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A PRE-INVESTMENT STUDY OF THE SODA INDUSTRY*

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* This report was prepared for the Centre for Industrial Development by C.R. Rao, M.I. Mech. E., Consulting Engineer, Oval View, Churchgate Reclamation, Bombay 1, India.

S/F Chemical industry – inorganic

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Explanatory Note.

This study of the Soda Industry has been prepared with the specific object of providing preliminary information to the planners and technical personnel in developing countries in order that they may assess the possibilities for establishing this industry in their respective regions.

If a preliminary study indicates that it is possible to establish manufacture of either soda ash or caustic soda in any particular region, it will be essential for a more detailed examination to be undertaken by a team of experts, well versed in the manufacture of the product proposed in the preliminary investigation.

Technical terms have been avoided wherever possible in order that the subject paper serves both the economists and technical personnel in the developing countries.

With these objects in view, the study begins with brief descriptions of the current processes of manufacture of soda ash and caustic soda and is followed by requirements of raw materials, chemicals and utilities and thereon to the requirements of operating personnel for different scales of manufacture. Investment costs and production costs are given for different scales of manufacture likely to be considered in developing countries.

The last section of the study deals with programming techniques and factors of location applicable to the soda industry.

Estimates for investment costs of plants and machinery are based on the average costs, currently prevailing in Japan and Western countries including U.S.A., with a provision of 10% towards sea freight and insurance. Customs tariffs, such as import and export duties have not been provided for.

The metric system of weights and measures and the American currency are used throughout the text.

Conversion factors to British system.

	Metric.	British.
Length ..	1 m	3.281 ft.
Area ..	1 sq.m.	10.764 sq.ft.
Volume ..	1 cu.m.	35.315 cu.ft.
Temperature..	x °C	(1.8 x + 32)°F

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Summary.

Soda Ash and Caustic Soda are the two common alkalis which are very widely used in modern industry. The soda industry deals with the manufacture of these two chemicals.

Natural Soda Ash is manufactured from trona, sodium sesqui-carbonate, a natural deposit occurring in some countries. The bulk of soda ash is manufactured by the ammonia-soda process invented by Solvay about a century ago. A variation of this process is to manufacture two products, soda ash and ammonium chloride simultaneously. Soda ash is manufactured in two grades - light and dense. The dense variety is particularly favoured by glass manufacturers.

Caustic soda is manufactured by two processes, the chemical process of causticization of soda ash with lime and the electrolytic process of electrolysing a solution of common salt, either in a diaphragm cell or in a mercury cell. By far the bulk of caustic soda is produced by the electrolytic process, as the demand for co-product, chlorine, is very large and increasing steadily.

For the manufacture of soda ash by the ammonia soda process the main raw materials are salt, limestone and coke. Ammonia required for the process is recovered and recycled in it and small quantities are required for replenishing losses. In the variation of the Solvay process for manufacturing dual products, ammonia is also a main raw material. Salt is the only raw material for electrolytic caustic soda. Chemicals for purification of brine are, by and large, common to both the alkali industries, except that, in the electrolytic caustic soda industry, the sulphate radical has also to be removed in addition to magnesium and calcium.

Regarding the requirement of utilities, such as steam, electricity, process water and cooling water, substantial quantities are required for the manufacture of either soda ash or caustic soda. The cost of electricity is a very important item in the production cost of electrolytic caustic soda.

The soda industry is not labour intensive as in most chemical industries. Since the processes utilize process control instruments to a large extent, literate skilled labour is preferable.

The investment cost of 100 TPD Soda Ash Plant is estimated at $ 7.2 million, of a 200 TPD Plant $ 10.7 million and of a 500 TPD Plant $ 18.3 million. The investment cost of a plant of 100 TPD dual products - soda ash and ammonium chloride - is estimated at $ 8.0 million, of 200 TPD dual products plant $ 12.3 million, and of 500 TPD dual products plant $ 20.9 million. A 20 TPD Chemical Caustic Soda Plant costs about $ 0.5 million, a 50 TPD Plant $ 1.1 million and a 100 TPD Plant $ 2.0 million, on the assumption that, in all these cases, the units are satellites to soda ash plants. Electrolytic Diaphragm Cell Caustic Soda Plants cost $ 1.5 million for 10 TPD, $ 3.9 million for 50 TPD and $ 5.7 million for 100 TPD capacities. Mercury Cell Plants are costlier than Diaphragm Cell Plants by about 10 to 15 per cent for similar capacities.

Production cost estimates based on Indian experience indicate that bare factory costs of soda ash in a 200 TPD factory would be $ 55.00 per ton by the ammonia-soda process. Similarly the cost of 1 ton of soda ash and 1 ton of ammonium chloride is estimated at $ 88.00.

A ton of caustic soda produced by the chemical process in a soda ash factory is estimated to cost $ 125.00. Cost of 1 ton of caustic soda by the electrolytic process in diaphragm cell with the co-products, 0.88 tons chlorine and 0.025 tons of hydrogen, is estimated to cost $ 118.00. The same in a mercury cell is estimated to cost $ 108.00.

Though estimates of production costs indicate that they are higher than market prices in the industrially advanced countries of the West, the developing countries can establish economical scale of manufacture, by adopting adequate programming techniques, and preferably integrated factories producing not only the basic chemical but also end products which are consumed in the country in question.

It is necessary to investigate all factors of location, viz. proximity to markets, availability of raw materials, availability of electricity, fuel, cooling and process water, facilities for disposal of effluent, communications, labour etc. for locating soda ash and caustic soda plants to ensure smooth and economical working.

New developments in the soda industry are primarily intended to reduce costs in large scale units.

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THE SODA INDUSTRY.

Chapter 1 - Uses & Specifications of the Products of Soda Industry.

Soda Ash and Caustic Soda are chemicals which are very widely used in every branch of industry in modern society. They are the alkalis, which with their acid counterpart, sulphuric acid, form the foundation of chemical industry all over the world.

The glass industry is the biggest consumer of soda ash. Other important uses are (i) as raw material in the manufacture of other sodium compounds such as silicates and phosphates; (ii) as detergent, in the textile, paper and pulp and metallurgical industries; (iii) as an additive in soaps and detergents and (iv) as a chemical in the water softening and many diverse industries.

The rayon and film industry is the biggest consumer of caustic soda. Pulp and paper industry, aluminium industry, soap industry, textile industry are also important consumers.

Besides the above large consumers of these alkalis, most industries use these chemicals for some application or other in their operations.

Tables 1 to 6 show the world production of these chemicals and the pattern of consumption in U.S.A., a well developed industrial country. These tables give an idea of the magnitude and distribution of this industry in the world.

In chemical terminology, soda ash is sodium carbonate, Na_2CO_3 and Caustic Soda is sodium hydroxide, NaOH. As their function in chemical processes is to serve as alkalis, the alkalinity of soda ash, in terms of equivalent Na_2O is 58.5% Na_2O and that of Caustic Soda is 77.5% Na_2O.

The sector of chemical industry dealing with the manufacture of soda ash and caustic soda is known as the Soda Industry.

Commercial grades of Soda Ash and Caustic Soda in the world markets are as below:-

1) Light Soda Ash 58% Na_2O, bulk.
2) -"- packed in paper bags or jute bags.

3) Dense Soda Ash 58% Na_2O, bulk.
4) -"- packed in bags.
5) Caustic Soda 76% Na_2O flakes packed in drums.
6) Caustic Soda Liquid 70-74% NaOH, in tank cars.
7) Caustic Soda Liquid, 50% NaOH, in tank cars.
8) Caustic Soda Solid, 76% Na_2O, packed in drums.

In the case of items (5) to (8), two grades are offered, depending on the NaCl content. Commercial grade contains NaCl upto a maximum of 2% and Rayon Grade contains NaCl upto a maximum of 0.2%.

Table 1 - WORLD PRODUCTION OF SODA ASH.

Unit - Thousand Metric Tons.

	Country.	1961.	1962.
1)	Bulgaria	129.4	179.6
2)	China - Taiwan	13.3	12.2
3)	Columbia	20.5	21.4
4)	Czechoslovakia	76.0	62.1
5)	France	849.3	924.6
6)	Germany E.D.R.	598.8	646.8
7)	Germany F.R.	1063.4	1011.7
8)	India	176.6	222.7
9)	Ireland	1.4	N.A.
10)	Japan	583.0	594.0
11)	Kenya, Africa	147.0	124.1
12)	Norway	21.1	N.A.
13)	Poland	493.4	490.0
14)	Romania	235.2	285.1
15)	Spain	156.7	161.0
16)	U.S.S.R.	2115.0	2332.0
17)	U.S.A.	4097.0	4179.1
18)	Yugoslavia	90.3	96.3
	Total ..	10867.4	11342.7

Source: U.N. Statistical Year Book 1962 & 1963.

Table 1 given above does not include the production of Austria, Australia, Belgium, China-Mainland, Canada, Great Britain, Pakistan and Switzerland, who are known to be producers. It also does not include the production of natural soda in U.S.A.

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An estimate of their production is given below:-

Table 2 - SUPPLEMENTARY WORLD PRODUCTION.

Unit - Thousand Metric Tons.

Country.	
1) Austria	120
2) Australia	100
3) Belgium	180
4) China - Mainland	400
5) Canada	260
6) Great Britain	1400
7) Netherlands	120
8) Pakistan	20
9) Switzerland	30
10) U.S.A. - Natural Soda Ash.	730
Total	3340

The current annual production of soda ash, both natural and synthetic, is thus about 15 million tons and it is produced in 62 plants spread over in 28 countries of the world, vide Table 41).

Table 3 - PATTERN OF CONSUMPTION OF SODA ASH BY INDUSTRIES IN U.S.A.

	In thousand tons.	%
Glass	1800	40
Other Chemicals	1550	33
Soap & Detergents	230	5
Pulp and Paper	230	5
Metaliurgical uses	270	6
Water Softening	135	3
Textiles	45	1
Others	320	7
Total	4580	100

Table 4 - WORLD PRODUCTION OF CAUSTIC SODA.

Unit - Thousand Metric Tons.

	Country.	1961.	1962.
1)	Algeria	2.4	1.8
2)	Argentina	53.6	54.7
3)	Australia	48.5	48.3
4)	Brazil	78.0	N.A.
5)	Bulgaria	19.1	18.6
6)	Canada	376.0	390.0
7)	China - Taiwan	36.5	37.9
8)	Colombia	28.8	29.9
9)	Czechoslovakia	133.0	142.0
10)	Finland	69.9	79.9
11)	France	272.0	213.0
12)	Germany EDR	335.0	355.0
13)	Germany FR	811.0	901.0
14)	Greece	1.7	1.9
15)	Hungary	18.8	34.3
16)	India	119.8	126.4
17)	Italy	498.0	493.0
18)	Japan	922.0	974.0
19)	Korea Rep.	0.8	1.4
20)	Mexico	71.3	83.4
21)	Norway	56.9	N.A.
22)	Philippines	3.2	N.A.
23)	Poland	186.0	196.0
24)	Romania	128.9	156.1
25)	Spain	143.6	143.3
26)	Turkey	2.4	1.4
27)	U.S.S.R.	897.0	961.0
28)	United Arab Republic	14.7	17.6
29)	U.S.A.	4443.0	4955.0
30)	Yugoslavia	48.5	53.7
	Total ..	9820.4	10559.6

Source: U.N. Statistical Year Book 1962 & 1963.

In Table 4, production figures of the following countries have not been given by the source referred to though they are known to be producers of caustic soda. Estimated figures of annual production are given below from other sources:-

Table 5 - Supplementary World Production.

Unit - Thousand Metric Tons.

Country.		
1) Austria	.. ..	60.0
2) Belgium	.. ..	40.0
3) China-Mainland	.. ..	300.0
4) Denmark	.. ..	3.0
5) Holland	.. ..	80.0
6) Norway	.. ..	45.0
7) Pakistan	.. ..	3.0
8) Phillipines	.. ..	2.5
9) Sweden	.. ..	150.0
10) Switzerland	.. ..	25.0
11) Other African countries	..	30.0
12) United Kingdom	.. ..	800.0
Total	..	1,538.5

Total world production is thus about 12 million metric tonnes per year and the industry is spread over 42 countries.

Table 6 - Pattern of Consumption of Caustic Soda by industries in U.S.A.

		In thousand tons.	%
Other chemicals	..	1,600	32
Rayons & Films	..	800	16
Paper & Pulp	..	500	10
Soaps & Cleansers	..	450	9
Petroleum	..	350	7
Textiles	..	300	6
Metallurgical	..	250	5
Others	..	750	15
		5,000	100

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Chapter 2 - Historical Methods of Manufacture in Outline.

It is evident from the origin of the words, alkali and potash, that the ancients were acquainted with some of the beneficial uses of these chemicals. The word 'alkali' is derived from the Arabic word 'al qili', meaning ashes of the plant, salt-wort. Potash was the name given to the residue found in the iron pots after boiling out the solution obtained* from the leaching of ashes. It is said in Pliny's time (AD 23-79) carbonates of sodium and potassium were leached and converted into caustic alkalis by treatment with lime for making soap. Experience had shown that the ashes of sea weeds produced hard soaps whereas the ashes of plants produced soft soaps. In 1736, a French Chemist established that the ashes of sea weeds contained sodium carbonate and the ashes of land plants potassium carbonate.

Particulars of some of the well known alkali producing sea weeds at the time are given in Table 7:-

Table 7 - Alkali Producing Sea Weeds.

Place of occurrence.	Name in Commerce.	Na_2CO_3 %
Southern Spanish Coast Alicante, Malage.	Barilla	25 - 30
Southern Spanish Coast Cantegina.	Bourdin	20 - 25
Southern French Coast Argeres-Mortes.	Blanquette	4 - 10
Northern French Coast Chaerbourg.	Varce	3 - 8
Southern French Coast Narbonne:	Soude de Narbonne	14 - 15
Western Scottish & Irish Coast	Kelp	10 - 15

Source: Manufacture of Soda by T.P. Hou - Page 14.

Apart from the ashes of plants, another source of alkalis which has been exploited from early times is natural soda ash found in solid deposits or dissolved in the brine of lakes in certain areas of the world. Though such deposits and brine lakes are found widely spread in many parts of the world, there are only a few large enough to have attracted industrialists to exploit them.

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*Ref. Encyclopedia Brittanica 1961.

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Table 8A COMPOSITION OF SOME NATURAL SODA DEPOSITS.

	Na_2CO_3	$NaHCO_3$	$Na_2B_4O_7$	Na_2SO_4	NaCl	KCl per cent.	In-soluble.	Water.	Remarks.
Wady Natrun (Africa)	39	25	-	-	-	-	-	-	
Moshi (Africa)	45	38	-	-	-	-	-	-	
Owens Lake Brine (Calif)	9	1.2	1.0	3	16	1.5	-	74.47	Total solid residue containing also other salts
Searles Lake Brine (Calif)	4.74	-	1.51	6.96	16.35	4.75	-	65.35	Containing also many other salts.
Ragtown (Nevada)	45.05	34.66	-	1.29	1.61	-	0.81	16.19	
Magadi Lake	45.44	33.84	-	-	2.30	-	1.66	16.75	
Dulla Khar, India	47.55	28.06	-	-	0.60	-	2.65	20.14	From saline crust containing also $MgCl_2$ 0.67, K_2CO_3 0.27.
Chinese Natural Soda Samples:-									
Barga(Heilungkiang) Lake Soda	28.9	-	-	11.9	-	-	-	58.2	
Polishan(Liao-Ning) Lake Soda	12.04	-	-	0.75	1.45	-	-	-	
Taboos-Nor (Kirin)	34.9	-	-	-	-	-	0.27	30.5	Gay-Lussite containing also $CaCO_3$ = 34.0%.
Cha-Han-Nor (Sui-Yuan)	42.80	35.51	-	2.20	1.74	-	0.81	16.92	Samples of Natural deposit.
Pa-Yen-Nor(Sui Yuan)	42.75	10.24	-	6.79	0.54	-	1.20	38.50	-"-
Han-Kai-Chi-Nor (Sui Yuan)	59.90	16.05	-	0.88	0.99	-	Trace	22.18	-"-
Shen-Mu-Hsien (Shensi)	78.32	0.50	-	0.91	4.94	-	0.14	15.00	
U-Tsu-Hsien(Shansi)	53.69	15.52	-	17.33	3.51	-	0.21	11.78	
Kian-Hsien(Kiangsi)	81.48	6.82	-	-	-	-	-	-	

Source: Manufacture of Soda by T.P. Hou - Page 17.

Table 8 is a list of the better known deposits, though all of them are not in commercial exploitation at the present time:-

Table 8 - <u>Deposits of Natural Soda Ash</u>.

Africa	(Lower Egypt: Wady Natrun
	(British East Africa: Magadi Lake
	(Former German East Africa: Moshi
	(Libya: Fezzan
The Americas	(United States:
	(California: Owens Lake (Inyo County); Searles Lake, Trona
	((San Bernardino County); Borax Lake (Lake County)
	(Nevada: Ragtown Soda Lakes (near Carson Sink)
	(Wyoming: Union Pacific Lakes, near Green River and (along Union Pacific Railroad)
	(Oregaon: Abert Lake.
	(Mexico: Lake Tezcoco
	(Venezuela: Lagunilla Valley
	(Chile: Antofagasta.
Asia	(Siberia: Chita and Lake Baikal Region, Barnaul, (Slavgorod
	(Armenia: Araxes Plain Lakes
	(India: Lake Lonar etc.
	(China: Outer Mongolia: Various "Nors"
	Sui-Yuan: Chan-Han-Nor, Na-Lin-Nor, Pa-Yen-Nor
	(Heilungkiang: Hailar, Tsitsihar
	(Kirin: Fu-U-Hsien, Taboos-Nor
	(Liao-Ning: Tao-Nan Hsien (Polishan lake, Tafusu (lake etc.)
	(Jehol: Various soda lakes
	(Chahar: Cheng-Lang-Chi
	(Shansi: U-Tsu-Hsien
	(Shensi: Shen-Mu-Hsien
	(Kansu: Ning-Hsia-Hsien
	(Tibet: Alkali deserts.
Europe	(Russia: Caspian Sea region
	(Hungary: Szegedin district

Source: Manufacture of Soda by T.P.Hou - Page 16.

Synthetic Soda Ash was manufactured for the first time by Le Blanc towards the close of the 18th century. The disturbed political conditions at that time in Europe were

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not conducive to the development of the process. After the end of Napoleanic wars in 1825, the Le Blanc process began to be exploited by chemists in Europe. The raw materials for this process were salt cake, limestone and coal. Salt cake itself had to be produced in the first instance by reacting salt with sulphuric acid. The difficulties in the safe disposal of the bye-products, hydrochloric acid and calcium sulphide, in this process gave an impetus to the chemists to develop other useful products, such as bleaching powder and sulphur. The necessity to use pyrites for the manufacture of sulphuric acid developed the recovery of bye-products, iron and copper, from the pyrites. Thus the Le Blanc process was the cause of an extensive development of the chemical industry in Europe in the 19th century. As it was already known that the addition of milk of lime to the ashes of sea weeds yielded caustic soda which could be used for making paper, manufacture of caustic soda from Le Blanc soda ash also expanded during this period.

About the year 1865 when Le Blanc soda ash factories had been established widely in Great Britain and France, Ernst Solvay built the first ammonia soda factory in Belgium. Within the next few years, the superiority of the process over the Le Blanc process was recognised by all the manufacturers as the process was far simpler and there were no troublesome bye-products such as hydrochloric acid and calcium sulphide to contend with. The last unit operating the Le Blanc process was shut down about the year 1918, the end of the First World War.

At the present time, the entire world production of synthetic soda ash is by the ammonia-soda process invented by Solvay. During the last hundred years it has been in use, the process has been fundamentally the same, though several improvements have been introduced in the mechanical equipment to reduce manufacturing costs.

Since 1950, Japanese manufacturers of soda ash have developed a variation of the normal ammonia soda process, by which they produce an equal quantity of ammonium chloride along with soda ash. It is claimed that this process is more economical than the ammonia-soda process, particularly when the cost of salt is high.

Regarding caustic soda, before the advent of the Le Blanc process, the natural ash containing soda ash was reacted with milk of lime to produce caustic soda. Though the solution was dilute, it could be used for making hand-made paper.

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With the development of soda ash manufacture by the Le Blanc process, caustic soda manufacture also increased substantially. Instead of producing dry soda ash for further processing, the solution of soda ash itself, produced after separation of insolubles, was treated with milk of lime and the clear liquor containing caustic soda used for making paper, soap and other products.

Towards the end of the nineteenth century, the direct current electricity generator was invented and soon after, the first electrolytic cell for the electrolysis of common salt was built to produce both caustic soda and chlorine simultaneously. Since then, though both processes, causticization of soda ash and electrolysis of brine, are in vogue for the production of caustic soda, the latter process is rapidly gaining ground with the growth of the organic chemical industry after the Second World War. The causticization process is apparently restricted to some of the large and long-established soda ash manufacturers, as there is no increase in world production by this process and the phenomenal growth in caustic soda output, since the end of the Second World War, has been entirely due to electrolytic caustic soda.

Since the first commercial diaphragms cell was put into operation towards the end of last century, a very wide variety of cells have been developed. Cells in use in the industry currently can be classified into two distinct categories, viz. diaphragm cells and mercury cells. The electrolyte from the diaphragm cell has a caustic soda content varying from 9 to 14 per cent with undecomposed NaCl ranging from 17% to 11%, depending on the extent of decomposition.

The mercury cell is built up in two sections, one, the main cell containing the electrodes which consists of fixed graphite anodes and a moving film of mercury serving as cathode, and a second section, the decomposer in which the mercury-sodium amalgam from the main cell meets a stream of water to combine with the sodium and produce caustic soda. The electrolyte from the mercury cell contains undecomposed NaCl only upto about 18%. The caustic soda produced in decomposer section of the unit is entirely free from NaCl and the strength of lye effluent from the decomposer is generally about 50% NaOH.

There are instances of mercury cells which produce caustic soda lye of 70% NaOH.

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The diaphragm cell caustic containing 9-14% NaOH and correspondingly 17% to 11% NaCl is further concentrated in steam heated vacuum evaporators, either double effect or triple effect type, to about 50% NaOH. During this process, the bulk of NaCl is separated for reuse. It is, however, characteristic of this process that the ultimate product of sale, whether in the form of lye, 50% NaOH, or as fused solid, has generally NaCl content of 0.5 to 2%. While this is not a disability for many end-uses, it is not permissible for some, particularly, manufacture of rayon. Since, in the case of mercury cells, the caustic soda is produced in the decomposer section of the cell, it is completely free from NaCl contamination. Caustic Soda produced in mercury cells is, therefore, known in trade as rayon grade caustic soda.

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Chapter 3 - Manufacture of Natural Soda.

Several processes are in vogue for the manufacture of soda ash from natural sources, each specially designed on the composition of the raw material. One of the best known producers is the American Potash and Chemical Corporation which has its factory at Trona, Searles Lake. The process adopted by them is an illustration of the complexities arising from the variations in the composition of the raw materials found in nature.

Flow sheets 1 & 2[●] are simplified versions of the complicated processes employed at the factory. The brine drawn from tube wells in the bed of the lake contains a mixture of salts, mainly, sodium chloride, sodium sulphate, potassium chloride, sodium carbonate and sodium tetraborate. It also contains small quantities of calcium, magnesium and lithium salts.

Flow sheet 1 shows the inter-relationship of the different sections for recovery of each of the salts. The raw brine preheated in the condensers of potassium chloride vacuum crystallizers is fed to the last effect of a triple effect evaporator, along with mother liquor from the borax plant. As the concentration proceeds, the salts crystallize and the slurry is continuously bled to the salt traps in the salt removal system for separating the crystals from the concentrated liquor. The concentrated liquor containing potash and borax is sent first to the potash recovery plant and thereafter to the borax recovery plant. The mother liquor after recovery of borax is returned to the triple effect evaporator. In the salt traps, the coarser sodium crystals are separated from the finer crystals of burkeite ($2Na_2SO_4$, Na_2CO_3) and dilithium sodium phosphate. In a subsequent process, the burkeite is separated from the phosphate and further split up to separate the Glauber salt by vacuum crystallization. The filtrate from the filter separating the Glauber salt crystals is a saturated sodium chloride solution, high in Na_2CO_3 but low in Na_2SO_4.

Flow sheet 2 illustrates the subsequent process of manufacture of soda ash. The filtrate from Glauber salt filter is cooled by vacuum to about $30^{\circ}C$. A small quantity of $NaCl$ separates and is removed by settling. The clear liquor is diluted slightly with a small amount of liquor bled from the carbonate evaporator and further cooled to $10^{\circ}C$ in a high vacuum crystallizer with ammonia cooling coil in the vapour space. The crystallization of sal-soda $Na_2CO_3\ 10H_2O$ is initiated at this temperature and some

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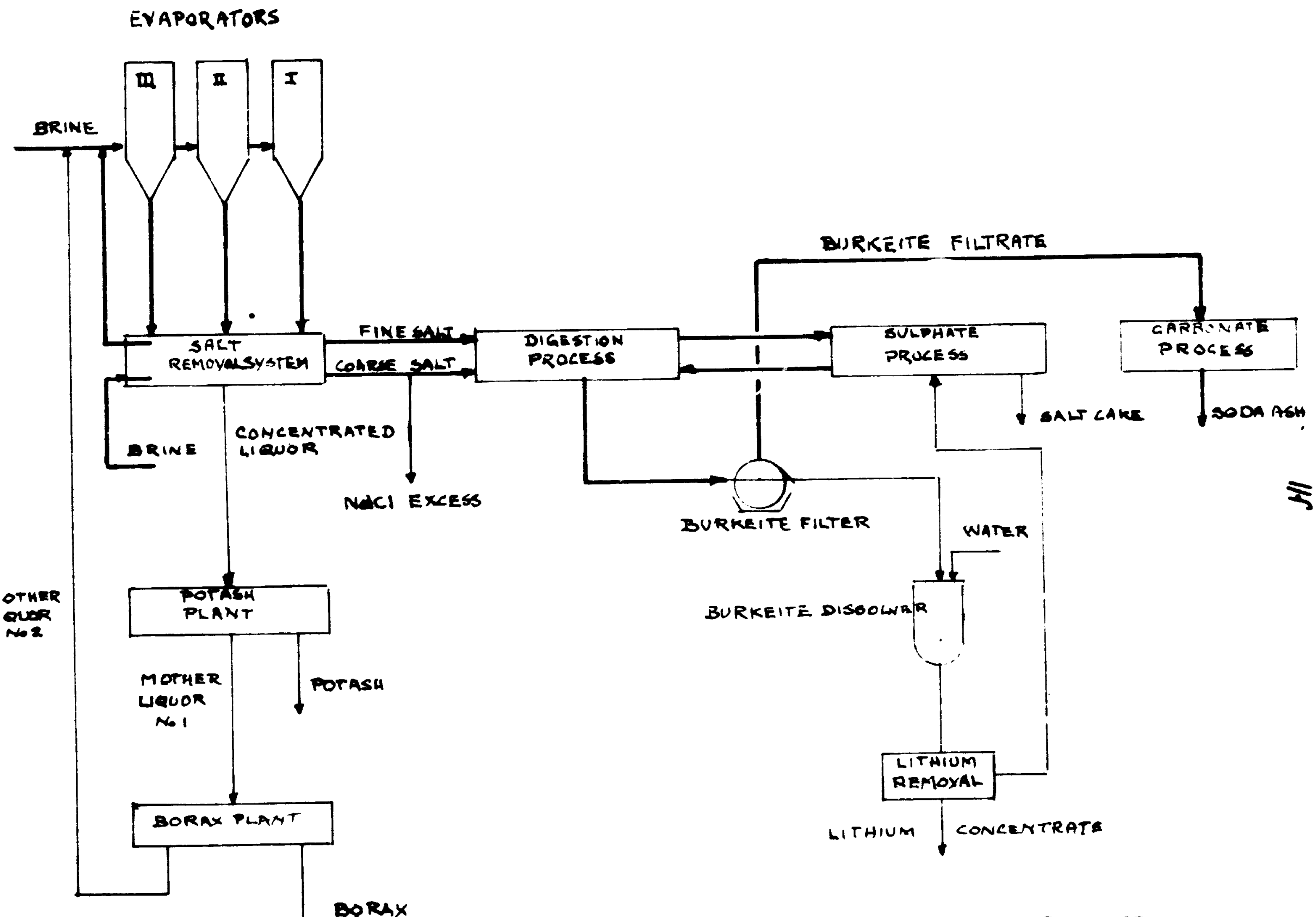
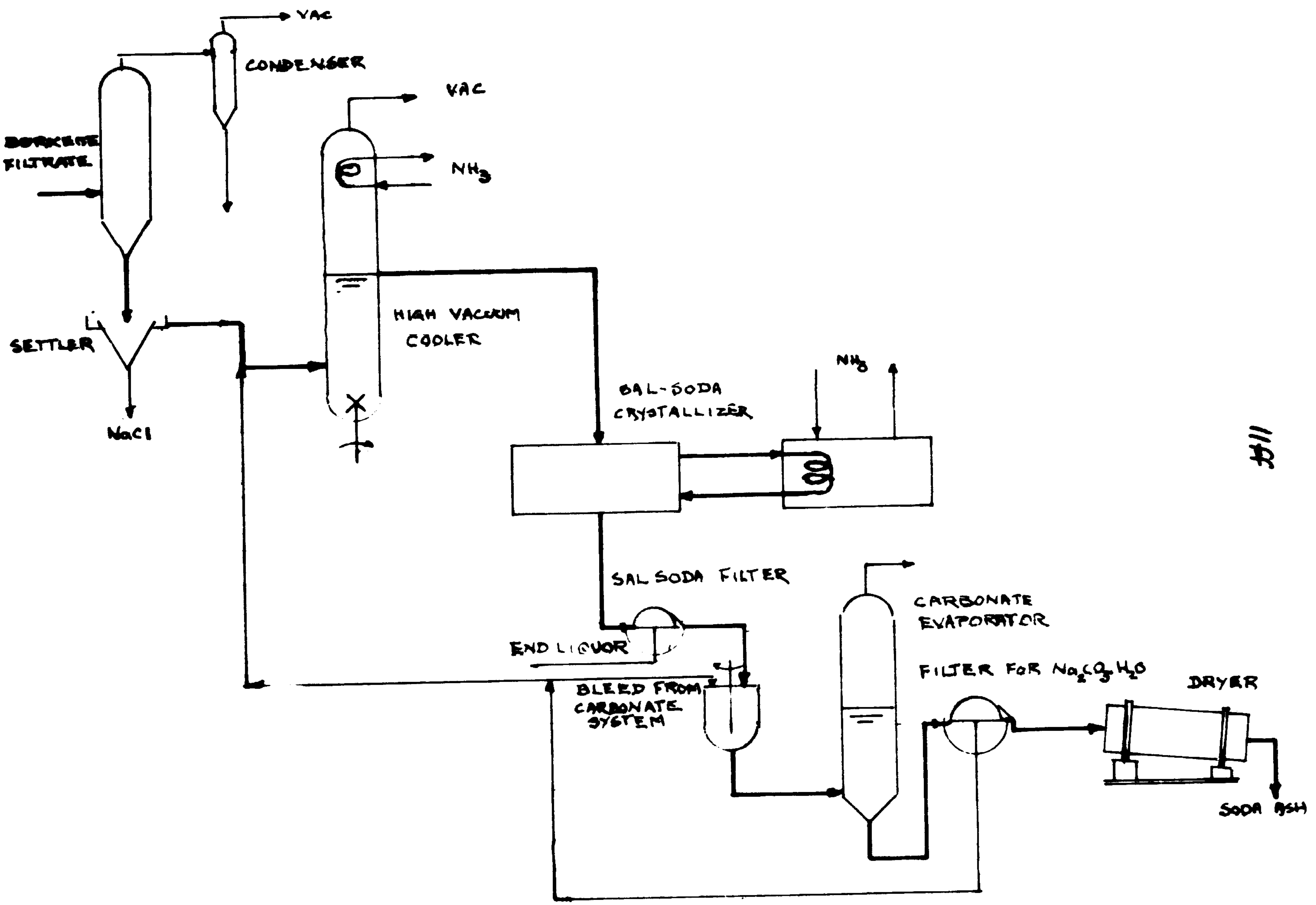
[●] Source Chemical Engineering Aug. 1951. The Trona Process and its unique features by J.V. Hightower.



FLOW SHEET 1 TRONA PROCESS



FLOW SHEET 2 SODA ASH SYSTEM TRONA PROCESS crystals are formed. The liquor is then transferred to another chilling system to cool it further to 3.3°C. The sal-soda crystals are filtered on a rotary filter and the mother liquor containing NaCl is rejected. The crystals are repulped with the mother liquor from the carbonate evaporator and converted to monohydrate ($Na_2CO_3.H_2O$) by heating in an evaporator. The crystals of monohydrate are separated from the mother liquor on a rotary filter and calcined in a rotary drier to produce soda ash. The mother liquor, as stated before, is used to pulp sal-soda crystals for feeding the evaporator.

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Chapter 4 - Manufacture of Soda Ash by ammonia-soda process.

This process of manufacture of soda ash is also known as the Solvay Process after the inventor, Ernst Solvay. All synthetic soda ash produced anywhere in the world since the beginning of the century is by this process.

The main raw materials used in this process are common salt and limestone. Ammonia is used as an intermediary to affect the carbonation of brine but is recovered for reuse again in the process. However, some ammonia is required to replenish losses.

The process and the manufacturing equipment are to some extent complicated. The plant may be considered to be built up of eight main sections, viz. (1) the brine preparation and purification section (2) the lime burning and hydrating section (3) the ammonia recovery section (4) the ammonia absorbing section (5) the carbonation section (6) the bicarbonate filter section (7) the calcining section and (8) the gas compression section. Brief description of each section follows:-

(1) The brine preparation and purification section:

Salt may be from surface salt mines, underground bedded deposits or salt obtained from solar evaporation of sea water in marine salt works. As salt from all these sources contains impurities, the raw salt is dissolved in water and purified with chemical reagents to produce a concentrated solution of pure sodium chloride near to saturation.

(2) The lime burning and hydrating section:

Limestone which is used for this process is generally of a dense grade with impurities not exceeding 10%. A few of the soda ash factories use shells instead of limestone in kilns specially designed for the purpose. The stone is burnt to produce lime (CaO) and carbon dioxide (CO_2). The lime is hydrated and the milk of lime used for recovery of ammonia for reuse in the process and the carbon-di-oxide gas is utilised to carbonate the ammoniated brine for producing sodium bicarbonate.

In the lime kiln, the limestone is decomposed by the heat supplied by the burning of coke. The reactions are

$$CaCO_3 + 43{,}500 \text{ cal} \longrightarrow CaO + CO_2 \qquad (1)$$

$$C + O_2 \longrightarrow CO_2 + 96{,}500 \text{ cal} \qquad (2)$$

Quick lime produced at the kilns is hydrated by the addition of water to produce milk of lime. The chemical reaction is represented by the equation

$$CaO + H_2O \longrightarrow Ca(OH)_2 + 15{,}900 \text{ Cal.} \qquad (3)$$

(3) Ammonia Recovery Section:

The ammonia required for the process of carbonation is recovered from the mother liquor separated at the bicarbonate filter for reuse in the process by reacting with milk of lime in the ammonia still. The chemical reaction is expressed by the equation

$$2\ NH_4Cl + Ca(OH)_2 + 31{,}800 \text{ Cal} \longrightarrow 2\ NH_3 + CaCl_2 + 2\ H_2O \qquad (4)$$

(4) Ammonia Absorption:

As it is necessary to ammoniate the purified brine prior to carbonation, it is effected in the ammonia absorber and the chemical reaction is represented by the equation

$$NH_3 + H_2O \longrightarrow NH_4OH + 8{,}400 \text{ Cal.} \qquad (5)$$

(5) Carbonators:

The next stage of the process is to carbonate the ammoniated brine in the carbonating towers. The chemical reactions in this stage are complicated and represented by the equations

$$2\ NH_4OH + CO_2 \longrightarrow (NH_4)_2CO_3 + H_2O + 22{,}100 \text{ Cal.} \qquad (6)$$

$$(NH_4)_2CO_3 + CO_2 + H_2O \longrightarrow 2\ NH_4HCO_3 \qquad (7)$$

$$NH_4HCO_3 + NaCl \longrightarrow NH_4Cl + NaHCO_3 \qquad (8)$$

(6) Bicarbonate Filters:

The sodium bicarbonate precipitated in the carbonating tower is passed through a vacuum filter to separate it from the ammonium chloride mother liquor, which is sent to the ammonia still for recovery of ammonia.

(7) Calcining Bicarbonate:

The sodium bicarbonate cake from the filter is heated in a calciner to convert it to carbonate. The chemical reaction is represented by the equation

$$2\ NaHCO_3 + 30{,}700 \text{ Cal.} \longrightarrow Na_2CO_3 + CO_2 + H_2O \qquad (9)$$

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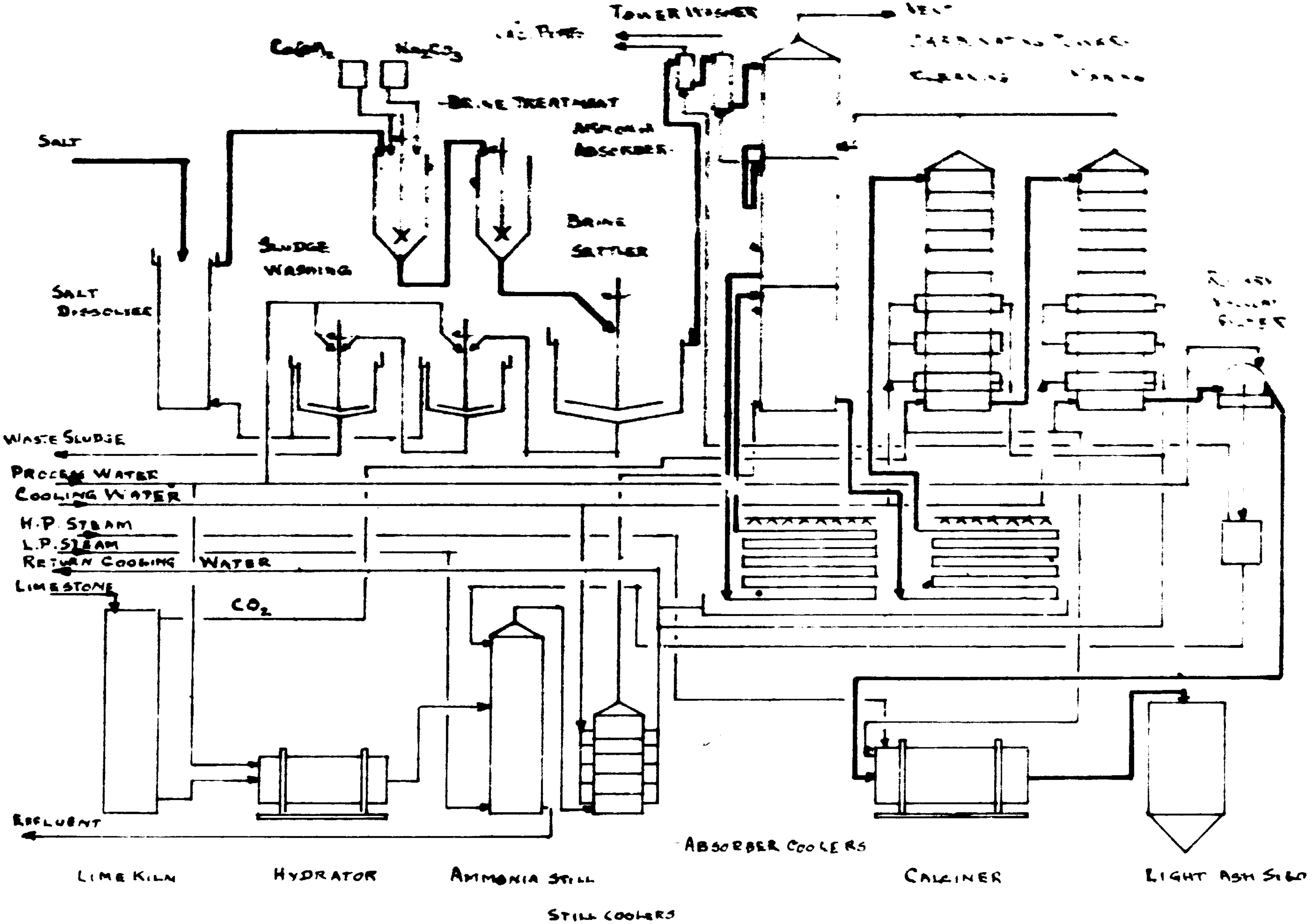

FLOW SHEET 3 — AMMONIA SODA PROCESS

(8) Gas Compression:

The CO_2 gas produced at the lime kilns, as also the gas produced during calcination are compressed to a pressure sufficient for passing it through the column of ammoniated brine in the carbonating towers.

The process of manufacture is illustrated in Flow Sheet 3. Raw salt is dissolved in the wash water used in washing the sludge from the thickener which serves both as pure brine storage and to settle the precipitates of impurities present in the raw salt. The common impurities present in salt of marine origin are calcium sulphate, magnesium sulphate and magnesium chloride. Salt produced in many inland brine lakes has no magnesium salts. Salt produced in surface mines and from underground bedded deposits has generally less soluble impurities either of calcium or magnesium than salt of marine origin. In the preparation of brine, the wash water is regulated to produce concentrated brine, near to saturation, at least 300 to 310 gms. of NaCl per litre. The insolubles are mostly retained in the dissolving tank and are periodically cleaned out. Whatever be the source, the raw salt is analysed to determine the nature of the impurity and the chemical treatment to be given to precipitate the impurities. As marine salt is the most common variety used in chemical industry, the flow sheet indicates the treatment which is necessary to purify it. The brine is taken to the reaction tanks and treated with pre-determined quantities of milk of lime and soda ash to precipitate the impurities in the raw salt. The chemical reactions are represented by the following equations

$$Ca(OH)_2 + MgCl_2 \longrightarrow CaCl_2 + \underline{Mg(OH)_2} \qquad (11)$$

$$Ca(OH)_2 + MgSO_4 \longrightarrow CaSO_4 + \underline{Mg(OH)_2} \qquad (12)$$

$$CaSO_4 + Na_2CO_3 \longrightarrow \underline{CaCO_3} + Na_2SO_4 \qquad (13)$$

$$CaCl_2 + Na_2CO_3 \longrightarrow \underline{CaCO_3} + 2\ NaCl \qquad (14)$$

'Underlined' indicates precipitates.

The treated brine flows from the treatment tanks to the thickener, which functions both as a storage tank for purified brine and a settler for the precipitates. These are drawn from the bottom in the form of a slurry and pumped to sludge washing tanks which are also built in the same manner as thickeners. Fresh water is used for washing the sludge in counter current flow to that of sludge. Two or three thickeners are used in series to reduce the loss of salt rejected with the sludge to the minimum.

The next step in the process is to ammoniate the purified brine. In order to reduce ammonia losses in the process, the purified brine is used to pick up traces of ammonia from tail gases, which would otherwise be exhausted to atmosphere. It enters in the first instance, the filter washer to absorb the NH_3 and CO_2 picked up by the air, as it is sucked through the layer of bicarbonate on the filter drum by the vacuum pump. It then passes on to the absorber washer to pick up whatever ammonia is in the tail gases which are exhausted from the ammonia absorber by the absorber vacuum pump. Further on, it enters the ammonia absorber which is split up into two sections with a cooler section in between. As is seen from equation (5) above, the absorption of ammonia in water is accompanied by the evolution of heat. As the solubility of ammonia decreases with increase in temperature, it is necessary to cool it in the intermediate stage in order that sufficient ammonia is absorbed by the brine. From the ammonia absorber, the brine is again cooled, prior to feeding the carbonating towers. In these towers, the entry of the brine is at the top and the entry of the carbon-di-oxide is at the bottom, so that the flow of brine is counter current to the flow of gas. As the chemical reactions in the tower are reversible according to temperatures and concentration, the temperature gradient in the tower is maintained at optimum conditions by providing cooling sections in the lower part of the tower where the maximum evolution of heat takes place due to higher concentration of gas. The magma consisting of the precipitated sodium bicarbonate and the mother liquor containing mainly ammonium chloride, ammonium bicarbonate and undecomposed salt is withdrawn continuously and fed to a rotary vacuum filter for separation of bicarbonate and the mother liquor.

Two carbonating towers are shown in Flow Sheet 3, one marked 'cleaning'and the other 'making'. Every carbonating tower requires 'cleaning' after it is operated for about 3 to 4 days as 'making', i.e. on production of bicarbonate. The precipitated bicarbonate crystals settle and build up on the cooling tubes and mushrooms, thereby reducing the transfer of heat from the ammoniated brine to the cooling water. When the tower gets into such a state, it is subjected to a 'cleaning cycle'. Cooling water is turned off and 'lean' carbon-di-oxide gas passed into the tower, in place of the 'rich' carbon-di-oxide gas used during the 'making cycle'. As $NaHCO_3$ is more soluble at higher temperatures, the ammoniated brine dissolves the material which has built up and passes on to one of the 'making' towers.

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The bicarbonate is calcined in an externally fired rotary calciner or in a rotary calciner provided with high pressure steam tubes. The latter type is a new development in the ammonia soda industry and being more economical is displacing the former even in existing plants.

The mother liquor from the rotary vacuum filter is sent to the ammonia still for recovery of ammonia for reuse. The ammonia still has two sections. The mother liquor enters the first section, in which it is heated to strip it of free ammonia from ammonium bicarbonate, and then passes on to the second section where it meets a stream of milk of lime. Low pressure steam provides the necessary heat to effect the chemical reaction between milk of lime and ammonium chloride and to release ammonia which is sent to the ammonia absorber system for reuse. If make-up ammonia is in the form of ammonium sulphate, it is added to this section of the still for release of ammonia with reaction with milk of lime according to the equation

$$(NH_4)_2SO_4 + Ca(OH)_2 \longrightarrow 2\ NH_4OH + CaSO_4 \qquad (15)$$

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Chapter 5 - Manufacture of Soda Ash by Ammonium Chloride and Soda Ash process.

The essential difference between the ammonia soda process and the ammonium chloride and soda ash process is that in the former ammonia is recovered for reuse in the process and the end product is only soda ash, whereas in the latter, ammonia is not recovered but is used to produce ammonium chloride in addition to soda ash. Ammonia is an additional raw material.

Japan is the only country in which this process is employed on a commercial scale. As the solubility of ammonium chloride in a saturated solution of common salt decreases significantly with decrease in temperature, the process is based on salting out with fresh salt, combined with refrigeration of the mother liquor after separation of the sodium bicarbonate.

Flow Sheet No.4 illustrates the process of manufacture. Raw salt is washed with saturated and purified brine from the brine refinery to reduce the Ca and Mg impurities to permissible limits. The washed raw salt is crushed in a salt crusher to minus 20 mesh. Typical analysis of washed salt is given below:-

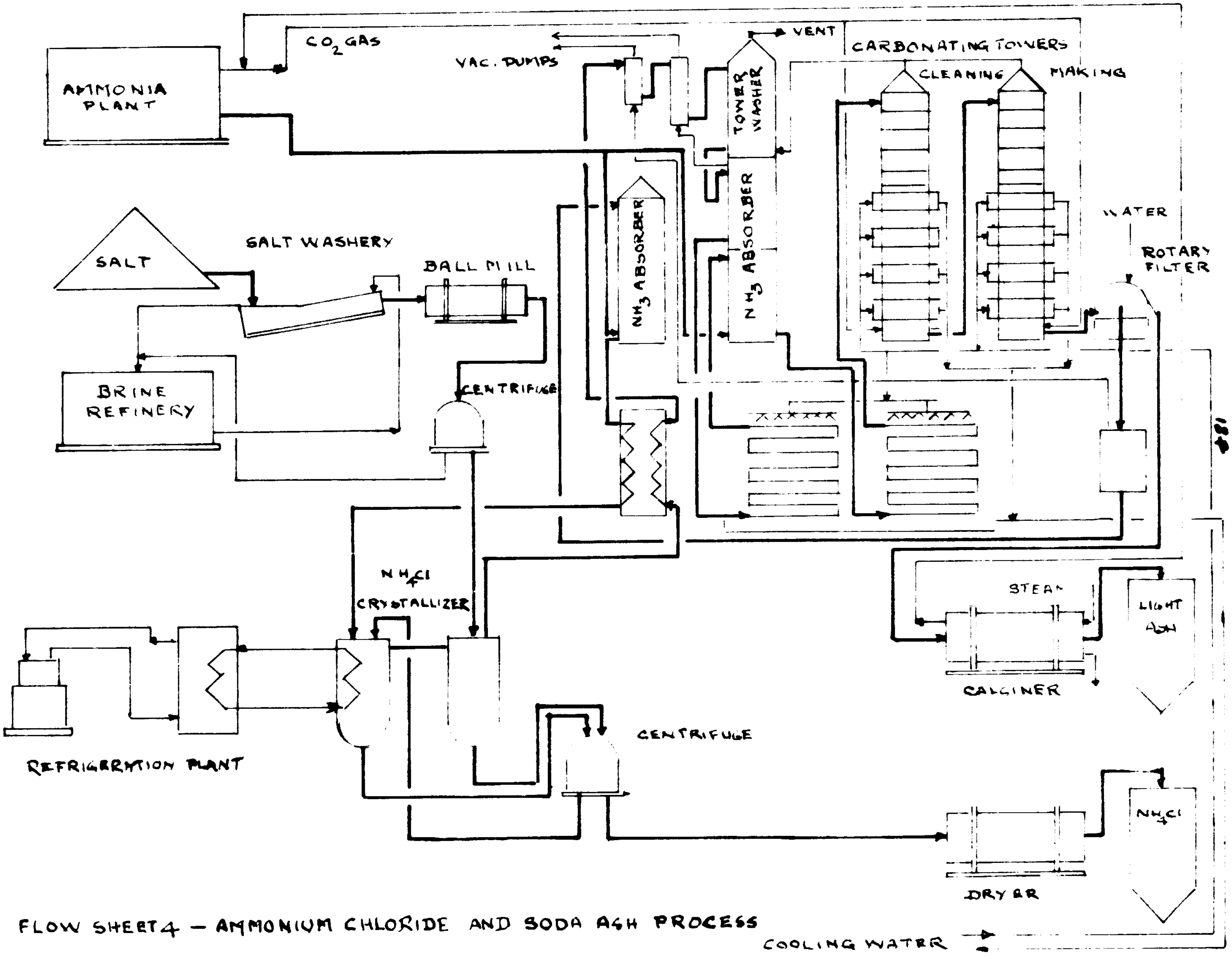
Table 9 - Composition of Washed Salt.

NaCl	93.71%	Mg	0.01%
H_2O	5.35%	K	0.01%
Water Insol.	0.08%	SiO_2	0.08%
SO_4	0.40%	Fe	0.003%
Ca	0.15%	Al	0.05%

Mesh	%	Mesh	%
+ 20	3	42-60	21
20-32	9	60-80	17
32-42	16	80-100	11
		- 100	23

Source: Reference 6 - Bibliography.

The washings from the salt washery containing the impurities of Ca and Mg salts are chemically treated for their removal and the purified brine used again at the salt washery for washing fresh supplies of raw salt.



FLOW SHEET 4 — AMMONIUM CHLORIDE AND SODA ASH PROCESS

The crushed and washed salt is added to the ammonium chloride crystallizer containing the ammoniated and cooled mother liquor from the bicarbonate filters. These crystallizers are maintained at a temperature between 5°C to 10°C by external cooling. The ammonium chloride crystals are continuously withdrawn from the bottom of the crystallizers and centrifuged in a continuous centrifuge to separate the ammonium chloride crystals from the mother liquor which is returned to the crystallizers. The ammonium chloride crystals are dried in a rotary drier heated with hot gases produced in an oil-fired furnace and sent to the ammonium chloride store for disposal. The clear liquor from the top of the crystallizers at a temperature of about 10°C is continuously withdrawn and after heat exchange with the incoming mother liquor at about 32°C from the bicarbonate filter is sent to the ammonia absorber and thereon fed at the bottom of the carbonating towers. The stream of ammoniated brine flowing down the tower interacts with the rising stream of carbondioxide to form sodium bicarbonate which precipitates. The magma containing the precipitate is continuously withdrawn and filtered on a rotary vacuum filter to separate bicarbonate from the mother liquor which is sent to the aforementioned ammonia absorber preceding the ammonium chloride crystallizer. The bicarbonate is treated in a steam heated drier, commonly known as calciner to produce light soda ash.

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Chapter 6 - Manufacture of Dense Ash.

Soda Ash is marketed in two commercial varieties, distinguished by their physical nature. The cheaper and the more widely used variety is Light Soda Ash, which is a white fluffy powder with a bulk density between 25 lbs. per cu.ft. to 30 lbs. per cu.ft., Sp. gr. 0.40 to 0.48. Dense ash has a bulk density of 60 lbs. to 65 lbs. per cu.ft., Sp. gr. 0.96 to 1.04, Compared to the light ash, it is a coarser powder and free from dust.

When sodium bicarbonate is calcined, as in the ammonia soda process as also in its modification, ammonium chloride and soda ash process, it results in producing light ash. When sodium monohydrate is calcined, as in the Trona process, the result is dense or heavy ash.

Flow sheet 5 shows the procedure commonly adopted to convert light ash to dense ash. The light ash is mixed with the requisite quantity of water in a hydrator. The water combines with the soda ash to form the monohydrate, $Na_2CO_3 \cdot H_2O$. As lumps are formed in the process, the material is passed through a screen and the oversize passed through a crusher. Both the screened and crushed materials are mixed and heated in an externally-heated rotary dryer similar to the calciner for bicarbonate. As in the case of the bicarbonate calciners, steam tube driers are being increasingly used for this purpose also in place of externally fired calciners. The product is finally screened in a double decker screen. Particles of desired size are collected as product. Oversize is reduced to size in a crusher and the fines returned to the hydrator for reprocessing.

Flow Sheet 6 shows an alternative process which has been developed during the last decade and which bids fair to replace the earlier one. In this case, the light ash is compacted under mechanical pressure into briquettes or pellets and reground in grinding mills. Thereafter, the ground material is passed on a double decker screen and particles of desired size collected. The oversize particles are returned to the grinding mill. The undersize or fines are returned to the compacting machine for reprocessing.

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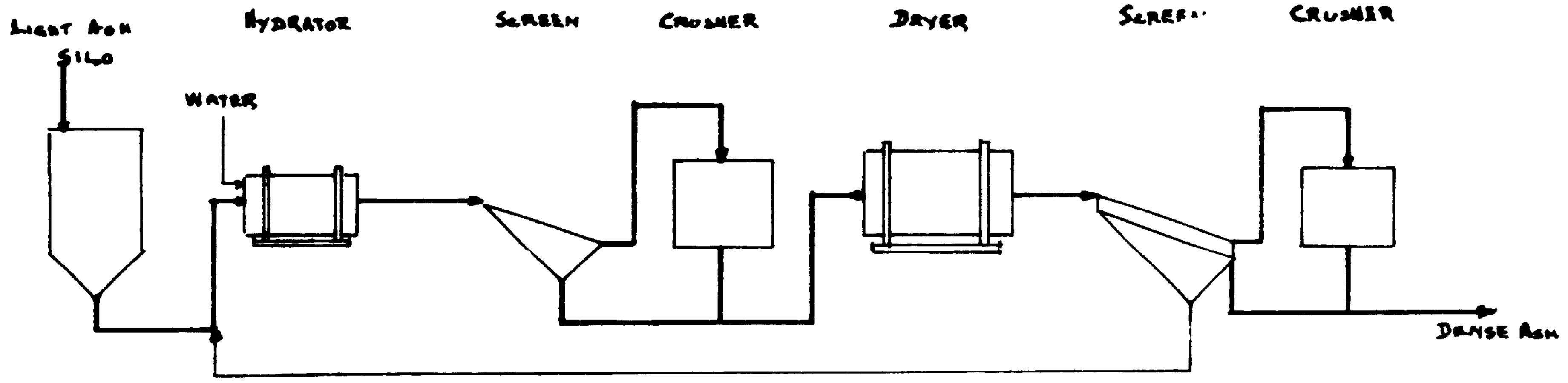

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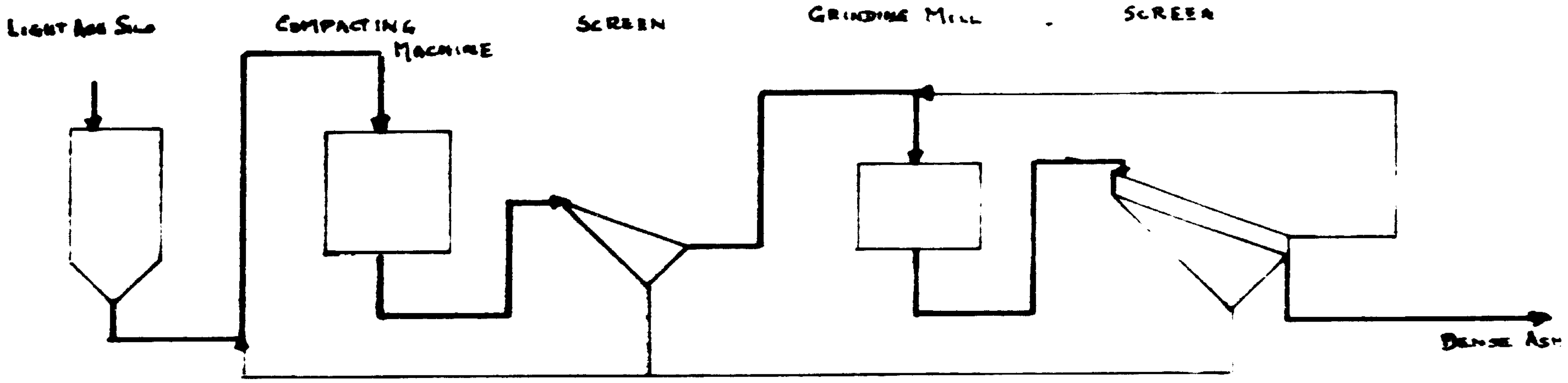
FLOW SHEET 5 - CHEMICAL PROCESS FOR DENSE ASH



FLOW SHEET 6 – MECHANICAL PROCESS FOR DENSE ASH

Chapter 7 - Manufacture of Caustic Soda - Chemical Process.

Causticization of Soda Ash.

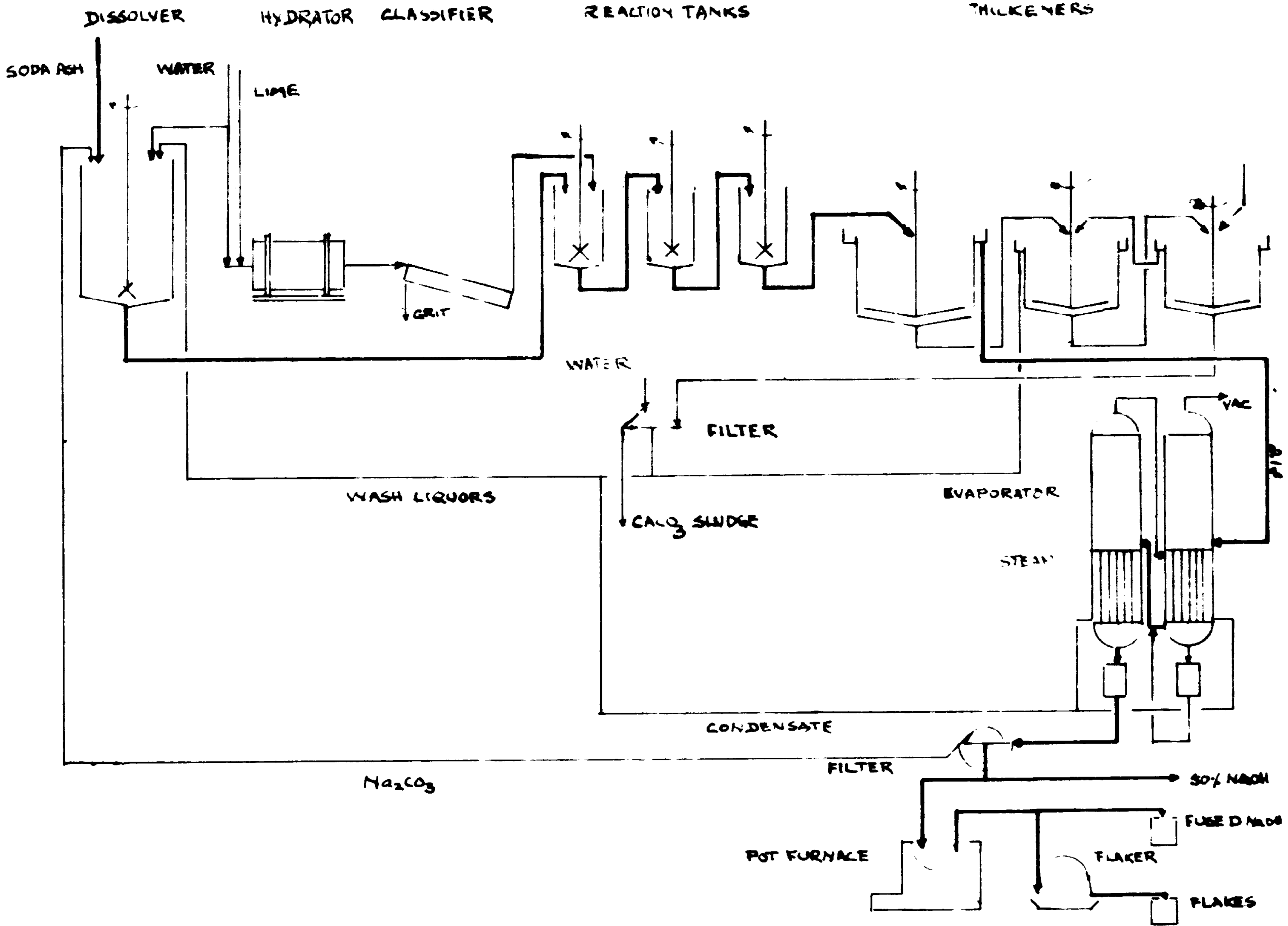
This, being the oldest process for manufacture of caustic soda, has undergone considerable changes with the development of chemical industry. Even now, there is no standardized process. Variations are found from one plant to another.

This chemical process for manufacture of caustic soda by causticization of soda ash with milk of lime is based on the following chemical reaction

$$Na_2CO_3 + Ca(OH)_2 \rightleftharpoons 2\,NaOH + CaCO_3 \qquad (1)$$

This reaction is reversible and the conversion of sodium carbonate to sodium hydroxide ceases when the relative concentration of the components has reached conditions of equilibrium. The governing factors for the conversion is the initial concentration of sodium carbonate in the solution and the concentration of calcium hydroxide in the milk of lime. Instead of milk of lime, dry lime or alternatively,dry slaked lime can also be used.

Flow sheet 7 illustrates the process adopted in a modern plant operating efficiently. Strong soda solution of 18-20 per cent sodium carbonate is made in a dissolver with mechanical agitation using the weak wash liquor produced at a later stage of the process. Strong milk of lime containing about 250 gms. of $Ca(OH)_2$ per litre is prepared also with weak liquor washings. In order to purify the milk of lime, it is passed through a mechanical classifier in which the grit consisting of unburnt stone, overburnt lime and sand particles are removed. The soda solution is treated with milk of lime in a vessel provided with mechanical agitators. In order to provide sufficient time interval to complete the reaction, the mixture is passed through two or three similar vessels with mechanical agitators. Thereafter it is passed through a thickener to thicken the precipitate of $CaCO_3$ and to clarify the lye of NaOH. The sludge is washed in two or three thickeners in series with water flowing counter-currently to the solids. The weak liquor obtained in the counter-current washing is used for dissolving fresh soda ash as also to hydrate the lime to produce the strong milk of lime. The sludge from the final thickener is filtered on a rotary vacuum filter and, during the process, the cake is given a further washing with fresh water. The filtrate is added



FLOW SHEET 7 - MANUFACTURE OF CAUSTIC SODA - CHEMICAL PROCESS to the water used in the counter-current washing system. The solid cake of $CaCO_3$ containing traces of alkali and unreacted $Ca(OH)_2$ particles is rejected to waste in small plants. In the larger ones, it is burnt in a rotary kiln for reuse as lime in the process. Some large producers use it for making portland cement.

The clarified lye has 10% to 14% NaOH, depending upon the method of operation. The higher concentration is achieved by sacrificing some loss in efficiency of conversion when the cost of fuel for concentrating the lye to the stage of 50% NaOH is high. Otherwise, a lye of lower concentration is produced with an efficiency exceeding 99.0%.

Multiple effect evaporators are used for concentrating the caustic lye to 50% NaOH. Further concentration to 70% NaOH is done in single stage evaporators by some manufacturers but generally, the 50% NaOH lye is concentrated to the final stage of fused caustic in externally fired cast iron pots. The evaporators for concentrating caustic lye are rather costly, as all the contact surfaces are of nickel to withstand the chemical effects of hot caustic soda lyes.

The final product in the fused state is filled in steel drums and allowed to cool and set into solid blocks. To produce flakes, the fused product is passed over a flaker, where it is cooled and flakes are scraped off into steel drums.

Caustic Soda is marketed commercially in three varieties, lye of 50% NaOH, fused caustic soda solid and flakes.

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Chapter 8 - Manufacture of Caustic Soda with Diaphragm Cells.

Since the invention of the first electrolytic caustic soda cell at the end of the last century, a large number of types have been devised and used for manufacture of caustic soda. Though sizes and shapes vary widely,they all have the same essential features. Between the anode of graphite rods or plates and the cathode of perforated iron plate or woven wire screen is placed on asbestos diaphragm built up of sheets or deposited on the cathode. In some types, the container is also of iron plate and is electrically connected with the cathode. The top and bottom of the container are generally of non-conducting material. The brine inlet, the chlorine outlet, the hydrogen outlet are provided in the top cover. The cell liquor outlet is placed towards the bottom or on the side depending on whether the cell has a submerged diaphragm, partially submerged or unsubmerged diaphragm.

Though several types of diaphragm cells are in operation currently, the one most widely used is the Hooker S. Type Cell. It is approximately cubical in shape and consists of three major parts, (1) the bottom section of cement concrete supporting the entire graphite anode assembly (2) the centre section supporting the cathode chamber on which the asbestos diaphragm is deposited and provided with hydrogen outlet and cell liquor outlet, and (3) the top section of cement concrete provided with the brine feed inlet and chlorine outlet. The electrical connection to the anode is made by embedding the ends of the graphite anode blades in lead cast in the bottom section. A heavy copper rod extending to the outside of the cell is also embedded in the layer of lead to conduct the current to the anodes. The cathode is formed within a rectangular frame of steel channel section with rows of parallel cathode chambers projecting inwardly between the anodes along the two opposite sides. These chambers are thin, elongated, parallel compartments made of heavy wire screen suitably shaped and welded into a single unit. The asbestos diaphragm is formed by immersing the steel cathode assembly in a suspension of asbestos fibres in water and depositing the fibres on the screen by sucking the suspension with a pump. When a sufficient layer is deposited, the assembly is lifted out and the layer of asbestos dried by sucking air. The concrete top and bottom sections are heavy enough to dispense with clamps or any other fixings. The brine is fed through a calibrated orifices in a broken stream to

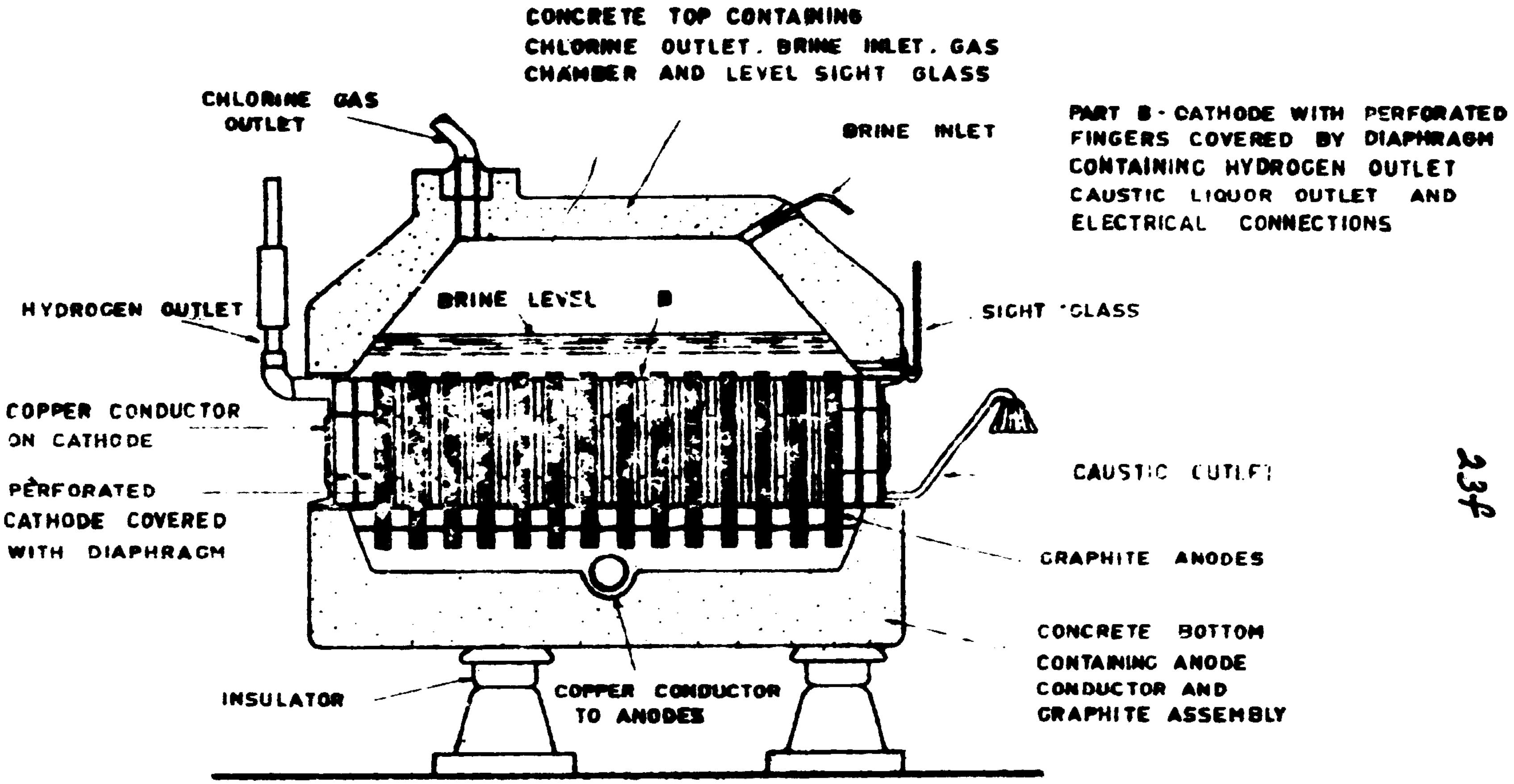


Fig 1 - SCHEMATIC DIAGRAM OF HOOKER TYPE S CELL prevent the stream from conducting electricity. The caustic effluent is withdrawn from the cathode chamber by a bent tube to assure that the diaphragm is fully submerged at all times. Fig.1 illustrates the construction of the cell with its components, inlets and outlets.

Flow sheet 8 shows the process of manufacture in a typical diaphragm cell plant, producing all the commercial grades of caustic soda, viz. Caustic Lye of 50% NaOH, Caustic Soda Fused and Caustic Soda Flakes. Commercial salt is dissolved into saturated brine and treated with chemical reagents, NaOH, Na_2CO_3 and $BaCO_3$ to precipitate the impurities and produce a pure brine containing only NaCl. The recovered salt from the caustic evaporator which is pure NaCl with about 1 to 2% NaOH is added to the pure brine to make up for the dilution that takes place in the brine treatment. The brine is preheated to about 90°C prior to feeding the cells.

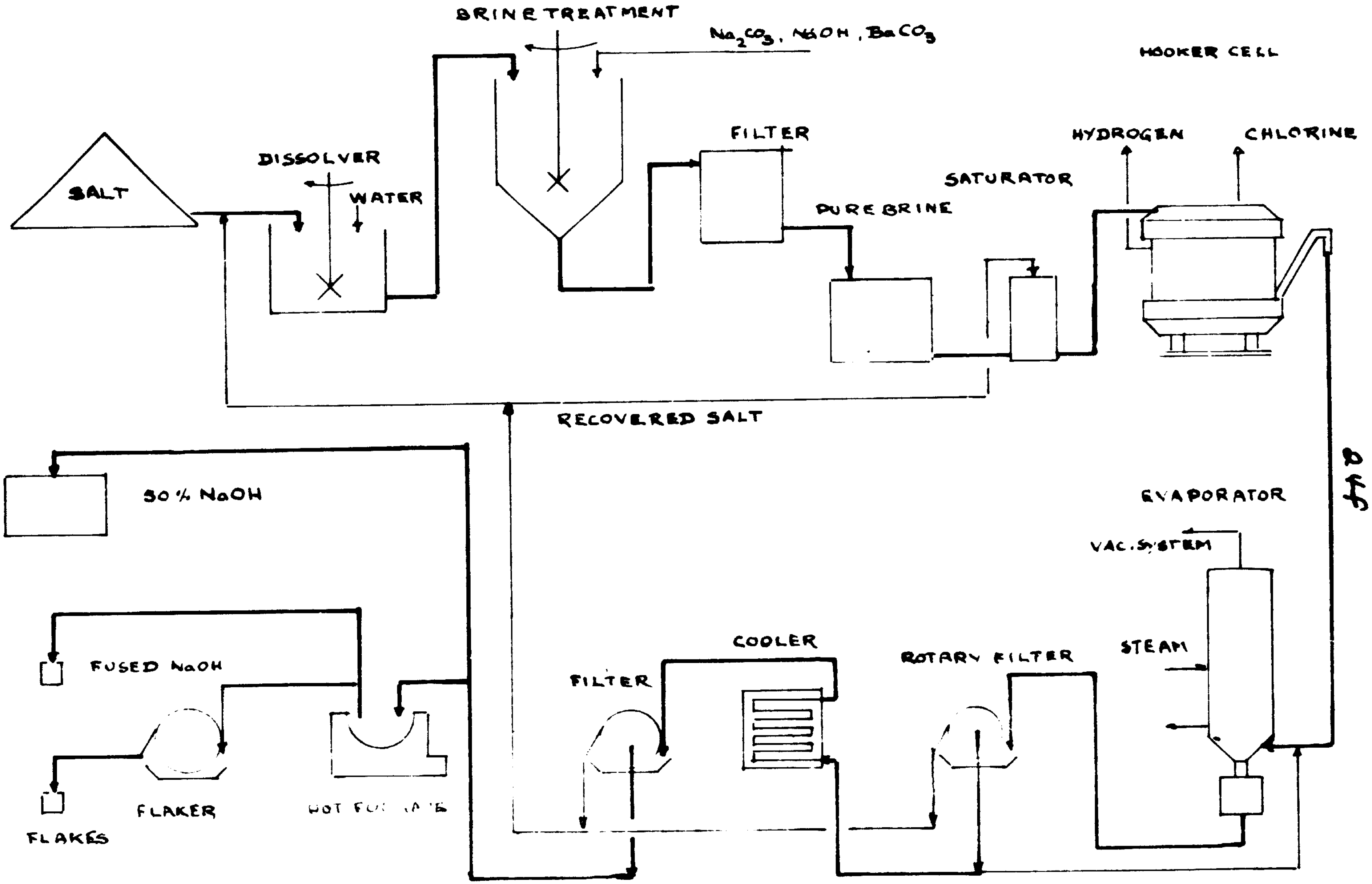
The chlorine and hydrogen are drawn through the respective outlets and sent to the consuming plants. The caustic lye is withdrawn continuously and sent to the multiple effect evaporator section for concentration.

As concentration proceeds in the evaporator, salt separates out. In order to withdraw the salt during evaporation, each evaporator body is provided with a salt box, in which salt accumulates. At desired intervals the salt slurry is withdrawn and filtered over a rotary vacuum filter or passed through a centrifuge. The solid salt is returned to the brine refinery for reuse and the clear liquor returned to the evaporators for concentration.

After the lye reaches concentration of 50% NaOH in the evaporator, it is withdrawn and cooled to 20°C with chilled water. On cooling, more salt crystallizes out. The salt is separated by passing the cooled lye through a centrifuge or over a rotary vacuum filter. This salt is also returned to the brine refinery for reuse.

The filtered lye of 50% NaOH is sent to the storage for disposal.

A further process is necessary to produce fused caustic soda in solid form. The lye of 50% NaOH is concentrated to 70% NaOH in a single effect vacuum evaporator and then fed to externally fired caustic fusion pots of cast iron. Alternatively lye of 50% NaOH itself is fed to the fusion pots. As the concentration increases due to



FLOW SHEET 8 -- MANUFACTURE OF CAUSTIC SODA WITH DIAPHRAGM CELLS evaporation of the water content, the boiling temperature also rises. The final boiling temperature reached after all the water has been evaporated is 1390°C. The material is allowed to cool down to about 500°C and filled into steel drums by pumping in the molten state. On further cooling in the drum, it sets into a hard solid block.

Caustic Soda flakes are produced by pumping the molten caustic soda on to a flaker, which consists of a drum rotating in a bath of the material to be flaked. L.P. steam circulation is provided in the drum to cool the layer of material it picks up as it rotates. The thin layer of solid formed on the drum is scraped off to produce flakes. These are also packed in steel drums for disposal.

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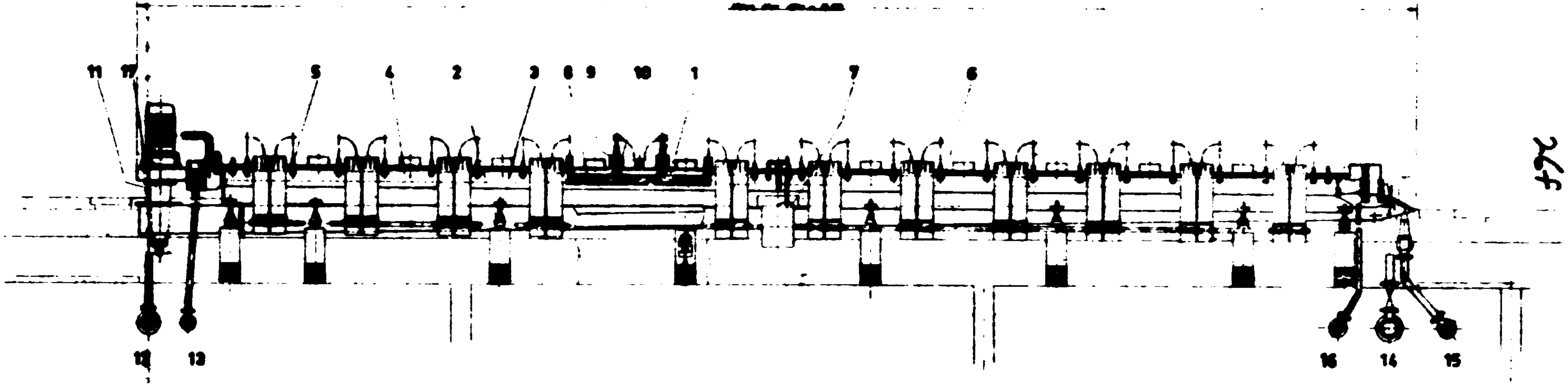
Chapter 9 - Manufacture of Caustic Soda with Mercury Cells.

As in the case of diaphragm cells, many types of mercury cells have been developed and several are currently in use. The type which has gained greater acceptance in the industry and adopted by the new installations is the trough type primary cell with either a trough type secondary cell lying alongside or a vertical one placed at one end of the primary cell. The formation of sodium amalgam in the primary cell takes place because of high over-voltage of hydrogen on mercury as a result of which the discharge potential of hydrogen is actually higher than that of sodium. Therefore the sodium ions released in the electrolyte combine with the mercury to form an amalgam instead of combining with water to liberate hydrogen. In the secondary cell, the mercury amalgam becomes the anode to a short-circuited iron or graphite cathode in an electrolyte of sodium hydroxide solution. The amalgam breaks up and the sodium combines with water to form sodium hydroxide with evolution of hydrogen.

Fig. 2 shows a modern trough type mercury cell with the decomposer also of a trough type placed directly below it. The bottom mild steel plate of the trough is accurately machined to form a true flat surface. The side mild steel plates and the top mild steel plate cover are rubber lined on the internal surface to prevent corrosion. The mercury inlet and amalgam outlet boxes as also the feed brine inlet and weak brine outlet boxes are also rubber lined. The graphite anodes consisting of flat plates of graphite are suspended with graphite rods protruding through the rubber lined cover plate and connected to copper bus bars feeding the electric current to the cell. A set of these copper bus bars are supported on a steel frame provided with a device for raising or lowering the set of graphite anodes suspended from it to adjust the gap between the bed of mercury and the face of the anode plate. The trough of the primary cell is laid in a gentle slope from the feed end to the discharge end, whereas the trough of the decomposer below is laid in a reverse slope as the direction of flow also is reversed. As the mercury and feed brine flow through the cell, the electric current decomposes the brine. The sodium ion combines with the mercury to form the amalgam and chlorine ion is liberated. Chlorine is withdrawn from the cell with the depleted brine from the end box and passed on to the degassifying towers. The mercury with the mercury amalgam flows to another end-box and thereon to the decomposer or secondary cell below it. A regulated feed of pure water enters the decomposer

FIG 2 — HOECHST - UHDE MERCURY CELL



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1	BRIGHT CELL BOTTOM	7	QUICK SWITCH	13	WATER INLET
2	BOTTOM STRENGTHENED BY RIBS	8	GRAPHITE ANODE	14	CHLORINE OUTLET AND ANOLYT OUTLET
3	CELL WALL	9	GRAPHITE ROUND STAFF	15	HYDROGEN OUTLET AND CAUSTIC LIQUOR OUTLET
4	CELL COVER	10	ANODE ADJUSTING APPARATUS	16	AIR DISCHARGE PIPE
5	LID CATCH	11	MERCURY PUMP	17	PUMP BODY
6	CURRENT COLLECTING RAIL TO ANODE	12	BRINE INLET		

at the opposite end. An outlet for hydrogen and caustic lye is provided in the end box of the decomposer. Mercury is also withdrawn through another end box and pumped back to the primary cell at the feed end.

The process for the manufacture of caustic soda with mercury cells differs from that with diaphragm cells in one important respect. Since the caustic lye is free from NaCl and it can be produced at any concentration upto 70% NaOH, caustic evaporators are eliminated in this process. The depleted brine flowing out of the cell contains about 260 gms. NaCl per litre and has a small quantity of chlorine dissolved in it. The brine is freed of chlorine by bubbling a stream of air through it. It is then returned to the brine refinery for resaturation with fresh salt and chemical purification as in the case of the diaphragm cells.

The caustic lye produced at the cells is generally of 50% NaOH. If fused caustic soda or caustic soda flakes are desired, it is processed in caustic pots in the same manner as diaphragm cell caustic lye of 50% NaOH.

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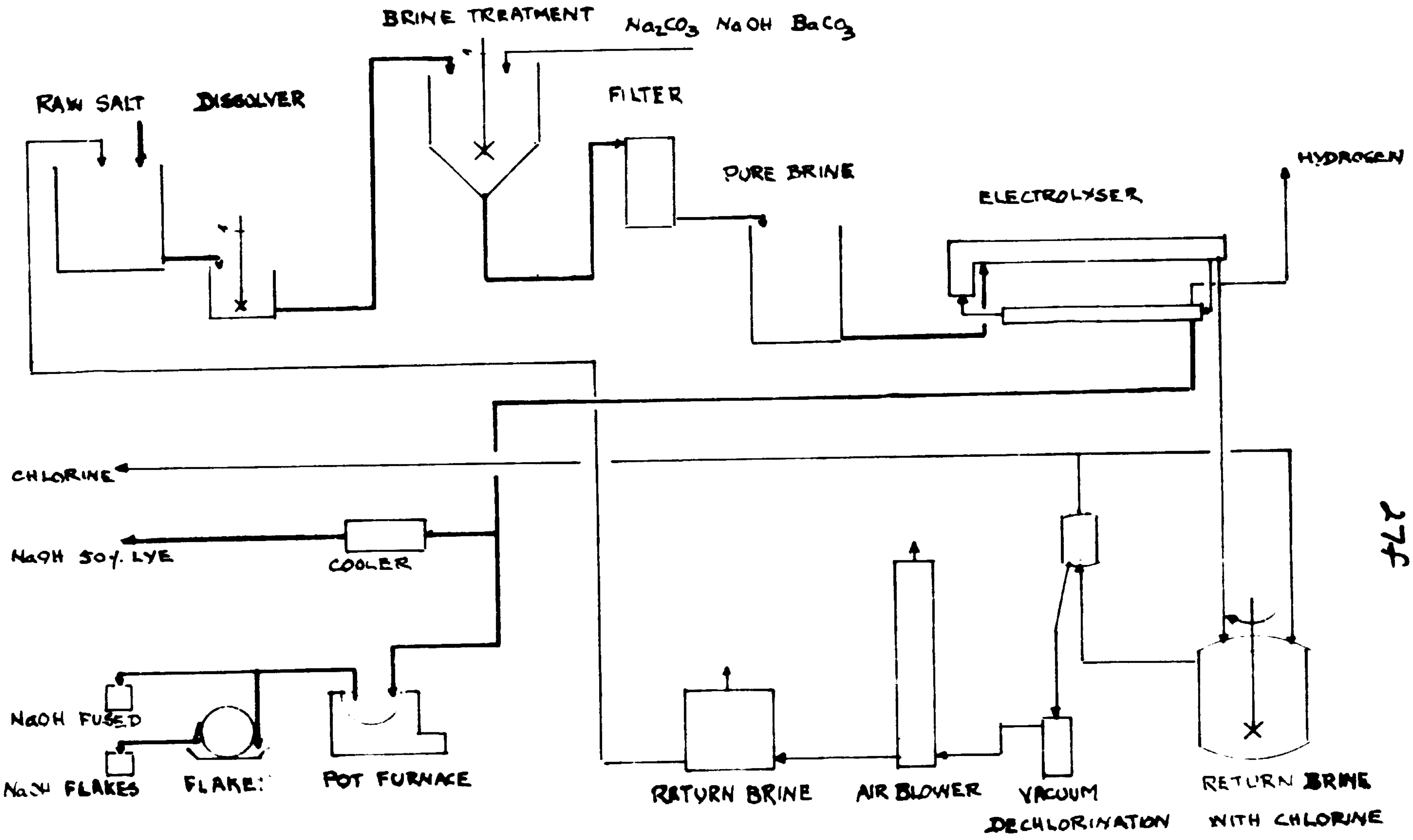

FLOW SHEET 9 - MANUFACTURE OF CAUSTIC SODA - MERCURY CELLS

Chapter 10 - Raw Materials for the Soda Industry.

(1) Salt: Common Salt is the main raw material for the manufacture of both Soda Ash and Caustic Soda, being the cheapest and one of the most abundant chemicals in nature.

Theoretical requirements of NaCl for the manufacture of Soda Ash and Caustic Soda are as below:-

1 ton Na_2CO_3	requires	1.094 tons of NaCl
1 ton NaOH	requires	1.461 tons of NaCl

In the ammonia-soda process, the maximum decomposition that can be attained before the concentrations of NaCl, NH_3, NH_4Cl and $NaHCO_3$ reach a condition of equilibrium is 75%.

Therefore, the theoretical requirements of NaCl for the manufacture of Na_2CO_3 by the ammonia-soda process will be 1.459 tons of NaCl for every ton of Na_2CO_3. This does not apply to the ammonium chloride and soda ash process, as though the carbonation in the carbonating tower is limited by the same condition as in the ammonia soda process, no salt is rejected from the system in this process but is recycled in it. In the ammonia-soda process, the unconverted salt is rejected with calcium chloride in the still effluent.

As common salt, recovered from surface mines or underground bedded deposits or manufactured by solar evaporation of sea water, has impurities associated with it and in addition, has some moisture, its consumption in the manufacture of either caustic soda or soda ash is necessarily higher than the theoretical.

Further, in the chemical treatment of brine to precipitate the impurities, some loss of NaCl is inevitable as it passes away with the sludge.

The impurities in the raw salt are of two kinds, soluble and insoluble. When salt is dissolved in water, the insolubles generally settle down and the clear brine is transferred to the treatment tanks for chemical treatment.

As stated in an earlier chapter, the chemical reactions in the purification of brine for manufacture of soda ash by the ammonia-soda process are as given below:-

(a) Removal of $MgCl_2$ impurity:

$$\underset{95.23}{MgCl_2} \quad \underset{74.10}{Ca(OH)_2} \longrightarrow CaCl_2 \quad \underline{Mg(OH)_2} \qquad (1)$$

$$CaCl_2 \quad \underset{106.00}{Na_2CO_3} \longrightarrow \underline{CaCO_3} \quad 2\ NaCl \qquad (2)$$

According to the above reactions, 1 gm. of $MgCl_2$ impurity in the salt requires 0.776 gms. of $Ca(OH)_2$ and a further 1.115 gms. of Na_2CO_3 for its removal.

(b) Removal of $MgSO_4$

$$\underset{120.38}{MgSO_4} + \underset{74.10}{Ca(OH)_2} \longrightarrow CaSO_4 + \underline{Mg(OH)_2} \qquad (3)$$

$$CaSO_4 + \underset{106.00}{Na_2CO_3} \longrightarrow \underline{CaCO_3} + \underline{Na_2SO_4} \qquad (4)$$

According to the above reactions, 1 gm. of $MgSO_4$ impurity in the salt requires 0.615 gms. of $Ca(OH)_2$ and 0.880 gms. of Na_2CO_3 for its removal.

(c) Removal of $CaSO_4$

$$\underset{136.14}{CaSO_4} + \underset{106.00}{Na_2CO_3} \longrightarrow \underline{CaCO_3} + Na_2SO_4 \qquad (5)$$

According to the above reaction, 1 gm. of $CaSO_4$ requires 0.776 gms. of Na_2CO_3 for its removal.

For manufacture of caustic soda, a different procedure is followed, since it is necessary to remove the sulphate radical. Chemicals used in this process are NaOH, Na_2CO_3 and $BaCO_3$.

(a) Removal of $MgCl_2$

$$\underset{95.23}{MgCl_2} + \underset{80.00}{2\ NaOH} \longrightarrow 2\ NaCl + \underline{Mg(OH)_2} \qquad (6)$$

1 gm. of $MgCl_2$ impurity requires 0.840 gms. of NaOH for its removal.

(b) Removal of $MgSO_4$

$$\underset{120.38}{MgSO_4} + \underset{80.00}{2\ NaOH} \longrightarrow Na_2SO_4 + \underline{Mg(OH)_2} \qquad (7)$$

$$Na_2SO_4 + \underset{197.37}{BaCO_3} \longrightarrow Na_2CO_3 + \underline{BaSO_4} \qquad (8)$$

1 gm. of $MgSO_4$ impurity requires 0.667 gms. of NaOH and 1.640 gms. of $BaCO_3$ for its removal.

(c) Removal of $CaSO_4$

$$\underset{136.14}{CaSO_4} + \underset{106.00}{Na_2CO_3} \longrightarrow \underline{CaCO_3} + Na_2SO_4 \qquad (9)$$

$$Na_2SO_4 + \underset{197.37}{BaCO_3} \longrightarrow Na_2CO_3 + \underline{BaSO_4} \qquad (10)$$

1 gm. of $CaSO_4$ impurity requires 0.776 gms. of Na_2CO_3 and 1.450 gms. of $BaCO_3$ for its removal.

'Underlined' indicates precipitates.

It is thus seen that the soluble impurities of Ca and Mg Salts can be removed only by additional expenditure on chemicals whereas the insolubles are removed by settling only. It is therefore advisable to produce the best grade of salt during its manufacture by adopting the necessary precautions.

In the ammonium chloride and soda ash process, it is even more important since the purification step is limited to washing with pure brine and it is not practical to remove all the soluble and insoluble impurities by this means.

According to the Table 7, in Chapter V, composition of washed salt used in the ammonium chloride and soda ash process is NaCl 93.71% with moisture content 5.35%. On dry basis, the NaCl content of this salt will be about 99%.

Typical analysis of rock salt brines used in the soda industry is shown below:-

Table 10 - Typical Analysis of Rock Salt Brines:

	Wyandotte, Mich. Sp.Gr. 1.20.	Saltville Va 1.196 at 15°C.	Tawenpao, Szechwan, China 1.199 at 23°C.	Cheshire England (Natural Brine).
		Gms. per litre.		
NaCl	303.6	297.0	297.84	300.0
$CaSO_4$	4.8	5.15	4.774	4.0
$MgCl_2$	1.6	0.49	1.676	0.6
$MgSO_4$	-	-	0.758	0.7
Na_2SO_4	-	-	-	-
$CaCl_2$	-	0.81	-	-
$CaCO_3$	-	0.15	-	0.2

Source: Stanley Smith, Martin's "Industrial Chemistry, Inorganic", Part II, Vol.I, p.304, London, Crosby, Lockwood & Son.

A good grade of sea salt produced in solar salt works should fulfil the specification in Table 11.

Table 11 - Specification of Salt for soda industry.

NaCl	..	98.00%	minimum on dry basis
SO_4	..	0.55%	maximum on dry basis
Ca	..	0.20%	maximum on dry basis
Mg	..	0.20%	maximum on dry basis
Water insolubles		0.50%	maximum on dry basis

Sea Salt stored in stacks has a moisture content ranging between 3% and 6%.

Consumption of sea salt of the specification mentioned above with 5% moisture per unit production in the soda industry would be as given below:-

1) Salt consumption per ton of soda ash by ammonia-soda process.	1.8 to 2.0 tons
2) Salt consumption per ton of soda ash by ammonium chloride and soda ash process.	1.3 to 1.4 "
3) Salt requirement per ton of caustic soda - electrolytic process.	1.8 to 2.0 "

If the source of salt is from surface mines or underground bedded deposits in the vicinity of the soda ash or caustic soda factory, the normal practice is to dissolve the salt at the mine itself and transport it to the factory as saturated brine. In such an event, the consumption of brine, calculated as NaCl, would be less than that of sea salt by about 10%.

Another factor that influences the consumption and the labour costs in manufacture is the system of brine refining. In the past, brine was treated with chemicals in batch tanks. A quantity of brine was taken in a tank and treated with the necessary chemical reagents to precipitate the impurities. It was then transferred to a thickener to clarify the purified brine which overflowed into the launder of the thickener. A sludge pump withdrew the slurry of precipitates for rejection.

This batch system of purification is limited to small units in current practice and a system of continuous purification with countercurrent washing of sludge as shown in Flowsheet 3 is practised. The loss of salt in the sludge is reduced to minimum in this process and operating labour charges also reduced considerably.

(2) Limestone:

Limestone is an important raw material for the ammonia-soda industry. On calcination, it furnishes the carbon-di-oxide gas for carbonation of ammoniated brine and the lime for making of milk of lime for recovery of ammonia from ammonium chloride in the mother liquor from the bicarbonate filters.

Since the lime should possess good hydration characteristics and the gas has to be collected for use, static kilns for burning the stone are preferred to other types, on account of simplicity and low cost of operation. The burnability and burning characteristics of the limestone are more important than the actual analysis. It should neither clinker nor decrepitate. A good lime retains the shape of the stone after burning but becomes much lighter.

It is generally observed in practice that a limestone which is sedimentary in nature and falling within the specification given below may prove suitable:

Table 12 - Specifications for limestone.

$CaCO_3$	90 to 99 per cent
SiO_2, Al_2O_3, Fe_2O_3 ..	0 to 3 per cent
Mg CO_3	0 to 6 per cent

Ref: Manufacture of Soda by Dr.T.P. Hou -
Second Edition, P.84.

The impurities of silica, Al_2O_3 and Fe_2O_3 lower the fusion temperature of pure lime which is 2570° C and causes the formation of clinkers in the kiln. As clinkers in turn cause arching in the kiln, it may result in complete stoppage of discharge and thereby a break-down of operations.

In order to prevent channelling or obstruction to the flow of the gas evolved in the decomposition of stone, it is necessary to limit the variation in size in the feed. A common size of feed is "minus 4 inches" and "plus 2 inches", or "minus 100 mm" and "plus 50 mm". For any particular kiln and limestone, the best size of feed is determined by experience.

The kiln gas should have 39 to 41% CO_2 and entirely free from CO. The CaO in lime ranges from 70 to 80 per cent depending upon the extent of the other impurities.

The consumption of limestone conforming to the specifications given above is about 1.35 to 1.45 tons per ton of soda ash manufactured.

(3) Coke:

The fuel generally used for burning the limestone in ammonia soda plants is coke, as it is both economical and convenient. It is fed mixed with the limestone in predetermined proportions.

The formula given below can be used to calculate the quantity of coke required for any limestone of known composition:-

$$100\ A\ x = 6.10\ C + 4.90\ M + 9.38 \qquad (9)$$

A .. Fixed carbon content of the coke expressed as a fraction.
x .. Parts of coke required for 100 parts of limestone.
C .. Parts of $CaCO_3$ in 100 parts of limestone.
M .. Parts of $MgCO_3$ in 100 parts of limestone.

Source: Manufacture of Soda by T.P.Hou - P.110.

For example, the proportion of coke containing 80% fixed carbon required for burning limestone containing 94% $CaCO_3$ and 2% $MgCO_3$ will be

$$100(0.8)X = (6.10)(94) + 4.90(2) + 9.38 \qquad (10)$$

$$X = \frac{1}{80}(573 + 9.8 + 9.38) = \frac{592.18}{80} = \underline{7.4\%}$$

High ash content in coke is not conducive to production of good lime for two reasons. The ash contaminates the lime and thereby lowers its quality. It also causes the formation of clinkers in the kiln. Therefore, the ash content of coke commonly used in static kilns does not exceed 20 per cent.

(4) Ammonia:

In the ammonia soda process, theoretically, all the ammonia is recovered for reuse in the process and it is necessary to provide the first charge only. In practice, however, losses occur at various points in the process and they have to be made good. The main sources of loss are (1) to the atmosphere at the bicarbonate filters, (2) with the effluent of the ammonia stills due to incomplete recovery, (3) at the pump glands pumping ammoniated brine and (4) at the absorber washers.

In efficiently-run plants, the loss of ammonia is as low as 2 kg. per ton of soda ash. It is much higher in others. The factors which are beyond the control of the operators are the atmospheric temperatures and temperatures of cooling water. High temperatures aggravate the losses at the sources listed above.

Make-up ammonia can be in any of the forms (1) anhydrous ammonia (2) liquor ammonia (3) ammonium sulphate or chloride.

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If anhydrous ammonia is to be added as make-up, it is added to the ammonia gas stream entering the absorbers. If it is liquor ammonia, it is added to the mother liquor entering the ammonia still. If it is ammonium sulphate, it is dissolved in water and added to the mother liquor in the same manner as liquor ammonia.

Ammonia is an important raw material for the ammonium chloride and soda ash process. Its consumption is of the order of 0.32 tons of anhydrous ammonia for every ton of soda ash. All modern processes for manufacture of ammonia produce a pure product of standard quality unlike wide variations invariably associated with natural products.

The raw materials required for the soda industry and their unit consumptions are given in Table 13.

Table 13 - Raw Materials for Soda Industry and their unit consumption.

Raw Material.	Specification.	Product.	Process.	Consumption per ton product.
Salt	93.4% NaCl, 1.6% $CaSO_4$, $MgSO_4$ & $MgCl_2$, 5% H_2O	Soda Ash	Ammonia-soda process.	1.8 to 2.0 tons.
Salt	-"-	-"-	Ammonium Chloride-Soda Ash process.	1.3 to 1.4 tons.
Salt	-"-	Caustic Soda	Electrolysis.	1.8 to 2 tons.
Limestone	94% $CaCO_3$	Soda Ash	Ammonia-soda process.	1.35 to 1.45 tons.
Coke	80% Fixed Carbon.	Soda Ash	-"-	100 kgs. to 107 kgs.
Ammonia	99.5% NH_3	-"-	-"-	2 Kgs.
Ammonia	-"-	-"-	Ammonium Chloride & Soda Ash process.	0.32 tons to 0.33 tons.
Soda Ash	98.5%	Caustic Soda	Chemical	1.49

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Chapter 13 - Chemicals used in the Soda Industry.

As stated in an earlier chapter, the chemicals required for the purification of salt in the ammonia soda industry are (1) milk of lime and (2) soda ash. The same chemicals are used in purifying the brine which is discharged at the salt washery prior to its reuse for washing raw salt.

In the manufacture of caustic soda by the electrolytic process, either barium carbonate or barium chloride is used to precipitate the sulphate radical as barium sulphate, and sodium hydroxide is used in place of milk of lime since the presence of sulphate in any form is detrimental to the process.

In addition to the above, Sodium sulphide is used in the ammonia soda industry to prevent iron contamination of the product, soda ash. The carbonating towers are universally built of cast iron as it withstands corrosion and is economical. The cooling tubes in the carbonating tower are also of cast iron. As traces of iron are picked up by the bicarbonate in contact with cast iron, a sulphide coating is provided to prevent this contamination. A solution of sodium sulphide is added to the ammoniated brine stream entering the carbonating towers to maintain 0.08 parts of sulphide to 100 parts of chloride in brine. Due to the strong affinity of sulphur to iron, a coating of sulphide is deposited on the iron surfaces thereby preventing iron contamination of the bicarbonate. All the above chemicals used in the soda industry are of commercial grades.

An idea of the quantity of chemicals required in the soda industry can be obtained from the examples given below:-

Table 14 - Chemical Composition of Raw Materials assumed.

Salt.		Limestone.		Coke.	
NaCl	93.40				
$MgSO_4$	0.20	$CaCO_3$	94.00%	Fixed Carbon	80.00%
$MgCl_2$	0.64	$MgCO_3$	2.00%	Ash	20.00%
$CaSO_4$	0.64	SiO_2, Al_2O_3 etc.	4.00%		
H_2O	5.00				
Insolubles and rest	0.12				

Raw Salt consumption per ton of Soda Ash by ammonia-soda process is 1.8 tons.

Chemicals required for purification of brine per ton of soda ash produced; vide Chapter 10

(a) $Ca(OH)_2$ requirements

(i) For removal of $MgCl_2$, $Ca(OH)_2$ required will be

$$\frac{0.64 \times 1.8 \times 0.776}{100} = 0.009 \text{ tons}$$

(ii) For removal of $MgSO_4$, $Ca(OH)_2$ required will be

$$0.20 \times 1.8 \times 0.620 = 0.002 \text{ tons}$$

Total $Ca(OH)_2$ requirements .. 0.011 tons

Limestone requirements to produce 0.011 tons of $Ca(OH)_2$,

assuming 90% conversion in kiln: $0.011 \times \frac{100.09}{74.10} \times \frac{1}{0.94} \times \frac{1}{0.90}$

$= 0.019$ tons = 19 Kg.

(b) Na_2CO_3 requirements:

(i) For removal of $MgCl_2$ .. $\frac{0.64 \times 1.046 \times 1.8}{100} = 0.01$ tons

(ii) For removal of $MgSO_4$ .. $\frac{0.20 \times 1.284 \times 1.8}{100} = 0.0046$ "

(iii) For removal of $CaSO_4$ .. $\frac{0.64 \times 1.284 \times 1.8}{100} = 0.0148$ "

Total Na_2CO_3 requirements: $0.01 + 0.0046 + 0.0148$

$= 0.0294$ tons = 29.4 Kg.

<u>Coke requirements</u>:

7.4 per cent of limestone requirements

i.e. $\frac{7.4}{100} \times 0.019$ tons $= 0.014$ tons $= 1.4$ kg.

Thus the chemical requirements for purification of brine per ton of soda ash manufactured are:-

(1) Total limestone requirements ..	19 kg.
(2) Total coke requirements ..	1.4 kg.
(3) Total Na_2CO_3 requirements ..	29.4 kg.

In a Soda Ash Plant producing 200 tons per day daily requirements for brine purification will be:-

(1) Lime stone	.. 0.019×200	.. 3.8 tons
(2) Coke	.. 0.0014×200	.. 0.28 "
(3) Na_2CO_3	.. 0.0294×200	.. 5.88 "

Similarly, an example has been worked out below to assess the chemicals required for brine purification in the caustic soda industry:-

Chemical composition of salt is assumed to be NaCl 93.40%
$MgSO_4$ 0.20%, $MgCl_2$ 0.64%, $CaSO_4$ 0.64%, H_2O 5.00%
Raw Salt consumption per ton of NaOH is assumed to be 2 tons.

NaOH requirements:

Na_2CO_3 requirements

(1) For removal of $CaSO_4$, Na_2CO_3 requirements will be

$$\frac{0.64 \times 2 \times 0.78}{100} \quad 0.010 \text{ tons}$$

Ba_2CO_3 requirements:

1) For removal of $MgSO_4$, $BaCO_3$ required will be

$$\frac{0.20 \times 2 \times 1.390}{100} = 0.0056 \text{ tons}$$

2) For removal of $CaSO_4$, $BaCO_3$ required will be

$$\frac{0.64 \times 2 \times 1.390}{100} = 0.0177 \text{ tons}$$

Total requirements for purifying 2 tons of raw salt required per ton of caustic soda are 13.5 kg. of NaOH, 10 Kg. of Na_2CO_3 and 23.3. kg. of $BaCO_3$.

For a plant capacity of 100 tons of caustic soda per day, requirements of chemicals for purification of brine will be 1.35 tons of NaOH, 1 ton of Na_2CO_3 and 2.33 tons of $BaCO_3$ per day.

In actual practice, a slight excess of NaOH is used as it is less detrimental to have NaOH as excess than the Ca and Mg salts.

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Chapter 12 - Utility requirements in the Soda Industry.

Utilities consist of steam, electricity, process water and cooling water.

In the manufacture of soda ash by either ammonia soda process or ammonium chloride soda ash process, all the four utilities are required in substantial measure:

I - Utilities in soda ash manufacture by ammonia soda process:

(a) Steam:

Steam is used at the ammonia stills to distil the ammonia recovered from the mother liquor for reuse in the process. Since its function is to heat the liquor to the boiling point of about 105°C, its pressure does not have to be more than 2 atm. and hence, it is generally back pressure steam from the turbo generator, which serves dual function of generating electricity from high pressure steam and supplying back pressure steam to process. The pressure ranges in practice from 0.6 atm. to 2.0 atm.(9 to 29 psig). The quantity required is 1.8 to 2.0 tons per ton of soda ash manufactured.

High pressure steam,of about 30 atm. to 36 atm. (440 to 530 psig),is used at the calciner to convert the bicarbonate to carbonate. Quantity of steam consumed at the calciners is of the order of 1.75 tons to 1.90 tons per ton of light soda ash.

(b) Electricity:

For driving the carbon-di-oxide compressors,some factories use high pressure steam and exhaust it at a sufficiently high pressure to utilise the steam at the ammonia stills. The current tendency is to use electric driven rotary compressors for this duty and generate electricity with back pressure turbo-generators.

The ammonia soda process utilises a large number of pumps for various duties, such as cooling water, brine, process liquors in intermediate stages etc. There are also vessels with agitators and rotary equipment such as lime hydrator, calciner, filter, vacuum pumps and blowers. All these units are driven by electricity.

Handling of raw materials, viz.salt and limestone, and the finished product, soda ash, is mechanised in varying degrees from plant to plant. On account of wide variations in the extent of mechanisation, the scale of operations and the type of machinery employed, the

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quantum of electric energy required to produce 1 ton of soda ash by the ammonia-soda process varies from 200 kwh to 330 kwh.

The influence of scale factor of operations on the electric energy consumption may be gauged from the experience of a factory which increased its capacity from 150 TPD to 500 TPD over a period of about two years. Electricity consumption came down from 300 kwh to 220 kwh per ton of soda ash.

(c) Water:

Water is required for two distinct functions. The major consumption is for cooling the process liquor and the other is for process use. In chemical industry, it is universally recognised that colder supplies of cooling water give better performance than warmer supplies. It is particularly so in the ammonia soda industry since it is very essential to maintain the draw temperature of the bicarbonate magma at the optimum level of 30°C. Allowing for a 5°C approach temperature, the temperature of the cooling water should not be more than 25°C. In the case of ammonia absorbers also it is desirable to have water of this temperature for best performance, though water upto 35°C can be tolerated.

The quantity of heat that has to be removed at the ammonia absorbers during the absorption of ammonia and to maintain the discharge temperature at the optimum level of 30°C amounts to nearly 400 T-calories for every ton of soda ash. So also another 400 T-calories have to be removed at the carbonating towers for the formation of bicarbonate and to maintain the draw temperature of the magma at the optimum level of 30°C.

Allowing an 8°C rise in temperature of the cooling water, the quantity of cooling water required to achieve this quantity of cooling is 50 cu.m. of water at 25° per ton of soda ash output at the ammonia absorbers and another 50 cu.m. at the carbonating towers.

Cooling is also required at the ammonia stills to cool the ammonia recovered from the mother liquor and to condense the steam vapours. The initial temperature of the cooling water for this duty does not have to be as low as 25°C nor is the quantity required as large as that for the absorbers and carbonators.

The total quantity that has to be provided for cooling purposes in the plant is about 110 cu.m. per ton of soda ash at a temperature of 25°C.

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In the event that temperatures of the water supply available for the plant is significantly above 30°C, it will be necessary to employ artificial cooling to bring the temperature down. In such cases, the temperature of the chilled water would be about 20°C and the quantity reduced suitably.

Regarding the quality of cooling water, the main requirement is that it should be sufficiently clean as not to choke up the cooling tubes. Common sources of supply are the sea, large rivers or lakes.

Process water is required in the ammonia soda process for the following duties:-

(a) <u>For dissolving salt</u>:

3 cu.m. of water are required for every ton of salt. The choice of the quality of water to be used is decided on economical consideration. If adequate quantities of fresh water at reasonable cost is available at the site, it is preferred. On the otherhand, if fresh water is costly, or is not available in adequate quantities, sea water itself is used for dissolution of salt. As sea water contains, besides sodium chloride, salts of calcium and magnesium, they have to be removed by addition of purifying chemicals. In assessing purification costs, credit will have to be given for the quantity of sodium chloride contained in the sea water entering the process.

(b) <u>For preparing milk of lime</u>:

Water is first required to hydrate the lime to form slaked lime and additional water is required for preparing the milk of lime containing ultimately 200 to 250 gms. of $Ca(OH)_2$ per litre of solution. The total quantity of water required for this purpose will be about 2.5 cu.m. to 3.0 cu.m. of water per ton of soda ash.

(c) <u>For washing bicarbonate cake on the filter and for the chemical densification process</u>:

The quality of water for both these duties is very important, as otherwise, the impurities in the water will contaminate the product. Therefore, this requirement is provided by collection of steam condensates or by water which has been purified in a demineralisation plant. About 0.4 to 0.5 cu.m. are required at the filters and 0.2 cu.m. are required for chemical densification for every ton of soda ash.

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(d) Water requirements of steam generation:

The steam requirements are, as stated in an earlier section, 1.8 to 2.0 tons of low pressure steam for the ammonia distillation and 1.75 to 1.90 tons of high pressure steam for calciners per ton of soda ash. The total quantity is thus in the range of 3.55 to 3.90 tons of steam per ton of soda ash. Allowing for condensate return from calciner and the use of steam for boiler auxiliaries the boiler feed water requirements will be in the range of 2.33 to 2.59 tons of pure water, equivalent to demineralised water.

Table 15 - Consumption of utilities for manufacture of soda ash by ammonia-soda process.

			Per ton of Soda Ash.
1)	Steam L.P.	..	1.80 to 2.00 tons
2)	Steam H.P.	..	1.75 to 1.90 tons
3)	Electricity	..	200 to 330 kwh.
4)	Process Water	..	6.0 to 6.5 m^3
5)	Cooling Water	..	110 m^3

II - Utilities on soda ash manufacture by ammonium chloride and soda ash process:

Utility requirements for manufacture of soda ash in the ammonium chloride soda ash industry differs from that in the ammonia soda industry in the following particulars:-

(a) Steam:

Since there is no recovery of ammonia, the steam requirements for the ammonia still are not required.

(b) Electricity:

Since no low pressure steam is required, there is no possibility of employing back pressure turbo-generators. Either all the requirements of power will have to be generated in condensing turbines at site or will have to be purchased from public utility companies. Further, this requires additional electricity to provide chilled brine for cooling the ammonium chloride crystallisers. In the event, ammonia is also manufactured at site, electrical requirements will have to be provided for it also.

(c) Cooling Water:

While there is a saving of cooling water on account of the elimination of still gas coolers in this process, there is an increase on account of the cooling of the ammonia condensers of the refrigeration plant providing chilled brine to the ammonium chloride crystallisers.

The consumption of utilities in the ammonium chloride and soda ash industry are given in Table 16:-

Table 16 - Consumption of utilities per unit production of dual products.
viz. 1 ton of light soda ash and 1.04 tons of ammonium chloride.

Utility.		Consumption.
Steam H.P.	..	1.75 to 1.90 tons
Electricity	..	370 to 400 kwh.
Cooling Water	..	100 to 110 cu.m.
Process Water	..	2.0 to 3.0 cu.m.
Fuel Oil	..	12 to 20 kgs.

III - Utilities in manufacture of caustic soda by chemical process:

(a) Water:

Water is required to dissolve the sodium carbonate as also to prepare the milk of lime. As considerable quantities of water remain in the system as wash liquors which are used for dissolving fresh material, the quantity of additional water required for the process is equivalent to the quantity that goes out with the caustic lye and the wet carbonate cake. The quantity of water in the caustic lye depends on its concentration which ranges in practice from 8% to 14% NaOH.

The actual consumption of water, therefore, varies from 7 cu.m. to 12 cu.m. per ton of caustic soda.

(b) Steam:

Steam is required to concentrate the caustic lye to 50% NaOH, in multiple effect vacuum evaporators. Assuming triple effect evaporation, the steam requirement would be 3 tons to 5 tons per ton of caustic soda. Steam pressure generally used is about 7 atm. or 100 psig.

(c) Electricity:

Electricity is required for driving the agitators, filters, pumps etc. Its consumption is about 20 to 30 kwh. per ton of caustic.

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(d) Coal or Fuel Oil:

Coal or Fuel Oil is consumed at the furnaces of fusion pots for dehydrating the 50% NaOH lye and drumming the product. Consumption of fuel oil, with calorific value of 10,000 kg.-Cal. per kg., is about 0.23 tons per ton of caustic soda. If coal of 5600 kg.-Cal. per kg. is the fuel, consumption is about 0.40 tons per ton of product.

Table 17 - Consumption of utilities per ton of Caustic Soda by Chemical Process.

Utility.		Consumption.
Steam	..	3 to 5 tons.
Electricity	..	20 to 30 kwh.
Process Water	..	7 to 12 m^3
Cooling Water	..	80 m^3
Fuel Oil	10,000 kg.cal/kg.	0.23 ton
or Coal	5,600 kg.cal/kg.	0.40 ton

IV - Utilities in manufacture of caustic soda by electrolytic process.

Since the caustic lye from diaphragm cells contains considerable quantities of NaCl and the strength of NaOH is also low, it has to be concentrated in multiple effect evaporators. Such is not the case with lye from mercury cells as it is free from salt and is sufficiently concentrated for charging fusion pots or for marketing as such.

The consumption of utilities for both the processes is given in Table 18:-

Table 18 - Consumption of utilities in manufacture of caustic soda per ton of product.

		Diaphragm Cell.	Mercury Cell.
Electricity	Kwh.	3500	3800
Steam	Tons	3 to 4	-
Process Water	Cu.m.	4	4
Cooling Water	Cu.m.	80	-
Distilled or demineralised Water	Cu.m.	-	1.10

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Chapter 13 - Personnel Requirements in the Soda Industry.

It is generally accepted that chemical industry is not labour intensive nor do the requirements increase proportionately to the output. This holds good in the soda industry also. Processes in modern soda ash and caustic soda plants are largely controlled by instruments. Literate labour is, therefore, essential in order to be able to read the instruments and to understand and regulate operations.

The universal practice in these industries is to operate the plants round the clock and throughout the year without weekly breaks. The operating labour has, therefore, to operate in shifts and provision will have to be made for them to have weekly rest days and holidays. For example, for any point duty in operation it is necessary to provide more than three persons. In highly industrialised countries, where operators have acquired high skills, it is possible to group a number of operations and provide a factor of 3.5 for manning this group of operations. In developing countries, it is advisable to provide five persons for each point duty to ensure that a trained operator is available at all times to man the point duty.

The personnel requirements for any particular industrial unit will have to cover several functions besides actual operations of the plant. These are administration, procurement of supplies, maintenance and repairs of plant and equipment, supply of steam, electricity and water, and marketing of products. Since locational factors vary widely from one unit to another and the manufacture of soda ash or caustic soda is generally integrated to manufacture one or more allied products, it is obvious that no general estimate of personnel can be made for manufacturing either of these products. It is however possible to indicate the personnel requirements for the manufacturing sections as illustrated in the respective flow sheets. This is done in the following section of this chapter.

I - Personnel requirements for manufacture of Soda Ash.

Ammonia Soda Process - Reference Flow Sheet 3.
Capacities of Plants 200 tons per day and
500 tons per day.

Supervision:

The supervisory organization for plants with capacities as above consists of a Production Manager, assisted by an Assistant Production Manager and three Works Engineers - one Electrical, one Mechanical and one for Instruments. Both the Production Manager and the Assistant Production Manager would be chemical engineers well versed in the ammonia soda process. Since the raw materials and finished products, as also the material in process has to be chemically analysed at frequent intervals, a laboratory manned by a chemist and assistants would be necessary. The shift personnel required to conduct the manufacturing processes in the several sections would be as shown below:-

Table 19 - Shift Personnel for Soda Ash Plant - Ammonia Soda Process.

	Number required.	
	200 TPD	500 TPD
Production Foreman	1	2
Brine Purification Section Operators	1	2
Lime Kiln Operator	1	2
-"- Assistants	1	2
Milk of Lime Operator	1	2
Ammonia Still Operator	1	3
Ammonia Absorber Operator	1	3
Carbonating Tower Operators	2	4
Rotary Filter Operator	1	2
Calciner Operator	2	4
Dense Ash Operator	2	4
Soda Ash Packing Operator	2	2
-"- Labourers	6	12
Analytical Testers	2	2
Water Treatment Plant Operator	1	1
Steam Boiler Operator	1	1
-"- Assistants	2	2
Electricity Generating Plant Operator	1	1
-"- Assts.	2	2
Shift Engineer Mechanical	1	1
Shift Mechanics	2	6
-"- Assistants	2	6
Shift Electricians	2	3
-"- Assistants	2	3
Total	40	72
Total No. of Employees on roll at 5 per shift point.	200	360

For manufacturing soda ash by the ammonium chloride and soda ash process, Ref: Flow Sheet 4, capacities ranging from 200 TPD to 500 TPD, the number would be larger since the process yields two products simultaneously.

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The Supervisory staff would, however, be the same consisting of a Production Manager, an Assistant Production Manager and three Works Engineers. The shift personnel would be as in Table 20.

Table 20 - Shift Personnel for Soda Ash Plant.
Ammonium Chloride and Soda Ash Process.

		Number required.	
		200 TPD	500 TPD.
Production Foreman - Soda Ash	..	1	1
-"- Ammonium Chloride	..	1	1
Brine Purification Section Operators	..	2	4
Ammonium Chloride Crystallizer Operators	..	2	4
Refrigeration Plant Operators	..	1	1
Ammonium Chloride Dryer Operators		2	2
Ammonia Absorber Operators	..	1	3
Carbonating Tower Operators	..	2	4
Rotary Filter Operators	..	1	2
Calciner Operators	..	2	4
Dense Ash Operators	..	2	4
Soda Ash Packing Operators	..	2	4
Soda Ash and Ammonium Chloride Packing Operators	..	4	4
-"- Labourers	..	12	24
Analytical Testers	..	2	2
Water Treatment Plant Operator	..	1	1
Steam Boiler Operator	..	1	1
-"- Assistants	..	2	2
Shift Engineer - Mechanical	..	1	1
Shift Mechanics	..	4	8
Electric Substations Operators	..	2	2
Shift Electricians	..	2	3
-"- Assistants	..	2	3
Total	..	56	93

Total number of employees for manning the shifts in this case would be 280 for a 200 TPD Plant and 465 for 500 TPD Plant.

II Personnel requirements for manufacture of Caustic Soda by Chemical Process - (Reference Flow Sheet 5).

Plant capacity 20 TPD and 50 TPD, with
10 TPD & 25 TPD Fused grade respectively.

As a plant of this category is generally attached to a Soda Ash Plant, the personnel requirement given below is based on this presumption.

The supervisory organization would consist of a Departmental Head, who is a qualified chemical engineer, well experienced in the process. The engineering supervision would be provided by the main soda ash plant.

The shift personnel would be as shown in Table 21.

Table 21- Shift Personnel for Caustic Soda - Chemical Process.

	20 TPD	50 TPD
Shift Production Foreman	1	1
Operator - Soda Ash Dissolver	1	1
" Lime Hydration	1	1
" Reaction Tanks	1	1
" Vacuum Filter	1	1
" Multiple Effect Evaporator	1	1
Assistants to the Evaporator Operator	2	3
Operator - Fusion Pots	1	2
Labour for Packing	6	12
Total	15	23

The total personnel to be employed to man all the shifts would be 75 for plants of 20 TPD capacity increasing to 115 for plants of 50 TPD capacity.

III Personnel requirements for manufacture of caustic soda by electrolytic process:

The main difference between requirements of a mercury cell plant and that of a diaphragm cell plant is that, in the former case, the multiple effect steam evaporator is unnecessary whereas in the latter case it is. In other respects, the personnel would be the same.

The personnel required for operations indicated in Flow Sheets 6 & 7, for plants of capacity 10 TPD, 50 TPD and 100 TPD would be as shown in Tables 22 and 23.

Table 22 - Hooker Cell Installation - Personnel.

	10 TPD.	50 TPD.	100 TPD.
Production Manager ..	1	1	1
Assistant Production Manager ..	-	1	1
Works Engineer -			
Mechanical	1	1	1
Electrical	1	1	1
Instruments	-	1	1
Assistant Engineer - Electrical	-	-	1
Cell Maintenance Operator ..	1	1	1
-"- Assistants ..	1	2	4
Total ..	5	8	11
Shift Personnel:			
Production Foreman ..	1	1	1
Electricians ..	1	1	1
Operator - Brine Purification Section..	1	1	1
Assistants -"-	-	1	2
Operator - Electrolyser Cells	1	2	3
Operator - Multiple Effect Evaporators	1	1	1
Assistants -"-	2	4	6
Operator - Fusion Pots ..	1	2	2
Labour for Packing ..	6	12	16
Total ..	14	25	33
Total Number of Shift Employees ..	70	125	165

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Table 23 - <u>Personnel for Mercury Cell Installation</u>.

	10 TPD.	50 TPD.	100 TPD.
Production Manager ..	1	1	1
Assistant Production Manager ..	-	1	1
Works Engineer-			
Mechanical	1	1	1
Electrical	1	1	1
Instruments	-	1	1
Assistant Engineer - Electrical	-	1	1
Cell Maintenance Foreman	1	1	1
Assistants ..	1	2	2
Total ..	5	9	9
Shift Personnel:			
Production Foreman ..	1	1	1
Electrician ..	1	1	1
Brine Purification Section Operator ..	1	1	1
-"- Assistants..	-	1	2
Electrolyser Cells - Operator ..	1	2	3
Fusion Pots Operator ..	1	2	2
Labour for Packing ..	4	8	12
Total ..	9	16	22
Total Number of Shift Employees ..	45	80	110
Total Personnel ..	50	89	119

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Chapter 14 - Quality Control in the Soda Industry.

Control of the processes at each stage in the soda industry is, perhaps, the most important factor in the smooth and satisfactory performance of the factories. Experience proves that when the processes are well controlled, the performance of the plant is also satisfactory in all respects and the products are of high quality. A defect at any stage results in upsetting the performance and causes deterioration of quality, as also output.

Rigid quality control is achieved in modern plants by the adoption of the following measures:-

1) Extensive instrumentation - for control of flows, temperatures and pressures.
2) A control laboratory in charge of a chemist well trained in analytical methods for daily analysis of composite samples at important stages of the process.
3) Shift testers who go round the plant conducting spot analysis of samples at each stage of the process at defined intervals.

In addition to the above, some producers have introduced statistical quality control methods for checking the process operations and initiating remedial steps when the process shows a tendency to fall out of line.

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Chapter 15 - Capital Investment Requirements - Soda Ash.

The Soda Ash Industry is a capital intensive industry. Broadly speaking, the capital investments on plant and equipment of any two plants bear the relation expressed in the formula:

$$\frac{(C_1)}{(C_2)} = \frac{(D_1)^{0.6}}{(D_2)}$$

where C_1 and C_2 are capital investments and D_1 and D_2 are the respective daily capacities. According to this formula, a 500-ton per day plant does not cost five times a 100-ton plant but only 2.63 times.

Soda Ash being a widely used but low priced chemical is generally manufactured in large units, thereby effecting a reduction both in capital investments and labour requirements per unit production. Developing countries, intending to instal new plants, have therefore to consider the installation of units of as large a capacity as possible consistent with local requirements.

The minimum size that could be considered economical for a soda ash plant on the ammonia soda process in any of the developing countries is for a daily capacity of 200 tons. The maximum size of a new unit is unlikely to exceed 500 tons per day as even though conditions may be favourable in a country, it would be necessary to build up an organization for the supply of raw materials and distribution of products on large scale. A 500 tons per day plant would require a daily supply of about 900 tons of salt and 700 tons of limestone and produce 500 tons of finished product for sale. Further, the new industry would require considerable number of technical and professional men at all levels.

Therefore, for purposes of this study, investment costs are given for three scales of manufacture, 100 TPD, 200 TPD and 500 TPD. The 100 TPD is given as an illustration of the high investment cost for a small unit.

The entrepreneur desiring to instal a new plant would necessarily have to provide for the supply of raw materials, chemicals and stores and for the provision of utilities of fuel, steam, electric energy and water. He should also build up an organization for marketing his production.

As there would be very wide variations from one country to another and even from one plant to another in the same country if all the factors have to be taken into consideration, it would be futile to attempt to estimate for complete projects in this study. The investment costs that are considered here are, therefore, for the battery limits shown in Flow Sheet 3. Buildings,where necessary are included.

Table 24 - Investment Costs on Soda Ash Plants.
(Ammonia Soda Process)
Ref: Flow Sheet 3.

		100 TPD US $	200 TPD US $	500 TPD US $
A -	**Manufacturing Sections:**			
1.	Brine Purification	200,000	280,000	500,000
2.	Lime Kiln & Milk of Lime	460,000	700,000	1,250,000
3.	Ammonia Stills & Effluent	200,000	280,000	500,000
4.	Ammonia Absorbers	280,000	420,000	750,000
5.	Carbonating Towers	1,200,000	1,800,000	3,000,000
6.	Bicarbonate Filters	280,000	420,000	750,000
7.	Light Ash Calciners	600,000	900,000	1,500,000
8.	Dense Ash Plant (50% capacity)	140,000	200,000	350,000
9.	Packing & Storage	100,000	200,000	500,000
B -	**Service Sections:**			
1.	Steam Boilers	400,000	600,000	1,000,000
2.	Power Generation	400,000	600,000	1,000,000
3.	Gas Compression	400,000	600,000	1,000,000
4.	Water Supply & Treatment	200,000	300,000	500,000
5.	Yard Piping	200,000	300,000	500,000
6.	Electricity Distribution	120,000	180,000	300,000
7.	Maintenance Shop	150,000	200,000	300,000
8.	Laboratory	100,000	150,000	200,000
		5,430,000	8,130,000	13,900,000
9.	Miscellaneous @ 10%	543,000	813,000	1,390,000
		5,973,000	8,943,000	15,290,000
C -	Engineering, Know-how & Training @ 20%	1,194,600	1,788,600	3,058,000
	Total A, B & C.	7,167,600	10,731,600	18,348,000
	Investment per 1 TPD capacity.	$ 71,676	$ 53,658	$ 36,696

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Notes on Plant & Equipment:

Ref.

A. 1. (a) Static Salt Dissolver in reinforced cement concrete (R.C.C.) construction;
(b) Solution Tanks of mild steel construction (for the chemical reagents):
(c) Reaction Tanks with agitators of mild steel construction;
(d) Clarifiers and Thickeners consisting of R.C.C. Tanks with the rake mechanism and other parts built of steel.

2. (a) Static Lime Kiln built of sheet steel and lined with refractory bricks with feed and discharge mechanisms in steel and cast iron construction;
(b) Lime Silo in R.C.C. construction;
(c) Hydrator consisting of a rotary shell built of steel plates;
(d) Vibrating Screen for filtering the milk of lime;
(e) Milk of lime storage tanks with mechanical agitators in mild steel construction.

3. (a) Number of fixed and cast iron circular tray sections each with specially designed bubble caps in the fixed still section. The overall height of stills ranges between 25 to 30 m. high.
(b) The effluent is presumed to be discharged into the sea nearby in M.S. Pipes.

4. Tall cylindrical vessels of cast iron packed with porcelain raschig rings or saddles, in two sections. The brine from the upper section passes through a cooler before entering the lower section. Another set of coolers is provided between the absorbers and the storage tanks for ammoniated brine.

5. Built of cast iron ring sections with specially designed bubble caps inside each ring and with cooling section in the lower half of the tower. Each tower would be about 25 m to 30 m overall height.

6. Rotary cast iron filters designed for operation with vacuum pumps. The filtering surface is canvas or nylon cloth wound on the perforated drum.

7. Rotating tubular dryers about 20 to 30 m. long and 2 to 4 m in diameter provided with H.P. steam tubes internally.

8. Mechanical densification process.

9. Automatic Weighing & Stitching machines for packing in jute bags. The silos of steel plate.

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Table 25 - Investment Costs of Soda Ash Plants.
(Ammonium Chloride -Soda Ash Process).
Ref: Flow Sheet 4.

	100 TPD US $	200 TPD US $	500 TPD US $
A - Manufacturing Sections:			
1. Salt Purification	350,000	500,000	850,000
2. Ammonium Chloride Crystallization	1,000,000	1,500,000	2,600,000
3. Ammonium Chloride Centrifuges & Driers.	650,000	1,000,000	1,700,000
4. Ammonia Absorbers	280,000	420,000	750,000
5. Carbonating Towers	1,200,000	1,800,000	3,000,000
6. Bicarbonate Filters	280,000	420,000	750,000
7. Light Ash Calciners	600,000	900,000	1,500,000
8. Dense Ash Plant (50% capacity)	140,000	200,000	350,000
9. Packing & Storage	100,000	400,000	1,000,000
B - Service Sections:			
1. Steam Boiler	270,000	400,000	700,000
2. Electricity Receiving Station	130,000	200,000	350,000
3. Gas Compression	300,000	450,000	600,000
4. Water Supply & Treatment	160,000	250,000	400,000
5. Yard Piping	200,000	300,000	500,000
6. Electricity Distribution	120,000	200,000	300,000
7. Laboratory	100,000	150,000	200,000
	6,030,000	9,290,000	15,900,000
8. Miscellaneous @ 10%	603,000	929,000	1,590,000
	6,633,000	10,219,000	17,490,000
9. Engineering, Know-how & Training @ 20% ..	1,326,600	2,043,800	3,498,000
Total A, B & C.	7,959,600	12,262,800	20,988,000
Investment per 1 TPD capacity.	$ 79,596	$ 61,314	$ 41,976

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Chapter 16 - Capital Investment requirements for Caustic Soda.

In Chapter 2, three processes are described for manufacturing caustic soda, viz. chemical process of causticization of soda ash, electrolytic diaphragm cell process, electrolytic mercury cell process.

Further it is stated in Chapter 1 that the product is marketed in three commercial forms and in two grades. The forms are liquid caustic soda of 50% NaOH, fused caustic soda solid and caustic soda flakes. The grades are 97% to 99% NaOH with NaCl not exceeding 2%, and 99.5% NaOH with NaCl not exceeding 0.2%. Further processing to the fused solid, and flake forms are common to all processes.

Accordingly, the following investment cost estimates, relate to manufacture of the product as 50% NaOH lye by each of the three processes, and the last relates to the manufacture of fused solid and flakes.

With the development of the organic chemical industry, the demand for chlorine has been growing faster than the growth of most industries. Since the simplest method of manufacture of chlorine is electrolysis of salt, yielding both caustic soda and chlorine as co-products, this process accounts for over 90% of current total production of caustic soda in the world. The chemical process is confined to the large soda ash factories and that too long-established ones.

At the same time, it must be recognised that in developing countries, the problem of chlorine disposal is likely to arise. The chemical process does not have this draw back. Therefore, new soda ash plants in such countries are likely to be in a position to manufacture caustic soda also economically.

While considering investment costs for manufacture of caustic soda by the chemical process, it is presumed that it forms part of a soda ash factory and all utilities and services are available from the main plant. The capacities considered are 20 TPD, 50 TPD and 100 TPD, which fit in with the range considered for soda ash manufacture.

Table 26 - Investment Costs on Caustic Soda Plants.

(Unit: Thousand US Dollars)

Chemical Process - Ref: Flow Sheet 7.

	20 TPD	50 TPD	100 TPD
A - Manufacturing Section:			
1. Soda Ash Dissolving ..	1.8	3.0	4.6
2. Lime Hydrator ..	0.9	1.5	2.3
3. Reaction Tanks ..	1.2	2.0	3.0
4. Thickener for Caustic Lye	1.2	2.0	3.0
5. Countercurrent Washing Thickeners ..	1.8	3.2	4.9
6. Rotary Vacuum Filter with Vacuum Pump ..	5.8	10.0	15.2
7. Lye Storage Tank ..	1.6	2.8	4.3
8. Building for housing items (1) & (7) above ..	18.0	30.0	45.6
9. Multiple Effect Evaporator and auxiliaries ..	400.0	800.0	1,400.0
	432.3	854.5	1,482.9
B - Utilities & Services:			
1. Steam Piping ..	0.6	1.0	1.5
2. Electricity distribution	0.6	1.0	1.5
3. Compressed Air distribution	0.3	0.5	0.8
4. Water distribution ..	0.6	1.0	1.5
	434.4	858.0	1,488.2
5. Miscellaneous @ 10% ..	43.4	86.0	148.8
	477.8	944.0	1,636.0
C - Engineering, Know-how & Training @ 20% ..	95.6	188.8	327.2
Total A, B & C. ..	573.4	1,132.8	1,963.2
Investment per 1 TPD capacity	\$28,670	\$22,650	\$19,630

In considering investment costs of electrolytic caustic soda plants, the entrepreneur has to bear in mind the necessity to provide plant and equipment for chlorine utilisation or for its safe disposal. Since chlorine can be liquified and marketed in gas cylinders to consumers, most electrolytic caustic soda manufacturers provide liquefaction plants. Further, it is necessary to provide an absorption tower with milk of lime circulation for sniff gases vented from the liquefaction plants, as chlorine produced at the cells is contaminated with small quantities of other gases which do not get condensed in the liquefaction process. While these are vented to the atmosphere, the chlorine which passes with them has to be absorbed in milk of lime. Hence the cost of investment on chlorine liquefaction and on the absorption tower for sniff gases has been indicated in the estimates. If there are other outlets for chlorine utilisation for any particular installation it is obvious that these investment cost estimates do not apply to them.

Table 27 - Investment Costs on Diaphragm Cell Installations- (Hooker).

Unit: Thousand US Dollars.

Flow Sheet 8. Daily capacity as 100% NaOH

	10 tons	50 tons	100 tons
A - Manufacturing Sections:			
1. Brine treatment and purification.	100	250	350
2. Electrolytic Cells	160	450	700
3. Caustic Evaporation	300	800	1,400
4. Chlorine - Liquefaction Section	200	500	750
B - Utilities & Services:			
1. Steam Generation	95	250	400
2. Electrical Substation & Rectification	90	350	500
3. Electricity Distribution	30	75	120
4. Compressed Air Distribution	40	60	80
5. Yard Piping	40	100	160
6. Water Supply & Distribution and Drainage	20	50	80
7. Cell renewal shop	70	85	100
Sub-total	1,145	2,970	4,290
8. Miscellaneous @ 10%	115	297	429
	1,260	3,267	4,719
C. Engineering, Know-how & Training etc. @ 20%.	252	653	1,028
Total A, B & C ..	1,512	3,910	5,747
Investment for 1 TPD capacity.	$151,000	$78,200	$57,470

Table 28 - Mercury Cell Installation.

(Unit: Thousand US Dollars).

Ref: Flow Sheet 9.

		10 TPD	50 TPD	100 TPD
A -	**Manufacturing Sections:**			
1.	Brine Treatment and Purification Plant.	200	350	475
2. *	Electrolytic Cells	650	1,950	2,800
3.	Chlorine Liquefaction Section	200	500	750
B -	**Utilities & Service Sections:**			
1.	Electricity Substation & Rectification Plant.	90	350	500
2.	Compressed Air Supply & Distribution	40	60	80
3.	Water Supply & Treatment	20	45	70
4.	Yard Piping	50	90	150
5.	Electricity Distribution	35	75	120
	Sub-total	1,285	3,420	4,945
6.	Miscellaneous @ 10%	129	342	495
		1,414	3,762	5,440
C -	Engineering, Know-how & Training @ 20%	283	752	1,088
	Total A, B & C.	1,697	4,514	6,528
	Investment per 1 TPD capacity.	$169,700	$ 90,280	$ 65,280

* World price of mercury $ 5,000 per ton.

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On the subject of investment costs on fusion and flaking plants, the current practice is to build units for continuous operation instead of batch operation in single pots. The capital investment in such plants is higher than that of the fusion pot furnace installation but operating costs are much lower especially in large plants.

In this study, however, fusion pot furnaces only have been considered from the point of view of simplicity in operation. This is an important factor for selection of processes in developing countries. A typical installation consists of a number of cast iron fusion pots of hemispherical shape individually mounted on coal-fired or oil-fired furnaces. The capacity of each pot is about 16 tons of fused caustic. Pre-heating pots are sometimes employed to achieve better economy in fuel consumption by mounting them on flues leading from the furnace to the chimney stack. The equipment is housed in a well ventilated building with gantry crane to facilitate replacement of pots, whenever necessary. A special type of submersible pump suspended from the gantry crane is provided to transfer the fused materials to the drums for packing. A flaker is also provided in the same building to produce flakes. It consists of a rotating drum with L.P. steam or water circulation. The fused material is dropped in a thin stream on the rotating drum and the solid film is scraped off the drum by a knife. The flakes are packed in steel drums.

Further, as the market price of caustic soda lye, 50% NaOH, is significantly less than that of solid or flakes and, therefore, preferred by consumers, all manufacturers of caustic soda do not provide fusion plants and, even those that have, limit the capacity of the fusion plants to the minimum necessary to market their output. It must be remembered that two tons of caustic soda lye, 50% NaOH, is equivalent to one ton of fused material. Being a hazardous material, its movement from the producing factory to the consumer has to be in railway or road tankers. Since 2 tons of lye contains only 1 ton of NaOH, transport charges on nett NaOH delivered will be doubled when lye is delivered instead of solid. Therefore, there is an economical distance between the point of production and that of consumption beyond which it will be cheaper to transport fused material. Therefore, the investment costs for fusion plants are indicated for lower capacities, viz. 5 tons per day, 25 tons per day and 50 tons per day.

Since the caustic soda flakes cost even more than the solid, its use is confined to applications where the

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other forms cannot be used with equal facility. Therefore, the daily capacity of flaking plants is comparatively much smaller than that of other forms of caustic soda. The investment costs indicated below are for 1 ton per day, 5 tons per day and 10 tons per day of flakes.

Table 29 gives the investment costs for fusion and flaking plants.

Table 29 - Estimate of Investment cost on Caustic Soda Fusion & Flaking Plants.
(Ref: Flow Sheets 7,8 & 9)

	4 TPD Fused 1 TPD Flakes. US $	20 TPD Fused 5 TPD Flakes. US $	40 TPD Fused 10 TPD Flakes. US $
1. C.I.Fusion Pots, 16 ton - NaOH capacity @ $ 3000 each.	9,000	27,000	54,000
2. Furnaces in units of 2 fusion pots and 1 preheating pot @ $ 2000 per unit with one smoke stack per unit.	2,500	6,500	12,500
3. Submersible pump with electric motor @ $ 2000 each.	2,000	2,000	4,000
4. Flaker with electric motor.	3,000	5,000	8.000
5. Building with 10 ton gantry crane, hand-operated.	16,000	36,000	56,000
6. Miscellaneous @ 10%	3,200	7,600	13,400
Total	35,700	84,100	147,900

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Chapter 17 - Production Costs in the Soda Industry.

In the preceding chapters, the quantum of raw materials and chemicals, the consumption of utilities and the requirements of personnel were discussed. This chapter deals with production costs.

As costs of raw materials and chemicals and wage rates vary from one location to another, it is obvious that no estimate of production costs can be of universal application. The estimates which follow are based on experience in India, which is a developing country and, perhaps, nearer to costs in other developing countries.

Production cost of any product consists of two components, variable and fixed.

Variable costs consist of all items of cost which vary with the quantum of production. These are raw materials, process chemicals, utilities, packing materials etc. Production rates vary from day to day in all factories due to a variety of causes and the variation is followed by a corresponding variation in the consumption of raw materials, chemicals and utilities.

Fixed costs consist of all items of cost which are independent of production rates. These are administration charges, wages and salaries, interest on borrowings, depreciation of plant, machinery and buildings, maintenance of plant, machinery and buildings and selling expenses.

In the cost estimates which follow, administration charges, interest on borrowings and selling expenses have not been covered, as they vary with the structure of the manufacturing organization.

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The data on which the estimate of production costs are prepared are given in Table 26.

Table 30 - Data for Production Cost Estimates.

Raw Materials & Chemicals.	UNIT	US $	Remarks.
Salt (NaCl 98%)	Ton	4.00	Presumed that the marine solar salt works is located adjacent to the soda factory.
Limestone ($CaCO_3$ 96%)	Ton	3.00	Presumed that the limestone quarries are within 100 kms. of the soda factory and connected by rail.
Coke (C-80%)	Ton	15.00	On the basis that cokeries are situated 2000 kms. away from the soda factory or imported.
Ammonia (NH_3 99.5%)	Ton	100.00	Cost is based on the ammonia content of ammonium salt such as sulphate or chloride.
Soda Ash (Na_2CO_3 98.5%)	Ton	50.00	
Barium Carbonate	Ton	200.00	
Caustic Soda (NaOH 100%)	Ton	100.00	Price applies to lye, 50% NaOH
Sodium Sulphide	Ton	150.00	
Slaked Lime	Ton	15.00	
Utilities:			
Steam H.P. 30 Kg./cm^2	Ton	3.00	Steam produced at the factory with coal or furnace oil.
Steam L.P. 1 Kg./cm^2	Ton	1.00	Cost of steam from back pressure turbo generator.
Electricity A.C.H.T.	Kwh.	0.013 to 0.021	0.013/kwh. applies to electro chemical industries from large utility concerns. 0.021/kwh. applies to self-generation in B.P. turbo generator

Utilities.	UNIT	US $	Remarks.
Cooling Water 28°C	m^3	0.023	This represents pumping costs only from a large source, river or sea.
Process Water (8° Hardness)	m^3	0.10	Cost of potable water from a town supply system.
Demineralised Water	m^3	0.40	Cost applies to distilled water also.
Fuel	10,000 Kg Calories.	0.02	Either liquid fuel or solid fuel.
Personnel.			
Works Manager	Annual salary	7,000	
Departmental Heads	-"-	5,000	
Section Chiefs	-"-	2,500	
Engineers & Chemists	-"-	1,200	
Office Clerks	-"-	500	
Accounts Clerks	-"-	500	
Plant Foremen	-"-	1,000	
Plant Operators	-"-	750	
Skilled Workers	-"-	600	
Semi-skilled Workers	-"-	400	
Manual Workers	-"-	250	

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Table 31 - Estimate of Production Cost of Soda Ash by ammonia-soda process - Capacity 200 TPD - Annual Production 66,000 tons.

Variable Costs:

Raw Materials & Chemicals:	Unit.	Cost/ Unit.	Consumption per ton of product.	Cost per ton of product.
		$		$
Salt	Ton	4.00	1.80	7.20
Limestone	Ton	3.00	1.40	4.20
Coke	Ton	15.00	0.10	1.50
Ammonia	Ton	100.00	0.002	0.20
Soda Ash (captive consumption)	Ton	50.00	0.03	1.50
Sodium sulphide	Ton	150.00	0.002	0.30
Miscellaneous Stores & Chemicals.		Lump sum		2.00
Packaging Material-Jute Bags	100 pc.	30.00	13.33 pcs.	4.00
Utilities:				
Steam H.P.	Ton	3.00	1.80	5.40
Steam L.P.	Ton	1.00	1.80	1.80
Electricity	Kwh	0.013	270.00	3.51
Process Water	m^3	0.10	12.50	1.25
Cooling Water	m^3	0.023	110.00	2.53
Laboratory Services				0.50
Fixed Costs:				35.89
Salaries & Wages - Total annual bill		139,150	2.10	
Repairs & Maintenance @ 3% on capital investment			4.50	
Depreciation of Plant & Building @ 10% on Plant, 2½% on building and civil engineering works.			13.00	19.60
Cost of 1 ton of Soda Ash				55.49

N.B. Administration overheads and sales expenses have not been provided.

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Table 32 - Estimate of Production Cost of Soda Ash & Ammonium Chloride by Soda Ash-Ammonium Chloride Process - Capacity 200 TPD - Annual Production 66,000 tons of Soda Ash & 66,000 tons of Ammonium Chloride.

Variable Costs:

Raw Materials & Chemicals:	Unit.	Cost/ Unit. $	Consumption per ton of dual products.	Cost per ton of dual products. $
Salt	Ton	4.00	1.33	5.32
Ammonia	Ton	100.00	0.33	33.00
Slaked Lime (50% CaO)	Ton	15.00	0.05	0.75
Sodium Sulphide	Ton	150.00	0.002	0.30
Miscellaneous Stores & Chemicals.		Lump sum		2.00
Packaging Material	100 pcs.	40.00	26.66 pcs	10.66
Utilities:				
Steam H.P.	Ton	3.00	1.80	5.40
Electricity	Kwh.	0.013	385	5.01
Process Water	m^3	0.10	3.00	0.30
Cooling Water	m^3	0.023	110	2.53
Laboratory Services				0.50
				65.77
Fixed Costs:				
Salaries & Wages - Total annual bill		186,650	2.84	
Repairs & Maintenance @ 3% on capital investment.			5.00	
Depreciation of Plant & Building @ 10% on Plant 2½% on building and civil engineering works.			14.40	
				22.24
Cost of 1 ton of dual products, i.e. 1 ton of Soda Ash and 1 ton of Ammonium Chloride.				88.01

N.B. Administration overheads and sales expenses have not been provided.

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Table 33 - Estimate of Production Cost of 2 tons of Caustic Soda Lye (50% NaOH) by Chemical Process in a Soda Ash Factory - Capacity 50 TPD of 100% NaOH, Annual output 33,000 of Caustic Soda Lye of 50% NaOH equivalent to 16,500 tons of 100% NaOH.

Variable Costs:	Unit	Cost/ Unit. $	Consumption per ton NaOH	Cost per ton NaOH $
Raw Materials, Stores & Chemicals:				
Soda Ash	Ton	50.00	1.49	74.50
Slaked Lime (50% CaO)	Ton	15.00	1.00	15.00
Miscellaneous Stores & Chemicals.				1.00
Utilities:				
Steam	Ton	3.00	3.75	11.25
Electricity	Kwh	0.013	25	0.33
Process Water	m^3	0.10	10	1.00
Cooling Water	m^3	0.023	375	8.60
Laboratory services		Lump sum		0.60
				112.18
Fixed Costs:				
Salaries & Wages - Total annual bill		76,000	4.60	
Repairs & Maintenance @ 3% on capital investment			2.00	
Depreciation of Plant & Buildings @ 10% on Plant & Machinery and 2½% on Buildings.			6.70	13.30
Total cost of 2 tons of Caustic Soda Lye, 50% NaOH equivalent to 1 ton of 100% NaOH.				125.48

N.B. This caustic soda plant is assumed to be part of a Soda Ash Plant which provides the utility services. Also, administration overheads and sales expenses have not been provided.

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Table 34 - Estimate of Production Cost of Caustic Soda in Diaphragm Electrolytic Cells. Capacity of plant equivalent to 50 tons of 100% NaOH per day - Annual production 33,000 tons of Caustic Soda Lye 50% NaOH.

Variable Costs: Raw Materials, Stores & Chemicals:	Unit.	Cost/ Unit. $	Consumption per ton NaOH.	Cost per ton NaOH $
Salt	Ton	4.00	2.00	8.00
Soda Ash	Ton	88.00	0.010	0.80
Caustic Soda (captive consumption)	Ton	100.00	0.0135	1.35
Barium Carbonate	Ton	200.00	0.0233	4.66
Graphite	Ton	700.00	0.003	2.10
Miscellaneous Stores & Chemicals		Lump sum		1.00
Utilities:				
Steam	Ton	3.00	3.75	11.25
Electricity	Kwh	0.013	3500	45.50
Process Water	m^3	0.10	4	0.40
Cooling Water	m^3	0.023	375	8.60
Laboratory Services		Lump sum		0.50
				84.16

Fixed Costs:			
Salaries & Wages - Total annual bill	71,000	4.30	
Repairs & Maintenance @ 3% on capital investment		7.10	
Depreciation on plant and buildings @ 10% on Plant & Machinery and 2½% on Buildings and Civil Works.		22.90	34.30
Total cost of 2 tons of Lye of 50% NaOH and 0.88 tons of Chlorine (gas) and 0.025 tons of Hydrogen Gas.			118.46

N.B. Administration overheads and sales expenses have not been provided.

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Table 35 - Estimate of Production Cost of Caustic Soda in Mercury Cells - Capacity of plant equivalent to 50 tons of 100% NaOH per day - Annual production 33,600 tons of Caustic Soda Lye 50% NaOH.

Variable Costs:

Raw Materials, Stores & Chemicals:	Unit.	Cost/ Unit. \$	Consumption per ton NaOH.	Cost per ton NaOH \$
Salt	Ton	4.00	2.00	8.00
Soda Ash	Ton	80.00	0.010	0.80
Caustic Soda (captive consumption)	Ton	100.00	0.0135	1.35
Barium Carbonate	Ton	200.00	0.0233	4.66
Graphite	Ton	700.00	0.003	2.10
Miscellaneous Stores, Mercury &Chemicals		Lump sum		3.00
Utilities:				
Electricity	Kwh	0.013	3800	49.40
Process Water	m³	0.10	4	0.40
Laboratory services		Lump sum		0.50
				70.21

Fixed Costs:

Salaries & Wages - Total annual bill	57,000	3.45	
Repairs & Maintenance @ 3% on capital investment		8.18	
Depreciation on Plant and Buildings @ 10% on Plant and 2½% on Buildings and Civil Works.		26.60	38.23
Total cost of 2 tons of Lye, 50% NaOH, 0.88 tons of Chlorine (gas), 0.025 tons of Hydrogen (gas).			108.44

N.B. Administration overheads and sales expenses have not been provided.

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Table 36 - Estimate of Production Cost of Fused Caustic Soda.

Installed Capacity 25 TPD
Fused Caustic Soda -
Annual Production 8,250 tons.

Variable Costs:

Raw Materials, Stores & Chemicals:	Unit.	Cost/ Unit. $	Consumption per ton NaOH.	Cost per ton NaOH $
Caustic Soda Lye 50% NaOH	Ton	50.0	2.02	101.00
Miscellaneous Stores & Chemicals.		Lump sum		2.00
Packing drums for 300 Kgs NaOH	No.	4.0	3.34	13.36
Liquid Fuel 10,000 Kg Cal/kg.	Tons	20.0	0.10	2.00
Electricity	Kwh	0.013	20.00	0.26
Laboratory Services		Lump sum		0.10
				118.72

Fixed Costs:

Salaries & Wages	- Annual Bill	13,750	1.66	
Repairs & Maintenance			0.30	
Depreciation on Plant & Buildings			0.60	
				2.56
Total estimated cost of 1 ton of Fused Caustic Soda.				121.28

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Table 37 - Estimate of Production Cost of Caustic Soda Flakes.

Installed capacity 5 TPD of
Flakes -
Annual Production 1650 tons.

Variable Costs:	Unit.	Cost/ Unit. $	Consumption per ton NaOH	Cost per ton NaOH $
Fused Caustic Soda in Pots	Ton	106.0	1	106.00
Packing drums of 50 Kg NaOH	No.	1.0	20	20.00
Electricity	Kwh	0.013	20	0.26
Fixed Costs:				
Salaries & Wages				1.66
Repairs & Maintenance				0.10
Depreciation on Plant & Buildings				0.30
Total estimated cost of 1 ton of Caustic Soda Flakes.				128.32

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Chapter 18 - Programming techniques for establishing Soda Industry.

Soda Ash and Caustic Soda are basic chemicals which are necessary for the development of the chemical industry in any country. This should be apparent from the fact that no other chemical except sulphuric acid is manufactured on the same scale. In the foregoing chapters, the requirements of raw materials, chemicals, utilities and manpower as also investment costs and manufacturing costs have been dealt with. This chapter deals with the programming techniques for the manufacture of these two chemicals in developing countries.

I - Programming technique for Soda Ash Industry:

For progr mming production of soda ash in any region, it is necessary to determine the extent of the demand which the manufacturing unit has to meet.

This can be assessed by reviewing the import statistics of not only soda ash, but also products in the manufacture of which soda ash is used to a significant extent. Table 38 gives the common end uses of soda ash and their consumptions on a broad basis.

Table 38 - End Uses of Soda Ash.

Industry.	Approximate consumption of soda ash per ton of product.
Glass ..	0.30 ton
Caustic Soda(Chemical process)	1.50 "
Sodium Bichromate ..	1.00 "
Sodium Bicarbonate ..	0.80 "
Sodium Silicate ..	0.10 "
Paper, Paper boards and newsprint ..	0.02 "
Cotton Textiles ..	2.50 " per million metres.

The end uses listed above are by no means exhaustive. There may be some other which is important for a particular country. For example, soda ash is used on a very large scale in laundries both organized and on cottage scale in India.

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After investigating the market potential in the country, the next step would be to review whether the scale of manufacture will be such as to produce the product economically. As Soda Ash is a basic chemical for other industries, it is necessary to ensure that cost of production is not excessive compared to world prices. In U.S.A., Soda Ash is sold at about $ 34.00 per metric ton. The same level of prices holds good in the industrially advanced countries of Europe. There is no doubt that no new unit in a developing country will be in a position to achieve production costs at these levels. Nevertheless, the cost of production, compared to the landed cost of imported products should not be excessively high for the simple reason, that if it is so, it will have an adverse effect on the growth of consuming industries.

By and large, it is not considered economical to build soda ash factories for less than 200 tons per day capacity.

The examination of the potential demand is likely to indicate, that notonly the basic chemical but one or more of the end use products too, have to be manufactured in order to build plants of economical scale of manufacture. For instance, a country may be importing large quantities of sheet glass in addition to soda ash itself. In such an event, the programming for indigenous manufacture would have to cover both the establishment of a sheet glass factory and a soda ash factory. Both in U.S.A. and Japan, there are large sheet glass factories producing soda ash also.

After investigating the market potential, the next step would be to examine the availability of raw material. It is apparent from a perusal of Chapter 10 that common salt is the principal raw material for the soda ash industry. Though manufacture of salt is very widely spread in the world, there are some countries which do not produce any on account of unfavourable factors. By and large, the availability of salt is a very important consideration for the development of the soda ash industry in any region. Japan, however, is the only country which has an extensive and well established soda ash industry based on imported salt. It is because indigenous demand for soda ash, availability of electricity, fuel and water, availability of technical skills and facilities of transport, are favourable for the development of the soda industry in that country. Since a developing country would not have these advantages, it is likely to find it difficult to build up the soda ash industry on the basis of imported salt.

Salt requirements for a 200 TPD Soda Ash Plant is indicated in the Table 39 below:-

Table 39 - Salt requirements for Soda Ash.

	Per day.	Per Year.
1. Soda Ash by ammonia-soda process, capacity 200 TPD. ..	360	120,000
2. Soda Ash by ammonium-chloride and soda ash process, capacity 200 TPD. ..	260	86,000

It is seen that quantities are substantial and transport charges will increase the cost substantially, if the source of salt is not located sufficiently near to the soda ash factory.

In the event the investigation of the market demand indicates that it would be necessary to initiate manufacture of another product, such as, glass or caustic soda in order to undertake an economical scale of manufacture of soda ash, the programming should obviously cover its manufacture too.

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II - Programming techniques for Caustic Soda Industry:

In Chapters 7-9, two processes, the chemical process and the electrolytic process, are described. It is also stated that currently the electrolytic process is more widely used, since the demand for chlorine, a co-product of caustic soda in the electrolysis of common salt has been growing very rapidly during the last few decades. While this is the state in industrially advanced countries, disposal of chlorine presents a very serious problem in developing countries. Therefore, the investigation for programming production of caustic soda has to include the utilization of both caustic soda and chlorine. Since utilization of chlorine is beyond the scope of this paper, it is not discussed at length in it, but it is essential that any entrepreneur venturing into the electrolytic caustic soda industry goes thoroughly into the subject.

The common end uses of caustic soda are given in Table 40.

Table 40 - End Uses of Caustic Soda.

	Industry.	Approximate Consumption of Caustic Soda per ton of product.
1)	Rayon, Cellophane ..	1.00 Ton
2)	Soaps (conventional) ..	0.13 "
3)	Aluminium ..	0.25 "
4)	Paper, Paper Boards and Newsprint ..	0.10 "
5)	Cotton Textiles (Per million metres)	6.00 "

These end uses are illustrative and by no means exhaustive. Having collected data about the imports of caustic soda, chlorine and the main end use products of these two chemicals, an assessment of the existing potential demand can be made and thereby the capacity of the industry that may be established in the region can be derived.

A perusal of the production cost estimates for electrolytic caustic soda reveals that the cost of electric energy is one of the main items of cost. These cost estimates also indicate the extra cost that would have to be incurred for converting caustic soda lye of 50% NaOH to

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the fused product. Further, being classified as hazardous chemicals, transport costs of chlorine and caustic soda between producer and consumer are heavy. At the same time, the investment costs on the basis of daily ton capacity are not particularly favourable to large scale plants.

These factors have resulted in a much wider distribution of manufacture of caustic soda in the world as a whole and also in any particular country. It is possible to build plants in areas of low cost electrical energy just large enough to meet the local needs and operate them economically. Such a location would have the further advantage of the facility to supply the consumer with caustic lye of 50% NaOH which is marketed at a substantially lower price due to the elimination of fusion costs in manufacture. Since the paper industry consumes both caustic soda and chlorine, it is not uncommon to find captive production of caustic soda in paper mills.

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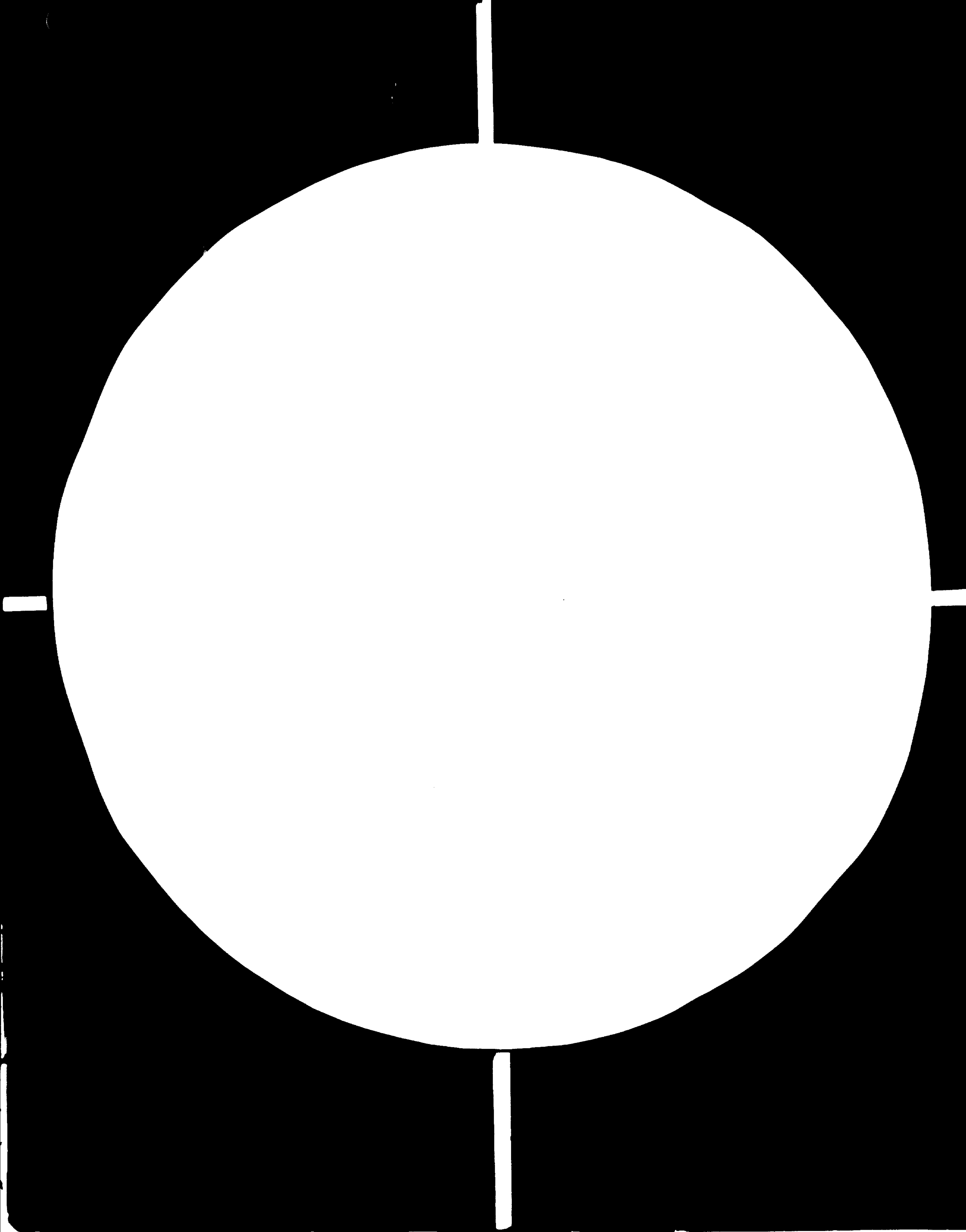

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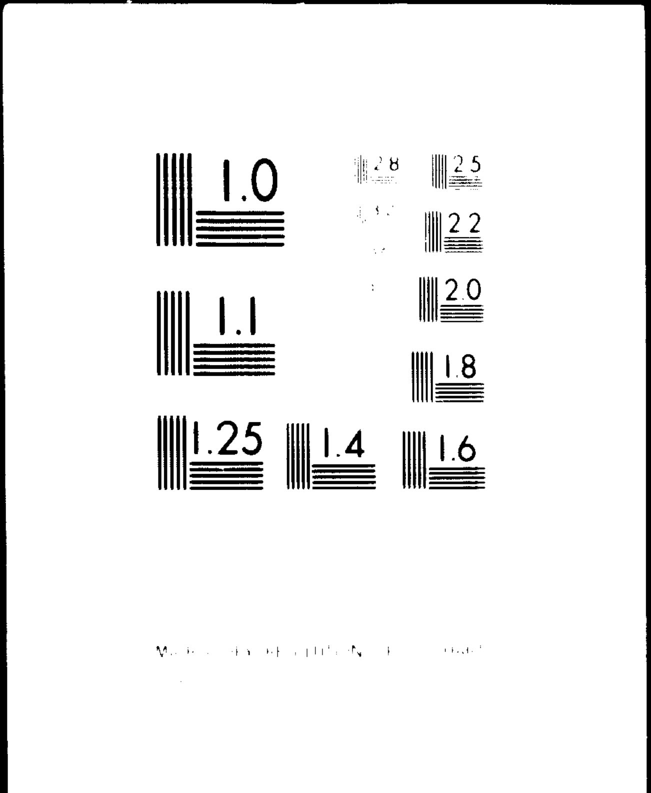

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Chapter 19 - Factors of Location for the Soda Industry.

The factors of location are (1) proximity to markets (2) availability of raw materials (3) availability of electricity, fuel and water (4) availability of personnel with the requisite skills (5) facilities of transport (6) facilities for disposal of effluent and (7) availability of land.

(1) Proximity to markets:

This is an important factor to determine the viability of a project to manufacture either soda ash or caustic soda. The import statistics of the country furnishes the data regarding imports of soda ash and caustic soda is determined by the existence of other industries consuming these products. In developing countries, it is likely that even the consuming industries are not well developed. The study of the import statistics should, therefore, be extended to cover the imports of other products in the manufacture of which either soda ash or caustic soda is consumed on a significant scale in order to assess the potential demand.

In the case of soda ash, the extent of the potential consumption demand in any country can be gauged by collecting data pertaining to the import of not only soda ash itself but also products consuming soda ash, such as glass, caustic soda, sodium bicarbonate, sodium bichromate, sodium silicate and sodium tripolyphosphate. It may be that though the scale of imports of soda ash does not justify a soda ash factory, an integrated unit to manufacture soda ash along with another product may be justifiable.

Regarding caustic soda, the main end uses are rayon and films, paper and pulp and soaps and cleansers. Therefore, the total potential demand can be assessed by collecting import data for not only caustic soda but also these products.

This factor of proximity to markets is particularly important for locating caustic soda manufacture. It is apparent from a perusal of production cost in Chapter 17, that the cost of fusion and packaging in drums adds substantially to the cost of caustic lye of 50% NaOH. Therefore, if the entire quantity can be marketed as lye, both manufacturer and consumer would benefit from the low cost. On the other hand, if the markets are situated far

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away, transport of 2 tons of lye of 50% NaOH may be far costlier than that of 1 ton of fused solid of 97% to 99% NaOH.

In Chapters 15 & 16, the influence of the scale factor on plant investment costs was discussed. It was seen that the relative investment costs are very high for small capacity plants. Therefore, it is necessary to assess the demand from the long range point of view, not only to meet the existing demand but also the demand likely to arise in the future.

(2) Availability of raw materials:

Raw materials required for the manufacture of soda ash by the ammonia soda process are salt, limestone, coke and ammonia. In the ammonium chloride and soda ash process, the raw materials are only salt and ammonia. Caustic Soda by chemical process requires soda ash and hydrated lime whereas caustic soda by the electrolytic process requires only salt as raw material. It is important to investigate the availability of these raw materials and their costs as a factor of location. In Chapter 10, the consumption of raw materials per ton of product has been discussed. Since 3.50 to 4 tons of raw materials are required per ton of soda ash, the proximity of the source of raw materials is obviously a very important factor of location for the soda ash industry.

(3) Availability of fuel, electricity & water:

In Chapter 12, the consumption of utilities for unit production of caustic soda and soda ash was indicated. In the ammonia soda process, since substantial quantities of low pressure steam are required, the common practice is to produce high pressure steam and use back pressure turbo-generators for generating electricity required in the process and supply the low pressure exhaust steam to the ammonia stills. This does not apply to the dual process of manufacture of ammonium chloride and soda ash and the manufacture of caustic soda. Therefore, these factories draw their electricity requirements from public supply power stations and generate steam to the extent necessary to meet the needs of any other use in the plants.

Regarding electrolytic caustic soda, the cost of electrical energy is one of the main factors of location. A perusal of the production cost in Chapter 17 shows that nearly 4,000 units of electricity are required to produce a ton of caustic soda. A difference of 0.1 cent (US) per Kwh in the cost of electricity means a difference of $ 4.00 in production cost of a ton of caustic soda. Therefore, while considering location for new units, the cost of electricity at each location should be given due consideration.

Some hydro-electric power supply authorities offer reduced rates for electricity supplied during periods of 'off-peak' hours, especially if the main load on the station is city lighting. In these instances, the peak hours would be about 4 hours after sunset. Electro-chemical industries, such as electrolytic caustic soda, can be located in these areas, operating at full capacity during off-peak load hours and at reduced capacity during peak hours, thereby achieving low cost of production. The possibility of such concessions being only of a temporary nature should not be overlooked. The power supply authorities generally withdraw these concessions, once other industries in the region are established and the load factor on the generating station rises to a satisfactory level.

It is learnt that some caustic soda units in Japan had been established some decades back near hydro-electric stations to operate at 'off-peak' hours at reduced rates. Since end of the Second World War, they have been transferred to other regions, nearer the markets where such concessions do not prevail.

In the same chapter, the requirements of water also has been discussed. Soda Ash factories operating the ammonia soda process require large quantities for dissolving salt and for making milk of lime and still larger quantities for cooling. While the cooling water does not have to be of the potable quality, it should be preferably so for dissolving salt in order to keep down the cost of brine purification. The temperature of the cooling water is, however, very important. It should not exceed 28°C. If it does, artificial cooling measures will have to be provided, thereby increasing manufacturing cost.

In soda ash manufacture by the dual product process, it is necessary to have water of potable quality to the extent of 3 cu.metres of water per ton of soda ash. The cooling water requirements would be the same as for ammonia soda process.

Water requirements for the manufacture of electrolytic caustic soda is of the order of 4 cu.metres per ton of caustic soda. It should be of potable quality. Cooling water is required for the vacuum system of multiple effect evaporators, if the electrolysers are of the diaphragm type.

Regarding fuel, since the quantities required in the soda industry are moderate, it is not an important factor of location.

(4) Availability of personnel with the requisite skills:

Since the manufacturing processes in the soda industry are controlled by instruments, it is advisable to provide labour educated at least to the middle school standard. Since the number required is moderate, it may not be a problem to recruit such labour. Training facilities are however necessary and should be provided adequately in all locations.

(5) Facilities for transport:

For a soda ash factory, it is advisable to choose a location where facilities for road, rail and water transport are all available. A 200 TPD soda ash factory operating the ammonia soda process consumes daily about 400 tons of salt, 280 tons of limestone and 100 tons of coal and produces 200 tons of product. A similar factory operating the ammonium chloride and soda ash process consumes daily 280 tons of salt and 70 tons of anhydrous ammonia and produces 400 tons of finished products. Since these quantities are large, the importance of having all mode of transport is apparent.

In the case of caustic soda factories, the extent of the facilities for transport depends on the scale of manufacture and the extent of the region for marketing the product.

(6) Facilities for disposal of effluent:

This factor is particularly important for a soda ash factory operating the ammonia soda process. About 10 cu.metres of effluent containing about 1 ton of calcium chloride and 0.5 tons of salt have to be discharged for every ton of soda ash produced. A 200 TPD plant will produce daily 2,000 cu.metres. As this is harmful to marine and plant life, it has to be discharged into the sea or a large river, so that it gets sufficiently diluted to be innocuous. The importance of this facility cannot be over estimated.

In the case of soda ash manufacture by ammonium chloride soda ash process, no effluent of this nature and magnitude is produced and therefore this facility is not an important factor for selection of location. The same applies to the manufacture of caustic soda.

(7) Availability of land:

Soda Ash plants employ equipment which are unusually tall and heavy on the foundations. It is therefore advisable to select sites which have good load bearing characteristics. Caustic Soda plants, on the other hand, do not have this feature and they can be located on any land with normal soil conditions.

Regarding the extent of the land required for establishing factories, it is advisable to bear in mind possibilities of future expansion as it may prove difficult to extend the factory limits at a later date. A rough thumb rule is to provide 0.1 hectare per daily ton capacity of soda ash or caustic soda at the time of establishing a new factory. This will enable expansion of the factory to increase capacity or to add new lines of manufacture to a substantial extent.

While considering the location of soda ash plants, it is necessary to bear in mind, the source of supply of salt which is the main raw material. If the source is surface mines or bedded deposits underground, it is obvious that the location of the factory should be in the immediate vicinity of the source consistent with other factors of location. In the event the deposits of salt are located far inland there is no satisfactory outlet for the effluent from the ammonia soda process, the dual product process would have to be considered.

If the supply of salt is to be from solar salt works on the sea coast, the location of the soda ash factory would then have to be in its immediate vicinity in order that transportation costs are reduced to the minimum.

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Chapter 20 - Recent Developments in the Soda Industry.

Both the branches of the soda industry of today may be considered to have born at the end of the last century. Ernst Solvay invented the ammonia soda process of manufacture of soda ash about the year 1870 and a little later, Siemens invented the direct current generator which led to the electrolysis of brine to produce caustic soda. Though both these industries are about a hundred years old, their development has not followed the same pattern.

(a) Soda Ash:

The soda ash industry was highly secretive and each factory was jealous of preserving its know-how with the result that even today there are only about 64 plants spread over 24 countries in the world as shown in Table 41. A perusal of Tables 1 & 2 shows that nearly 80 per cent of the world production is accounted by hardly a dozen producers in the six highly industrialised countries, viz. U.S.A., U.S.S.R., U.K., Germany, France and Japan.

Such being the situation, information about new developments in the soda ash industry is rather sparse in the technical press. Nevertheless, the author has been able to collect a few instances of new developments in the industry. These are:-

(1) Use of dry lime in place of milk of lime in the ammonia stills. The dry lime which has been crushed and screened, is injected with a special device in the fixed still section of the ammonia still. Since the use of dry lime means a considerable reduction in the amount of water fed into the still, it results in corresponding saving in steam consumption and saving in power on disposal of reduced quantities of effluent.

(2) Elimination of return ash at the calciners. The usual practice is to mix equal or more quantities of the hot ash with the wet bicarbonate prior to feeding the calciner, as otherwise the wet bicarbonate builds up encrustations inside it and obstructs free flow of the material. In the new process, a specially built sprayer sprays the wet bicarbonate well inside the calciner, in the form of a mist. It is claimed that the elimination of return ash reduces the load on the calciner and saves fuel.

(3) Mechanical Densification. This has been described in Chapter 6 in the text.

(b) Caustic Soda:

The electrolytic caustic soda industry has not been so secretive as the soda ash industry. It has undergone considerable development since the first cell was built towards the end of the last century.

The development that is most in evidence today is higher current ratings in both diaphragm and mercury cells. Hooker cells are being offered with 40,000 amps. ratings against the 10,000 amps. of the earlier type but only slightly larger in physical dimensions. Mercury cells are being built with current ratings of 150,000 amps. and above, and current densities on the cathode surface of 5 to 6000 amps. per sq.metre. The objective underlying these developments is to get higher output without corresponding increase of cell dimensions. Investment costs are reduced thereby both on buildings and on plant.

Another development is the use of platinized titanium anodes * in place of graphite anodes. Unlike graphite anodes which wear in service and require replacement, the platinized titanium anodes do not wear in service. The chlorine produced in these cells is also purer. Ti is used as it resists chlorine corrosion by forming a tough oxide film. To overcome the electrical resistance of this film, a thin Pt coating is applied to the surface of Ti.

Modern caustic soda fusion plants operating on the continuous principle are replacing open-fired caustic pots. One manufacturer of plants builds plants similar to multiple effect vacuum evaporator with dowtherm heating. Another builds plants with four pots in series but installed as a cascade in a common furnace. Caustic lye, 50% NaOH, is fed continuously into the highest pot and fused caustic is drawn also continuously from the lowest pot.

Another development which is of particular interest to developing countries is that many well-known manufacturers in the West and Japan are prepared to assist them to set up new factories and to undertake engineering and acquiring plant and equipment and to train the personnel at all levels. Such assistance and collaboration was unobtainable before the Second World War. In the last decade or two, several new plants in developing countries have been set up successfully with technical collaboration from some of the large and experienced manufacturers.

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*Source: Chemical Engineering Vol.69, No.2, Jan.22, 1962.

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FIG 3 - COMPLETED SIX-TENTHS FACTOR NOMOGRAPH

BY A.B. BABCOCK JR., CHEMICAL ENGINEER,
JULY 1954, CHEM. ENGINEERING, PAGE 244

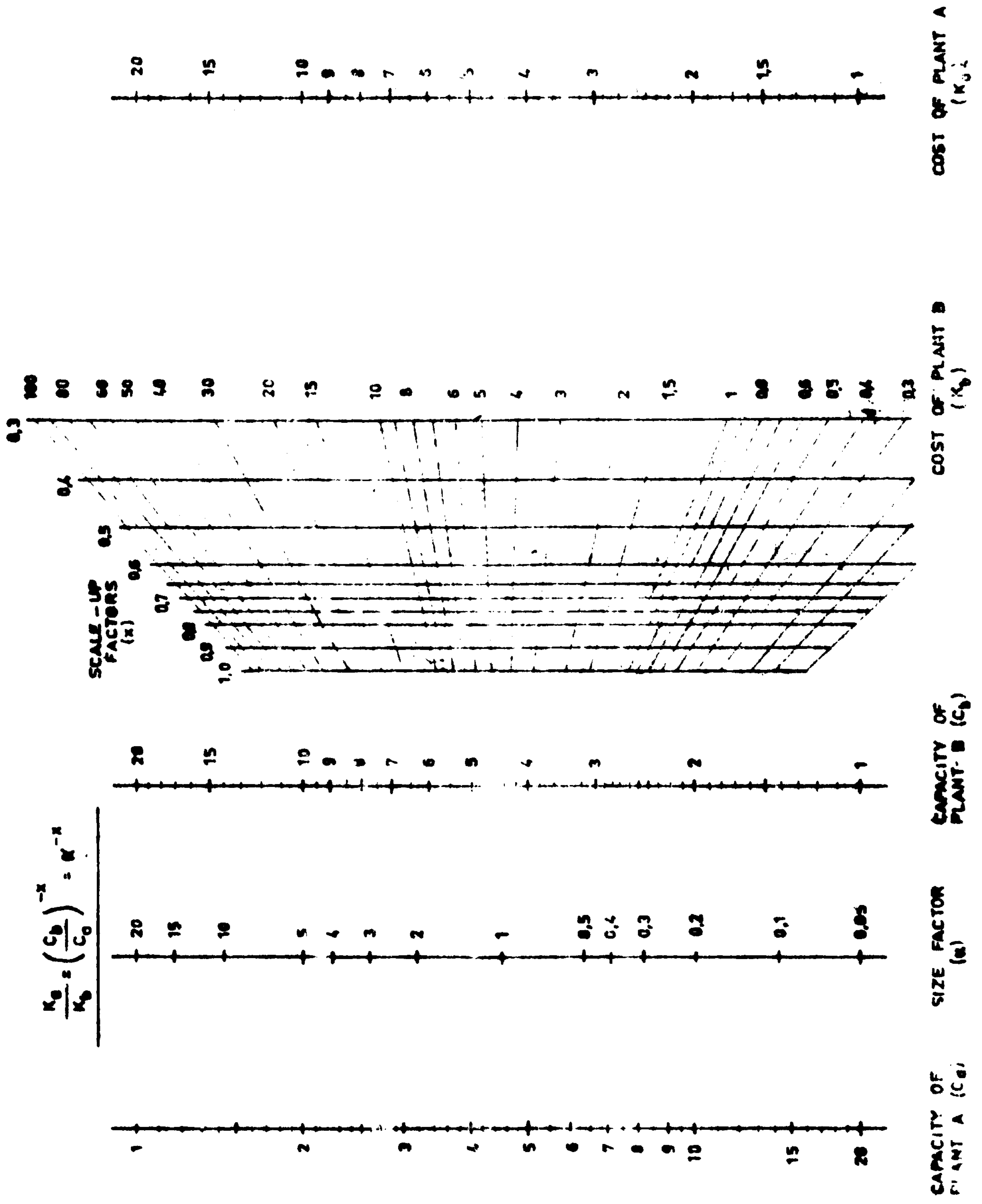

Table 41 - World's Ammonia-Soda Plants.

Name.	Location.	Year Built.	Estimated daily soda ash capacity. (short tons).
I -	AUSTRALIA		
1. Imperial Chemical Industries Ltd.,	Adelaide	1940	100
II -	AUSTRIA		
2. Solvay Sodabetriebsgeselleschaft.	Ebensee	1885	200
III -	BELGIUM		
3. Solvay & Cie.	Couillet	1863	250
IV -	CANADA		
4. Brunner-Mond (Canada) Ltd.	Amherstburg	1917	250
V -	CHINA (Mainland)		
5. Yungli Chemical Industries Ltd.	Tangko	1921	250
6. Yungli Chemical Industries Ltd.	Wutungchiao	1941	50
VI -	CHINA (Taiwan) @		
7. The South East Soda Manufacturing Co.	Suad, Ilan, Taiwan	1957	100
VII -	CZECHOSLOVAKIA		
8. Chemische Werke Aussig-Falkenau (I.G. Farben)	Nestomitz	1906	350
9. -"-	Aussig	1885	150
10. Synthesia Chemical Works Ltd.,	Semtin	1934	10 *

*All as $NaHCO_3$ by modified process.

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Name.	Location.	Year Built.	Estimated daily soda ash capacity. (short tons).
VIII - FRANCE			
11. Solvay & Cie.	Saaralben	1885	300 (Dense only before heavy war damage).
11(a) -"-	Dombasle	1874	1200
12. -"-	Salins de Giraud	1896	200
13. -"-	Tavaux	1937	500
14. -"- (indirect)	Soudiere de Adour	1918	100
15. Comptoir de l'Industrie du Sel et Chimiques de l'Est.	Soudiere de La Madeleine	1882	260
16. Societe Saint-Gobain Chauny et Cirey.	Soudiere de Varangeville	1891	300
IX - GERMANY			
17. Deutsche Solvay Werke	A.G. Bernburg	1883	1200
18. -"-	Rheinberg	1908	830
19. -"-	Wyhlen	1880	175
20. Kali-Chemie	Heilbron	1900	450
21. Chem.Fabrik Kalk	Koeln-Kalk	About 1870	360
22. Matthes-Weber	Duisberg	About 1885	500
23. I.G.Farbenindustrie (and several small establishments).	Oppau	1915	60 *
X - INDIA @			
24. Tata Chemicals Ltd.	Mithapur (Gujarat)	1941	400
25. Dhrangadra Chemical Co.Ltd.	Dhrangadhra(Gujarat)	1926	130
25(a) Saurashtra Chemicals	Porbunder (Gujarat)	1950	200
25(b) Sahu Chemicals & Fertilizers Ltd.	Varanasi(Uttar Pradesh)	1956	110
XI - ITALY			
26. Soc. Montecatini	Monfalcone(Trieste)	1913	300
27. Solvay & Cie	Rosignano	1919	800

* In conjunction with nitrogen-fixation plant. Final products NH_4Cl and $NaNO_3$.

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Name.	Location.	Year Built.	Estimated daily soda ash capacity. (short tons).
XII - JAPAN			
28. Asahi Glass Co.Ltd.	Makiyama (Fukuoka)	1916	600
29. -"-	Chiba (Chiba)	About 1960	380
30. Central Glass Co.Ltd.	Ube (Yamaguchi)	1936	330
31. Tokuyama Soda Co.Ltd.	Tokuyama (Yamaguchi)	1917	550
32. Toya Soda Co.Ltd.	Tonda (Yamaguchi)	1935	550
XIII - NETHERLANDS @			
33. Koninklijke Soda Industries.	Del-Fzjil	1957	400
XIV - NORWAY			
34. Norsk Hydro-Elekt.	Heroja	1933	75
XV - PAKISTAN @			
35. Imperial Chemical Industries Ltd.	Khewra (Punjab)	1941	80
XVI - POLAND			
36. Solvay & Cie.	Montwy (posen)	1881	200
37. -"-	Podgorze (Galicia)	-	100
XVII - RUMANIA			
38. Uzinele Solvay (2 plants)	Turda and Maros Ujvar.	-	150
XVIII - SPAIN			
39. Solvay & Cie.	Torrelavega	1908	320
XIX - SWITZERLAND			
40. Solvay & Cie.	Zurzach	1915	100
XX - UNITED KINGDOM			
41. I.C.I. Alkali Ltd.	Winnington	1874	1500
42. -"-	Middlewich	1889	350
43. -"-	Sandbach	1875	1100
44. -"-	Wallerscote	1890	700
45. -"-	Lostock	1925	800
46. I.C.I. (General Chemicals Ltd.	Fleetwood	1890	400

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Name.	Location.	Year Built.	Estimated daily soda ash capacity. (short tons).
XXI - UNITED SOVIET SOCIALIST REPUBLIC (Before World War II).			
47. Lubimoff-Solvay et Cie.	Beresniki	1883	400
48. -"-	Donetz	-	1000
49. Slavyansker	Slavyansk	-	500
XXII - UNITED STATES OF AMERICA			
50. Solvay Process Co.	Syracuse, N.Y.	1881	2600
51. -"-	Detroit, Mich.	1898	2200
52. -"-	Baton Rouge La.	1935	700
53. Wyandotte Chem. Corp. (North Plant).	Wyandotte, Mich.	1893	1200
54. Wyandotte Chem. Corp. (South Plant.	-"-	1927	800
55. Diamond Alkali Co.	Fairport, Ohio	1910	2000
56. Pittsburg Plate Glass Company (Columbia Chemical Div.)	Barberton, Ohio	1900	1400
57. Pittsburg Plate Glass Company (Southern Alkali Co.)	Corpus Christi, Tex.	1934	600
58. Mathieson Alkali Works	Saltville, Va.	1894	850
59. -"-	Lake Charles, La.	1934	550
XXIII - VENEZUELA			
60. Comp. Anon. Ind. Quim. Nac.	Maiquetia	1935	3
XXIV- YUGOSLAVIA			
61. Solvay & Cie. And Aussiger Verein	Lukavac (Bosnia)	-	200
62. -"-	Hrasnica	-	100

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Source: Encyclopedia of Chemical Technology by Raymond E.Kirk and Donald F. Othmer. Vol. 1, Pg. 388-390, except those marked @.

@ from records published by respective Governments and Author's personal enquiries.

Figures in metric tons.

Capacity in 1965.

Table 42 Composition of brine in three inland lakes in India, viz. Sambhar, Didwana, Pachbadra and Sea Brines.

(Figures in percent weight on dry basis).

	Sambhar	Didwana	Pachbadra	Sea
		(Percent)		
Calcium Carbonate	-	-	-	0.345
Calcium sulphate	-	-	2.970	3.600
Sodium Chloride	87.300	77.190	85.660	77.758
Sodium Sulphate	8.650	20.650	-	-
		0.600		
Sodium Carbonate) Sodium bicarbonate)	3.870	1.560	-	-
Magnesium Sulphate	-	-	9.440	4.737
Potassium Chloride	0.129	-	-	2.465
Magnesium Chloride	-	-	1.930	10.878
Magnesium Bromide	0.051	-	--	0.217
Total ..	100.000	100.000	100.000	100.000

Source: Report of The Salt Experts Committee published by the Manager of Publications, Government of India Press, Delhi in 1950, Page 50.

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Table 43 Analysis of Sea Water from different sources.

	Suez Canal	Atlantic Ocean.	Gulf of Mexico	Contai Coast (Bengal)	Madras Coast	Bombay Coast.
	(Percent on dry basis).					
Calcium Carbonate	0.02	0.30	0.11	0.36	-	0.10
Calcium Sulphate	3.57	4.31	4.08	3.65	4.06	3.05
Sodium Chloride	79.25	78.00	78.20	80.02	81.50	78.00
Potassium Chloride	1.22	2.01	2.01			2.14
Magnesium Sulphate	6.44	6.01	5.76	6.90	5.64	7.50
Magnesium Chloride	9.29	9.15	9.64	8.82	8.77	9.10
Magnesium Bromide	0.14	0.22	0.20	0.25	0.30	0.08
Rest	0.07	-	-			0.03
	100.00	100.00	100.00	100.00	100.00	100.00

Source: Report of Salt Experts Committee 1950 (Page 6)

Published by Managerof Publications, Government of India, Delhi.

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SUMMARIZED INDIAN STANDARD SPECIFICATION FOR ALKALIS.

TABLE 44.

Indian Standard IS:251 - 1962

Specification for Soda Ash, Technical.

Description	White, uniform product, free from dirt and other foreign matter.

Bulk Density

(a) for dense grade	950 to 1,200 gms. per litre
(b) for light grade	465 to 650 " "

Requirements:

Figures in percent by weight.

Sl. No.	Characteristic.		Requirement (on dry basis)
1.	Total alkalinity (as Na_2CO_3)	Min.	98.5
2.	Matter insoluble in water	Max.	0.15
3.	Sulphates (as Na_2SO_4)	Max.	0.08
4.	Chlorides (as NaCl)	Max.	1.00
5.	Iron (As Fe_2O_3)	Max.	0.007

TABLE 45.

Indian Standard IS:252 - 1962.

Specification for Caustic Soda, Tehnical

Description: Powder, Blocks, Flakes, Sticks, Pellets or Solution, free from dirt, foreign matter and other visible impurities.

Requirements:

Figures in percent by weight.

Sl. No.	Characteristic.	Requirements(on dry basis)	
		Solid	Solution.
1.	Sodium Carbonate (as Na_2CO_3) Max.	2.0	2.0
2.	Sodium Hydroxide Min.	95.0	95.0
3.	Total Chlorides (as NaCl) and Sulphates (as Na_2SO_4) Max.	3.0	3.5
4.	Iron (as Fe_2O_3 Max.	0.05	0.05
5.	Matter insoluble in water. Max.	0.2	0.2

TABLE 16.

Indian Standard IS:1021 - 1964.

Specification for Caustic Soda, Pure.

Description: Solid or solution, free from dirt, foreign matter and other visible impurities.

Requirements on dry basis.

Sl. No.	Characteristic.		Requirement.
1.	Sodium Hydroxide (NaOH) content.	% by weight Min.	99.5
2.	Carbonates (as Na_2CO_3)	" Max.	0.40
3.	Chlorides (as Cl)	" "	0.10
4.	Sulphates (as Na_2SO_4)	" "	0.10
5.	Silicates (as SiO_2)	" "	0.02
6.	Iron (As Fe_2O_3)	Parts per million "	25.0
7.	Copper (as Cu.)	" "	2.0
8.	Manganese (As Mn)	" "	1.0

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