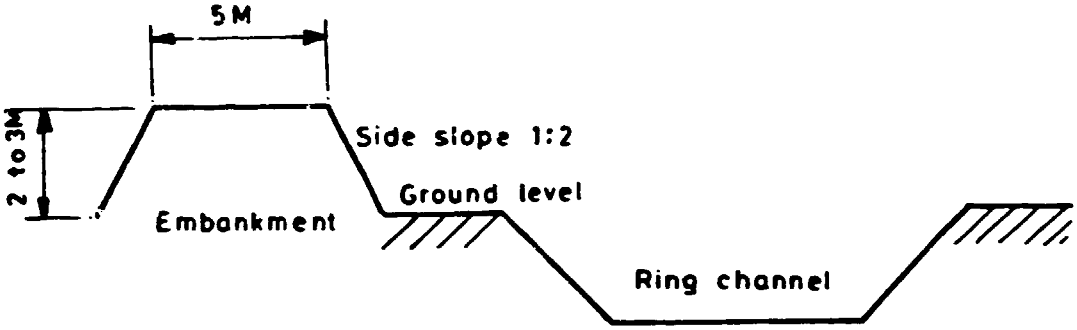
Embankments:

The salt works is bounded by an embankment and a ring channel to protect it from storm water flowing in from the adjoining catchment areas. The embankment must have a free board of 1 M above the highest flood level recorded in the area. The top width and side slopes of the embankment must be sufficient to provide the required strength to the bund. If the embankment is to act as an inspection road a minimum top width of 5 M is required.

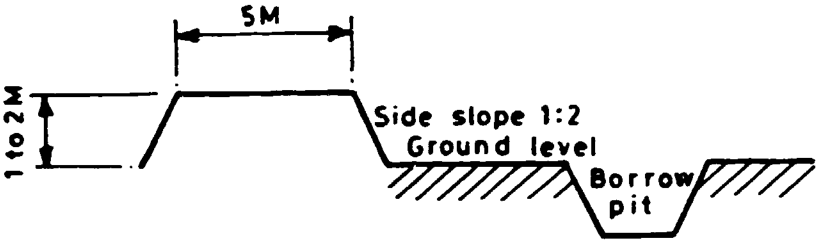
Along the boundary embankment perimeter runs a ring channel to divert catchment storm water into a nearby creek, lake or river. The ring channel must be designed with sufficient bed width and slope to drain off water accumulated by a peak rainfall recorded in the area for a 24 hour period.

The internal partition bunds separating different reservoirs and concentrating ponds need not be of as great a height as the boundary bunds. Their height can be fixed based on the height of water to be stored providing for a free board of about 60 cms. Their top width can be restricted to about 3 metres except where they also serve as inspection roads in which case a minimum top width of 5 metres is required. Where wave action is excessive embankments are lined with loose boulders.

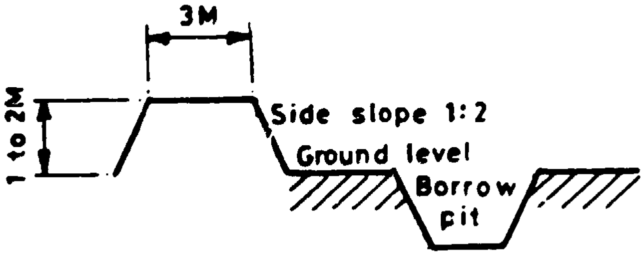
Embankments are constructed from earth from adjoining borrow areas. Typical embankment and borrow pit cross sections are shown in Figure 5.7.



c) Boundary embankment



b) Internal embankment (cum road)



c) Internal embankment (Non vehicular)

FIG.5.7. TYPICAL EARTH EMBANKMENT CROSS SECTION

Where labour is cheap, embankments may be constructed manually in layers of 15 - 20 cms and compacted by hand drawn rollers to provide the requisite strength to the embankment. Where equipment is available bulldozers can be used to scrape off adjacent earth on both sides to form the embankment and then to run over it to compact it. The compaction required is determined by the soil bearing capacity.

A cheap and effective way of protecting embankment slopes is to promote shrub growth along the sides. Certain thorny bushes like proscopis grow quickly in saline soils. Sometimes dressing the bund with paddy grass mixed with mud is also helpful.

Areas where top sand occurs over an impervious layer below resulting in heavy percolation, can be productively used by forming a key trench of clay and an impervious wall to seal off cross percolation from the pond (Figure 5.8).

Shallow open wells and borewells:

In areas where concentrated brines are available close to the surface up to a depth of 8 M, these are tapped by digging shallow open wells of about 10 - 15 M dia (Figure 5.9). However, when the brines are available lower down and

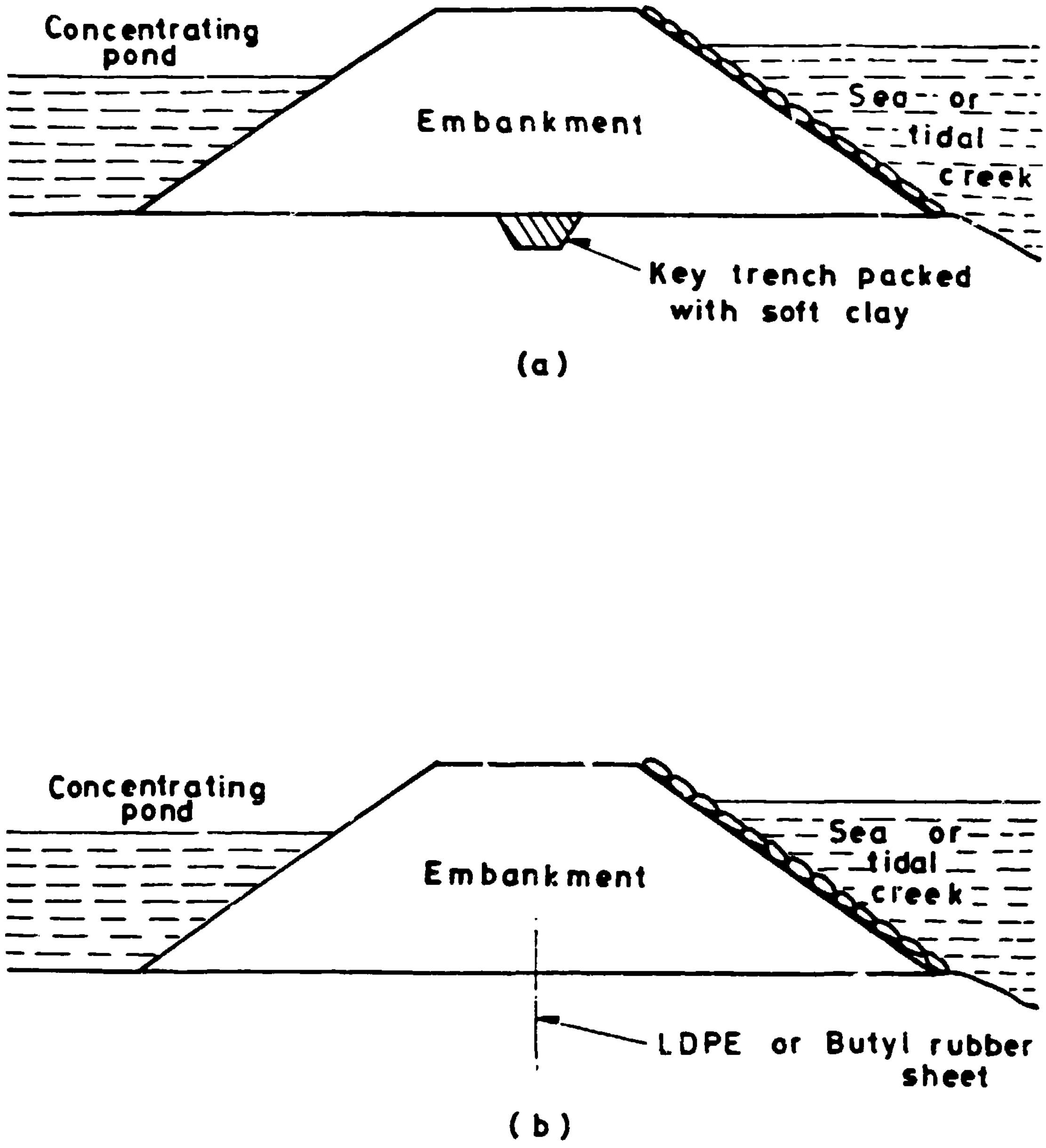
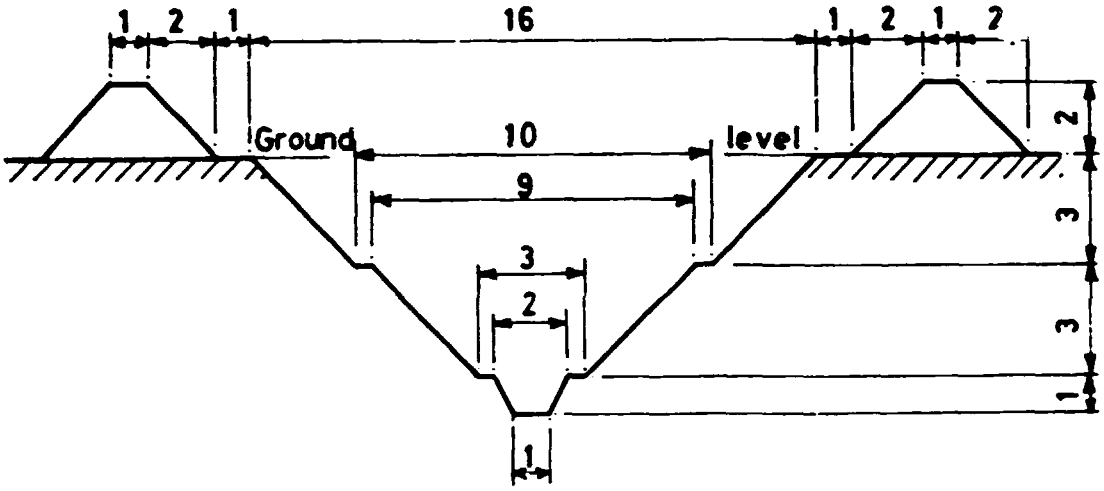


FIG 5.8. PREVENTION OF CROSS SEEPAGE ACROSS EMBANKMENT.

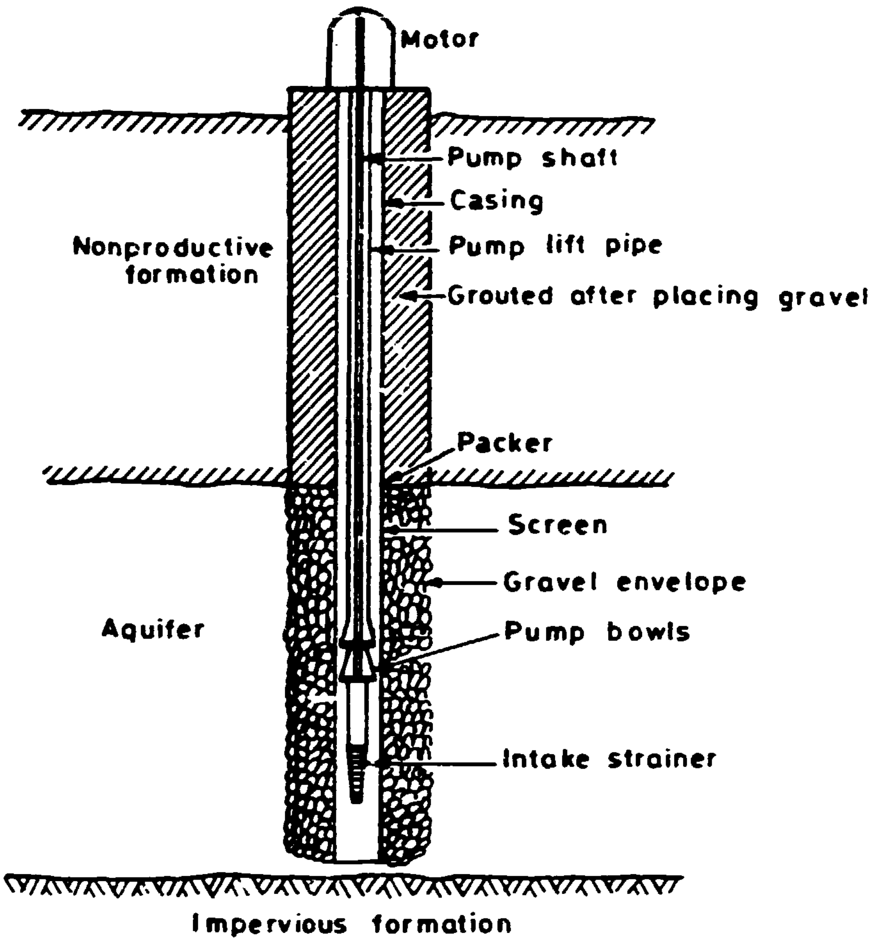


All dimensions in metres

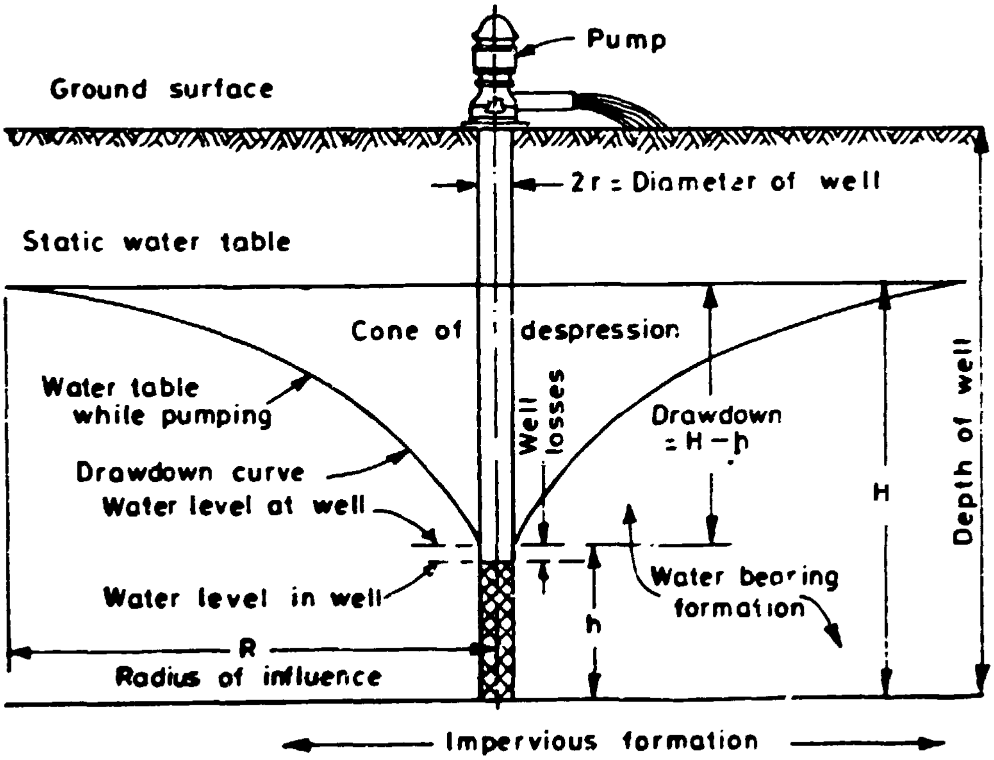
FIG. 5.9. TYPICAL CROSS SECTION OF AN OPEN BRINE WELL.

when the brine table tends to fall in summer, it is advisable to sink borewells. This consists in drilling a hole vertically either by using a hand auger or by using a pneumatic drill. The diameter of the bore is normally in the range of 15 to 25 cms. Where the earth is firm no casing pipe is provided. But lower down where the soil is weak and tends to collapse, it is necessary to sink casing pipes to support the side walls. The drilling should continue until the water strata is reached. Solid casing pipe can be used for the upper portions of the borewell. However, in the lower portions where cross seepage is required to feed the borewell, slotted casing pipes are used. Casing pipes are of cast iron, Polyvinyl Chloride or High Density Polyethylene. A borewell cross section is shown in Figure 5.10.

Borewells vary in depth from about 20 M to over 300 M. The water table should not drop below 8 M even under continuous pumping if ordinary centrifugal pumps are to operate. Where water tables are 10 M below ground level, it is necessary to lower the pumps to a level where suction does not exceed 8 M or to use special deep well submersible pumps which are lowered into the water strata.



CROSS SECTION THROUGH A GRAVEL-PACKED WELL.



CROSS SECTION OF A TYPICAL GRAVITY WELL IN HOMOGENEOUS SOIL.

FIG.5.10. TYPICAL BOREWELL CROSS SECTION DETAILS.

Prospecting for good locations for borewells is still largely based on hydrographic studies and systematic trial bore testing to identify the water strata. Electrical resistivity methods commonly used for freshwater prospecting very often yield erroneous figures for saline brines and are not useful. The proper location of a borewell is very crucial and borewells located as close as 100 metres apart may have widely varying outputs. The spacing between borewells should not normally be less than 100 metres. Except, in cases where the output of a single well is insufficient, a series of wells closely spaced are combined and coupled to a single pump.

Transport of Salt from Crystalliser:

There is various equipment for transporting salt as it is harvested to wash plant or direct to stackpile. The scope of the manual does not permit detailed explanation and description of various types of equipment and procedures. Following is an outline for guidance.

Hand Operation (some of the many variations)

1. Harvested under brine, placed into baskets holding 10-20 kg, rinsed while in the basket and placed directly into flat shallow draft boats (± 30 cm deep by 1.5 M X 3 M) and pushed to unloading dock.

2. Crystalliser is drained, shovel placed until salt bed and lifted into wheelbarrows and transported to edge of crystalliser where it is dump loaded into dump trucks.

3. Harvested by hand into 50 kg baskets and placed on workers head who walk to edge of crystalliser.

4. Harvested by hand or shovel, in small piles to drain then sacked and transported.

Machine Transport (loaded directly by harvestor into transport)

In most all cases transport equipment travel above the new crop salt or a salt floor so as not to damage the crystalliser floor.

1. Loaded into end or side dump trailers pulled by an agricultural tractor. These vary in size from 4 to 15 M tons capacity pulling one to several units at speeds of 10-25 km/hr.

2. Loaded into bottom dump trailers 15 to 100 ton in capacity pulled by truck tractor fastened by a 5th wheel or large earth moving tractor pulling one to several units. Speeds vary from 25 to 75 km/hr.

3. Cutter type floating dredges loading into small boats, single or in tandem, pulled by a power boat to the dock where boats are dumped mechanically into a hopper for reclaiming and washing.

4. Locomotives pulling bottom dump cars traveling on portable track above the salt that is moved as the harvestor proceeds over the crystalliser.

Salt Wash Plants

There are many variations of wash plants and should be designed to meet the local conditions and quality requirements. The writer strongly recommends before any design or conclusions be made as to what system be used a careful study be made of the paper presented by Masuzawa at the 5th Salt Symposium and the practical use of his findings into crystalliser and wash plant design (see the following pages). Breaking up salt clusters in a wash plant is essential to expose impurities to achieve maximum quality. If there is clay, silt, or weed the washer should dissintegrate this material and remove from the salt. This material is dissintegrated in conventional log washers, Aikens spiral washers, lump breakers, screw classifier, etc. Figure 5.11 shows such a layout. The crude salt is fed into an agitated tank where it is mixed with saturated brine from the crystallisers to form a slurry which is pumped or gravity flowed into one or several of the above devices in series. The wash liquor overflows. The salt then passes onto a slow moving S/S mesh conveyor for further impurity removal. Banks of 20-24 Be sprays on this conveyor are used to displace Mg^{++} and generally a bank of sea water sprays is used to finish the Mg^{++} removal.

Since the specific gravity of salt, gypsum and certain types of rock contamination such as coral or limestone is similar, the above washing treatment is both not effective, but very costly for power, maintenance and capital investment.

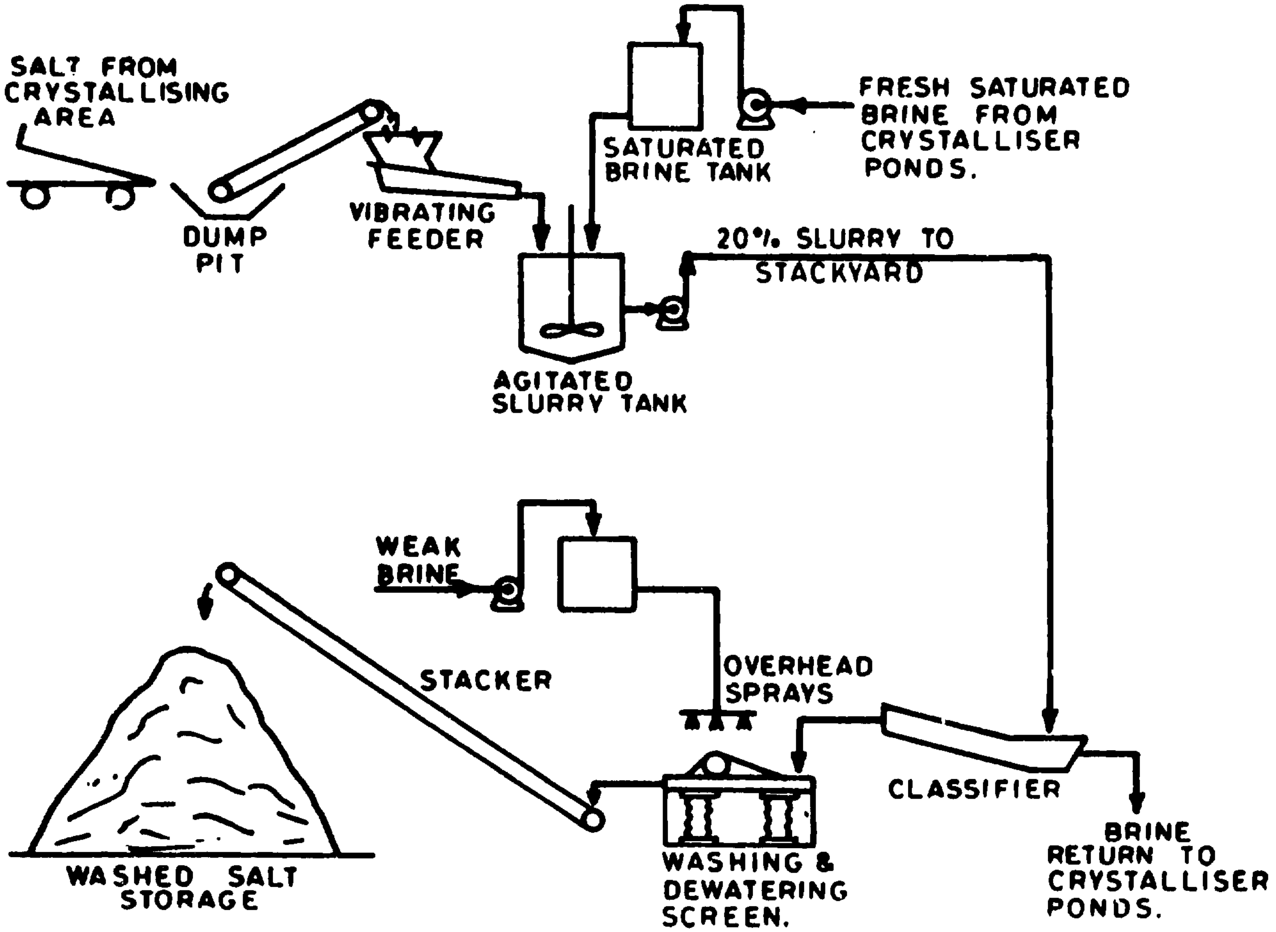


Figure 5.11

LAYOUT OF THE SALT WASHERY

Review and interpretation of portions of Masuzawa paper:[1]

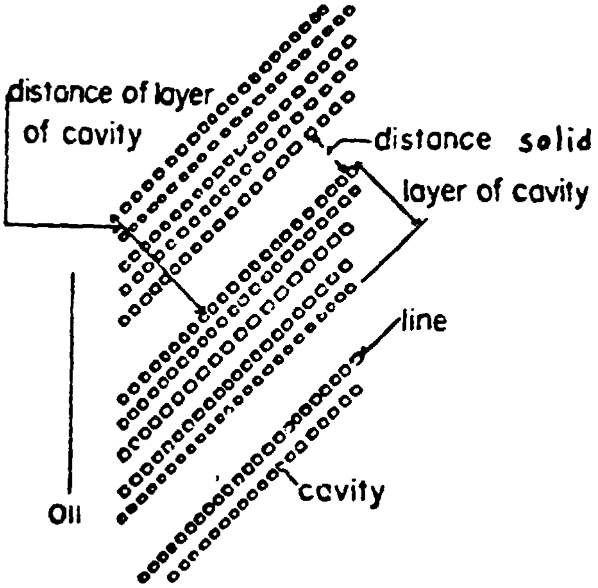
Salt crystallises into hopper shaped crystals (upside down pyramids) and partly on the bottom of the brine regular cubes; the majority being hoppers.

The hopper crystals grow upon themselves to become enlarged. In so doing voids are developed that trap mother liquor containing impurities of Mg, Ca, K, SO_4, clay and organics. This is shown in the following drawing by Masuzawa. There are also impurities within the crystals inside minute cavities in the crystal structure. Tests have been conducted which determined quantitatively the amount of impurities which can be removed by washing and which remain within the crystal irrespective of the method of washing. Following is the range in percent of impurities within the crystals as gms/100 gms of salt from many salt works (but do not include salt from Italy, Turkey, Greece and Yugoslavia which are produced from brine having a high organic content).

	Solar salt	Vacuum refined
water	0.2-0.9	0.10-0.13
potassium	0.009-0.011	0.02-0.015
magnesium	0.007-0.013	0.008-0.012
calcium	0.009-0.011	0.005-0.012
sulfate	0.015-0.018	0.014-0.018

[1] World Salt Symposium, 1978.

Cavities are easily detected within individual crystals by microscope. Following is a sketch by Masuzawa of what is seen in the microscope of a thin slice across a salt crystal. It is interesting to note that for the salt deposited during the daytime there is an opaque layer and at night a solid transparent layer that was about 1/3 of the 0.24 mm total deposited.



The thickness of layer that was opaque (had cavities) ranged between 0.03-0.7 mm. Mexican salt had a cavity layer of 0.21 of the 0.24 mm deposited per day or 88% of cavity layer. Salt crystals made up of entirely opaque (maximum cavity situation) indicated that the night time deposit also created cavities and entrapped the maximum Mg within the crystal from mother liquor. It is theorized that where large percentage of cavities exist it may be caused by excessive organics suspended in the brine.

It was found that the Mg within crystals was directly proportional to the percentage of cavities and to the Mg content of the brine.

Tests indicated that salt produced from brine having low Mg produced about 1/4 of the cavities as normal brine and about 1/8 of the Mg or roughly 0.003% Mg. Low Mg brine could be obtained by dissolving up deposited salt from salt deposited by further evaporation of bittern and pickle ponds. Another measurement of cavities is from both the density and the water content. Maximum % cavity is at 2.16 and minimum cavity at 2.11; cm^3 density and water content of 2.2% down to 0%, respectively.

The Mg within crystals (not removable by washing) will be roughly in the same relation for salt having equal cavities, i.e., 0.008 fr 0.14% Mg and 0.03 for 0.44% Mg.

It is not possible that salt produced from 28-29 Be brine can be washed well enough to meet a 0.04% Mg specification. It, therefore, follows that it is advisable to separate salt in the stackpile for petrochemical use (less than 0.04% Mg). The remainder of the salt will be suitable for other uses. It is simple to separate low Mg produced salt in the stackpile. This is based on an efficient wash plant design and operation.

Control of Ca:

Of many samples the Ca within crystals was about 0.01% regardless of the total Ca. The remainder of the Ca was deposited on the crystal surfaces which can be removed in the wash plant. The success in removal of Ca, Mg, and insolubles depends upon the degree in which the hopper shaped crystals are broken open in handling at the wash plant. Ca as Ca SO_4 $2H_2O$ particles are about 0.1 mm in size and can be removed from the salt slurry in a hydrocyclone because of the vast difference between calcium sulfate and fine solar salt received from crystallisers. It is reasonable to expect reducing the Ca impurity to less than 0.04% after washing.

Insoluble impurities:

The degree of success in removing insolubles in the hydrocyclone will depend on the specific gravity and size of the impurity and the degree to which the hopper crystals can be broken down while pumping salt slurry to the hydrocyclone. For the most part the wind blown dust particles are very fine and have a specific gravity less than 2.1 which can be separated out in the hydrocyclone. The majority of the organics and clay dust can be removed by washing, however, insolubles within the cavities can be as high as 0.14%. In pond systems that are in biological balance, the organics have been largely consumed and converted to halophilic bacteria before fed to crystallisers; thus, the importance of successful hydrobiology control of the salina.

A very effective wash plant consists of simply mixing crude salt with saturated brine as fed to an open impeller pump to break up salt clusters, a hydrocyclone to remove silt and gypsum, and a S/S woven wire mesh to remove Mg^{++} and to dewater. It is preferred where timber is available to construct the wash plant from wood with concrete for hoppers and sumps. The entire structure for belt conveyor systems (except stackers) should be timber mounted on precast concrete supports (see Figure 5.12).

Wash plant losses vary widely from plant to plant with a range reported to be a low of 10% to as high as 30%. This is a vitally important consideration before deciding upon the wash plant design to be adapted. The hydrocyclone process has a loss of about 16% when properly designed and operated.

The washery and stackpile is located as close to the crystallisers as possible. The top of the stackyard should be above any flood potential, base well compacted, properly levelled and given a gentle gradient to effectively drain out rain water. A ditch should be around the area to prevent backup of water into the salt.

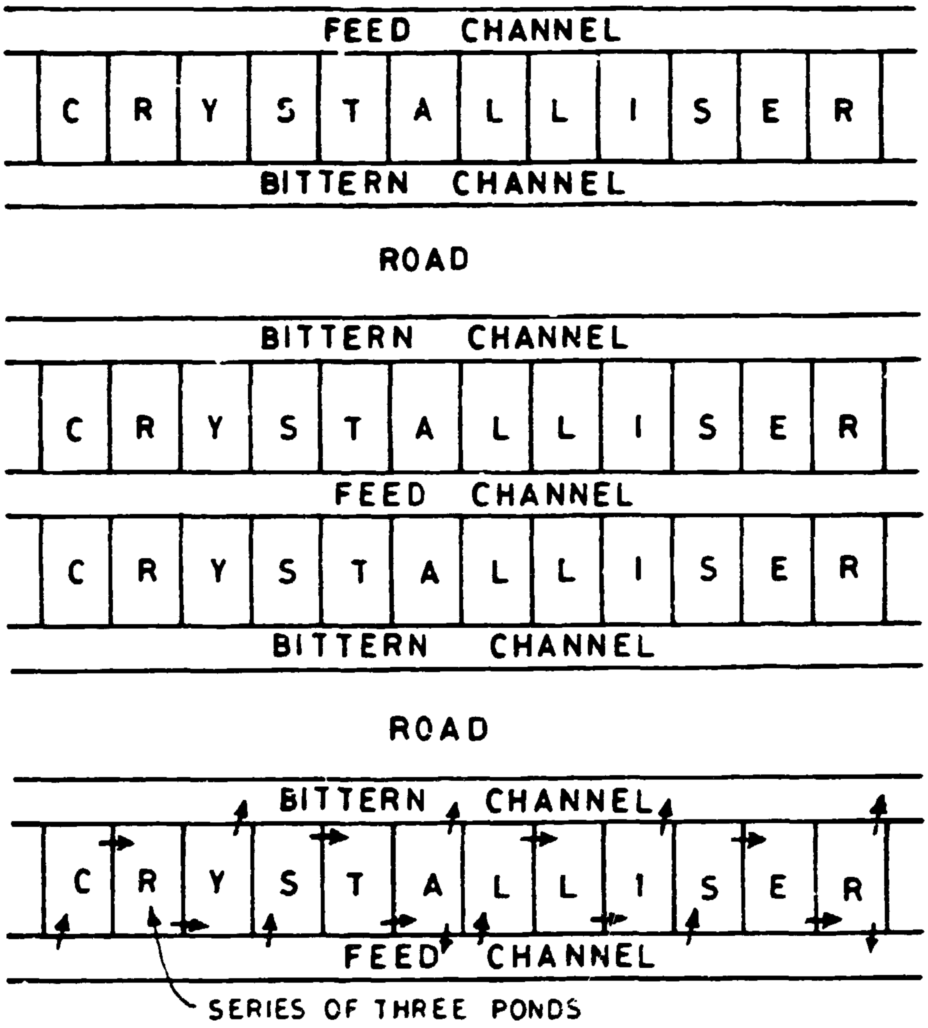


Figure 5.12 LAYOUT OF CRYSTALLISER AREA

Salt in heaps exceeding 8 M in height can be safely stored in the open without any covering to withstand a rainfall of even up to 100 cms. After the first shower, the top crust of the heap hardens and therafter, the rainwater slides off the surface of the heap. If the heaps are small and rain is excessive it is necessary to protect the salt with palmyrah leaf covering (where available) or with low density polyethylene covers.

OPERATION OF THE SALT WORKS:

At the commencement of the manufacturing season, sea water is drawn into the reservoirs either by tidal action or by pumping. The preferred depth of brine in the ponds is maintained between 20 cm and 60 cm. The variation largely depends on pond bottom elevation. The brine remains in the reservoirs until it reaches a concentration of about 6° Be. During this period the suspended impurities settle down at the bottom and the volume of the brine gets reduced to almost 60% of the original quantity drawn into the reservoirs. The brine at a density of about 6° Be is transferred to the first series of ponds in the concentrating area. In the concentrating ponds the depth of charge is maintained between 40 cms initially and 20 cms in the final stages. Between 6° Be and 10° Be calcium carbonate settles down. The brine is further concentrated to 16° Be and transferred to gypsum ponds. Here the bulk of the calcium sulphate in the brine separates out and settles down as long needle shaped crystals. The brine is retained in these ponds until it reaches 24.5° Be, which is almost the saturation point with respect to sodium chloride. Density at different stages in the salt pond system is measured by using a simple glass hydrometer calibrated in °Be (0-40). Some operators use a salometer (roughly % of saturation equals Be X 4). Others use specific gravity.

The brine close to saturation is passed through deep storage pickle ponds before filling the crystallisers. This is because gypsum has a tendency to supersaturate. If brine enters the crystalliser undersaturated or has rapidly reached salting point it can deposit several times more gypsum than otherwise. The pickle pond will aid deposition of as much gypsum as possible before the brine enters the crystalliser.

Before being fed with saturated brine, the crystallisers are cleared of all slush and well compacted with the addition of sand and rolled. Cast iron drum rollers with a dead weight of about one tonne are suitable for this rolling operation. These rollers can be filled with water so as to increase the weight up to 3 tonnes depending upon the type of soil. After the crystallisers are rolled they are fed with a small quantity of saturated brine and a thin layer of salt is allowed to form. This layer is uniformly dragged over the bed of the pond. The crystallisers are then charged to a depth of 20 to 40 cms through the brine supply channels. As described earlier, the crystallisers are charged in series, the brine entering the first pond at 25.6° Be and leaving the last pond of the series at 30° Be (see Figure 5.12).

Before stacking about 5 ppm sodium ferro cyanide can be added as an anti-caking agent. Drainage continues in the heap before the material is offered for sale.

After washing, solar salt crystals range in size from 2 mm to 15 mm which depends on the conditions and operating technique. In the case of industrial salt, the crystals can be despatched without crushing. For edible purposes, the salt has to be ground to a size of 0.5 mm to 1 mm. This is done using roll crushers or pin mills as shown in Figure 5.13. Prior to crushing wet salt may have to be dried. This can be done by spreading the salt in thin layers in the open sun for a few hours or with the help of a rotary drier. If required, additives are added for specialty salt production after grinding. Caking caused by moisture absorption in table salt is reduced by adding up to 1.5% free flowing agents, such as magnesium carbonate and tricalcium phosphate. Iodised salt contains 0.01% potassium iodide, 0.01% calcium hydroxide and 0.1% sodium thisulphate as stabilisers when free flowing agents are used.

The material is packed in 50/75/100 kg bags for despatch as shown in Figure 5.14. In the case of bulk trans-

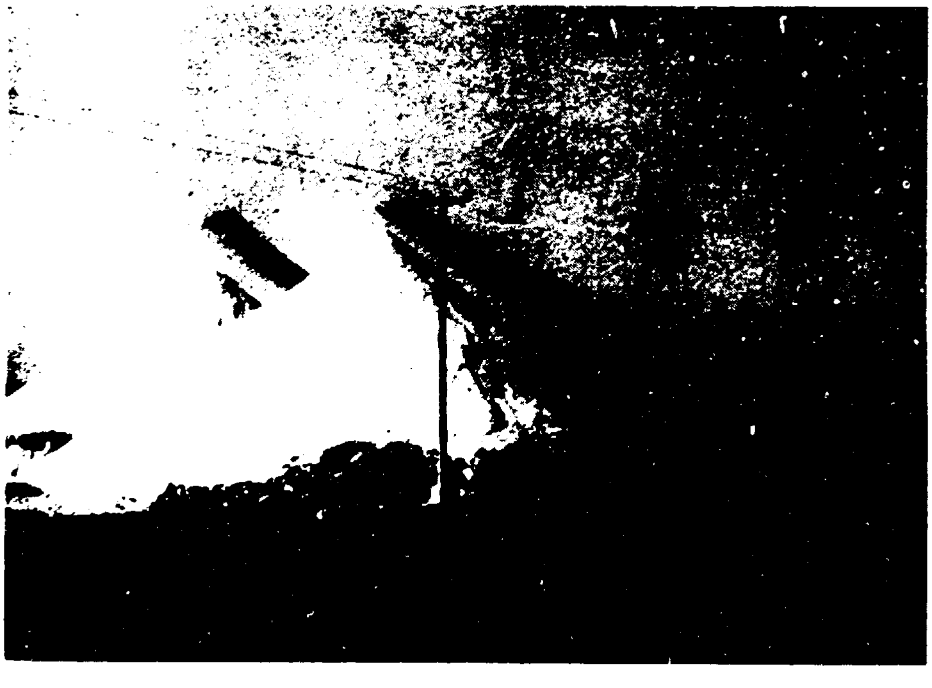
Fig. 5.13 Crushing of salt

Fig. 5.14 Despatch of salt in bags

Crystallisers ready for harvest

Manual collection of salt in crystallisers

Transport of salt from crystallisers to stackyard



Stacking of salt

port by road the material is directly loaded into trucks and despatched to the destinations. For table salt, machines are available for packaging in 1/2 kg/'1 kg polyethylene bags.

Brine Handling Techniques

Certain basic principles exist related to brine handling procedures, but each salina is unique and specific procedures must be established to best suit the local conditions.

Outline of Basic Principles

1. Capacity of intake gates or pumps need to be adequate to obtain the needed sea water during months of highest Be and highest evaporation rates (yearly averages should not be used).
2. Provisions are generlly advisable to be able to drain-back (run-back) brine during and after rainy periods. This is known as counter current flow. The first pond if below sea water Be would be returned to the sea. Second pond would flow into first pond, etc.

This requires judgement and well established operating procedures to avoid over reacting causing bare ground to exist and excessive pumping costs to refurbish the pond system after the run-back. Double acting plywood gates are practical to use for this purpose (see Figure 5.4).

3. A form should be prepared showing desired level and gravity ranges on which actual weekly measurements are recorded to evaluate conditions and possible action needed.

4. Procedure and results of salt recovery from bittern (brine discarded from crystallisers at 29 - 30 Be).

5. Decant equipment and procedure.

6. Value and design of deep storage of pickle (saturated brine for feeding crystallisers).

7. Hydrobiology of solar pond system.

8. Sealing ponds with algae deposits and impregnating sub soils.

9. In most situations it is far less expensive to build concentrators than crystalliser ponds roughly 1:30, therefore, the pond system should be designed to provide an excess supply of pickle over the basic crystalliser requirements. There are several techniques to maximize crytalliser production that will be discussed further. These depend on various factors.

Ratio of Concentration to Crystallisers

To determine this consideration must be given to the brine handling technique to be used, such as ability to flow brine counter currents during and after heavy rains, provision for effective decanting pickle pond and crystallisers, improving solar heat absorption by algal growth and the development of red colored brine from halophilic bacteria, use of dry storage for pickle, salt recovery from bittern, seasonal variations of intake gravity, seepage, etc. This ratio can and does vary between 7:1 and 15:1. Based on data published by Marrett Research Figure 3.7 was prepared for a typical salinas labelled estimating Be related to area.

Pickle Pond Layout and Operation

It is recommended that the pickle pond area be capable of holding the volume of brine contained in the crystallisers, plus the volume of pickle normally stored, plus an allowance for gain in volume from rainfall during the wet season. With a 2.5 meter dry pickle pond containing 1 metre depth at end of dry season, 30 cm average crystalliser depth and 30 cm rainfall after decanting the pickle pond would need to be in area about 50% of the crystalliser area. It is generally desirable to lower crystalliser depths toward the end of the dry season to force as much brine up to the bittern stage and removed from crystallisers. One error that has been made is to drain high Be brine back into the concentrating area for two reasons, i.e., one is that the evaporation factor is reduced in the concentrator system and, secondly, the brine must be evaporated to above 25.6 Be before crystallising will take place again.

Withdrawal from the pickle pond should be from a bottom well (sump) to draw off the most saturated brine from the bottom. Modest amounts of rainfall will be slow to mix and remain in the upper strata. Where elevations permit pickle removal is through a gate operated culvert through the dyke, otherwise by pump with suction as low as practical.

The end concentrator pond should normally have a Be of 24.5 - 25 to assure always having a 25.6 - 26 Be to feed crystallisers.

As previously reported provision is needed to add low Be brine to such facilities to prevent or remove salt build up.

Where soil conditions have appreciable seepage 10^{-6} or more shallow pickle ponds of 30 - 60 cm are required, until algae seal is obtained or a permanent salt cake can be deposited on the bottom.

In laying out pickle ponds consideration should be given to dividing the area into two parallel ponds, obviously with the exits at the end opposite the inlets. A suitable arrangement is to have a roughly rectangular area divided by a diagonal dyke. This allow for proximity of the two inlets and the same for the outlets.

There are a number of valuable reasons for having parallel pickle ponds. There are times when it is necessary to use one pickle pond to be saturated to fill crystallisers while the alternate crystalliser is being filled with unsaturated brine and allowed to saturate before using in crystallisers.

An additional important feature is that in alternate years while one pickle pond is being fed to crystallisers the alternate can be drained and depending on condition of the bottom or if it has a salt floor below the new crop the new crop can be harvested even though high in $Ca\ SO_4$. Otherwise it can be scarified with agricultural type equipment, filled with sea water or weak brine to dissolve the salt and saturate the brine to fill crystallisers. Sea water is preferred as by so doing the resultant pickle is low in Mg^{++} which produces a higher purity salt and higher crystalliser output/ha. Depending on the ability to drain off the brine from the salt the reconstituted saturated brine will have a 3 - 4 g/l Mg^{++} content. By using nomogram Figure 3.3 the difference in the evaporation factor can be seen.

In locations having prolonged periods of high humidity and low fresh water evaporation this procedure can be adapted by providing "pre-crystallisers" to produce low Mg++ pickle to feed crystallisers. Without doing this a thin cake would result in the crystalliser that might not be suitable for low cost mechanical harvesting. The additional advantage is to reduce Mg++ and $CaSO_4$ in the salt produced.

Decant System

Solar salt operators attempt to decant rainfall from the surface of brine in crystallisers and pickle ponds. This is impractical to do with weir boards at gates because pond levels change from wind action, rainfall, and by build-up of salt on the boards.

A method of using floating decants was devised and successfully used as illustrated in Figure 5.15. During or after a rain the decants are lowered to float in the brine which is designed so that automatically the lip of the decant is 2.5 to 4.0 cm below the surface of the brine. The opening of decant box is 1M by 1M. The discharge through the gate is by two 12.7 cm PVC pipes using flexible rubber connectors having S/S spiral wire internally imbedded to prevent collapsing (Gates Rubber Company). A hook is used to suspend the decant when not in use above the brine from a timber extended out from the gate or structure. With a Δ H of 45 cm between brine and level on other side of gate about 3.75 M^3/min is obtained from the two pipes or 7.5 M^3/min from two gate structures.

A 10 cm rain in 24 hours on a 10 ha crystalliser requires 6.9 M^3/min removal. An attempt is made to place the

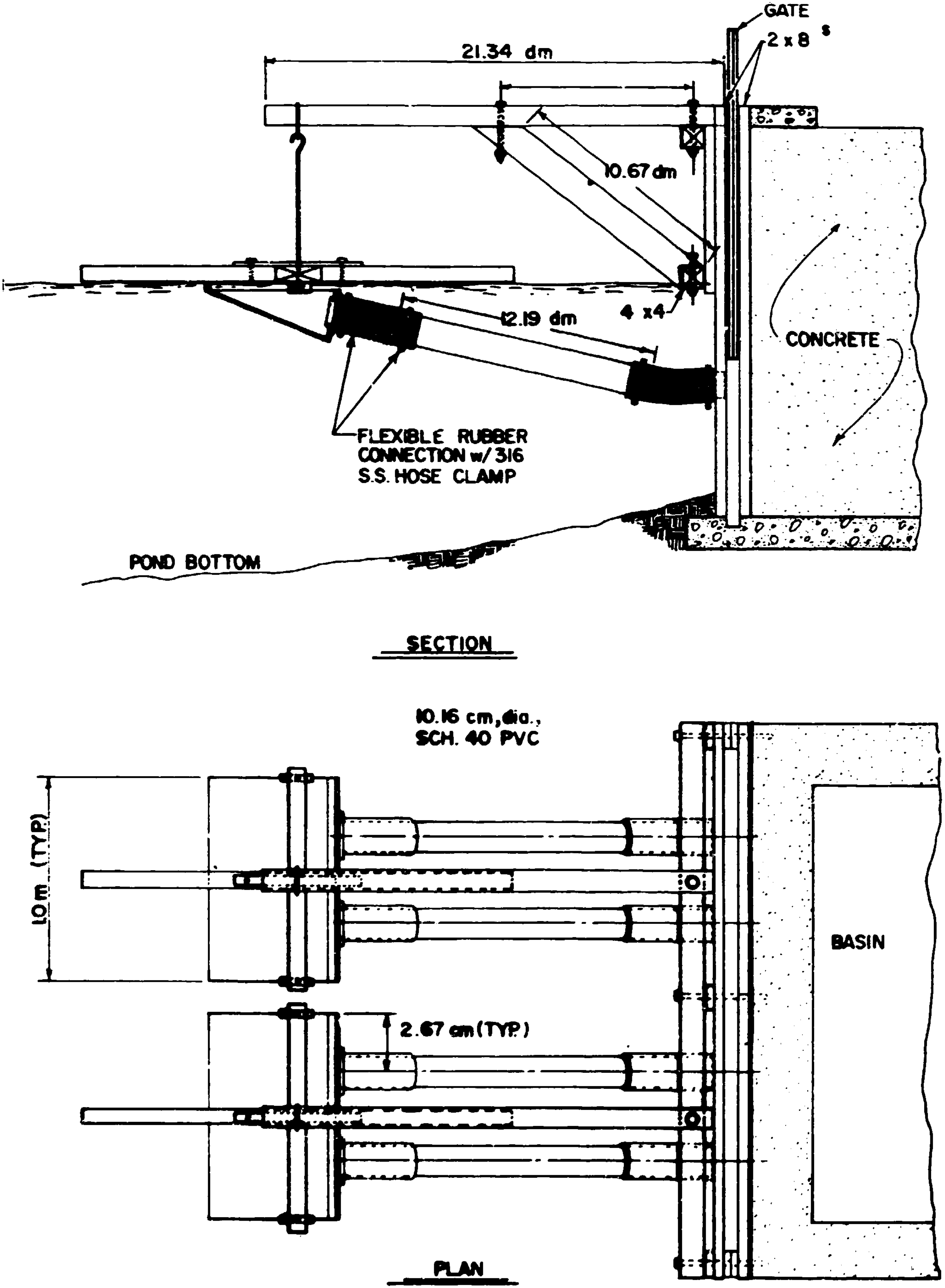


FIG.5.15 FLOATING DECANT TO REMOVE RAINWATER

decant effluent back into the pond system after the initial essentially fresh water is decanted. To design a decant system wind direction and velocity and variations during storms is needed. Baume readings are taken hourly from decants and as density approaches 15-20 °Be decants are lifted. For large ponds a bank of decants can be provided through a bulb head wall.

Salt Recovery From Bittern

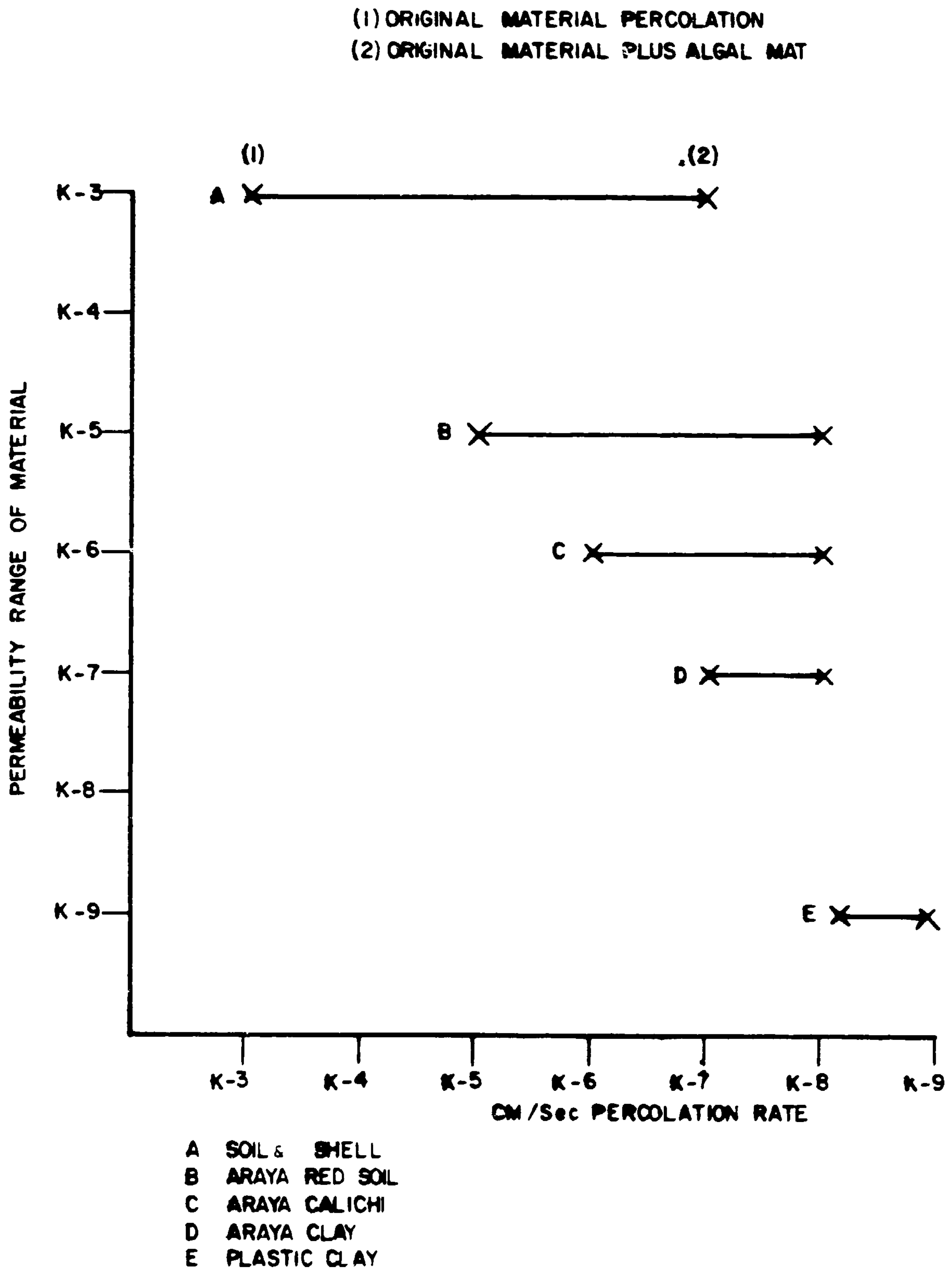
In localities having a long dry season and low relative humidity bittern discarded from crystallisers is further concentrated in additional ponds to crystallise salt until reaching the maximum Be at which effective crystallising can be accomplished. By use of nomogram Figure 3.3 the maximum Be can be calculated. In a locality for example, having fresh water temperature of 20°C and relative humidity 70%, and assume satisfactory land utilization would be at an evaporation factor of 0.4, bittern can be brought up to near the salting point of $MgSO_4$ (32 Be). The salt recovery from brine would then be increased from 86% to 95% or roughly 10% discarding at 32 Be bittern as compared to 30 Be.

Some operators discard bittern at 29 Be which is a 76% salt recovery. In this case a bittern salt recovery system would increase salt reocovery from 76% to 95% or a 25% greater salt recovery. When the maximum desired Be is reached bittern is drained from such pond or ponds, the salt is scarified, than dissolved using weak brine or sea water and returned to the system. The Leslie Salt operations in California at one time used about 100 ha for bittern salt recovery out of a total output of 500,000 tons per year.

Hydrobiology of Salinas and Pond Sealing

The technology and need for hydrobiological technical service to a salina has been well documented in recent years. See bibliography. It is recommended that the services of a marine biologist either as a regular employee or by part time outside technical persons to perform a biological monitoring program. This service can maximize development of an algal mat for sealing purposes if percolation is a problem. Interpretation of data of Jones et al. were plotted in Figure 5.16, demonstrated how algae deposits reduce seepage. A one mm deposit can reduce the percolation rate by a factor of 10.

New salinas historically have seepage problems of varying degrees that have been corrected by adding trace amounts of fertilizer (0.7 ppm) for one to two years to enhance the growth of algae. The light transmission of pond brine is thusly reduced from 96% to 55-70% as measured by a light spectrometer. Colloidal algal particals plugs voids in sandy silty soils and also deposits a rubbery like blanket on the pond bottom.



(SOURCE: JONES et al.)

Figure 5.16

REDUCTION IN PERCOLATION BY DEPOSITING ALGAL MATERIAL

This technical service can establish and control the microorganism population to some reasonable degree of balance to avoid or minimize development of mucliage (high viscosity of brine) in the saline. The result of high viscosity brine is reduced evaporation rates, increased production of fine salt and lower quality. It has been established that production of halofilic bacteria (red color of brine) in final ponds and crystallisers contributes to maximum evaporation. Large scale costly addition of dye to brine in crystallisers has been used commercially to maximize crystalliser production only to find that the red color from halofilic bacteria grown naturally is almost as effective as dye (Jones _et al_.).

The monitoring program should be tailored to the particular needs of the saline in question. Data should be gathered monthly of pond brine in areas of low, intermediate and high salinity ponds to include:

1. Total nitrogen and phosphorus content o.
2. Identification and estimation of the sources of nitrogen and phosphorus contributors.
3. Oxygen, salinity, Ph and percent of light transmission of brine.
4. Identification of dissolved and particulate organic matter in brine.
5. Depth and identification of bottom deposits.
6. Color of brine.

7. Corrolation of data with salina operation.

The minimum basic equipment neede is:

1. A high quality compound binocular microscope with 10X, 40X, and 100X objectives, equipped with an integral photographic camera.
2. Light spectometer to measure turbidity of brine.
3. Centrifuge
4. Burettes, BOD bottles, reagents.
5. Vacuum pump
6. Low temperature drying oven.
7. Portable oxygen metre for use in salina or laboratory.

Figure 5.17 plots the total kinds and amounts of living organisms in a salina having a balanced microorganism population at various salinity of brine (Davis).

In many salinas the microorganism population is out of balance causing an accumulation of highly viscous by product of coccochloris and organic suspension that seriously supresses evaporation. By operating crystallisers in series the retention time of brine is reduced and consequently the high viscosity brine is purged. At one salina the operating practice was to operate crystallisers in parallel and discard bittern at 27

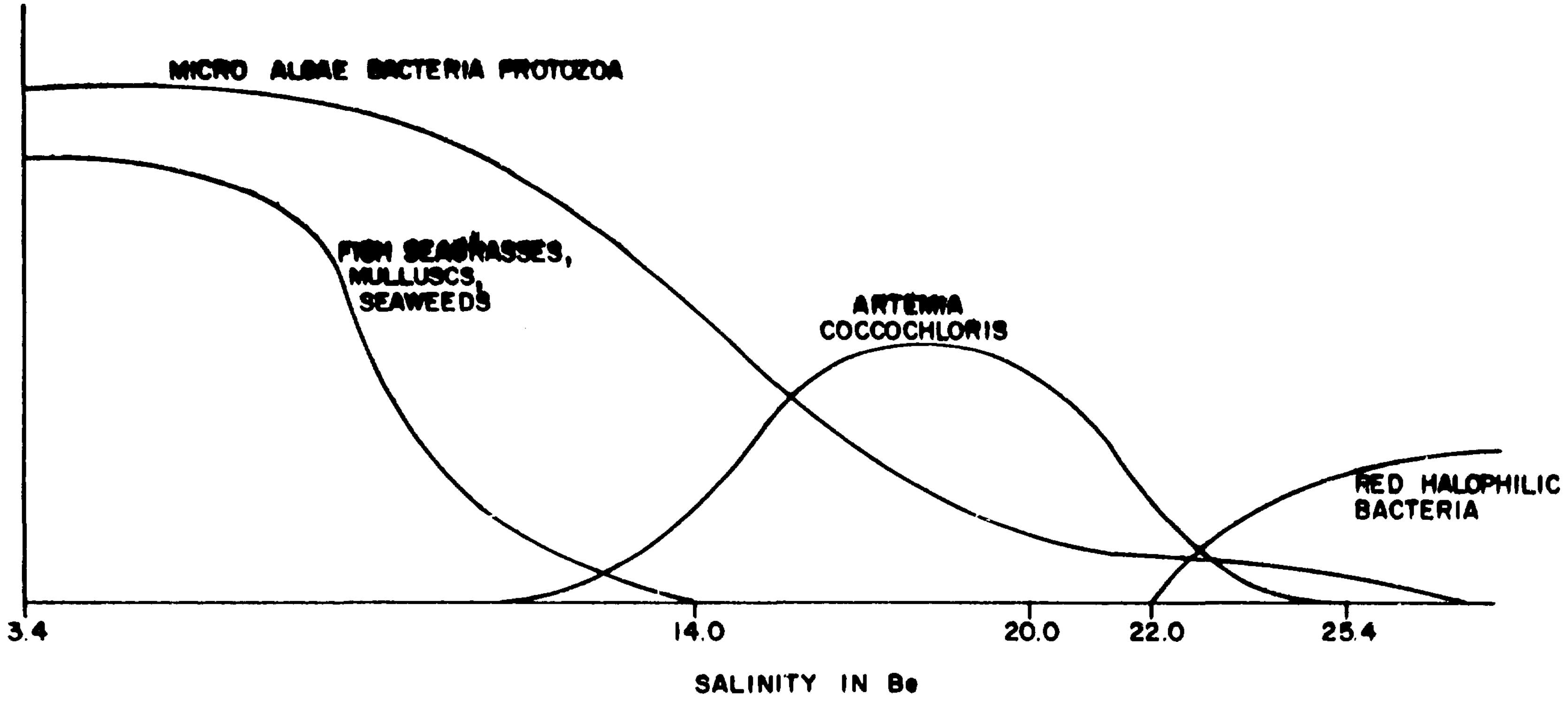


Figure 5.17
TOTAL BIOMASS VS. SALINITY FOR PROPERLY FUNCTIONING SALINA (SOURCE: DAVIS)

Be' because of high viscosity brine. The resultant recovery of salt from brine was only 50% (Figure 3.6). A program was adopted to reduce the input of nutrients (from bird droppings) and to increase the consumers of organics. These are typically certain grasses, small shell population and artimia (brine shrimp). The microorganism population was in balance at another salina in the same ountry and this problem of viscous brine did not exist.

ESTIMATION OF PROJECT COST, PRODUCTION COST AND PROFITABILITY:

Project Cost:

The construction of the salt works is spread over a period of two to three years depending upon the length of the dry season when development work is possible. During this period, the project area is progressively developed. Simultaneously, buildings and civil works are erected, machinery and equipment are procured and installed. Miscellaneous accessories are also purchased. The capital investment in the project is classified under five heads:

i) Earthwork
ii) Buildings and civil works
iii) Plant and equipment
iv) Miscellaneous accessories
v) Preliminary and pre-operative expenses

Details of capital investment under each head are discussed below:

(i) Earthwork

This item covers all land development operations classified under three sub heads:

a) Concentrating area earthwork

b) Crystalliser area earthwork and

c) Miscellaneous earthwork and roads

Earthwork in the concentrating area consists principally of boundary embankments, internal embankments and storm water drains. Embankment construction consists of cutting and formation of earth with lead and lift (horizontal and vertical distances over which the earth is conveyed) within 50 metres and 2 metres, respectively. Earthwork in the crystalliser area consists of formation and levelling of crystalliser ponds generally involving cut and fill and import material. Here, provision has to be made for additional lead cost keeping in view longer distances involved in transporting the earth. Under the sub heading of roads and miscellaneous earthwork, gravel topping of some roads, boundary embankments, and transport roads in the crystalliser area are provided. Based on the design of the salt works, the volume of earthwork with lead and lift specifications is computed. The unit cost is based on prevailing rates in the area for earthwork under different conditions of lead and lift and for different types of soils.

(ii) Buildings

A typical list of buildings for a salt works would be:

a) Site office and laboratory
b) Intake brine pumping station/borewell pump houses
c) relift pumping station
d) workshop and stores shed
e) workers rest shed

Space estimates for the buildings are based upon the requirements of the salt works when it reaches full production. Construction costs for standard height buildings with reinforced cement concrete or asbestos cement sheet roofs depend on local cost of materials and wage rates.

Provision should also be made for the following civil structures:

a) Sluice gates, brine transfer weirs, pipes, culverts and syphons
b) Sumps for pumping stations
c) Fresh water sump and overhead tanks and distribution lines in the office area

(iii) Plant and equipment

The following items are provided under this head:

a) Intake brine pumps coupled with motors or diesel drives

b) Suction and delivery piping and sluice valves

c) Relift pumps similar to intake brine pumps of smaller capacity coupled to motors or engines, piping and valves

d) Vacuum priming pumps for intake brine and relift pumps where required

e) Electrification equipment and distribution lines

f) Washery equipment

g) Crushing mill and drier

h) Additive mixing and packaging equipment

(iv) Miscellaneous Accessories

Details of investment under this head are given below:

a) Vehicles

b) Furniture

c) Laboratory equipment and accessories

Laboratory tables, wooden racks and cupboards, glassware and chemicals, ovens, muffle, furnace and hot plates, electric balance, vacuum pump, sieving machine and sieves, sink and water supply, drainage fittings, flame photometer, reference books and charts, distilled water plant, soil testing equipment, miscellaneous laboratory equipment and fittings.

d) Workshop equipment - Lathe, flexible shaft grinder and bench grinder, welding set, tools set and accesssories, electrical testing equipment, drilling machine, workshop racks, chain pulley blocks, miscellaneous equipment not elsewhere specified.

e) Garage equipment - Washing ramp, diesel oil storage tank and metering pump, compressor and air pressure gauge, pump connections and fittings, oil storage tanks, miscellaneous and sundry items.

f) Tractors and trailers

g) Survey and meteorological equipment - Dumpy level, compass, levelling staffs and theodolite, double stevenson's screen, thermohygrograph, rainfall recorder and rain gauge, evaporimeter, hydrometers, miscellaneous fittings.

h) Staff amenities - Fresh water trailers, canteen and accessories, toilet facilities for staff and workers.

(v) Preliminary and pre-operative expenses

Under this head the following items are normally included:

a) Registration and company formation expenses
b) Financial institutions inspection charges
c) Mortgage charges, if any
d) Legal charges
e) Salaries and administrative charges during construction
f) Travel and conveyance during construction

Production cost:

The items of expenditure that constitute the cost of production of salt can be broadly grouped under the following heads:

I. FIXED EXPENSES:	Staff salaries
	General administrative expenses
	Rent, rates, and taxes
	Maintenance and service expenses
	Earthwork repairs
II. VARIABLE EXPENSES:	Brine pumping and distribution
	Harvesting and handling
	Washing and storage
	Packing and forwarding

During the construction period, all expenditure incurred on supervision, general administration and conveyance is allocated to capital account under preliminary and preoperative expenses. Once production commences, these are covered under production expenses even though construction may continue for another year or two and the full rated capacity of the salt works may be reached after three or four years.

Details of expenditure under each head of account are given below:

(i) Staff salaries - This item covers salaries and prerequisities for a small batch of supervisory and technical staff and shift operators. An organisation chart for a small to medium sized salt works is presented in Figure 5.18.

(ii) General administration expenses - This head includes all expenditure of a general and fixed nature incurred in connection with the operation of the salt works like postage, telephone, stationery and printing, insurance, office maintenance, staff travelling and conveyance expenses.

(iii) Rents, rates and taxes - The lands leased to most solar salt projects generally belong to the government of the country. The policy of rental varies from country to country and within countries themselves, varies from province to province. Normally a ground rent per hectare of area leased and a royalty per tonne of salt produced is levied. The leases are granted for varying periods which could be as long as 99 years.

(iv) Maintenance and service expenses - This item provides for routine maintenance of all plant and equipment, civil structures and foundations. It includes cost of parts replacement, lubrication, painting and other general maintenance required for upkeep of the assets. Since the environment in which the plant and equipment operate is extremely corrosive, periodic maintenance and painting is essential to ensure the longevity of the equipment. Buildings need to be frequently white washed

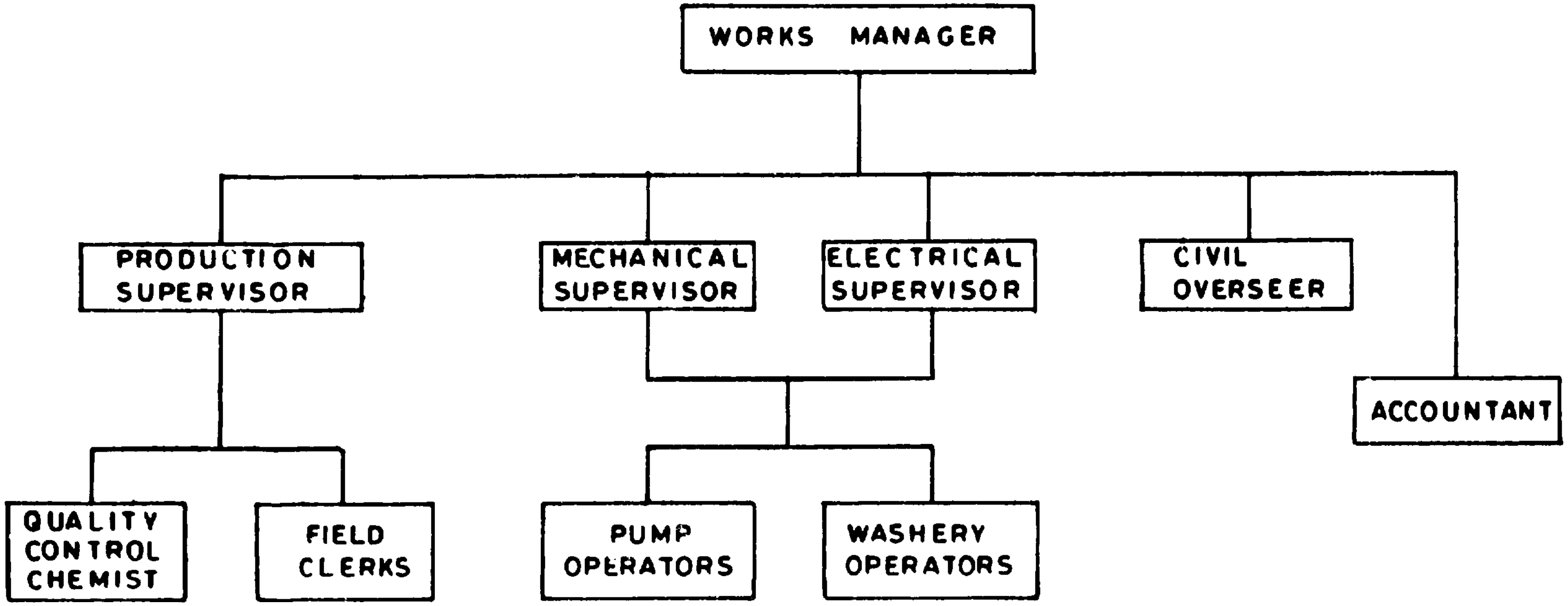


Figure 5.18 **ORGANISATION CHART FOR SMALL TO MEDIUM SIZED SALT WORKS.**

since even cement plaster is subject to saline corrosion. In addition, painting has to be done with a good primer followed by an anti-corrosive epoxy paint. Plant and equipment maintenance cost per year could be as high as 8 - 10% of the value of the equipment.

(v) Earthwork repairs - Salt fields comprising of embankments, channels and roads will require maintenance every year after the rains, especially in areas where the silt and sand content of the soil is high. All earth embankments are subject to erosion and formation of ruts along the sides. Gravel topped roads have to be frequently checked to prevent the formation of pot holes. The repari work is usually carried out round the year. Provision for this item of expenditure is made based on the prevailing site conditions and could vary from 5% to 10% of the capital cost of the earthwork.

(vi) Brine pumping and distribution - The composition of electric power/diesel oil and lubricants for operating motors and engines to drive the brine intake and relift pumps is covered under this head of account.

(vii) Harvesting and handling - The cost of annual crystalliser maintenance and compaction, salt extraction, transfer to the nearest road and transport to the washery/stackyard is covered under this head.

(viii) Washing and storage - The cost of operating the washery, washing losses, storage and heap covering expenses fall under this head.

(ix) Packing and forwarding - Under this head the cost of crushing and additive mixing (where applicable), packing and loading trucks/railwagons/ships is provided.

In addition to the above expenses, depreciation is normally charged on the assets. The following depreciation rates are typical:

Earthwork	40 years
Buildings and civilworks	25 years
Plant equipment and pumps	15 years
Portable equipment, haulage, harvest, etc.	5 years

Profitability:

Based on the prevailing market factors, the value of the product that can be realised ex-factory is estimated. This is done by determining the 'economic marketing zone' that lies within which the salt produced is competitive in terms of the landed cost in the market.

Based on the ex-factory price and production schedule, a schedule of revenues can be worked out. These are normally made at constant price without providing for escalation so that the estimation of the profitability is in real terms, i.e., after adjusting for the effect of inflation. The absense of any differential changes in price indices is a conservative assumption, since the profitability worked out would be lower than the estimate based on a progressive rise in revenues and costs.

Based on the year-wise schedule of revenue and expenditure the gross profit is worked out. After deducting depreciation, the profit before tax, tax payable to government, profit after tax and operating cash flow can be worked out. In the cash flow calculation any special taxes/incentives applicable may be incorporated.

The discounted cash flow (DCF) method is used to assess the profitability of the project. This involves the calculation of a DCF rate of return at which the present values of net annual inflows and outflows are equated. Due to the consideration of the time value of money DCF returns are generally lower than the conventional return on investment of projects with a long gestation period. DCF return expected may vary from country to country depending on the opportunity cost of investment.

The following financial data are then worked out to establish the viability of a project:

1) Capital outlay
2) Share capital

3) Maximum long term debt
4) Maximum debt equity ratio
5) Repayment period for long term debt
6) DCF rate of return

In addition to the DCF method as a yard stick for measuring the viability of the project, in several cases the development of the project must be viewed in the larger context of developing a basic industry for the production of a vital raw material of daily use and for industrial application. In addition, this industry provides employment and encourages the use of local skills.

CHAPTER - VI

MODERNISATION AND MECHANISATION OF THE SOLAR SALT INDUSTRY

The traditional method of making salt has been to bale out brine from creeks or backwaters into a pond and evaporate it using solar heat in shallow pans. The salt that is formed is scooped out using shovels or scraping planks and sold without further processing. This has been the method practiced for centuries. It is an inefficient method of production and yields a low quality product since the salts other than NaCl are not separated out. This crude salt is suitable only for consumption as edible salt or as preservative in villages. It cannot achieve the specifications prescribed for table salt and is not suitable for use in any chemical industry on account of its impurities. The size of the farms that can be controlled by this method is a few hectares and such small sized farms can support neither a modern chemical industry or an export trade. Today a number of countries follow the traditional method to some extent purely to meet limited local requirements for edible purposes.

With the advancement of science and technology, several refinements have been developed in order to produce a high purity salt at minimum cost. Modernisation can go hand in hand with manual labour being employed up to a particular level of production. Above that level, mechanisation of operations becomes more economical. This level is different for different countries depending upon the prevailing wage and price levels. For a developing country where labour is cheap, this level is in the region of 40,000 tonnes per annum.

Modernisation is applicable in every phase of operation of a salt works viz., layout, intake of brine, pumping systems, concentrating ponds, crystallisers, harvesting, storage and transport. The salient developments in each of these aspects is now recounted (see Figure 6.1).

Layout: Scientific design methods of layout area are now available to maximise production. Mathematical models and computer programmes have been developed for solar pond systems to specify optimum pond depths to be maintained at different stages of concentration and prescribe procedures for brine transfer and concentration control at different times of the year based on prevailing weather conditions and other inputs.

Brine intake systems: To control tidal intake of brine, electrically operated tidal gates are being used. During low tide the brine pumps are automatically switched on to maintain a continuous inflow into reservoirs. Where tidal inflow is

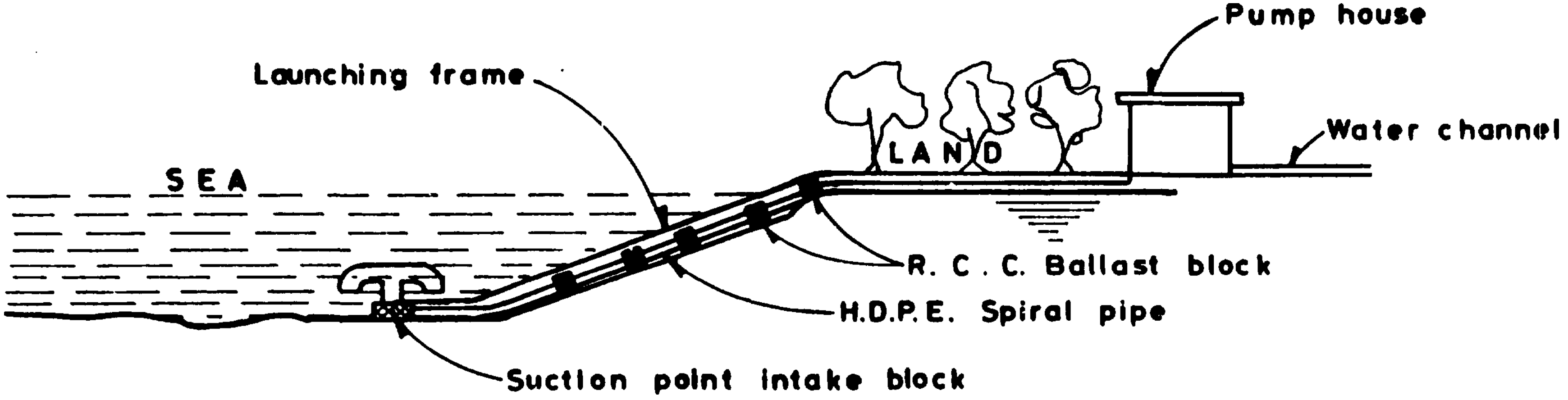


FIG. 6.1. SEAWATER INTAKE SYSTEM USING FLEXIBLE PIPES.

inadequate, salt works are resorting to direct pumping from the sea using flexible high density polyethylene pipes resting on the sea bed and connected to a concrete intake block to draw brine close to the surface of the sea to minimise intake of sand (Figure 6.1). This system ensures continuous drawal of undiluted sea water. Large turbine type pumps that require no priming and consume very little power are being increasingly used for intake brine and relift pumping (Figure 6.2). An added advantage in using these axial flow pumps is that they can be erected in the open, as shown in Figure 6.3. Among diesel engines used as prime movers, marine type engines are preferred since they are cooled by the intake brine itself. New plastic materials are replacing the older metallic piping. These are poly vinyl chloride (PVC), high density polyethylene (HDPE) and fibreglass reinforced plastics (FRP). These are non-corrosive and often less expensive than cast iron or steel pipes.

Concentrating ponds: It is now the practice to maintain the depth in the concentrating ponds fairly high so that a permanent buffer of brine is created within the salt works. Several salt works in advanced countries maintain reservoir and concentrating pond depth of 2 to 3 metres. The concentrating pond embankments are well protected with boulders to prevent breakage as shown in Figure 6.4. Thus a salt works is designed to receive only direct rainfall which can be allowed to

Fig. 6.2 Relift pump between concentrating ponds

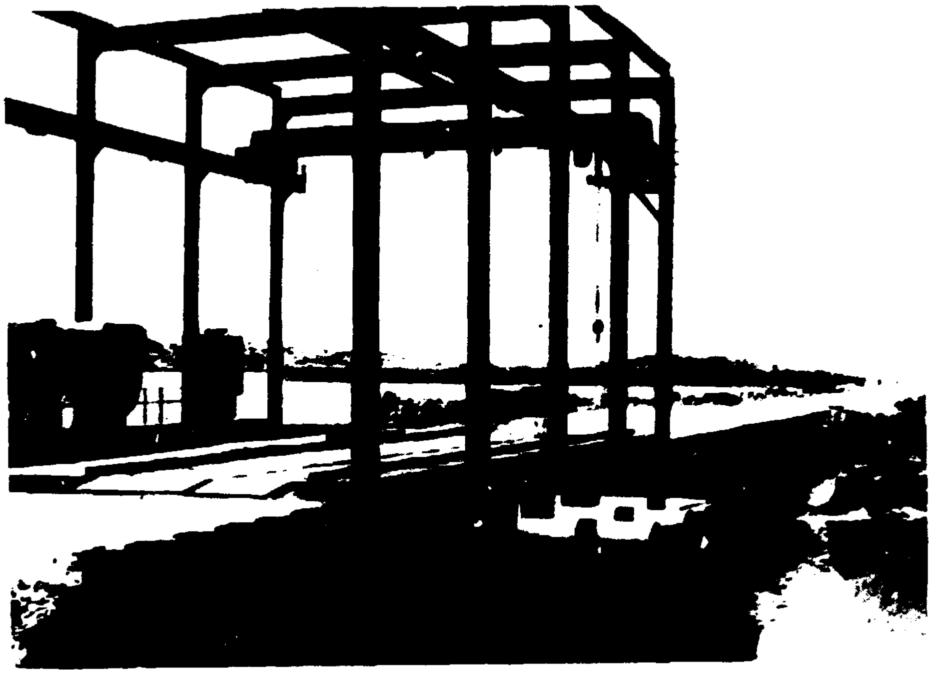


Fig. 6.3 Large capacity pumping station with overhead crane

Fig. 6.4 Internal embankments lined with boulders

Fig. 6.5 Large crystallisers with series feeding arrangement

overflow. The salinity within the salt works is thus preserved and increased year after year. In several salt works brines that are two to three years old are still in storage.

Crystalliser area: Crystallisers are now made of large size of many hectares each (as shown in Figure 6.5). The soil is properly compacted and treated chemically when required to ensure sufficient bearing strength and to make the crystalliser beds as impervious as possible. It is also common practice to charge the crystallisers deep (say 20 - 40 cms) so as to facilitate uninterrupted crystallisation of salt. When the concentration reaches 29° Be the crystalliser is replenished with fresh brine. The process is repeated two or three times before the brine is discharged fully. Colouring the brine with chemicals like naphthol green B dye helps absorption of radiation and increases production by 15 - 20%. Also the growth of certain algae halophilic bacteria in the brine imparts a pink colour to it. This improves evaporation rate. Thus a thick layer of salt 10 to 15 cms is formed for harvesting mechanically. Harvesting equipment is available in different shapes and sizes. They can be independently driven, pushed or pulled, mounted on tracks, rollers, caterpillars, wheels or floats. Most of them operate on a common principle of scooping the salt off the crystalliser pond by inserting a blade underneath the salt layer and transporting it through a drag conveyor/truck moving alongside the harvesting machine inside the crystalliser. Figures 6.6 and 6.7 show different types of harvesters. Where the crystalliser beds do not permit plying of vehicles inside the pond a series of portable belt conveyors are used to transfer the harvested salt to the nearest road as shown in Figure 6.8. The harvesting operations are restricted to about four to six weeks at the end of the season during which time the machines work for nearly 14 - 16 hours per day. Where climate and ground conditions permit a permanent salt floor of a thickness of one or more years harvest is maintained. This is the most preferred form of harvesting since the salt floor provides the necessary ground bearing capacity to support heavy harvesting equipment and there is little chance of contamination of the salt with clay or sand. However, in areas where rainfall is high, maintenance of a salt floor is not possible. In ponds with high seepage rates, percolation is being arrested by lining the floors with low density polyethylene (LDPE) sheets.

Salt washing: The harvested salt is transported by trailers or trucks to the washery where it is dumped into a pit and subjected to a thorough agitation in agitators and screw classifiers (Figure 6.9). Hydrocyclones are also used in some salt works (Figure 6.10). The thorough scrubbing with brine removes most of the insoluble impurities, a good portion of the magnesium salts and about 50 - 70% of the calcium salts. Today

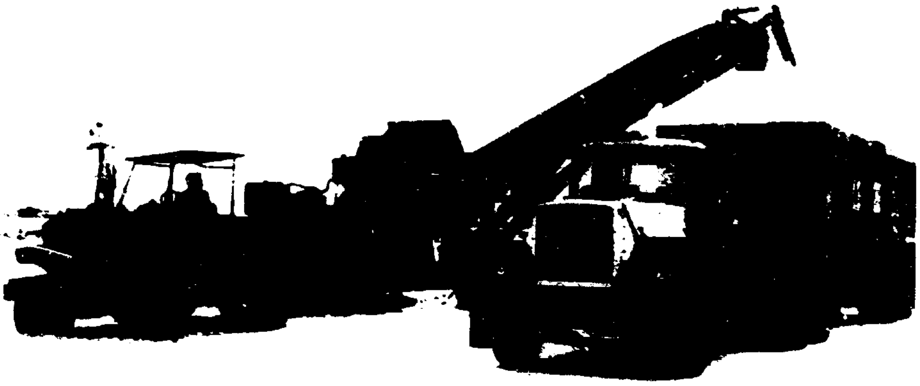


Fig 6.6 1000 tonnes/hour salt harvester workiing on salt floor with truck transfer

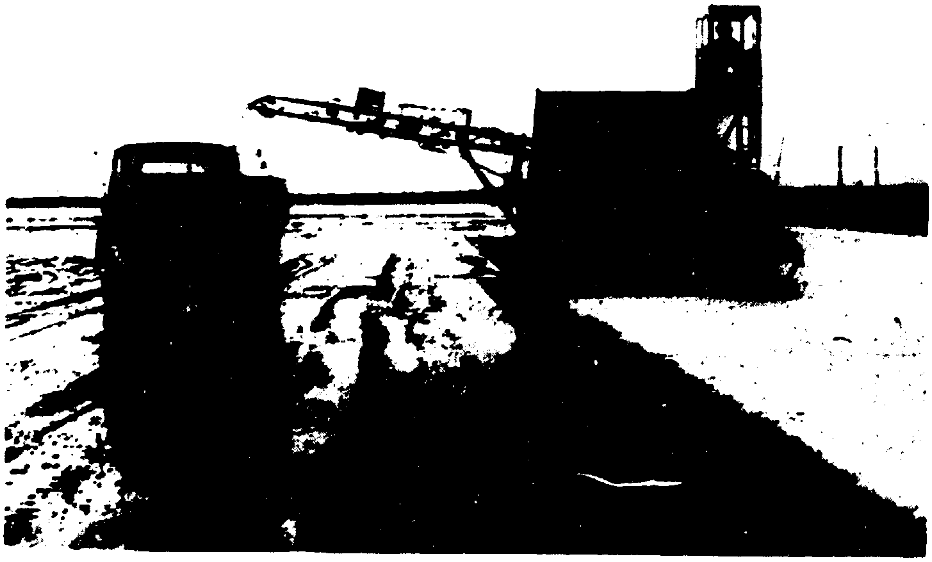


Fig 6.7 200 tonnes/hour salt harvester on clay floor with truck transfer

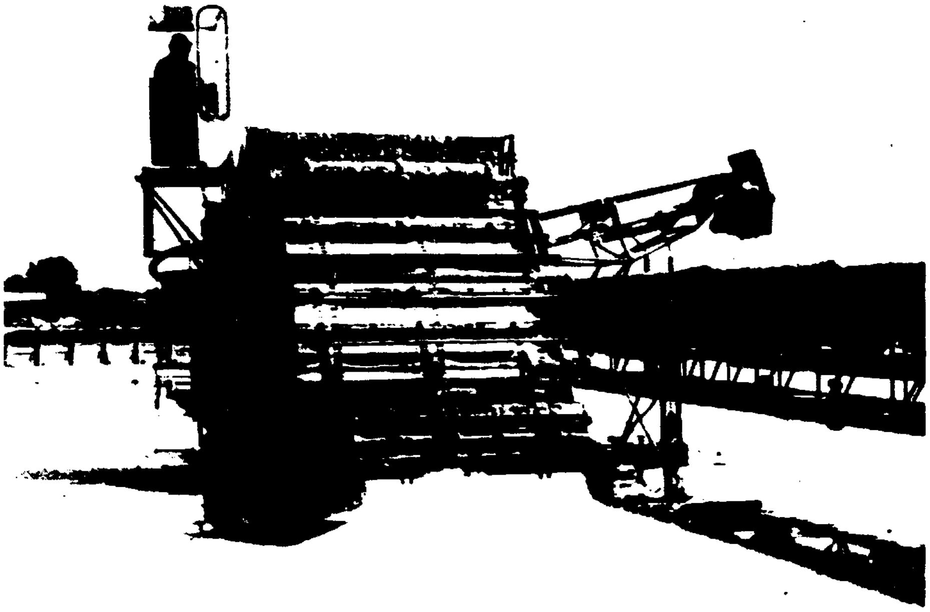


Fig 6.8 200 tonnes/hour salt harvester on clay floor with conveyor belt transfer

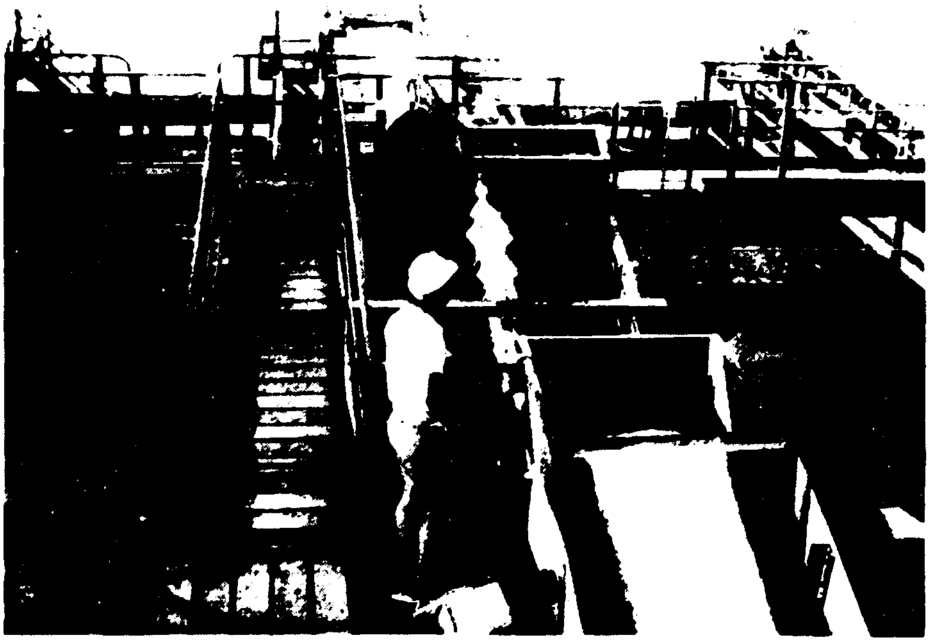


Fig. 6.9 Mechanical salt washery with screw classifier and woven wire belt

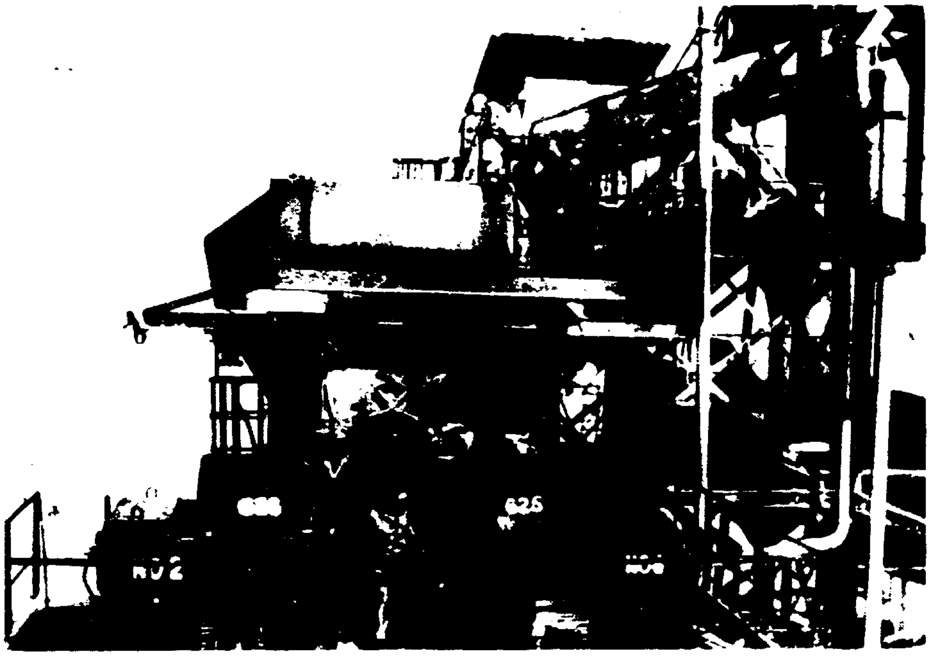


Fig. 6.10 Mechanical salt washery with dewatering screen and centrifuges

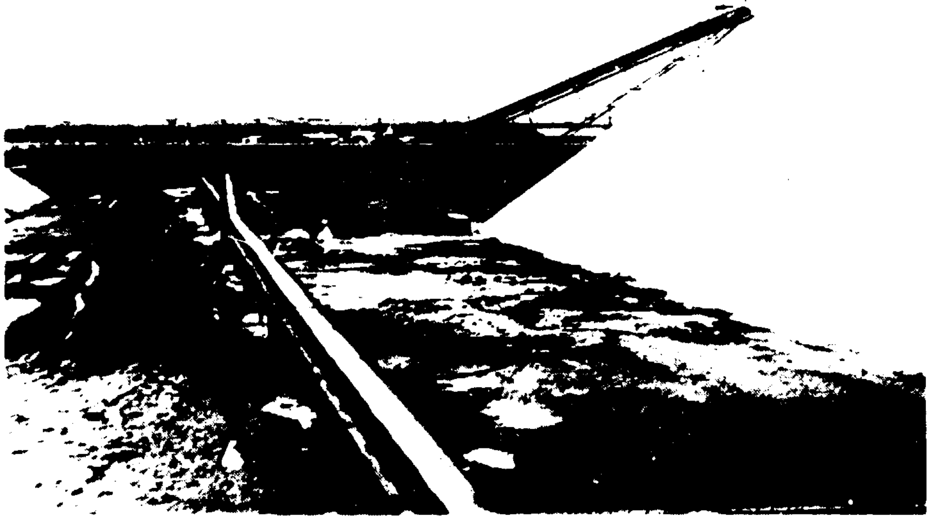


Fig. 6.11 Linear stacking of salt

solar salt works are able to supply salt having a purity of 99.7% NaCl with calcium and magnesium contents below 0.05% and sulphate content below 0.1%.

Storage of salt: The traditional practice of covering salt heaps is now being replaced by mechanised stacking of salt in large heaps. The larger the size of the heap, the smaller is the area exposed per unit quantity to rainfall. As a result, the loss is reduced to less than 8%, when salt is stored in heaps with height in excess of 8 metres in quantities of more than 5000 tonnes, even when the heap is subjected to a total rainfall of 1200 mm. Both linear and radial stackyards are used (Figures 6.11 and 6.12). The stacking belt conveyors move on rails.

Destacking: Stored salt over a period of time hardens. Bucket wheel excavator type destackers have now been developed to mechanically remove the salt from the heaps.

Refining of salt: In certain salt works the crude solar salt is dissolved in fresh water. The brine is purified to remove all impurities. The brine is then evaporated in multiple effect vacuum pan evaporators. The salt crystallises as a fine powder. The slurry is then filtered and dried in rotary kilns and cooled to achieve a very high purity product of uniform grain. It is made free flowing after treatment with anti-caking agents.

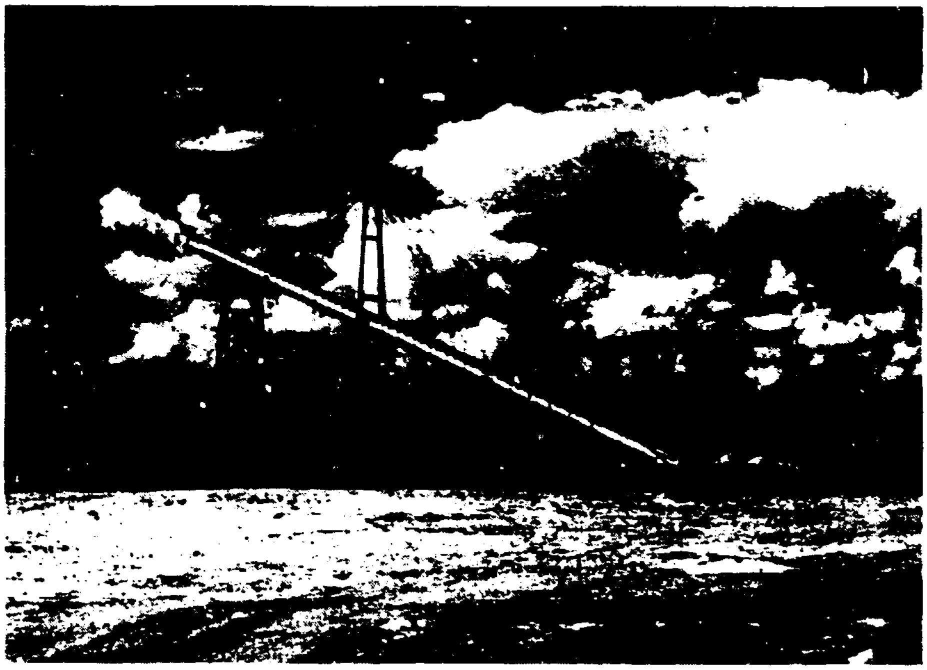


Fig. 6.12 Radial salt stacker

Fig. 6.13 Jetty for direct loading of salt into ships

However, in view of rising fuel costs several alternative salt refining methods that do not involve recrystallisation have been developed. These involve a multi-stage washing and scrubbing process followed by centrifuging, fluid bed drying and screening.

Varieties of salt: In the advanced counties a high degree of sophistication has been achieved in producing several varieties of salt for different applications. While the chemical composition of the salt is the same in all cases, the physical properties and the additives used vary to suit different applications. Some of the varieties are iodised salt, trace mineralised salt for cattle, salt blocks, compressed water softener salt, enriched dough salt, etc. A process has been recently developed to fortify salt with iron to reduce iron deficiency anemia.

Transport: A major feature of all recent solar salt developments is their access to direct ship loading facilities in bulk (Figure 6.13). The high rate of loading achieved by these salt works running up to 30,000 tonnes per day has helped them capture the large Japanese and South Korean markets for industrial salt. In addition to the normal methods of transport, transmission of salt as a slurry through pipelines is being adopted in some areas.

Artificial methods: High cost of land, low temperature, high humidity, sandy soil are inhibiting factors in the manufacture of solar salt and the Japanese have developed special techniques to overcome these handicaps. One method uses multiple effect vacuum evaporates to concentrate brine. In another method initial concentration is effected by making the seawater flow down a series of slopes resulting in partial evaporation. The resultant brine is collected, pumped up to a height from where it drips down elongated bamboo poles which causes further evaporation. When the required concentration is reached, the brine is fed into thermo compression evaporators. Salt is obtained in the form of a slurry from which impurities are then removed and the salt is dried. A recently developed technique is the electrodialysis of sea water in chambers partitioned by ion exchange membranes alternately arranged. By this process a high degree of initial concentration is achieved and the concentrated brine is fed to evaporating crystallisers provided with external heating. Salt comes out in the form of a slurry and is centrifuged and then dried. This process has eliminated salt fields and replaced them by factories and converted salt making from an agricultural type of operation to a purely chemical industry. Research is also being conducted to improving desalination processes and recover salt as a byproduct.

Bittern salts: Where salt fields are of medium size and the production is of the order of 50,000 tonnes or less, the amount of bittern recovered is inadequate for any further use. Above this level the bitterns form the basis for recovery of bromine and magnesium and sometimes of potash on a commercial scale. On a medium scale, production of the following salts from bitterns is now commercially feasible:

Magnesium sulphate

Magnesium chloride, magnesium hydroxide and magnesium tri silicate

Bromine and bromo compounds

Plaster of Paris (from gypsum)

Research is being conducted on the production of other compounds including uranium on a commercial scale from sea water. The solar salt industry forms the nucleus for the development of a basic chemical industry in a developing country. The proper planning and development of this industry therefore assumes crucial importance.

APPENDIX I	BIBLIOGRAPHY
APPENDIX II	SOURCES OF INFORMATION ON THE SOLAR SALT INDUSTRY
APPENDIX III	CONFERENCES ON SOLAR SALT AND ALLIED TOPICS

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Street, Alexandria, Virginia 22314 USA

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Box 300, A-1400, Vienna, Austria

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11 Bis, Av.Victor Hugo, 75116 Paris,
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Industry, Government of Australia,
Canberra, Australia.

8. Bureau of Mines (Non Metallic Minerals
Section) U.S.Department of the Interior,
2401, E Street, NW, Washington, DC 20241
USA.

APPENDIX - III

CONFERENCES ON SOLAR SALT & ALLIED TOPICS

1. World Salt Symposia: Held once in 5 years. Five held so far. (Last held in 1978 in Hamburg, West Germany) Next in Toronto, Canada in May 1983. For information contact Northern Ohio Geological Society, C/o. Department of Geology, Case Western Reserve University, Cleveland, OH 44106, USA.

2. International Symposium on Salt & Marine Chemicals held once so far in March 1982 in Bhavnagar, India. For information contact Central Salt & Marine Chemicals Research Institute, Bhavnagar, India.

TRAINING PROGRAMMES

Training programmes can normally be fixed on a Government to Government basis with the assistance of the UNIDO. For instance, the Government of India has trained sponsored candidates from several foreign governments. For information write to the Salt Commissioner, Government of India, Jaipur, Rajasthan, India. Private Companies do not normally offer training programmes.