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Technology Compendium

on

Energy Saving Opportunities

Chlor-Alkali Sector

August 2013

Disclaimer

This report is part of Shakti Sustainable Energy Foundation (SSEF) and CII – Godrej GBC's effort to assist the Indian industry achieve greater energy efficiency levels and to facilitate designated consumers meet their Perform, Achieve & Trade (PAT) targets set by Bureau of Energy Efficiency (BEE), Government of India.

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Foreword by Director General – Bureau of Energy Efficiency

With the growth of economy, the demand for energy has grown substantially. Further, the high level of energy intensity in certain major industrial sectors, and more so, the variation between the most & least efficient facility within them is a matter of concern. In such scenario, efficient use of energy resources and their conservation assume tremendous significance and become imperative for sustainable growth of the industrial economy and the country at large.

The efficient use of energy and its conservation is the best option to meet the increasing energy demand, Government of India has enacted the Energy Conservation Act, 2001. The Act provides for institutionalizing and strengthening delivery mechanism for energy efficiency services in the country and provides the much-needed coordination between the various entities.

The Ministry of Power and Bureau of Energy Efficiency (BEE) are entrusted with the task of preparing the implementation for the National Mission on Enhanced Energy Efficiency (NMEEE) under National Action Plan on Climate Change (NAPCC). This mission has a component which deals with the market based mechanism to improve the energy efficiency in energy intensive large industries and facilities by certification of energy savings which could be traded.

This scheme known as Perform, Achieve and Trade (PAT) is expected to save about 6.686 million metric tonne of oil equivalent (mMtoe) by 2014-15. Eight industrial sectors namely Power, Iron & Steel, Fertilizer, Cement, Aluminium, Pulp & Paper, Textile and Chlor-alkali have been included in this scheme where in about 478 industries (known as Designated Consumers (DCs)) are covered. In the ensuing PAT scheme, all the DCs will be required to achieve a reduction of Specific Energy Consumption (SEC) from their baseline SEC within 3 years time (2012-13 to 2014-15).

These industry specific technology compendiums will provide ready-to-use information on national & international energy conservation opportunities, Best Operating Practices (BOP), Best Available Technologies (BAT), with their techno-economic considerations. These compendiums will be helpful for DCs to prepare their energy efficiency action plans and to achieve their SEC reduction targets set by BEE.

I am sure that this Technology Compendium manual will receive an overwhelming response from the cross section of the industry. I take this opportunity to thank Shakti Sustainable Energy Foundation (a part of Climate Works Foundation) for supporting this initiative.

(Ajay Mathur)

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EXECUTIVE SUMMARY

The Chlor-Alkali industry is the oldest and one of the important industries of the country in the inorganic chemical industry. It comprises of caustic soda, liquid chlorine and soda ash. These products are commonly used in various applications such as finishing operations in textiles, manufacture of soaps and detergents, alumina, paper and pulp, control of pH (softening) of water, general cleansing and bleaching etc.

Globally the size of the Chlor-Alkali industry is 170 million tonnes ($70 billion). The size of the Indian chlor-alkali sector is at 7 million tonnes. Despite its large size and significant global contribution, Indian Chlor-Alkali sector represents only 4% of world market. Chlor-Alkali sector is one of the fast growing industrial sectors in India.

Chlor-Alkali industries are increasingly working towards reducing energy intensity of their operations, adopting latest technologies, minimizing pollution emissions, and increasing the share of recyclable products in their portfolio. In such scenario, efficient use of energy resources and their conservation assume tremendous significance and becomes an imperative for sustainable growth of the industrial economy and the country at large

To become a designated consumer in Chlor – Alkali Sector, the identified threshold limit is 12500 MTOE. In the first PAT cycle, 22 designated consumers from various States have been identified with target 0.05 million ton of oil equivalent /year (MTOE), which is 0.81% of total national energy saving targets assessed under PAT.

Chlor-Alkali sector is facing some barriers in its wide spread development. Some of the barriers are import duty on spares of existing membrane cell plants, Impact of severe hike in coal prices, etc.

The potential development of the caustic soda production through the new Oxygen Depolarizing Cathode (ODC) technology is gradually emerging in the market. India needs to take part in this future advancement.

With this background, this Technology Compendium, which comprises of various technologies and best practices to save energy, has been prepared. This compendium is expected to assist the designated consumers to improve their energy efficiency levels and finally to achieve the targets under PAT scheme.

However, implementation of these technologies calls for a sustained effort from the designated consumers. Some of the technologies mentioned in this report are capital intensive and time consuming to implement. But implementation of these projects can surely be beneficial in a long term perspective for the sector.

METHODOLOGY ADOPTED

The following methodology has been adopted for preparing the "Technology Compendium report for the Chlor-Alkali sector:

Formation of Technology Advisory Committee:

A Technology advisory Group consisting of following key industrial experts from Chlor-Alkali sector has been identified.

- Mr Subhash Tandon, Vice President, DCW Limited
- Mr Arunesh Bhala, Vice President, Gujarat Fluoro Chemicals Limited

The Technology advisory group has reviewed the project methodology and approach during the inception phase and while implementation phase, the group reviewed the findings of the project.

Secondary Research:

Secondary research formed an important activity in this project. This was conducted for gathering sectoral information, identification of international best practices and the major technological advancement in the sector. The following were some of the sources that were referred for the secondary research:

a. National / International best practices manuals

b. Chlor-Alkali sector journals

c. Clean technologies from international association like World Chlorine Council, etc.,

d. Stakeholder interactions – Sector associations, Industry experts, Technology service providers, Funding Agency, etc.,

e. CII Detailed Energy Audit Reports

f. CII Energy award questionnaires – last several years

g. PAT Baseline Studies

h. Best practices captured from the National & International Conferences

Stakeholder Interactions:

The team interacted with CII Godrej GBC's Chlor-Alkali working group members to understand their present levels of technology competence and usage, processes and sub-processes, energy efficiency commitments, etc.

The team also presented at Chlor-Alkali workshop to seek wider views & inputs and also interacted with several technology service providers to seek their views & suggestions on the best available energy efficient technology and to identify existing and in-development technologies to assess their utility.

Best operating practices were identified during the national and international conferences in Chlor-Alkali sector. During the conference, experts from various plants, stakeholders share the best operating practices & technologies for reducing the Specific Energy Consumption.

Review and Analysis:

All the information derived from the secondary research and stakeholder consultation were studied and analyzed. The analyzed data was incorporated into this report which covers the following.

- Mapping of Technologies/Process and sub-processes in the Chlor-Alkali sector
- Understanding of energy trends from the past and adaptation of technology and its influence on energy performance in the Chlor-Alkali sector
- Identification of clean technologies available in Chlor-Alkali sector
- Identification of best operating practices in Chlor-Alkali sector this also includes;
    - Energy savings & Environmental benefits
    - Investment required & Payback period
    - Technology providers

Draft report on Chlor-Alkali Technology compendium had been prepared to seek inputs from the multi stakeholder group. The draft report contained the following

- Overview of the Indian Chlor-Alkali Industry
- Energy consumption trend
- Environmental Issues being faced by the Sector
- Policy / Regulations favorable and non-favorable to Sector
- List of best practices & Technologies Proposed.

1.0 INTRODUCTION

Electrolysis of saturated brine results three products - caustic soda, chlorine and hydrogen in the proportion of 1.0/0.89/0.025. Caustic soda is the main product while Cl_2 & H_2 are by products. The process flow diagram is as follows:

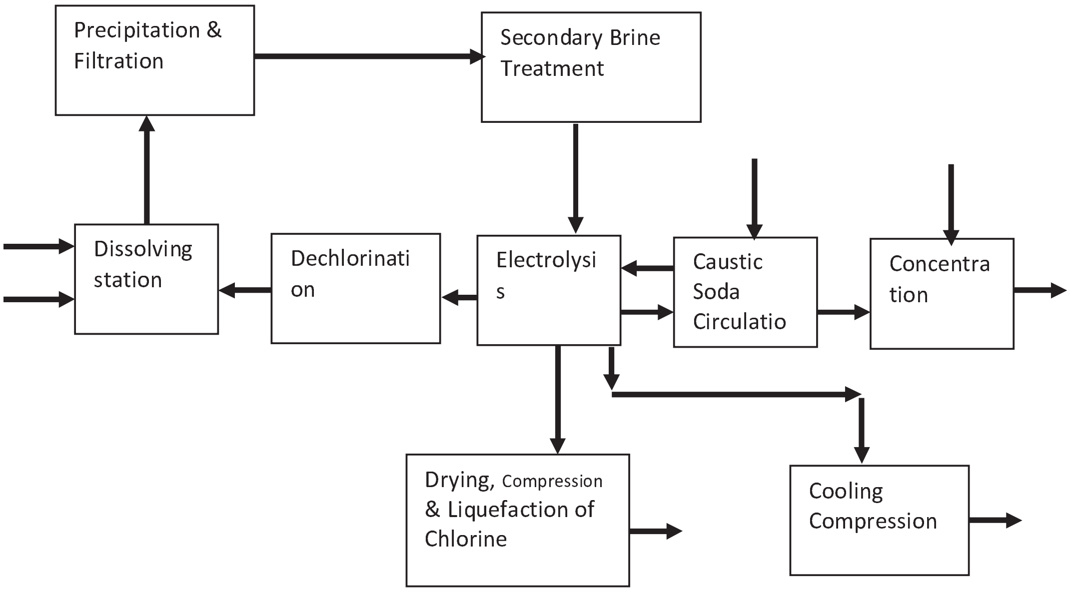


Figure 1: Typical layout of the Chlor - Alkali process

Caustic soda is produced by electrolysis of brine solution. Power and salt form the key inputs. More than 75% of the production and sales is in the lye form because caustic soda is generated in liquid form. This liquid form called 'lye' is then evaporated to obtain solids or flakes. Most of the end users use aqueous solution of caustic soda.

In India, caustic soda is more in demand than chlorine. However, in global markets it is the demand for chlorine, which drives the demand-supply of caustic soda. Textile, Alumina, Soaps & detergents, Paper & pulp sectors are the largest consumers of caustic soda in India.

For caustic soda manufacturers balancing the prices of caustic soda and chlorine becomes critical to get maximum returns. However as caustic soda and chlorine are used in different kinds of industries, the demand for them is rarely balanced. This creates problems for manufacturers in marketing these two products.

BACKGROUND OF INDIAN CHLOR-ALKALI INDUSTRY

During the last half of the 19^{th} century, chlorine, used almost exclusively in the textile and paper industry, was made by reacting manganese dioxide with hydrochloric acid.

An important discovery during this period was the fact that steel is immune to attack by dry chlorine. This permitted the first commercial production and distribution of dry liquid chlorine by Badische Anilin-und-Soda Fabrik (BASF) of Germany in 1888. This technology, using sulphuric acid (H_2SO_4) for drying followed by compression of the gas and condensation by cooling, is much the same as is currently practiced.

In 1800, Cruickshank was the first to prepare chlorine electrochemically. The process was, however, of little significance until the development of a suitable generator and of synthetic graphite for anodes in 1892. These two developments made possible the electrolytic production of chlorine, the Chlor-Alkali process, on an industrial scale. About the same time, both the diaphragm cell process (Griesheim cell, 1885) and the mercury cell process (Castner-Kellner cell, 1892) were introduced.

BASIC CHEMICAL REACTIONS:

$NaCl + H_2O \longrightarrow NaOH + \frac{1}{2} Cl_2 + \frac{1}{2} H_2$

$NaOH + HCl \rightarrow NaCl + H_2O$

The membrane cell process was developed later (1970). Since 1970 graphite anodes have been largely superseded by activated titanium anodes in the diaphragm and mercury cell processes. The newer membrane cell process uses only activated titanium anodes. Production of chlorine was very low in the 1800s and chlorine was only used for bleaching. Chlorine production since the 1940s has risen enormously, on the back of the burgeoning demand for plastics, notably PVC and polyurethanes, since 1903.

Sodium Hydroxide / Caustic Soda (NaOH), is manufactured commercially by the electrolytic process based on the Faraday's law of electrochemistry. The basic chemical equations are given below for manufacture of caustic soda commercially: The above reaction is initiated by passage of DC current through an aqueous solution of sodium chloride (Brine). Chlorine gas is liberated at the anode and hydrogen is liberated at the cathode of the electrochemical cell as byproducts

The electrolyte anolyte leaving the electrolyte cells is saturated with chlorine. Most of the chlorine is removed by adding acid and then the remaining chlorine is converted to chloride by adding caustic soda and sulphite. Some of the chlorine from the dechlorination process and from other streams of the plant, is reacted with caustic soda to produce sodium hypochlorite. Sodium hypochlorite is sold and is used for bleaching.

Some of the chlorine gas formed in the electrolytic cell is burnt with hydrogen. This reaction produces hydrogen chloride gas ($Cl_2 + H_2 \rightarrow 2HCl$). This gas is dissolved in water to form a 32% hydrochloric acid solution.

MAJOR PLAYERS

The units are mainly located on the west coast of India, due to two reasons, namely abundant availability of salt, one of the key inputs required for the production of caustic soda and proximity to user industries. Power and salt form the key inputs in the manufacturing of caustic soda. Power is a major cost item as it accounts for almost 65% of the total cost of production.

FUTURE SCENARIO

The capacities in the domestic sector have outstripped demand growth. Thus, only those producers who have access to cheap power and use latest technology will be able to survive in the long-term. The growth profile of caustic Chlor-Alkali industry in India is about 4%.

1.1 BRIEF DESCRIPTION OF THE TECHNOLOGIES

Caustic Soda can be produced electrolytically by using three technologies: diaphragm cells, mercury cells and membrane cells. Following is a brief discussion of the three electrochemical processes that are dominant in Caustic Soda production.

DIAPHRAGM CELL

Diaphragm cell contains a diaphragm, usually made of asbestos fibers. This separates the anode from the cathode and allows ions to pass through electrical migration simultaneously reducing the diffusion of products. The diaphragm permits a flow of brine from anode to cathode and prevents side reaction. Sodium ions along with sodium chloride are discharged into the cathode chamber. Thus sodium chloride is separated in evaporators when caustic soda is obtained in the form of aqueous solution. The recycled salt is combined with fresh salt for further use.

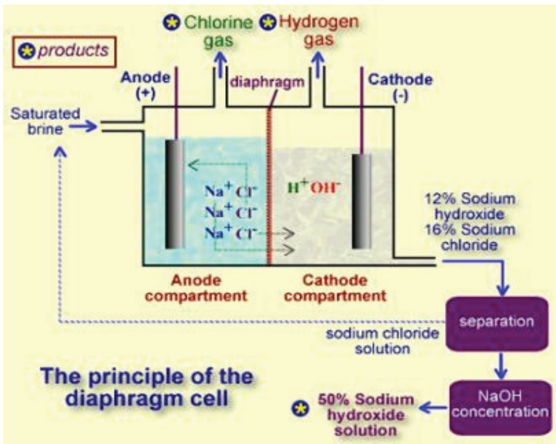


Figure 2: Schematic view of Diaphragm cell process

This process is now obsolete and is not being used in any commercial manufacturing process in India.

MERCURY CELL

This process is one of the older processes being used in India. In India some of the plants are still operating with the mercury cell technology. The caustic soda producing from the mercury cell technology accounts for 4.6% of the installed capacity.

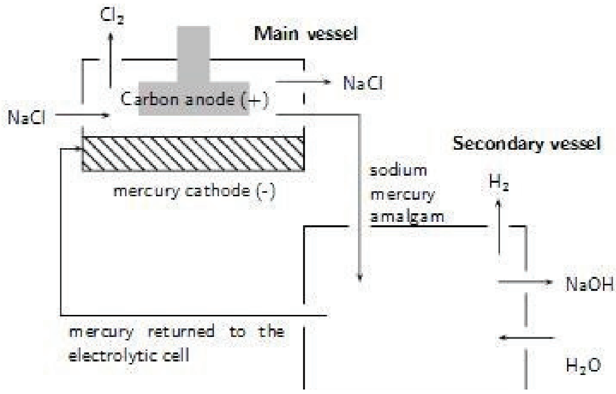


Figure 3: Schematic view of Mercury cell process

In mercury-cell process, a saturated brine solution floats on top of the cathode which is a thin layer of mercury. Chlorine is produced at the anode, and sodium is produced at the cathode where it forms a sodium-mercury amalgam with the mercury.

The amalgam is decomposed using in a separate vessel with soft water producing 50% caustic solution and hydrogen gas. The depleted salt water is cleansed of chlorine, re-saturated with salt, purified and recycled. The process is depicted schematically below:

This is an older process and has the advantage of relatively lower capital costs. However, it has two significant disadvantages:

- Power consumption is high at around 3,200 kWh/T of caustic soda (100%) compared to low power consumption in diaphragm cell and membrane cell.
- Mercury cell plants have pollution hazards since mercury is a major pollutant and also evaporates in small quantities at the operating temperature.

Because of the high specific energy consumption and pollution hazards, the process is now being phased out.

MEMBRANE CELL

This latest green technology accounts for about 95.4% of caustic soda production in India. This cell uses a semi-permeable membrane to separate the anode and cathode compartments. Membrane cells separate the compartments with porous chemically active membranes that allow sodium ions to pass, but reject hydroxyl ions.

Sodium ions diffuse to the cathode area where they react with de-mineralized water to produce 30-35% caustic soda and hydrogen gas (The caustic soda is subsequently concentrated to 50% levels). The salt water is dechlorinated, purified, and recycled in the process. The schematic diagram of a typical membrane cell is shown below:

This process has been gaining importance in the country because of number of advantages over the mercury cell process which are as follows;

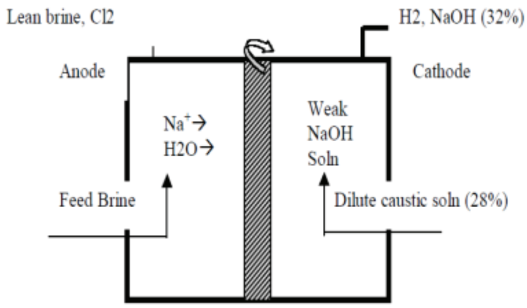


Figure 4: Schematic view of Membrane cell reduction process

- It has lower power consumption of 2,400 - 2,500 kWh/T of caustic soda as compared to around 3,200 kWh /T in the mercury cell process.
- The environmental impacts by this technology is less compared to the other technologies
- When a mercury unit is converted to membrane cell, it is able to increase its capacity by nearly 20% because the available power, setup of the rectifiers & transformers capacity can be utilized to produce more quantities of caustic soda.
- It has lower maintenance cost than the mercury cell process and simpler plant operations. Caustic soda produced have high purity and thus find more market like in pharmaceuticals, semiconductor, biotech, food industry etc.

The disadvantages of this process are:

- The selectively permeable membrane cell know-how is manufactured under patent by only a select company in the world. The major names in this business are UHDE, Asahi Kasei Chemicals Corporation (AKCC), Chlorine engineers Corporation Limited, Japan, AkzoNobel, Netherlands, Industrial chemicals Limited (ICL chemicals) UK & Denmark.
- It requires high quality of salt solution, as membranes are sensitive to uniformities like Ca, Mg present in the salt.
- The major impurities in the raw salt (NaCl) are sodium sulphate, Calcium chloride and magnesium chloride which needs to be removed to the traces level (parts per billion) as they directly affect the membrane operation and life.
- Membranes need to be replaced once in every 3 – 4 years, because of reduced effectiveness and increase in energy consumption
- Power consumption of the membrane cells increase by 60 KWh/Ton of caustic per year because of the contamination of the membranes and deactivation of electrodes.
- For ease of transportation and requirement at the user end, a small percentage of caustic soda is converted to flakes.

Power is the most important input in the production of caustic soda. It accounts for about 65% of the total cost of production. Generally, the cost of power from co-generation is half the purchased power. The producers with the co-generation plant therefore benefit from low variable cost. However the initial capital cost for setting up these power plants is very high.

In India major amount of caustic soda is produced using membrane cell technology which is more energy efficient technology with least power consumption than the mercury & diaphragm technology. The Chlor-Alkali industry forms a significant part of the Indian chemical industry. The key products in the Chlor-Alkali industry are:

- Caustic soda
- Chlorine (including liquid chlorine)
- Soda ash

The main drivers for the export of Alkali Chemicals are Flakes of Sodium hydroxide (Caustic Soda), Disodium Carbonate Light (Soda Ash), Sodium Hydroxide in Aqueous Solution (Soda Lye) and other Disodium Carbonate.

CHLOR-ALKALI MEMBRANE CELL PROCESS

The typical Indian Chlor-Alkali plant process of a membrane cell carried out in various stages is as follows.

1.1.1. Brine Purification

Brine House consists of saturated Primary Brine & secondary brine purification section & their associated equipment. Brine for Ion exchange membrane process is prepared by dissolving salt in the depleted brine from the electrolysis plant and primary purification. The membrane Chlor-Alkali process however, requires a secondary brine purification process to produce ultra pure quality of brine required by the ion-exchange membrane process.

After the primary treatment, brine is purified with anthracite filter, brine filter and ion - exchange resin column in order to obtain quality of brine suitable for the ion-exchange membrane process.

1.1.2 Cell House

ELECTROLYSIS

Cell House consists of electrolysers and their associated equipment. Electrolyser consists of a number of cell frames with the titanium anode and the activated nickel cathode, the Ion exchange membrane, press unit for mounting cell frames, sub-headers for feeding saturated brine and catholyte, sub-headers for discharging electrolysis products, hoses for connecting cell frames with sub-headers, and oil pressure unit which supplies oil to oil cylinders.

DE-CHLORINATION OF DEPLETED BRINE AND CHLORINE RECOVERY

De-chlorination Section is composed of De -chlorination tower, De-chlorination tower cooler, Ejector, Ejector cooler and associated facilities. Depleted brine (anolyte) from electrolysis section is saturated with chlorine. In the tower, chlorine is stripped together with water vapor, and passed through Dechlorination tower cooler.

The vapors are condensed and the chlorine gas is sucked by the steam ejector to ejector cooler. Chlorine gas is then introduced to chlorine gas product main line. The depleted brine after Dechlorination still contains small amount of free chlorine, which can damage filter elements and Ion exchange resin, therefore, sodium sulphite is added to neutralize free chlorine. Depleted brine is then fed to return brine tank & pumped to salt saturator.

ELECTROLYSIS OF BRINE

The process of electrolysis of brine is done in electrolysers. Electrolyser consists of a number of cell frames with the metal anode, activated cathode and the Ion exchange membrane. Chlorine House consists of Drying, Compression, Liquefaction, Storage, Bottling, dispatch and their associated equipments.

1.1.3 Chlorine Gas Handling

CHLORINE GAS DRYING

The cooled chlorine gas is led to chlorine gas drying tower. The moisture of chlorine gas is absorbed into 98% sulphuric acid fed in gas-drying tower. The acid gets diluted by absorption of moisture from chlorine gas. Chlorine gas drying tower has its cooler to cool circulating sulphuric acid with chilled water, and circulation pumps of sulphuric acid. The dry chlorine gas is sent for chlorine compression.

CHLORINE GAS COMPRESSION

Dry chlorine gas from chlorine gas drying section is compressed to 3.0 kg/cm^2 (g) approximately by using acid ring type compressors.

CHLORINE GAS LIQUEFACTION AND FILLING & DISPATCH

Chlorine gas from compressor is sent to chlorine liquefier where liquefaction is carried out by using Freon - 22 as a Refrigerant. The un-liquefied gas along with inert gases from liquefier is taken to HCl Synthesis Unit. Liquefied chlorine is stored in chlorine storage tank from where it is transferred by means of compressed dry air to filling station. In filling stations chlorine tonners are filled. Each chlorine tonner contains ~ 900 kg liquid chlorine. These filled tonners are dispatched to customers in trucks.

1.2 PRESENT SCENARIO

There are 34 manufacturers of caustic soda, having aggregate installed capacity to the extent of 31.261 Lakh MTPA. These plants co-produce chlorine in the ratio of 1:0.89. Today 95.4% plants are of energy efficient membrane cell technology. Rest 4.6% operating on mercury cell process, which are gradually switch over membrane cell technology in future.

In India the west cluster is the largest caustic soda producing region with 16.60 Lakh MTPA. Caustic soda manufacturing is energy consuming process & consumes 2.5 MW per MT of Caustic soda production[1].

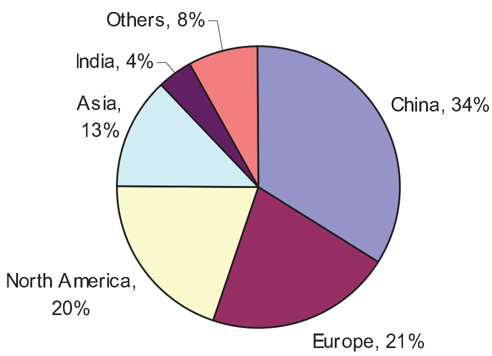


Figure 5: Global Percentage wise caustic soda installed capacity[2]

As per the latest industry statistics the total installed caustic soda capacity in India constitutes to 31.261 Lakh MTPA with a production of 25.558 Lakh MTPA from 34 Chlor-Alkali plants[2] for the FY 2011-12. The installed capacity and the caustic soda production of different Chlor-Alkali plants are given in the below table:

[1] As per Indian Chemical Industry – 12th five year plan planning commission report

[2] Alkali Manufacturers Association of India (AMAI) & 35th Annual Reports

Table 1: Installed Capacity & production of Chlor-Alkali plants in India[2, 3]

REGION	Sl. No.	NAME OF THE UNIT	INSTALLED CAPACITY	PRODUCTION
			(As on 31.03.2011)	2011-12
			Lakh MTPA	Lakh MTPA
EAST	1	Aditya Birla Chemicals (India) Ltd. (formerly Bihar Caustic & Chem. Ltd.)	1.1435	1.0192
	2	ABCIL, Renukoot Chemical Division	0.8300	0.8069
	3	Durgapur Chemicals Ltd.	0.3300	0.2109
	4	Hindustan Paper Corporation (Cachar)	0.1700	0.0810
	5	Hindustan Paper Corporation (Nagaon)	0.1950	0.0722
	6	HJI-Div. of Orient Paper Mills	0.5234	0.3027
	7	Jayshree Chemicals Ltd.	0.5320	0.4523
		Sub Total		2.9453
WEST	8	Aditya Birla Nuvo Ltd.	0.9900	0.8198
	9	Atul Ltd.	0.2235	0.1402
	10	Ballarpur Industries, Ballarshah	0.1320	0.0963
	11	Century Rayon	0.2050	0.2091
	12	DSCL (Shriram Alkali), Jhagadia	1.5750	1.2751
	13	Grasim Industries Ltd.	3.0840	2.6033
	14	Gujarat Alkalies (Baroda)	1.6995	3.8509
	15	Gujarat Alkalies (Dahej)	2.5910	
	16	Gujarat Flouro Chemicals Ltd.	1.2045	0.9478
	17	Meghmani Finechem.Ltd	1.4175	1.0207
	18	Nirma Ltd.	0.7920	0.6389
	19	Reliance Industries Ltd.	1.6815	1.6399
	20	Tata Chemicals Ltd.	0.3600	0.1064
	21	United Phosphorus Ltd.	0.6480	0.5192
		Sub Total		13.867
NORTH	22	DSCL (Shriram Vinyl Chem), Kota	1.1725	1.0880
	23	Lords Chloro Alkali Ltd.	1.1121	0.1262
	24	Punjab Alkalies & Chem. Ltd.	0.9900	0.8817
	25	SIEL Chemical Complex (A Unit of Mawana Sugars Ltd.)	0.8250	0.6196
		Sub Total		2.7154
SOUTH	26	Chemplast Sanmar Ltd.(Karaikal)	0.5100	0.4686
	27	Chemplast Sanmar Ltd. (Mettur)	0.6120	0.6061

	28	Chemfab Alkalis Ltd.	0.4200	0.2766
	29	DCW Ltd.	1.0000	0.9057
	30	Solaris Chemtech Ltd.	0.5940	0.4214
	31	Sree Rayalaseema Alkalies & Allied	1.2395	1.2353
	32	Tamil Nadu Petroproducts Ltd.	0.5610	0.4971
	33	The Andhra Sugars Ltd.	1.3200	1.0464
	34	The Travancore Cochin Chemicals Ltd.	0.5775	0.5727
		Sub Total		6.0299
		Grand Total	31.2610	25.558

1.3 GEOGRAPHICAL SPREAD OF CHLOR-ALKALI INDUSTRY

As per AMAI, Chlor-Alkali plants located in 4 regions of India. The geographical spread of chlor-alkali plants in India is given in the below map.

[3]

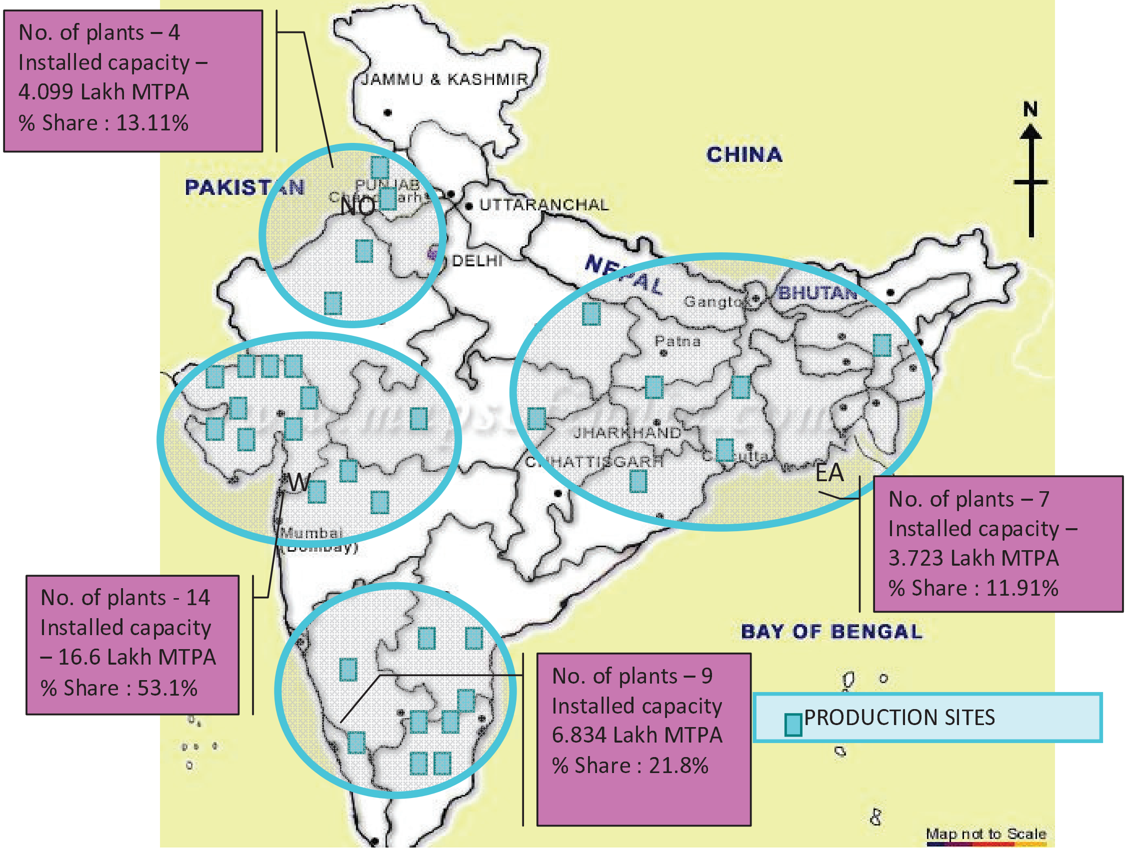


Figure 6: Geographical spread of Chlor-Alkali plants in India*

The percentage share of the Chlor-Alkali plants in four regions is depicted in the table below:

[3] AMAI, Seminar on Associated Processes of Chlor-Alkali Industry

Table 2: Chlor-Alkali production by region wise in India[4]

Sl. No.	Cluster area	No. of Plants	Installed Capacity (Lakh MTPA)	% Share
1	East	7	3.7239	11.91
2	West	14	16.6035	53.11
3	North	4	4.0996	13.11
4	South	9	6.834	21.86

Out of four regions, west region contributes major share of Chlor-Alkali plants in India accounting to 53.11%.

GROWTH TREND OF INDIAN CHLOR-ALKALI INDUSTRY

The industry has always seen an increase in capacity and production over the past two decades. The production and capacity trend of the Indian Chlor-Alkali industry is shown in the below graph.

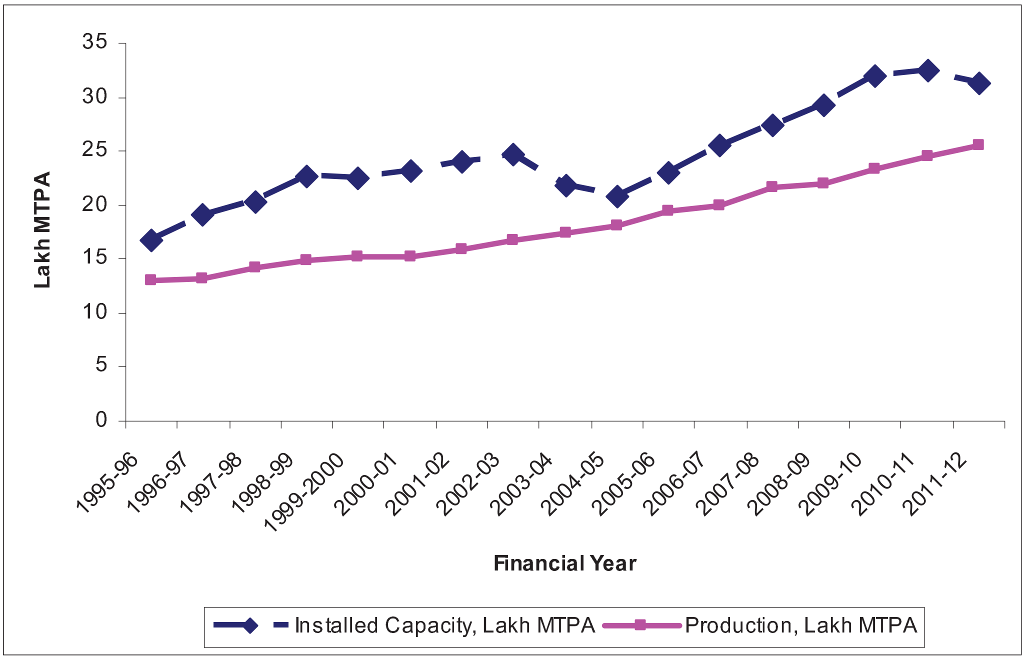


Figure 7: Growth trend of Indian Chlor-Alkali

[4] Alkali Manufacturers Association of India (AMAI) & 35th Annual Report

REDUCTION IN SPECIFIC ENERGY CONSUMPTION

Indian Chlor-Alkali industry has been a fore-runner as far as energy efficiency in the caustic soda manufacturing process is concerned. Some of the Indian plants are operating with the lowest specific energy consumption numbers in the world. The cost of energy had been the predominant driving factor for such advancements in energy efficiency.

The specific energy consumption of mercury cell house is around 3100 - 3300 kWh per ton of caustic soda (including utilities) compare to 2400 - 2500 kWh per ton of caustic soda for a membrane cell based plant. Due to this there is huge reduction in specific energy consumption of caustic soda production. The reduction in specific energy consumption of the Indian Chlor-Alkali sector is given below:

Table 3: Details of the Average operating SEC of the Chlor-Alkali sector[5]

Sl. No.	Financial Year	Average Specific Energy Consumption, kWh / T of caustic soda produced
1	1990 – 1991	3351
2	1994 – 1995	3130
3	1999 – 2000	2977
4	2009 – 2010	2350

[5] GOI, Ministry of Environment and forests and Teri

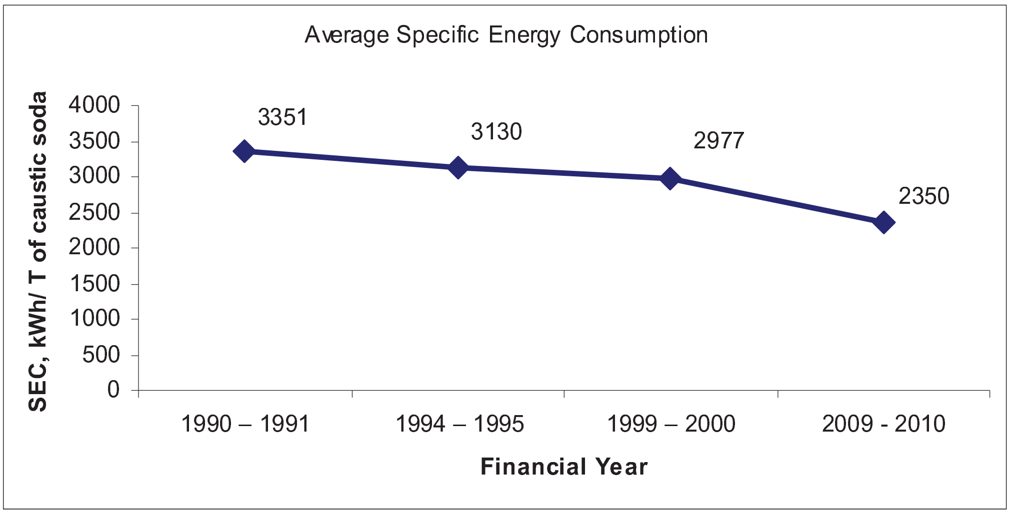
6 

Figure 8: Trend of Average specific energy consumption for the last 20 years[13]

MAJOR PLAYERS IN CHLOR-ALKALI SECTOR

The major share of the Chlor-Alkali production in India is from the strong major players in the industry. The top 15 players constitute 71.081% of the total installed capacity of Chlor-Alkali in India. The following table illustrates the Capacity share & caustic soda production in the FY 2011-12 of the major players in India.

Table 4: Installed & Production capacity of 2011 -12 of major Indian Players[7]

Sl. No.	NAME OF THE UNIT	Installed Capacity, Lakh MTPA[8] (As on 31.03.2011)	Production, Lakh MTPA 2011-12	% Share of total Installed capacity
1	Grasim Industries Ltd.	3.084	2.60326	9.87
2	Gujarat Alkalies (Dahej)	2.591	0	8.29
3	Gujarat Alkalies (Baroda)	1.6995	3.8509	5.44

[6] GOI, Ministry of Environment and forests and Teri

[7] Alkali Manufacturers Association of India (AMAI) & 35th Annual Report

[8] 1 Lakh = 100,000 or 1 Lakh = 0.1 million

4	Reliance Industries Ltd.	1.6815	1.63986	5.38
5	DSCL (Shriram Alkali), Jhagadia	1.575	1.27508	5.04
6	Meghmani Finechem.Ltd	1.4175	1.0207	4.53
7	The Andhra Sugars Ltd.	1.3200	1.0464	4.22
8	Sree Rayalaseema Alkalies & Allied	1.2395	1.2353	3.97
9	Gujarat Flouro Chemicals Ltd.	1.2045	0.9478	3.85
10	DSCL (Shriram Vinyl Chem), Kota	1.1725	1.0880	3.75
11	Aditya Birla Chemicals (India) Ltd. (formerly Bihar Caustic & Chem. Ltd.)	1.1435	1.0192	3.66
12	Lords Chloro Alkali Ltd.	1.1121	0.1262	3.56
13	DCW Ltd.	1.0000	0.9057	3.20
14	Aditya Birla Nuvo Ltd.	0.9900	0.8198	3.17
15	Punjab Alkalies & Chem. Ltd.	0.9900	0.8817	3.17
16	ABCIL, Renukoot Chemical Division, Renukoot	0.8300	0.8069	2.66
17	SIEL Chemical Complex (A Unit of Mawana Sugars Ltd.)	0.8250	0.6196	2.64
18	Nirma Ltd.	0.7920	0.6389	2.53
19	United Phosphorus Ltd.	0.6480	0.5192	2.07
20	Others	5.9454	4.5135	19.02
	Total	**31.261**	**25.55804**	

GRASIM INDUSTRIES LIMITED

Grasim Industries Limited, Chemical Division was set up in early 1970s to manufacture Caustic Soda, Liquid Chlorine and its allied products. Initially in 1972 a 100 Tons per day Mercury Cell plant based on the technology supplied by DENORA, ITALY, was set up. Thereafter another Mercury Cell Plant was set up in 1983 and by the year 1989 the Caustic Soda production capacity of Chemical Division was enhanced to 350 Tons Per Day.

In 1994, the 1st Mercury cell Plant was converted to Membrane Cell Plant based on the finite gap technology supplied by M/s. Uhde Germany. There after it was converted in to narrow gap technology. Subsequently the 2nd Mercury Cell Plant also converted in 2006 with highly energy efficient Membrane Cell Plant based on worlds latest zero gap technology supplied by M/s. AKCC Japan.

GUJARAT ALKALIES AND CHEMICALS LIMITED (GACL)

The Company was established in 1973 and over a period of time, it has emerged as the one of the largest producer of Caustic Soda in India with present installed production capacity of 4.2905 Lakh MTPA of Caustic Soda as on 31st March, 2012. The Company has about 13.72% share in the domestic Chlor-Alkali market.

GACL has upgraded and adapting eco friendly and green technologies while it outpaced the industry average capacity utilization of 75% with its 97% capacity utilization.

DCM SHRIRAM CONSOLIDATED LIMITED

DCM Shriram Consolidated Limited (DSCL) Chlor- Alkali business is one of the leading manufacturers of Caustic Soda (Lye and flakes), Chlorine and associated chemicals including Hydrochloric acid, Stable Bleaching powder, Compressed Hydrogen and Sodium Hypochlorite. The Company has two manufacturing facilities located at Kota (Rajasthan) and Bharuch (Gujarat) with full coal based captive power. The Company's total Chlor-Alkali installed capacity is 832 TPD. The Company has about 8.79% share in the domestic Chlor-Alkali market.

RELIANCE INDUSTRIES LIMITED

Relinace Industries Limited (RIL), Dahej Manufacturing Division is located near Bharuch, Gujarat. It comprises of an ethane / propane recovery unit, a gas cracker, a caustic chlorine plant and 4 downstream plants, which manufacture polymers and fibre intermediates.

RIL has an installed capacity of 1.6815 Lakh MTPA. The caustic soda production for the FY 2011 – 12 is 1.6398 Lakh MTPA. The capacity utilization of the plant is 97.5236%. The company has about 5.38% share in the domestic Chlor – Alkali market.

1.4 DEMAND & CONSUMPTION

INDIAN SCENARIO

Demand growth for caustic soda depends on growth in the user sectors. Demand is further affected by the substitution of caustic soda with other alkalis. Paper & pulp, textile, soaps and alumina are the major user sectors of caustic soda and they account for more than 42% of the domestic demand.

[9]Pulp and paper sector has been growing at the rate of around 4% pa, in volume terms. Soap industry is expected to grow at the rate of around 4% pa. The demand for caustic soda is growing from these industries. Caustic soda is used in the conversion of bauxite into alumina. The demand from this sector is however sluggish. The textile industry is expected to grow at 12%. Thus overall the demand is expected to grow at a moderate rate of around 4-5% pa.

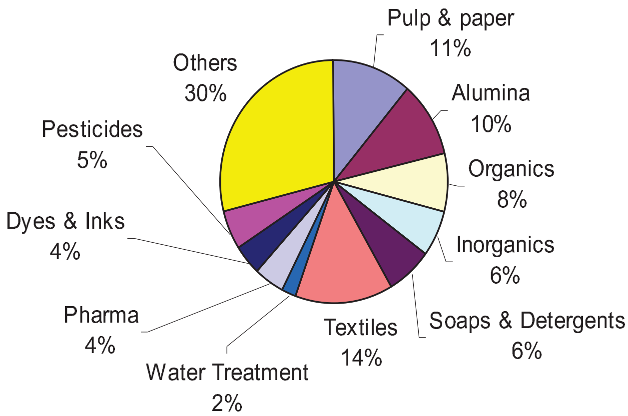


Figure 9: Percentage Consumption of Caustic Soda in various Industrial sectors[4]

Apart from these industries, caustic soda and chlorine find use in other industries such as, chemical, water treatment, etc., Demand spread over various user sectors insulates caustic soda from the downtrend in any one sector. Conversely, spurt in demand in any one of the user sectors does not translate into equivalent growth in demand for caustic.

Demand also suffers from substitution effect to some extent. Based on the considerations such as price, availability and the final application, it is substituted by other alkalis such as soda ash. Though the extent of substitution is small, its effect gets magnified during recession when demand from user sector falls.

The caustic soda consumption in various end users of the Indian Industry are given in the above chart.

GLOBAL SCENARIO

Globally the Chlor-Alkali industry is driven by the demand-supply of chlorine unlike in India and therefore globally, caustic soda is considered as a byproduct. Demand for chlorine is higher than that of caustic and many a times caustic produced in the process is surplus.

China has the highest caustic soda capacity at 27 million tonnes, accounting for 34% of world capacity[10]. North America has a capacity of 15 million tonnes China and Middle East are fast emerging as key production hubs for caustic soda. It is expected that there would

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[9] Alkali Manufacturers Association of India (AMAI) & 34th Annual Report

[10] Indian Chemical Industry – 12th five year plan report

not be any significant capacity additions in developed countries like North America and Western Europe, primarily due to unattractive cost structures and flat demand.

Current global consumption of caustic soda is estimated at 65 million tonnes[5]. Asia is the largest consumer of caustic soda and is expected to remain the same in near future. Majority of caustic soda is exported from North America, the Middle East and Asia. Australia and Latin America are the leading importers.

1.5 CAPTIVE POWER GENERATION IN INDIAN CHLOR-ALKALI INDUSTRY

Chlor-Alkali industry is one of the energy intensive sectors in India. Power is a major parameter that influences the operating cost in this sector. Grid power purchased from SEBs is costlier than captive power from coal-based plants by more than 25-30 percent in some of the areas.

The aggregate power requirements have grown rapidly with rising Chlor-Alkali capacity without commensurate growth in power generating capacity in the country. To offset the power crisis situation, many chlor alkali plants have set up installations for captive power generation.

The need of Captive Power Plant (CPP) has also become the need of the hour with the increased cost of grid power. The average auxiliary power consumption in CPPs of Indian Chlor-Alkali industry ranges between 9-14%, whereas the best operating CPPs in the India has its auxiliary power consumption ranging from 5.8-6%. In case of CPP heat rate the average value stands at about 3200kCal/kWh when compared to the best operating value of 2550-2575 kCal/kWh.

With such a wide variation in CPP auxiliary power consumption and heat rate values, this offers an excellent lever for energy efficiency improvement. Energy efficiency improvement opportunities in CPPs can be achieved by focusing on optimization of operations and technology up-gradation.

1.6 ENERGY CONSUMPTION TREND

The raw material necessary in the production of caustic soda consisting of salt and water is abundant and inexpensive. Conversely, the electrical energy required to process salt into caustic soda and chlorine is expensive. Energy costs represent 50 to 65% of the total cost of production based on the cost of power.

In any Chlor-Alkali industry the electrolysis phase is the most energy intensive. The process necessitates large quantities of direct current electric power that is usually obtained from a high voltage source of alternative current through a rectifier and involves energy losses.

The mercury cell has a higher decomposition voltage and therefore requires more power than the diaphragm and membrane cells. However, the thermal energy requirement is null in the mercury process as the caustic soda solution formed is highly concentrated (50%). The diaphragm process results in a caustic soda solution with a much lower concentration of around 10%, and thermal energy is needed to evaporate and concentrate the solution to 50%. The membrane cells produce a solution of about 30-35%, requiring less thermal energy. However, the additional thermal energy requirement is not always necessary as highly concentrated caustic soda need not always be produced.

ELECTRICAL ENERGY

Chlor-Alkali Industry is power intensive as power is used as a raw material in electrolyses process of Sodium Chloride Solution. 85% to 90% power is required for electrolyses and balance 10 to 15% power is required for running equipments i.e. Auxiliary Power. So, it is always important to monitor electrolysis process very closely to minimize power consumption. The total power consumed in the Chlor-Alkali plant is divided in to cell house & auxiliary power consumption. The percentage wise electrical energy consumption is given in the pie chart.

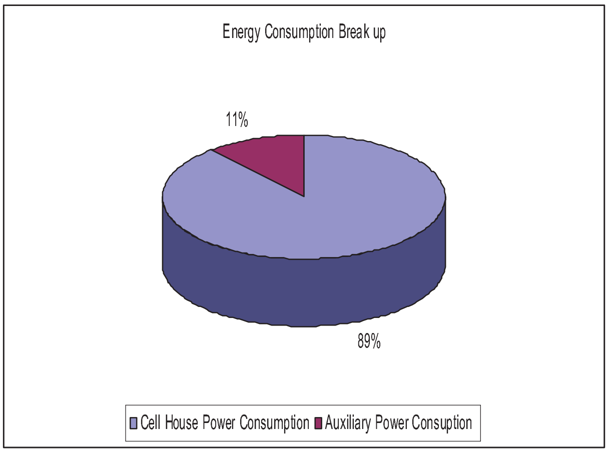


Figure 10: Typical energy consumption break up for Chlor-Alkali Production

STEAM

Also steam is needed in the chlor-alkali production e.g. for salt preparation and concentration of the caustic soda. How much steam is necessary depends on the production process used in the plant. Steam consumption is less in membrane process compared to diaphragm technology.

1.7 FUTURE GROWTH OPPORTUNITIES

Chlor-Alkali is the oldest and largest segment of the chemical industry. The production of caustic soda and chlorine grew at a rate of 5.4% over the XIth five year plan period. Production is targeted to grow at 8.1% p.a. over the XIIth plan period to keep up with demand growth. The growth in production of soda ash was 4.3% during the XIth five year plan and is expected to grow at 7% during XIIth five year plan period. Overall, Chlor-Alkali production is targeted to grow at 8% p.a. over the next five years[11].

India's soda ash demand is expected to reach 3.6 million tonnes by FY17. Accordingly, the industry can target a capacity of 3.6 million tonnes (from current capacity of 3.161 million tonnes) by the end of the XIIth five year plan to ensure self-sufficiency.

Similarly Caustic Soda demand is expected to reach 4.0 million tonnes. A domestic Caustic Soda capacity of 4.0 million tonnes (from current capacity of 3.246 million tonnes) should be targeted for the XIIth five year plan period. This implies a capacity growth of 3% p.a. over the XIIth five year plan to meet the targets.

As per the 35th AMAI annual report, to facilitate the accomplishment of this aspirational capacity, the government and industry will have to jointly work towards implementing the following action items

1. Government Initiatives on chlorine consumption, duties & taxes, allocation of fuel to captive power plants etc
2. Facilitate R&D towards development & commercialization of non-conventional and renewable energy sources
3. Reward innovations in all areas across energy management, waste minimization, recycling, reuse & reduction in the overall energy footprint of industries
4. Indian ports need to be improved on PPP model to facilitate cost effective and safe coastal movements to transport raw materials & feedstock
5. Technological change

The Indian Chlor-Alkali sector has witnessed robust growth in past few years with spurt in demand of caustic soda & soda ash from user companies.

[11] As per Indian Chemical Industry – 12th Five year plan report of Planning Commission

1.8 BARRIERS TO THE GROWTH OF INDIAN CHLOR-ALKALI INDUSTRY

Chlor – Alkali industry is quite important, and produces basic chemicals. However, it is facing unique challenges like high input costs, high rates of taxes & duties and cess on captive power plant.

Chlor-Alkali sector faces some barriers in energy efficiency & policies front, for the growth of the sector. The following are the some of the issues impacting Chlor-Alkali sector represented by AMAI:

- ❖ Accelerated depreciation is not allowed for major technological intervention in the sector (e.g. membrane cell technology doesn't qualify for accelerated depreciation)
- ❖ Lack of easy financing for energy efficiency projects
- ❖ Enhance End Product Usage – Government should take measures to promote use of chlorine for disinfection of drinking water. Use of hydrogen in fuel cells and as green fuel should be encouraged

2.0 ENERGY EFFICIENCY PRACTICES

Substantial reduction in specific energy consumption levels was observed in the past decade. The improvements in energy performance of Chlor-Alkali sector in the recent past have been possible largely due to retrofitting and adoption of energy efficiency equipment, better operation control, better monitoring and management information system, up-gradation of process control and instrumentation facilities. The Chlor-Alkali sector has always practiced the sharing of information among them, which has also helped in replication of national and international best practices and cleaner technologies.

NATIONAL & INTERNATIONAL BEST PRACTICES

PRODUCTION PROCESS

1. Conversion of mercury cell to membrane cell for caustic soda production wherever mercury cell technology is adopted
2. Conversion of monopolar membrane / Bipolar cells to 6th generation Bipolar membrane cells, reduces the specific energy consumption (Power reduction by 95 kWh/Tonne of caustic soda production)
3. Specific power consumption of the electrolysers is reduced by maintaining zero gap Electrolysers causing less voltage drop at electrolysers
4. Installing high performance membranes for reducing the energy consumption in the electrolysis process
5. Optimization of Electrolysers for current consumption by monitoring cell voltages and replacing membranes & Recoating of Electrodes in time. This reduces the power consumption of the electrolyses due to reduction in the over voltages, increase in the efficiency of the membranes.
6. Use of high purity brine in electrolysis process to reduce power consumption due to better membrane performance and enhanced life span of membrane
7. Brine acidification - The brine is acidified prior to electrolysis to reduce the formation of chlorate and oxygen.
8. Brine recycling up to 40% for retention of thermal energy
9. Reducing the voltage at electrolysers by 30 % reducing power (energy) by same amount in Oxygen Cathode instead of Hydrogen-evolving Cathode
10. Installation of advanced cell controls systems - Cell parameters like temperature, pressure, concentration of brine, brine and caustic flow to electrolysers etc. needs to be monitored and controlled for optimum performance of membrane cells.

11. Heat recovery by provision of brine and chlorine re-cuperator for preheating the feed brine towards the cell

12. Improvement of activated cathode for ion exchange membrane electrolysis for caustic soda production

13. Use of mono-ethylene glycol (MEG) based chlorine evaporators instead of using steam to supply chlorine gas to user industry or in-house consumers

14. Switching from diaphragm electrolytic process to ion exchange membrane electrolytic process reduces the specific energy consumption

15. Replace Steam Ejector with Water Ring Vacuum Pump for Brine Dechlorination. This reduces the specific steam consumption of the plant through minimal increase in the power consumption. The savings achieved in terms of difference in power generation by the steam and power consumption of the vacuum pump.

16. Usage of vapors generated in manufacture of caustic flakes in caustic evaporation (48% Lye manufacture) and optimization of steam consumption in concentrating 32 % to 48 % caustic by using multiple effect evaporators. (Triple effect evaporative system)

17. Heat recovery by Provision of Brine and Chlorine recuperator for pre heating the feed brine towards the Cell.

18. Burner design of Caustic concentration unit (Flakes Production) to be done at available cell hydrogen pressure.

19. The power consumption of chiller compressor can be reduced by utilizing the Waste steam in Vapor Absorption machine (VAM) Refrigeration Unit to meet Chilled Water requirement.

20. Use of heat recovery system in each section of caustic evaporation unit. The heat from 50% Caustic product is recovered by preheating of 37% and 41% Caustic through Heat exchangers.

21. Conversion of Rubber Lined to Bare Bottom Configuration in electrolysers, reduces the millivolt drops and bus losses. This will reduce the cathodic mV drop to the tune of 40%

22. Installing Plate evaporators: using metal plates to transfer heat from steam to dilute caustic in order to evaporate water

23. Minimization of exposed surface area of clarifiers and providing water seal for surface loss reduction.

24. Reduction in power consumption by avoiding continuous running agitator and optimizing its running hours

25. Installation of UPS for polarization rectifiers to protect cathode coating and life of cathode of electrolysers which leads to indirect benefit of reduction of energy consumption

26. Effective insulation of pipelines carrying hot cell liquor at 85 ^{0}C from the cells to the evaporators to save about 0.3 tonne of steam per tonee of caustic soda

27. Controlling the water addition to the filters reduces the steam consumption

PUMPS

28. Impeller trimming to optimize the flow & head of the pump

29. Replacement of the inefficient pump with high efficiency pumps

30. Installation of VFD to the pumps to avoid valve throttling & recirculation

31. Installation of correct size pump

32. Applying hydraulic coating technology for higher capacity pumps which improves pump efficiency by 5 – 8 %

COMPRESSORS & COMPRESSED AIR SYSTEM

33. Replacement of inefficient Cl_2 compressors with the high energy efficiency Cl_2 compressors

34. The power reduction in air compressors can be achieved by operating the air compressor pressure close to the end user required pressure

35. Installation of intermediate controller for instrument air compressor system

36. Optimize the pressure drop between the generation end & user end by maintaining the air velocity less than 15m/sec in the pipe line

37. Replacement of purging type dessicant dryer or heated type dessicant dryer with heat of compression (HOC) dryer reduces the power consumption of the air dryer, because the HOC dryer does not require any power for its operation.

38. Continuous monitoring minimizes the compressed air leakages. By following the red tag system reduces the percentage air leakage.

39. Avoid unloading power consumption of the compressors by interconnection of two near by compressors

40. Provide VFD for one chlorine compressor and avoid bypass control during load variation

41. Increase the efficiency of the chlorine compressors by applying Hydraulic coating technology

42. Installation of cogged flat belt drives in place of conventional V- belt drives

43. Install auto drain valves and avoid venting of compressed air into the atmosphere

44. Adoption of energy efficient chlorine handling systems

ELECTRICAL SYSTEM

45. The efficiency of the rectiformers can be increased by 4% by replacing the old rectiformers with the new energy efficient rectiformers.
46. Power consumption of the tube lights can be reduced by replacing the T12 tube lights with T8 / T5 tube lights
47. Power consumption of the high pressure mercury vapour (HPMV) lamps can be reduced by replacing the 400W HPMV lights with 150W metal halide lamps
48. Installation of Light pipes in MCC rooms. This reduces the lighting power consumption of MCC rooms in day time
49. Install lighting voltage regulator for all the lighting circuits by maintaining 210 V at the output of the lighting transformer
50. The power consumption in the under loaded motors (<40% loading) can be reduced by Converting into star mode
51. Installation of solar street lights reduces the power consumption of the street lights in the night time
52. Replacement of old motors with new high energy efficient motors
53. Reduce “mv” drop in the eletrolyzers bus bars joints.
54. The demand can be reduced by operating the plant power factor close to the unity
55. Switching of the MCC lights whenever there is no one inside the MCC room by interlocking the MCC door with the target switch

COOLING TOWER

56. Replacement of aluminum material fan blades with Fibre Reinforced Plastic (FRP) fan blades material. The power reduction due to the aerodynamic profile of the FRP of blades and reduction in weight of the FRP blades
57. The power consumption of the cooling tower fan can be reduced by interlocking the fan with respect to the water outlet temperature of the cooling tower..

58. Increase the effectiveness of the cooling tower by operating the cooling tower operating parameters close to the design parameters like approach, range, COC, air flow, algae removal etc
59. Installation of VFD to the cooling tower fans and operate in closed loop with the CT outlet water temperature

CAPTIVE POWER PLANT

60. Waste Heat Recovery from Coal Fired Boiler Flue Gas to Generate 'High Purity' Water from Seawater with simultaneous Recovery of Water from Flue Gas, Leading to Increase in the Overall Thermal Efficiency of Coal Fired Boilers
61. By utilizing the hydrogen generated in electrolyses process in vapour absorption machine (VAM), the power consumption by the chillers for producing the chilled water can be reduced.
62. Increase the operating parameters of hydrogen boiler and install a micro back pressure steam turbine to generate steam and power
63. Install Thermo-compressor and Utilise Flash Steam in the I - Effect Heat Exchanger
64. Installing Economizer in boiler to increase boiler feed temperature by using hot flue gas stream
65. Optimize the oxygen percentage in hydrogen boiler Installation of solar water heating system for boiler makeup
66. Optimize the feed water temperature of hydrogen gas fired boiler
67. Installation of VFD for the condensate & boiler feed water pumps and avoid valve throttling
68. Optimize the operation of FD, ID & PA fans by installing VFD
69. Reducing the air ingress in the boiler flue gas path, reduces the power consumption of the ID fan and also reduction in thermal energy consumption
70. Steam ejector is used for removing the incondensable gasses in the condenser. By replacing the steam ejector with vacuum pump reduces the auxiliary power consumption of the unit

3.0 MAPPING STAKEHOLDER INITIATIVES

Indian Chlor-Alkali industry is pioneers in energy efficiency activities and can be compared globally in terms of its lowest specific energy consumption levels. Several initiatives have been taken by the sector by itself in terms of energy efficiency and GHG emission reduction opportunities with the help of industrial associations and suppliers.

INDUSTRY ORGANIZATIONS

In order to cater a conducive environment to promote the growth of Indian Chlor-Alkali industry there are several national organizations which works closely with government in terms of various policy issues, enhancing efficiency, competitiveness, growth and development opportunities for the sector.

Major industry organizations working closely with the Chlor-Alkali sector to cater to its growth include

- Alkali Manufacturers' association of India (AMAI)
- World Chlorine Council (WCC)
- Confederation of Indian Industry (CII)

ALKALI MANUFACTURERS' ASSOCIATION OF INDIA (AMAI)

Alkali Manufacturers' Association (AMAI) of India was established in 1960 & registered in 1977. AMAI is a Registered Non-profit making Public Limited Company under Section 25 of Companies Act, 1956.

AMAI is an apex body representing Indian Chlor-Alkali Industry at various fora like regulatory bodies, Govt. of India, concerned Department of Ministries like Department of Chemicals & Petrochemicals, Ministry of Environment & Forests, etc. Salt Commissioner, Bureau of Indian Standards, Bureau of Energy Efficiency, Department of Explosives, Inspectorate of Factories, ICC, FICCI, CII, etc.

Globally, AMAI is represented at World Chlorine Council representing Regional Chlorine Associations in about 27 countries, covering 90% World Chlorine Capacity. The Association is also represented at UNEP thro' WCC Mercury Partnership Programme and Global Safety Team of WCC. AMAI is also represented on WCC Governing Council, after it recently joined WCC as full Member on 16th February, 2012 during WCC-AMAI Membership Signing Ceremony at New Delhi.

Website: - http://www.ama-india.org

WORLD CHLORINE COUNCIL (WCC)

The World Chlorine Council (WCC) is a global network representing the chlorine and chlorinated products industries. It brings together national and regional trade associations, along with their member companies. The WCC currently represents over 23 national / regional associations in over 27 countries accounting for over 80 percent of global chlorine production.

The WCC was formed in 1993 to improve awareness of the benefits of chlorine chemistry; further the practice and understanding of responsible stewardship; and anticipate and respond to relevant health, environmental and public policy issues. Through stewardship, research and advocacy, WCC works to ensure that the products and applications of chlorine chemistry continue to be regarded by policymakers and the public as sustainable and commercially viable.

Website: http://www.worldchlorine.org

CONFEDERATION OF INDIAN INDUSTRY & CII- SOHRABJI GODREJ GREEN BUSINESS CENTRE

CII is a non-government, not-for-profit, industry led and industry managed organization founded over 117 years ago plays a proactive role in India's development process. CII works to create and sustain an environment conducive to the growth of industry in India, partnering industry and government alike through advisory and consultative processes.

CII - Sohrabji Godrej Green Business Centre (CII - Godrej GBC) is one of the 10 Centres of Excellences of the Confederation of Indian Industry (CII). CII-Sohrabji Godrej Green Business Centre offers advisory services to the industry in the areas of Green buildings, energy efficiency, water management, environmental management, renewable energy, Green business incubation and climate change activities. The Centre sensitises key stakeholders to embrace Green practices and facilitates market transformation, paving way for India to become one of the global leaders in Green businesses by 2015.

CII – Godrej GBC has been very closely associated with energy efficiency improvement of the Indian industry. CII – Godrej GBC had carried out more than 1300 detailed energy audits till date in different sectors of industries. CII- Godrej GBC has conducted energy efficiency studies across many Designated Consumers like Cement sector, Power sector, Iron & Steel sector, Pulp & Paper sector, Chlor-Alkali sector, Fertiliser, Textile, Aluminum, Sponge Iron sector, Engineering & Automobile sector & buildings.

Website: - *www.cii.in* and *www.greenbusinesscentre.com*

4.0 ENERGY EFFICIENCY IMPROVEMENT OPPORTUNITIES

TECHNOLOGY - 1

LOW ENERGY CONSUMPTION IN CHLOR-ALKALI CELLS USING OXYGEN REDUCTION ELECTRODES

BACKGROUND

The membrane cell technology as a recent advancement since its introduction in 1970 has fewer exhausts to the environment and is relatively more efficient in the use of electric power. Despite the fact that the overall specific energy consumption has been reduced due to the successive introduction of ion exchange membrane cells instead of the mercury and diaphragm process, the issue of energy consumption is still a major concern.

The amount of electrical energy needed for driving the electrode reaction depends mainly on the type of the electrolytic cell with their respective thermodynamic decomposition potential difference (ΔE). In the electrolytic process as shown in the below reaction for every ton of chlorine produced, about 1.1 tons of caustic is generated and 28 kg hydrogen is evolved as a byproduct.

Standard reaction: $2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH$

ODC chemical reaction: $O_2 + 2H_2O + 4NaCl \rightarrow 4NaOH + 2Cl_2$

During the hydrogen evolution reaction (HER) a high voltage input, i.e., 1.23 V more than the oxygen reduction reaction (ORR) / oxygen depolarized cathodes (ODC) is required and thus, results in higher energy consumption for producing the products & by products. Furthermore, investments in equipment and energy input associated with the recovery, further purification, handling and storage of the hydrogen are also needed.

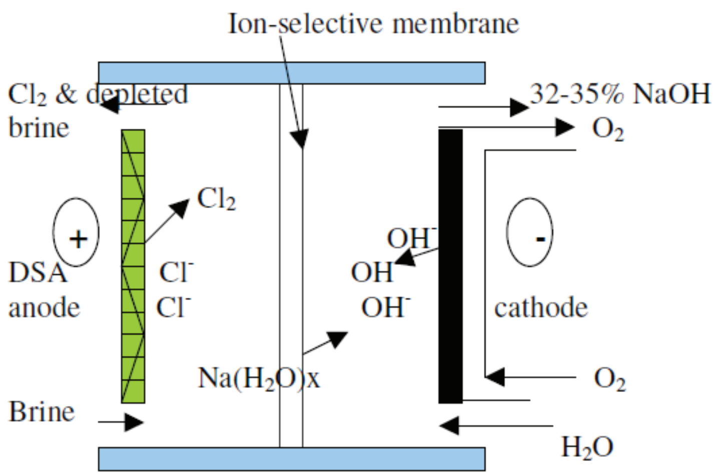


Figure 11: Ion-Selective Membrane

Gas diffusion electrodes were manufactured using the rolling method. In order to reinforce the non-wettability of the electrodes, the initial concentrations of PTFE suspension with 60 wt.% were diluted with Millipore water and painted on the diffusion layer. This procedure was repeated four times on one and the same layer, while drying in oven consequently after each step at 70°C. The amount of electrode materials and the catalyst loading was kept constant with slight variations. The active layer is made up of catalysts containing mixtures of perovskite ($La_{0.1}Ca_{0.9}MnO_3$) and pyrolysis product of CoTMPP with less proofed carbon.

Half-cell electrochemical tests were carried out in small 4 cm^2 size gas diffusion electrodes with nickel wire mesh as counter electrodes in 8M NaOH and an Hg/HgO as reference electrode.

The temperature 70°C was regulated by a thermostated water bath and the flow of reactant oxygen to the rear side of the electrode was kept at 40 ml min^{-1} and current-potential readings were obtained for the assessment of the various types of electrodes.

The results of the replacement of hydrogen evolution reaction with oxygen reduction reaction shown that

- Improved and optimized gas diffusion electrodes, demonstrating high activity and good stability for more than 1000 hrs at a constant load of 300 mA cm^{-2},
- 10% additional teflon painted on the gas diffusion layer reinforces protection of electrolyte intrusion with stable performances
- With the cell configuration used, electrolysis could be carried out for about 600 hrs at a current density of 300 mA cm^{-2} and a total voltage of ca. 2.0 V
- The overvoltage and ohmic loss lies at about 1.0 , where high contributions emanate from electrode base contacts and membrane and
- Current efficiency lies at around 92-97% in the series of electrolysis with low energy consumption and energy savings between 30-35% compared to membrane process with HER.

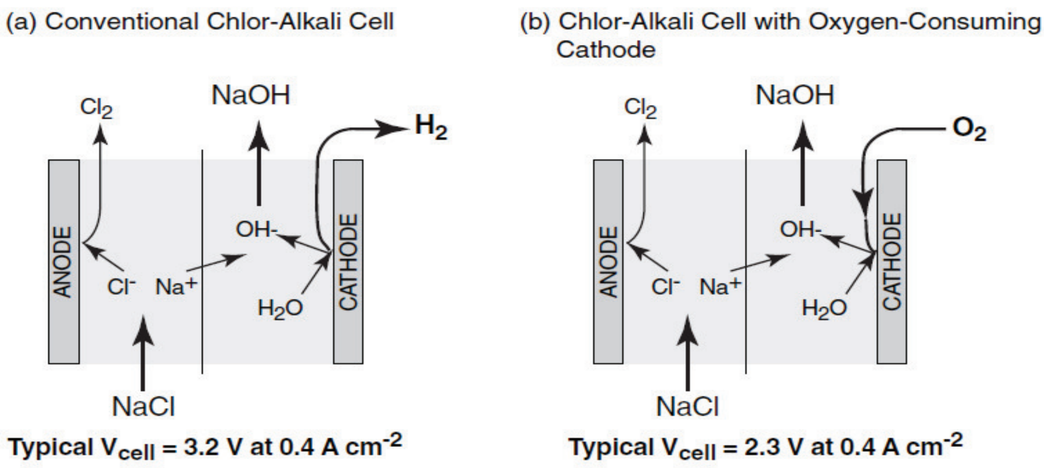


Figure 12: schematic layout of conventional and oxygen consuming cathode system Issues

Only 18% of chlorine is produced by the most energy-efficient (2500 kWh/t) membrane technology. The remaining 82% is generated in less energy-efficient diaphragm (70%, 2900 kWh/t) and mercury (12%, 3700 kWh/t) cells. While replacement of all the diaphragm and mercury cells in India with the most energy-efficient membrane cells would result in no more than 14% energy savings, much more significant savings, around 40%, would be expected upon replacement of all the cells with **oxygen-consuming electrolyzers**. One of the key R&D issues to be addressed in this project is to develop materials that can maintain a stable interface between liquid and gas within the active layer of the gas diffusion cathode in order to ensure long-term operation of the cell.

APPROACH:

R&D for the project focuses on the areas of cell fabrication and testing. It consists of completing development of effective oxygen cathodes, optimizing cathode and anode structures for enhanced throughputs, and improvement of performance characteristics to match or exceed present industrial standards for state-of-the-art membrane cells. Accomplishing these tasks would bring the oxygen cathode Chlor-Alkali process to the point where it becomes attractive enough for the industry to invest in the process scale-up and eventually implement the technology.

ENERGY SAVING PROJECT

From the experimental study, it is clear that the replacement of the hydrogen evolution reaction with oxygen reduction reaction shows that there is minimum requirement in energy consumption about 25 – 35% compared to electrolysis process. The Oxygen Depolarized Cathodes (ODC) technology is currently developed with substantial potential energy savings of around 440-530 kWh per ton of caustic soda production.

COST BENEFITS

As per the research conducted, the annual energy saving achieved by switching to oxygen reduction reaction technology gives is **Rs. 115.00 million**. This is successfully implemented in a pilot scale and would be an emerging technology in immediate future. This reduces **7840 MTOE**.

REPLICATION POTENTIAL

As per the research conducted by Department of Chemical Engineering and Technology, Chemical Reaction Engineering, Royal Institute of Technology (KTH), Sweden, the project has been successfully completed with an substantial potential energy savings of around 440 – 550 kWh/ T of caustic soda. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)*		
	Without PAT	With PAT benefit
Energy savings	Rs. 115 million	Rs. 115 million
MTOE equivalent	2480	2480
PAT benefit	--	Rs.25.0 million[12]
Total benefit	Rs. 115 million	Rs. 140 million
Replication Potential		
Number of plants	80% of the plants	
MTOE savings	59600	

*This is an emerging technology. As pilot study successfully completed, details of the investment are not available.

[12] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 2

RECOATING OF ELECTRODES REDUCES THE SPECIFIC POWER CONSUMPTION OF CAUSTIC SODA PRODUCTION

BACKGROUND

In India, 25.58 lakh MT of caustic soda is produced annually. Membrane cells account for around 24.75 lakh MTPA. Anodes and cathodes are vital components of Membrane cells.

Normally the life of the cell elements (anode & cathode) varies from 6 – 8 years. The specific power consumption of each cell has to closely monitor on regular basis. As the years go on the specific power consumption keeps on increasing continuously due to damage of anode & cathode surfaces.

In this regard, the plant team has continuously monitoring the cell power regularly and utilized the recoating technology for the damaged cell elements for reducing the specific power consumption, whenever it is required. Thus there is good potential to recoat the cell elements for reducing the power consumption.

The reduction in power consumption of the cell is 400 kWh, due to recoating of anodes & cathodes electrodes in a 250 TPD plant.

Advantages of the recoating in anode cells

- Low, stable chlorine over voltages
- Low levels of oxygen in the chlorine product

Advantages of the recoating in cathode cells

- Guaranteed energy savings as a result of significant overvoltage reduction over uncoated cathodes
- 3 or 4 membrane cycles (depending on economics)
- Stable overvoltage performance resulting from built-in resistance
- Corrosion resistance
- Applicable to monopolar and bipolar electrolysers

ENERGY SAVING PROJECT

In India, many plants are operating with membrane cell technology. Recoating of the cell elements immediately when damaged reduces huge reduction in power consumption of the membrane cell process.

COST BENEFITS

The reduction in power consumption of the cell is 400 kWh, due to recoating of anodes & cathodes electrodes in a 250 TPD plant. The investment for recoating some of the damaged electrodes is approximately **Rs 40 million**. This resulted in an annual savings of Rs **16.10 million** (including increased in efficiency of the cells). This gives a simple payback of **30 Months**. This reduces **930 MTOE**.

REPLICATION POTENTIAL

This project can be implemented in any membrane cell plants, where the specific power consumption of the cells increased due to damage of the anodes & cathodes. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs.16.10 million	Rs. 16.10 million
MTOE equivalent	290	290
PAT benefit	--	Rs.2. 90 million[13]
Total benefit	Rs. 16.10 million	Rs. 19.00 million
Investment	Rs. 40.0 million	Rs. 40.0 million
Payback period	30 months	25 months
Replication Potential		
Number of plants	60% of the plants	
MTOE savings	6540	

[13] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 3

INSTALL ADAPTIVE CONTROL SYSTEM AND MINIMIZE VARIATION IN FEED TEMPERATURE

BACKGROUND

Ion exchange membrane cell process is the latest and energy efficient technology, for production of caustic and chlorine. The process involves fine control of multiple parameters to obtain desired performance. Some of the critical parameters are current density, temperature, gas pressure, % caustic concentration, electrolyte flow rate, Brine purity etc.

The online monitoring and control of all the parameters is facilitated by the shift engineers with the support of distributed control system (DCS).

The plant team has observed the, marginal variation in Specific energy consumption (SEC). Further the team carried out in-depth analysis and proved that the variation in critical parameters effected the variation in SEC.

The parameters were monitored and the values were recorded on hourly basis for a finite time period to obtain real time trend.

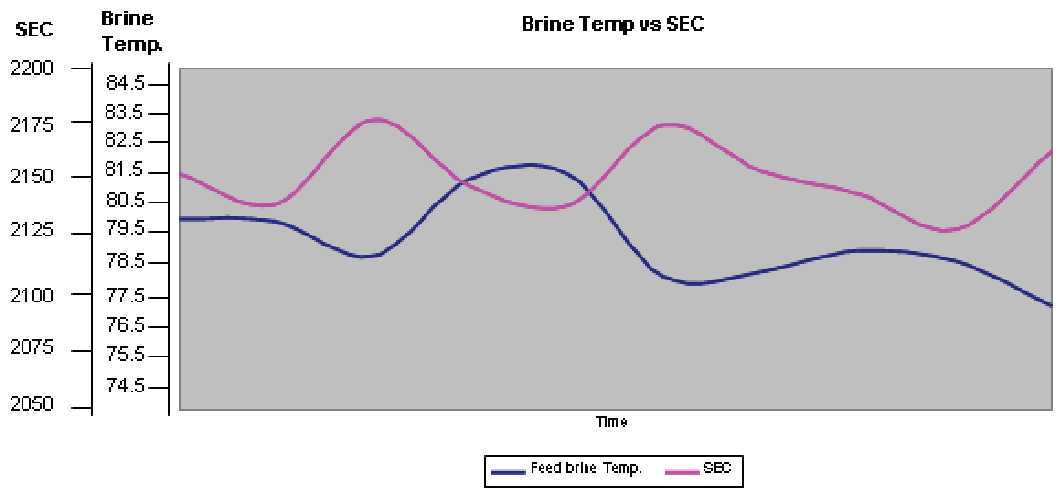


Figure 13: Graph shows brine temperature Vs SEC w.r.t time

The above figure shows the trend obtained based on the data collected.

From the analysis, it is determined that the variation in Feed brine temperature has major effect on SEC variation. The observed variation in SEC is from 2090-2200 units/ton of caustic with feed brine temperature variation of 6^0C.

The curve indicates that higher feed brine temperature improves the cell performance thereby reduces the SEC and vice versa.

At any load condition the catholyte return temperature should be maintained less than 90^0C (as recommended by the OEM). Presently the average temperature is maintained at 89^0C.

The control of feed temperature varies with operating load. The degree of control is set manually by the shift engineers. The present control mechanism at low load and at high load is discussed below.

At low load condition (<80 kA)

The catholyte return temperature is monitored on a continuous basis and feed brine temperature is controlled manually to maintain cathoyte return temp at <90^OC.

Steam is used to heat the feed brine and the steam flow is adjusted to control the temperature of feed brine. In this case the feed caustic temperature is not controlled.

At high load condition (> 80 kA)

The catholyte return temperature is monitored on a continuous basis. Now both the feed brine and feed caustic temperature is controlled manually. In this case the feed caustic is cooled using chilled water to maintain the desire temperature of return caustic at less than 90^OC.

The major factors of manual operation, which lead to higher band-width of variation in feed temperature, are

- **The Time response -** It is the time interval between the occurrence of variation in the system and the manual activation of control to minimize the variation.
- **Accuracy of control** - It is the degree of conformity of control to the actual control required. Presently the accuracy of manual control is dependant on sequence of degree of error and the rate of change of error. This results in prolonged variation in the system.

These factors results in variation in feed temperature and when ever the feed temperature is on lower side there is a significant increase in specific energy consumption.

There exists an excellent energy saving opportunity to reduce the SEC (kWh/ton of caustic) by minimizing the variation in feed electrolyte temperature.

The latest, automated adaptive and predictive control logic (fuzzy logic) can operate the system more stable with reduced band-width of variations in less time span.

RECOMMENDATION

The methods to control the variation of feed electrolyte temperature are discussed below:

METHOD: 1 - FEED BACK CONTROL

1. Control and maintain feed caustic temperature constant for a particular load
2. Install a logical control to feed brine temperature with feed back from return caustic temperature.
3. The feed back should be delayed for finite time period.
4. The delay time can be determined by trial and error. The delay time is the time taken for a substance to flow through an element. The delay time needs to be determined for different flow rates.

METHOD: 2 - ADAPTIVE AND PREDICTIVE CONTROL

1. Install fuzzy based control system for monitoring and control of system parameters.
2. The fuzzy system is used for control of multiple variables in a system. It studies the system parameter variation and corresponding performance over a period of time and maintains signature (record). Based on the signatures (records) it controls the system parameters to obtain the best performance.

The variation in SEC w.r.t. feed brine temperature is given below:

Based on the curve, a second order polynomial equation has been derived and the equation is as below.

The equation of the curve is,

$$SEC = 1.3595\, T^2 - 227.86\, T + 11670$$

Where,

SEC - kWh/ton of caustic; T- temperature of the feed brine

Based on the equation, the reduction in SEC w.r.t to reduced band-width of variation in Feed brine temperature is calculated. It is recommend implementing a control system and to minimize the variation in feed temperature and reap the benefits.

COST BENEFITS

On conservative basis, at least 10 kWh/ton of caustic can be reduced. The annual energy savings for 250TPD plant is **Rs. 3.30 million** with an investment of **Rs. 10.00 million** for installing adaptive predictive control system, with an simple payback of **36 months.** This reduces **225 MTOE**.

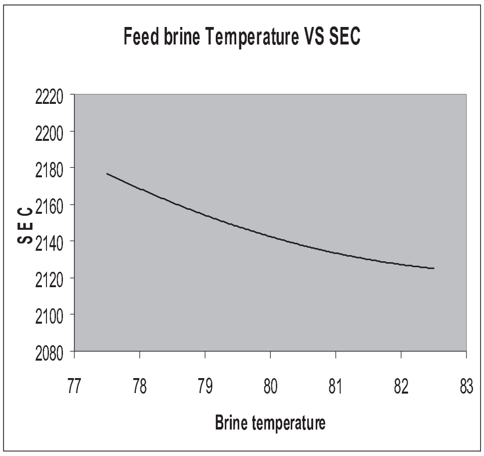


Figure 14: Graph shows brine temperature Vs SEC

REPLICATION POTENTIAL

This project can be replicated to other units. Thus there is good replication potential to conserve energy by implementing this technology. Similar control systems are adopted in several other process industries are working successfully.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 3.30 million	Rs. 3.30 million
MTOE equivalent	70	70
PAT benefit	--	Rs.0.70 million[14]
Total benefit	Rs. 3.30 million	Rs. 4.00 million
Investment	Rs. 10 million	Rs. 10 million
Payback period	36 months	30 months
	Replication Potential	
Number of plants	40% of the plants	
MTOE savings	850	

[14] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 4

REPLACE STEAM EJECTOR WITH WATER RING VACUUM PUMP FOR BRINE DECHLORINATION

BACKGROUND

Brine dechlorination of the return brine is an essential process requirement of any caustic chlorine plant. This dechlorination is done by using vacuum of the order of 400-450 mm HG on the hot return brine thereby sucking the excess free chlorine.

Steam ejectors are normally installed to meet the vacuum requirements of the return brine dechlorination section. The vacuum required in the section is to the tune of 400-450 mmHg. 200-250 Kg of steam per hour at 8-10 Kg/cm^2 pressure is utilised in this ejector system.

The plant team of a 250 TPD Chlor-Alkali unit in India observed good potential to reduce the cost of operation, by installing water ring vacuum pump in place of steam ejector. The operation of cost of an ejector is more than the water ring vacuum pump.

This is a proven project and has been implemented in many other plants. A vacuum of 600-650 mm Hg is easily achievable with a water ring vacuum pump. This will meet the requirement of vacuum conditions to be maintained in the brine de-chlorniation section.

ENERGY SAVING PROJECT

The plant team installed a water ring vacuum pump in place of steam ejector for the brine dechlorinating condenser. The capacity of the vacuum pump was the same as that of the existing ejector. This step has resulted in reduction of atleast 50% of steam requirement.

COST BENEFITS

The annual energy saving achieved by replacing steam ejector with water ring vacuum pump is **Rs. 0.4 million** (at a steam cost of Rs 350/Ton) with an investment **Rs. 0.35 million,** which had a simple payback period of **11 months**. This reduces **27 MTOE**.

REPLICATION POTENTIAL

This project has been implemented only in one or two units. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 0.40 million	Rs. 0.40 million
MTOE equivalent	9	9
PAT benefit	--	Rs. 0.08 million[15]
Total benefit	Rs. 0.40 million	Rs. 0.48 million
Investment	Rs. 0.35 million	Rs. 0.35 million
Payback period	11 months	9 months
Replication Potential		
Number of plants	50% of the plants	
MTOE savings	155	

[15] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 5

CONVERT EXISTING MERCURY CELL BASED PLANT TO MEMBRANE CELL BASED PLANT

BACKGROUND

The latest technology for manufacturing caustic chlorine is membrane cell. The power consumption in a caustic chlorine plant is a major issue since it shares 70% of the total cost of production. Any reduction in power consumption leads to high profitability.

The conversion of mercury cell to membrane cell technology of caustic soda and chlorine is as follows.

Caustic soda is still produced by conventional mercury cell technology in few plants. It is an old technology and has only advantage of low capital cost. The percentage share of caustic soda production using mercury cell technology is 4.5%. The installed capacity of caustic soda is 1.43 Lakh MTPA with a production 0.8 Lakh MTPA in FY 2011-12 using mercury cell technology.

The specific energy consumption of mercury cell house is around 3200 kWh per ton of caustic soda (including utilities) compared to 2400 - 2500 kWh per ton of caustic soda for a membrane cell based plant. Also carry over of mercury from mercury cell house leads to pollution hazards, as mercury is a major pollutant. This makes the product un-acceptable to the high end users like pharma, biotech and electronic industry.

In mercury cell technology caustic comes out at 47-48 % concentration and in membrane cell caustic comes out at 32 % concentration, so a caustic concentrator is required to concentrate the caustic to required percentage. The specific energy consumption of membrane cell house and the membrane life is highly affected by the impurities in brine. The major impurities in raw salt are sodium sulphate, calcium chloride and magnesium chloride.

The impurity level should be in ppb instead of ppm. To convert from the existing mercury cell to membrane cell, the cell house has to be completely changed and replaced with the new electrolysers. Rectifiers also need replacement as the cells are in parallel instead of series in mercury cell. The other major revamp is needed in the brine purification section. Since ultrapure brine quality is needed for membranes, a brine filtration and polishing system is required. The suppliers of membrane cell technology is enclosed in the annexure.

A caustic concentration unit also needs to be added to concentrate caustic from 32% to 47.5%. This increases the steam consumption by 0.65-0.7 Tons/Ton caustic.

ENERGY SAVING PROJECT

A 250 TPD plant in India converted its earlier mercury cell based unit to new membrane cell based technology.

COST BENEFITS

The total cost of the project including civil work is around **Rs 1900 million**. This resulted in an annual savings of Rs **165 million** (including increased revenue from high quality product). This gives a simple payback of **138 Months**. This reduces **11200 MTOE**.

Potential for Replication

As per the AMAI statistics the caustic soda production using mercury cell technology is 243.7TPD. Thus there is good potential in these plants converting to high energy efficiency & cleaner technology. The purity of the caustic soda also increases due to conversion of mercury to membrane cell technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 165 million	Rs. 165 million
MTOE equivalent	3540	3540
PAT benefit	--	Rs. 36.00 million[16]
Total benefit	Rs. 165 million	Rs. 201 million
Investment	Rs. 1900 million	Rs. 1900 million
Payback period	138 months	113 months
Replication Potential		
Number of plants	4.58% of annual production	
MTOE savings	3455	

[16] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 6

PROVIDE VFD FOR ONE CHLORINE COMPRESSOR AND AVOID BYPASS CONTROL DURING LOAD VARIATION

BACKGROUND

Acid ring centrifugal chlorine compressors are normally employed for chlorine compression before liquifaction in any caustic plant (using any process). In a typical 250 TPD plant, five chlorine compressors were available in the plant (4 X 70 TPD and 1 X 40 TPD). The suction pressure of the chlorine header is to be maintained at –45 mm WC.

It was observed by the plant team that the suction pressure of chlorine header is very crucial for the plant operation (maintaining differential pressure across membranes between hydrogen and chlorine compartments). This is maintained by regulating the bypass control valve of one of the chlorine compressors.

In a 250 TPD plant in India, there were four compressors running (3 x 70 TPD and 1 x 40 TPD). Three compressors were operated with full valves opening and header suction pressure was controlled by controlling the bypass valve of one compressor.

Bypass control is one of the most energy efficient methods of capacity or head control as there is no reduction in the energy consumption with process load. This poses a good saving potential in the compressor.

ENERGY SAVING PROJECT

The plant team observed that after initial startup of the compressor the bypass valve need not be used and a VFD may be installed in one of the compressors. Any variation in load can be taken care of by giving a closed feedback control to the VFD from the suction header pressure and keeping the set point as –45 mm WC. This ensures optimum supply of chlorine, as per requirement.

COST BENEFITS

The annual energy saving achieved by installing a VFD to one of the chlorine compressors for a 250 TPD reference plant is **Rs. 0.70 million** with an investment of **Rs 0.90 million**. This investment is paid back in **15 months**. This reduces **45 MTOE**.

REPLICATION POTENTIAL

This project has been implemented only in one or two units. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 0.70 million	Rs. 0.70 million
MTOE equivalent	15	15
PAT benefit	--	Rs. 0.15 million[17]
Total benefit	Rs. 0.70 million	Rs. 0.85 million
Investment	Rs. 0.90 million	Rs. 0.90 million
Payback period	15 months	13 months
Replication Potential		
Number of plants	70% of the plants	
MTOE savings	385	

[17] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 7

INSTALL DEMAND SIDE CONTROLLER FOR THE COMPRESSED AIR SYSTEM

BACKGROUND

The air compressors used for meeting the instrument air requirement. Normally one compressor is in continuous operation and the second one is kept as hot stand by. Incase of lower pressure in the header, the standby compressor starts automatically.

Considering the average operating pressure is 7.65 kg/cm^2. Based on the set pressure limits, the compressor is operated in load / unload mode.

Base duty compressor : 7.3 kg/cm^2 (load) – 8 kg/cm^2 (unload)

Normally instrument air compressors are over designed than the requirement. Due to this reason the compressors are loaded for 75 to 80% of the time, and rest of the time it is operated in unloaded mode.

As there are multiple users of compressed air system, there is a continuous variation in the compressed air consumption. Sudden demand in compressed air leads to pressure fluctuations in the compressed air system. There is a time delay between the system demand and the compressor to sense the pressure and come to load mode.

Majority of time, the time delay is significant that by the time the compressor comes to load mode the system demand vanishes. The compressor pumps in the compressed air to the maximum pressure. This leads to artificial loading of the compressor and additional power consumption.

Hence there is a need for proper balancing of demand and supply. This can be achieved by installing intermediate controller in the compressed air system.

The intermediate controller creates a useful storage by introducing a pressure regulator across the upstream receiver and users. This storage isolates the compressor from the demand side. Peak requirements are dealt with reserve compressed air stored in the storage tank.

Thus by providing the air at controlled optimum pressure, the consumption at the user end is reduced. This leads to increase in unload time of the compressor and hence reduction in overall energy consumption of the compressor.

This project has been implemented in many plants and significant energy saving has been achieved.

RECOMMENDATION

It is recommended to install demand side controller for the air compressor system. On a conservative basis atleast 10 - 12% reduction in power consumption can be achieved due to pressure optimization.

COST BENEFITS

The annual energy saving potential is **Rs. 0.13 million**. The investment required for installing intermediate controllers is **Rs. 0.20 million**, which is paid back in **18 months**. This reduces 8 MTOE.

REPLICATION POTENTIAL

This project can be replicated to other units of the sector. Thus there is good replication potential to conserve energy by implementing this technology. Similar intermediate control systems are adopted in several other industries and are working successfully.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 0.13 million	Rs. 0.13 million
MTOE equivalent	2	2
PAT benefit	--	Rs. 0.028 million[18]
Total benefit	Rs. 0.13 million	Rs. 0.158 million
Investment	Rs. 0.20 million	Rs. 0.20 million
Payback period	18 months	15 months
Replication Potential		
Number of plants	70% of the plants	
MTOE savings	72	

[18] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 8

REPLACE EXHAUST BLOWERS WITH NEW ENERGY EFFICIENT BLOWERS

BACKGROUND

Exhaust blower has good energy savings potential for replacement with the new energy efficient blower.

The comparison between the measured parameters with the design parameters indicates that the fan is oversized for the application in terms of flow. Due to oversized the fan operation will be controlled by damper. Damper control is an inefficient way of controlling the fan. This results in operating point of the fan shifting to an inefficient zone on its performance curve.

Due to damper control there will be pressure drop across the damper. Capacity control with damper is an energy inefficient practice as part of the energy fed to the fan is lost across the damper. Hence about 7 % of the power consumed by the blower is lost across the damper.

Thus, there is a very good potential for energy saving by installing a new correct size blower of higher efficiency.

RECOMMENDATIONS

It is recommended installing a new high efficiency blower as per the present operating conditions (having an operating efficiency of at least 70%).

COST BENEFITS

Replacing the exhaust blower with high efficiency fan will result in an annual saving of **Rs. 0.40 million.** This will require an investment of **Rs. 0.40 million**, which will have a simple payback period of **12 months**. This reduces **25 MTOE**.

REPLICATION POTENTIAL

This project can be replicated to other units of the sector by calculating the efficiency of the present operating blowers. Wherever the efficiency of the blower is lower, it can be replaced with the high energy efficiency blowers.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 0.40 million	Rs. 0.40 million
MTOE equivalent	8	8
PAT benefit	--	Rs. 0.08 million[19]
Total benefit	Rs. 0.13 million	Rs. 0.48 million
Investment	Rs. 0.40 million	Rs. 0.40 million
Payback period	12 months	10 months
Replication Potential		
Number of plants	60% of the plants	
MTOE savings	190	

[19] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 9

INSTALL THERMOCOMPRESSOR AND UTILISE FLASH STEAM IN THE 1st EFFECT HEAT EXCHANGER

BACKGROUND

Caustic at 130°C is entering the flash vessel and comes out at a temperature of 80 – 90°C. In the process of flashing, the caustic concentration increases by upto 3% in the flash tank and the temperature falls from 130°C to 80 – 90°C. The temperature of caustic has to be maintained in the vertical heat exchanger of about 130°C.

To maintain the temperature of 130°C, the typical ΔT of maximum 30°C is required, which needs a steam of condensing temperature of 160°C, this equivalent to a steam pressure of 8 kg/cm^2. The flash vessel is at a temperature of 80°C, which is equivalent to a steam saturation pressure of 0.5 kg/cm^2(a). Since the vapors from flash vessel contain some caustic vapors also, the pressure has to be maintained lower say about 0.3 kg/cm^2, to get the equivalent temperature.

RECOMMENDATION

There is an excellent potential to recover heat by installing a thermocompresor and using live steam at a pressure of 12 kg/cm^2 as a motive steam. The flash generated in the vessel can be recovered and reused in the plant. Care has to be taken of material of construction of Heat exchanger and ejector. Installation of a thermocompressor (ejector) has been successfully implemented in many plants and resulted in good savings.

COST BENEFITS

In a 250 TPD caustic chlor unit, by implementing this proposal **Rs. 3.50 million** savings achieved with an investment of **Rs. 4.75 million, which will have a simple payback period of 16 months**. This reduces **235 MTOE**.

REPLICATION POTENTIAL

Thermocompressor is widely used in many plants for recovering the flash steam. This project can be replicated to other units where the flash steam is venting out into the atmosphere.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 3.50 million	Rs. 3.50 million
MTOE equivalent	75	75
PAT benefit	--	Rs.0.76 million[20]
Total benefit	Rs. 3.50 million	Rs. 4.20 million
Investment	Rs. 4.75 million	Rs. 4.75 million
Payback period	16 months	13 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	1113	

[20] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 10

REPLACE EXISTING RECIPROCATING REFRIGERATION COMPRESSORS BY ENERGY EFFICIENT COMPRESSOR

BACKGROUND

Refrigeration load is the major power consumer in caustic chlorine plant. It is required for Chlorine Liquification. The process is quite energy intensive as a lot of cooling water and chilled water load is required. Any reduction in the energy consumption in the compressor will result in very high saving.

Many caustic chlor units in India have installed reciprocating compressors (350 TR approximately) were operating in the refrigeration system and meeting the demand of 250 TPD plant.

The compressors were in continuous operation as there was very low load variation in the system. The load variation occurs only when demanded by production schedules or during peak load hours. The specific energy consumption for producing chilled water at 10^{0}C was 1.0 - 1.2 KW/ TR

ENERGY SAVING PROJECT

The plant team had carried out detailed study on the performance of Reciprocating and Centrifugal / Screw compressors, based on the other plant visits and discussions with industry experts. It was observed that the Centrifugal / Screw compressors operate with specific power consumption of 0.60 - 0.65 KW/ TR.

The plant team replaced the existing reciprocating compressor with screw/centrifugal compressors. The power consumption of the compressors can be reduced by around 40% by operating the compressor at present operating conditions.

On a load of 350 TR the existing power consumption in the reciprocating compressors is 385 KW. The new centrifugal/screw compressors have a power consumption of 220 KW.

BENEFITS

The annual savings achieved by this replacement of reciprocating compressors is **Rs 4.40 million** with investment of **Rs. 7.0 million** for installing high energy efficient compressor, which had a simple payback period of **19 Months**. This reduces **300 MTOE**.

Replication Potential

This project can be replicated to other units of the sector. Thus there is good replication potential to conserve energy by implementing this technology. Similar energy efficient screw refrigeration compressors can be used in place of reciprocating compressors. This reduces the SEC of the system.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 4.40 million	Rs. 4.40 million
MTOE equivalent	95	95
PAT benefit	--	Rs.0.95 million[21]
Total benefit	Rs. 4.40 million	Rs. 5.35 million
Investment	Rs. 7.00 million	Rs. 4.75 million
Payback period	19 months	17 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	1411	

[21] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 11

INSTALL COMMERCIAL CO-GENERATION SYSTEM FOR CHLOR – ALKALI INDUSTRY

BACKGROUND

Chlor – Alkali plants require uninterrupted quality power at cheaper cost for a sustained operation. Generating power through captive power plant can be a solution in terms of quality and cost. A co-generation plant can be used for efficient utilisation of energy in various processes.

Power quality plays an important role in a caustic chlorine plant. Refrigeration and steam requirement also contribute to a significant figure to total energy cost. Considering the above factors Co-generation is best solution for a caustic chlorine plant in terms of low specific energy consumption and quality of power. The following case study involves setting up of a co-generation plant in a typical caustic chlorine plant of 250 TPD involving membrane cell technology.

The power requirement for a caustic chlorine plant of 250 TPD is around 2650 kWh/Ton Caustic which comes to around 30 MW so a captive plant based on furnace oil/naptha/hydrogen of 35 MW capacity will be sufficient to support the plant power needs. Back pressure turbines can either be single stage or multi stage which can often used in industrial plants. The turbine serves as a reducing station between boiler and process steam header. These turbines can either be used for drive application or power generation application in which case the turbine drives the generator.

These back pressure turbines may also have bleed points to satisfy steam demands at medium intermediate pressures. This provision is applicable when the bleed steam volume demand is low and pressure variations can be tolerated. These turbines are of bleed cum back pressure turbine.

The breakup of which is as follows (the consumption pattern may vary slightly depending on technology used and product mix):

1. Evaporator house: 0.7 Ton/ Ton of caustic soda (Caustic concentration unit)

2. Brine House: 0.4 Ton/ Ton of caustic soda

3. Flaking Plant: 0.2 Ton/ Ton of caustic soda

About 1.5 TPH steam left out of total generation after fulfilling the requirement in various processes. This steam / hot water can be use for refrigeration of capacity 300 TR at the rate of 220 TR per TPH of steam. The refrigeration can be use to for room air conditioning.

Refrigeration contributes a significant role in a caustic chlorine industry. Refrigeration is required for chlorine liquefaction. For a 200 TPD plant the refrigeration load is about 600 TR, considering 80 % of chlorine is liquefied (rest goes in the production of hydrochloric acid). The steam / hot water can be used to produce refrigeration through a Vapor Absorption System based on hot water @ 40 TR/MW of generation. This will result in drastic reduction of refrigeration cost as refrigeration power consumption is around 55 KWh/Ton of chlorine liquefied.

COST BENEFIT

By installing captive cogeneration plant for a plant of 200 TPD based on membrane cell technology the total annual savings from all the sources come out to be around **Rs 4.00 million**. This requires an investment for VAM machines and other control equipments to the tune of **Rs 13.00 million**. This offers a simple payback of **39 months**. This reduces **270 MTOE**.

REPLICATION POTENTIAL

This project can be implemented in other Chlor-Alkali plants also. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 4.00 million	Rs. 4.00 million
MTOE equivalent	85	85
PAT benefit	--	Rs. 0.86 million[22]
Total benefit	Rs. 3.50 million	Rs. 4.86 million
Investment	Rs. 13.00 million	Rs. 13.00 million
Payback period	39 months	33 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	1258	

[22] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 12

REDUCTION IN FURNACE OIL CONSUMPTION IN AUXILIARY BOILER BY PROCESS MODIFICATION

BACKGROUND

The plant is operating with the energy efficient membrane cell technology process. The process starts by dissolving common salt (i.e. sodium chloride) into water. The salt solution is known as brine. The optimum temperature of brine is 60^0C for optimum performance of Ion Exchange columns where the impurities such as Ca, Mg are removed in ppb (parts per billion) levels.

The plant team has carried out detail heat balance analysis, which has revealed that by eliminating the brine heating requirement through modification and better control of vacuum in dechlorination tower, where chlorine is removed from brine by vacuum. There was only a manual valve in the steam line going to dechlorination ejector as per OEM design. This valve was kept fully open. The absolute pressure in the dechlorination tower was remaining in the range of 0.32-0.34 kg/cm^2.

Due to higher vacuum, the brine temperature at outlet of dechlorination was remaining in the range of 72-74^0C (saturation temperature of brine at 0.32-0.34 kg/cm^2) 52-54^0C brine temperature was obtained at inlet of Ion exchange columns as there was a drop of 20^0C in brine circuit as per block diagram.

Earlier System

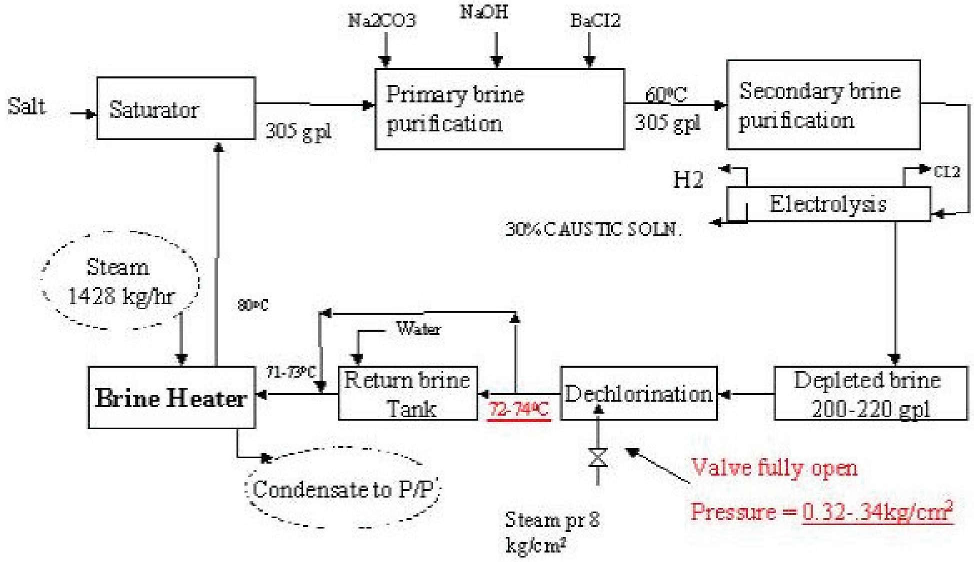


Figure 15: Brine circuit Process flow block diagram (Before modification)

Therefore, to maintain the brine temperature of 60^0C at the inlet of Ion exchange columns, the brine was heated from 72-74^0C to 80^0C in a plate type heat exchanger at return brine tank outlet. At low load operation when the waste steam was not available this heating was done by using steam generated in FO based package boiler. The furnace oil consumption was 210 MT/annum.

RECOMMENDATION

Now a pressure control valve is installed in steam line going to dechlorination tower for auto control of pressure. The absolute pressure is increased from 0.32-0.34 to 0.4 kg/cm^2 corresponding to 81^0C brine temperature at dechlorination outlet as per below modified block diagram.

Modified System

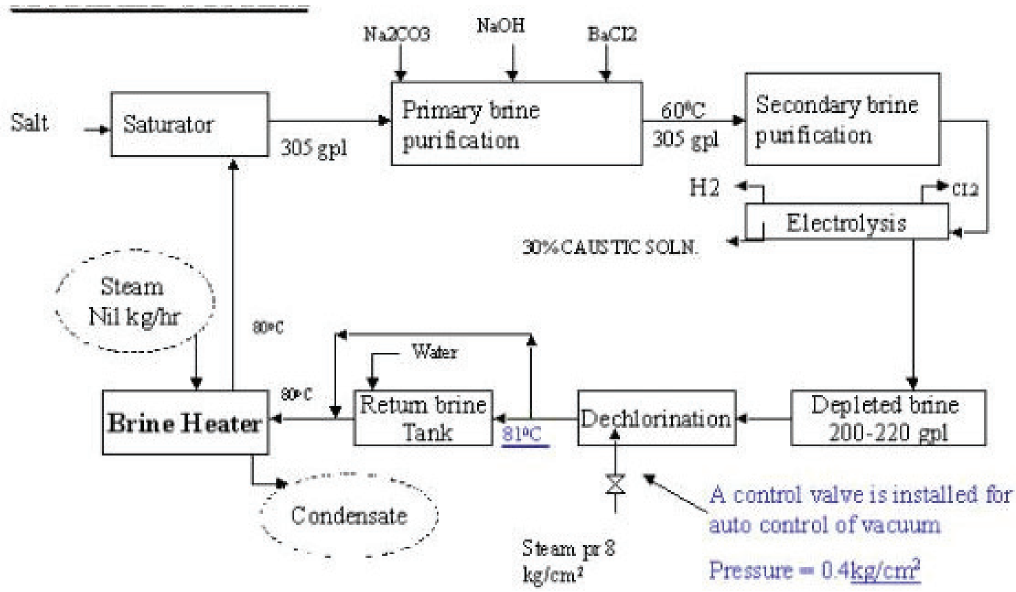


Figure 16: Brine circuit Process flow block diagram (After modification)

ENERGY SAVING PROJECT

The brine temperature is 60^0C without any heating. Now there is no need to run furnace oil based packaged boiler.

COST BENEFITS

The annual energy saving achieved by installing auto control valve gives **Rs. 2.0 million**. This called for an investment of **Rs. 0.5 million**, which had a simple payback period of **3 months**. This reduces **135 MTOE**.

REPLICATION POTENTIAL

This project can be implemented in other Chlor-Alkali plants also. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 2.00 million	Rs. 2.00 million
MTOE equivalent	43	43
PAT benefit	--	Rs.0.43 million[23]
Total benefit	Rs. 2.00 million	Rs. 2.43 million
Investment	Rs. 0.5 million	Rs. 0.50 million
Payback period	3 months	3 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	636	

[23] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 13

INCREASE THE OPERATING PARAMETERS OF HYDROGEN BOILER AND INSTALL A MICRO BACK PRESSURE STEAM TURBINE TO GENERATE STEAM AND POWER

BACKGROUND

The possibility of utilization as per design and the feasibility to further increase the energy generation potential in Hydrogen boiler was studied in detail by the plant team and the observations made during the course of time are as follows:

The plant is having one hydrogen fired boiler for generating medium pressure steam for the process application. The design steam generation specifications of the hydrogen boiler are given below:

- Capacity = 9 TPH
- Pressure = 24 kg/cm^2
- Temperature = 340^{0}C (Super heated steam)

The operating parameters of hydrogen fired boiler in-terms of steam flow, pressure and temperature are as follows:

- Flow = 9 TPH
- Pressure = 10 kg/cm^2
- Temperature = 1800C (saturated)
- Enthalpy of steam = 665 kCal/kg

The plant takes main process steam from adjacent boiler. The extracted steam of 16 kg/cm^2 pressure from adjacent boiler steam turbine is connected to the plant common header.

The 16 kg/cm^2 steam pressure is reduced to 10 kg/cm^2 by passing through PRV and de-superheating the steam to saturated temperature using DM water spray. After that, the medium pressure steam line is connected to the hydrogen boiler steam outlet line.

The main users of steam in the plant are given below:

- 10 kg/cm^2 – Medium pressure steam
    - Membrane Cell House – I and II

- 7 kg/cm^2 – Medium pressure steam
  - Vapour Absorption Machine (VAM)
- 3 kg/cm^2 – Low pressure steam
  - Membrane – I and II Cl2/HCL
  - Stable Bleaching Plant (SBP)
  - Poly Aluminium Chloride (PAC)
  - Caustic Soda Flake (CSF)
  - Chloro Sulphonic Acid (CSA)

Power generation option has been considered while selecting the boiler of present capacity. There is a good potential to generate power and steam simultaneously.

The present boiler can be used to generate steam upto 24 kg/cm^2 instead of 10 kg/cm^2 and the feed water can be super heated upto 340^0C. The only requirement to achieve this is to install super heater coils for super heating the steam.

It was also observed that nearly 10,400 Nm^3/day (say 400 Nm^3/hr) of excess hydrogen (H2) is vented out into the atmosphere. This is almost 25% of the production. Thus there is a potential available to utilize the excess hydrogen for generating steam and power.

The latest trend is to install package type micro turbines with required back pressure. The back pressure steam can be used in the process.

These micro turbines are tailor made and supplied as per the required specifications. The main advantages of micro turbine are

- Compact in size and shape
- Easy to install and maintain
- Package type
- Exhaust steam dryness fraction - 0.92
- Increased power generation

The new proposed scheme of steam turbine system and the operating conditions are shown below:

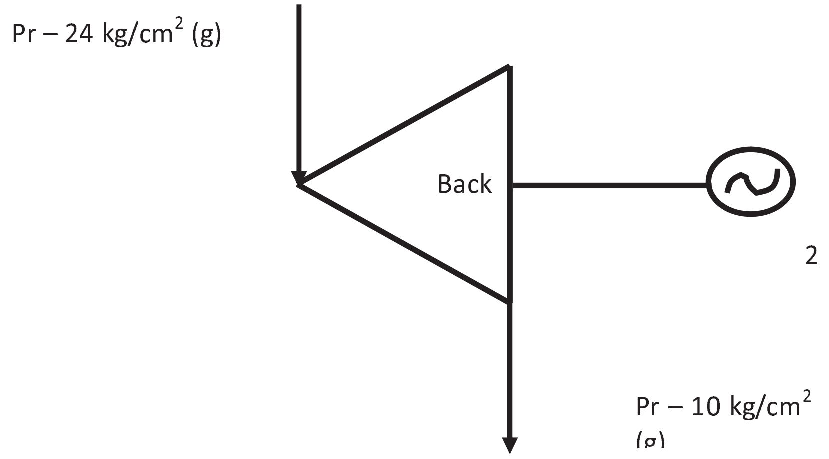


Figure 17: Proposed scheme of steam turbine system and the operating condition

ENERGY SAVING PROJECT

- Increase the operating parameters of pressure and temperature of boiler from present to
  - Pressure = 24 kg/cm^2
  - Temperature = 340^{0}C
- Install a micro back pressure steam turbine of following specifications
  - Inlet pressure = 24 kg/cm^2
  - Exhaust (back) pressure = 10 kg/cm^2
  - Steam flow = 9 TPH
- Power generation potential is 250 kW
- The back pressure steam can be used for process requirements

COST BENEFITS

The annual energy saving potential is **Rs. 8.50 million**. This requires an investment of **Rs. 10.00 million** for installing new steam turbine and generator, which gets paid back in **14 Months**. This reduces **575 MTOE**.

NOTE:

Presently the excess Hydrogen is venting out @ 400 Nm^3/hr. Hydrogen cost is incurring cost (running cost). This project may not be economically feasible, if the cost of hydrogen is included.

REPLICATION POTENTIAL

This project can be implemented in other Chlor-Alkali plants also. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs.8.50 million	Rs. 8.50 million
MTOE equivalent	182	182
PAT benefit	--	Rs. 1.85 million[24]
Total benefit	Rs. 8.50 million	Rs. 10.35 million
Investment	Rs. 10.0 million	Rs. 10.0 million
Payback period	14 months	12 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	2700	

[24] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 14

UTILISATION OF HYDROGEN RELEASED DURING ELECTROLYSIS PROCESS IN VAPOUR ABSORPTION MACHINE (VAM)

BACKGROUND

The possibility of utilization of excess hydrogen, which is currently has vented into the atmosphere, in the Vapour Absorption Machine (VAM) was studied in detail by the plant team for reducing the steam consumption. The observations are as follows

Three VAM systems are available in the plant, out of which two 150 TR capacity systems are in continuous operation and one 120 TR capacity system is kept as standby.

The operating parameters of the 150 TR system are as given,

- Steam consumption = 700 to 800 kg/hr
- Steam pressure = 5.5 kg/cm^2
- Capacity = 115 TR

The chilled water operating parameters are as follows,

- Chilled water flow = 175 m^3/hr
- Water I/L temp to VAM = 15^{0}C
- Water O/L temp of VAM = 13^{0}C

Based on operating parameters, the heat capacity and specific energy consumption (SEC) of VAM system was estimated. The SEC of the present system is in the range 6 to 7 kg/hr/TR. The optimum specific energy consumption for a steam operated Vapor Absorption Machine (VAM) system should be in the range of 4 to 5 kg/hr/TR. This shows that there is an opportunity to save energy in the existing VAM system.

The plant team has estimated the quantity of excess hydrogen venting into the atmosphere. The estimated quantity is 10,400 Nm^3/day (say 400 Nm^3/hr). This is almost 25% of the production. Thus a good potential is available to generate chilled water by using excess hydrogen.

ENERGY SAVING PROJECT

The vented hydrogen can be effectively used in the hydrogen fired Vapour absorption machine by installing of Hydrogen (H_2) fired VAM system. The actual requirement of hydrogen in VAM is estimated as 200 Nm^3/hr

Hence the present steam operated VAM system can be kept as standby for any future requirements. By installing a H2 fired VAM system, at-least 0.8 TPH of steam can be saved i.e 18 Tons per day.

COST BENEFITS

The annual saving that can be achieved by implementing this project is Rs. 4.50 millions. The investment required for installing hydrogen fired VAM is Rs. 10.00 millions, which gets paid back in 27 months. This reduces 305 MTOE.

NOTE:

Presently the excess Hydrogen is venting out @ 400 Nm^3/hr. Hydrogen cost is incurring cost (running cost). This project may not economically feasible, if the cost of hydrogen is included.

REPLICATION POTENTIAL

This project can be implemented in other Chlor-Alkali plants also. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs.4.50 million	Rs. 4.50 million
MTOE equivalent	95	95
PAT benefit	--	Rs. 0.98 million[25]
Total benefit	Rs. 4.50 million	Rs. 5.48 million
Investment	Rs. 10.0 million	Rs. 10.0 million
Payback period	27 months	22 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	1431	

[25] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 15

REDUCE 'MV' DROP IN MC-1 ELECTROLYZERS BUS BAR JOINT

Background

The voltage drop at the cable joints will be having very high potential for energy saving. The following case study was taken up by the plant team for reducing the cable joint losses. The plant team has carried our rigorous measurements across the bus bar joints.

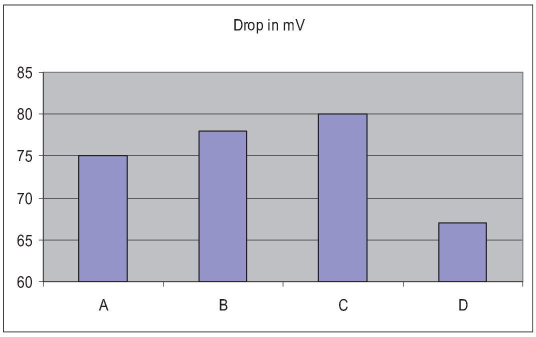
The details of the measured mV drop at each bus bar joint are given in the below table:

Table 5: mV drop and the corresponding Joint

	A	B	C	D	E	F	G	J
Flexi. Joint to +ve bus bar	16.2	11.75	13.9	11.5	16.5	17.75	17.9	26.6
Flexi. Joint 1	264	107.1	165	96.8	236	105.6	128	220
Flexi. Joint 2	203.7	123.7	121.5	195.7	140.5	130.7	175	110

Note: All valves are in 'mV'

MC II



MC I

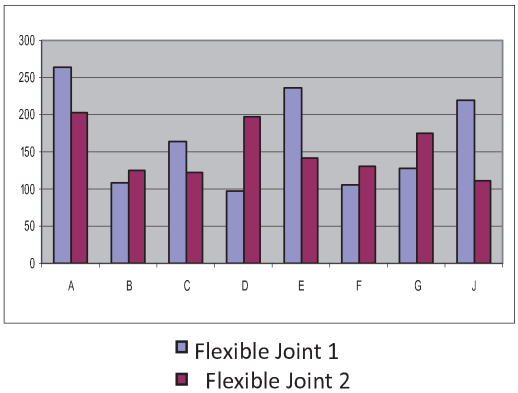


Figure 18: Drop in mV at different bus bars

The similar joints in membrane cell house-2 are operating at 'mV' drop less than 75mV. Considering 75mV as base level, as first step, the approach should be formulated to maintain all the joints at MC-1 less than 75mV drop level. The average current through each electrolyzer is 8kA.

The plant team has calculated the total power loss at the joints. It is found that in total 10 kW of power is losing across the joints.

ENERGY SAVING PROJECT

By maintaining the electrical joints properly the voltage drop can be reduced.

COST BENEFITS

The annual saving that can be achieved by implementing this project is **Rs. 0.30 millions**. This was carried out with operational improvement. This reduces **20 MTOE**.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs.0.30 million	Rs. 0.30 million
MTOE equivalent	6.8	6.8
PAT benefit	--	Rs. 0.06 million[26]
Total benefit	Rs. 0.30 million	Rs. 0.50 million
Investment	NIL	NIL
Replication Potential		
Number of plants	60% of the plants	
MTOE savings	150	

[26] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 16

REPLACEMENT OF OLD RECTIFORMER'S WITH THYRISTER BASED RECTIFORMERS

BACKGROUND

The DC power required for electrolysis process is supplied by rectiformers in chlor alkali plants. The rectiformer consists of Step down power transformer and rectifier unit. The capacity and DC voltage output from the rectifiers are based on the size of the plant.

All old generation chlor alkali plants have diode based rectifiers which is the simplest rectifier technology. However, a straight diode rectifier is very seldom applied because it does not, by itself, offer any means to control the output voltage and current as required by chlor alkali plants. Control of current and voltage for diode rectifiers is achieved by changing the rectifier AC input voltage adding to the system equipment requirements like special on load tap changers and saturable reactors.

However, the major drawback with the on load special tap changers is the wear and tear on the mechanical on load tap changer that results in a need for regular preventative maintenance and service of the contact systems. The control range of saturable core reactors are mainly limited by mechanical restrictions.

An achievable control range is about 60-80VDC. Saturable core reactors are typically used together with on-load tap-changers to provide stepless regulation characteristic. Generally in plants, the diode-rectifiers have the operating efficiency range of 91 to 94%.

Today, all modern plants have the thyristor rectifiers which is having high reliability and efficiency. It has become the most commonly used rectifier configuration for high power converter applications. The SCR (Silicon Controlled Rectifier) or thyristor rectifier is from a design point of view very similar to the diode rectifier. However, unlike the diode, the thyristor rectifier is controlled electronically. Electronic control eliminates the need for special tap changers and saturable reactors.

A thyristor rectifier is built by replacing the diode devices with thyristor devices and saturable reactor control with thyristor control. When a thyristor rectifier is controlled at small delay firing angle it performs similar to a diode rectifier using saturable reactor control.

Another benefit is the fast and smooth output control within milliseconds. Thyristor rectifiers have a higher efficiency when compared to its diode rectifier counterparts. Typically the efficiency of a thyristor rectifier varies around 97 to 98%.

ENERGY SAVING PROJECT

In India, some of the plants are operating with Diode based rectifiers. For a diode system including a regulating transformer the efficiency would be lower than a thyristor system. The thyristor system including power factor and harmonic filter would be the most efficient of today's technologies.

Thyristor based converters are available with an operating efficiency of 97%. The reliability is also good and is operating successfully in many plants. The estimated savings by replacing old diode rectifier with thyristor rectifier is in the range of 4 to 6% depending the efficiency of existing system.

COST BENEFIT

The improvement in efficiency by replacing diode rectifiers with thyristor rectifier is around 4 to 6%. There is a good potential to save energy by replacing existing diode rectifier with thyristor rectifiers. There is a potential to save minimum 5% on the total load connected.

In a 250 TPD reference plant, the annual savings that can be achieved by implementing this project is **Rs. 11.80 million** with an investment of **Rs. 20.0 million** for installing thyristor rectifier. This calls for an simple payback period is **21 months**. This reduces **800 MTOE**.

REPLICATION POTENTIAL

This project is already implemented in some of the Chlor-Alkali plants. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs.11.80 million	Rs. 11.80 million
MTOE equivalent	255	255
PAT benefit	--	Rs.2.59 million[27]
Total benefit	Rs. 11.80 million	Rs. 14.39 million
Investment	Rs. 20.0 million	Rs. 20.0 million
Payback period	21 months	17 months
Replication Potential		
Number of plants	40% of the plants	
MTOE savings	3780	

[27] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

TECHNOLOGY - 17

AVOID VALVE THROTTLING AT THE IDENTIFIED PUMPS OF BRINE SECTION BY PROVIDING VFD WITH CLOSE FEEDBACK CONTROL

BACKGROUND

The caustic soda plant consumes substantial power for pumping brines due to feed variation, fine capacity control of the pumps. Pumps therefore are essential for operation of plant at lower energy consumption. A case study involving the VFD control of the pumps in a caustic soda plant is described below.

System is designed for 250 TPD caustic production. The plant team observed that almost all brine pumps have control valve in re-circulation on main line. Control valve on these re-circulation not open more than 30 – 40%. Heavy throttling on the re-circulation valves indicates high capacity and rating for the pumps.

Valve control is an energy inefficient way of capacity control. The best energy efficient method of capacity control for a pump (or for that matter any centrifugal equipment) having varying capacity requirements is to vary its RPM, which can be best achieved with a variable frequency drive (VFD).

ENERGY SAVING PROJECT

The plant team installed Variable Frequency Drives (VFD) for all identified pumps with discharge pressure of the main header as feedback control from the main header.

The VFD can be provided with a closed loop pressure sensor control. This pressure sensor will continuously sense the pump discharge header pressure and give a signal to the VFD, to either increase or decrease the RPM of the pump, thereby matching the varying capacity requirements.

COST BENEFITS

Installation of VFDs for 15no's pumps which are valve controlled / having recirculation has resulted in an annual energy saving potential is **Rs. 4.75 million**. This called for an investment of **Rs.6.75 million**, which had a simple payback period of **17 months**. This reduces **320 MTOE**.

POTENTIAL FOR REPLICATION

Typically in caustic soda unit, there are about 30 pumps (brine and water) in operation and there is a potential for application of VFD in atleast about 25 pumps. Only about a quarter of this potential has been tapped. Thus there is good replication potential to conserve energy by implementing this technology.

Reference Plant (250 TPD)		
	Without PAT	With PAT benefit
Energy savings	Rs. 4.75 million	Rs. 4.75 million
MTOE equivalent	102	102
PAT benefit	--	Rs. 1.03 million[28]
Total benefit	Rs. 4.75 million	Rs. 5.78 million
Investment	Rs. 6.75 million	Rs. 6.75 million
Payback period	17 months	14 months
Replication Potential		
Number of plants	55% of the plants	
MTOE savings	2043	

[28] PAT benefits calculated based on the MTOE Savings. One MTOE equals Rs.10154 for the year 2011-12 as per the PAT official notification. Refer Annexure 2 for detailed calculation.

5.0 FUTURE ENERGY SAVING OPPORTUNITIES

By implementing the following advanced technologies in Chlor-Alkali sector, the Specific Energy Consumption of the caustic soda production will be is further reduced.

1. Low energy consumption in chlor-alkali cells using oxygen reduction electrodes: By replacing present hydrogen evolution reaction with Oxygen reduction electrodes, Improved and optimized gas diffusion electrodes, electrolysis could be carried out for about 600 hrs at a current density of 300 mA cm^{-2} and a total voltage of. 2.0 V, The overvoltage and ohmic loss lies at about 1.0 and Current efficiency lies at around 92-97%. Due to the some of the above reasons the reduction in specific energy consumption is about 440 – 530 kWh / Tonne of caustic soda production

2. Conversion of Monopolar membrane / Bipolar cells to 6th generation technology: The advantages of the 6^{th} generation Zero gap technology is brine and chlorine on the anode side as well as caustic soda and hydrogen on the cathode side are transported to the upper end of the compartments, a high degree of safety will be achieved, the foamy gas-liquid mixture is completely separated inside the channels resulting in an outlet flow of two homogeneous phases, significant energy saving, extension of membrane service life. By shifting to the latest technology (6^{th} generation Bipolar memberane, reduces the specific energy consumption (Power reduction by 95 kWh/Tonne of caustic soda production):

3. Installation of advanced cell controls systems: the major factors in manual controlling are the time of response, accuracy of the control, individual person operating bandwidth. Due to the above said factors range of SEC of caustic soda production varies from person to person. The operating SEC band width can be reduced by installing advanced cell control systems, which continuously monitors the Cell parameters like temperature, pressure, concentration of brine, brine and caustic flow to electrolysers etc. and controlles the performance of membrane cells.

4. Replace Steam Ejector with Water Ring Vacuum Pump for Brine Dechlorination. This reduces the specific steam consumption of the plant through minimal increase in the power consumption. The savings achieved in terms of difference in power generation by the steam and power consumption of the vacuum pump. The specific energy consumption for operating the vacuum pump is 1.0 – 1.3 kW/MW. Thus there is good potential to produce more power by passing steam into the turbine & install vacuum pump for creating vacuum instead of steam ejector.

5. The efficiency of the rectiformers can be increased by 4%, by replacing the old rectiformers with the new energy efficient rectiformers: the advantages of thyrister rectifier is, it is controlled electronically, replacement of diode devices with thyristor devices and saturable reactor control with thyristor control. When a thyristor rectifier is controlled at small delay firing angle it performs similar to a diode rectifier using saturable reactor control and also it is having fast and smooth output control within milliseconds.

6. Installation of HT variable frequency drives for the condensate water pumps (CEP) & boiler feed water pumps (BFP).: valve controlling is an oldest method of controlling any equipment (fan / pump / compressor). valve controlling is not an energy efficient way of controlling any equipment. By operating the equipment with valve controlling some of the energy consumed by the equipment is lost across the valve. In present scenario there is good potential to save energy by operating the equipment with VFD instead of valve controlling. The loss in VFD is very less compare to valve controlling.

PRIORITIZING THE PROJECTS:

The Best Available Technologies can be categorized into three heads namely, Level 1, Level 2, Level 3 based on the simplicity of implementation level 1 being the easiest and level 3 being the most difficult to implement.

Level 1: Low investment and easier to implement

Level 2: Medium investment and moderate level of difficulty in implementation

Level 3: High investment and high level of difficulty in implementation

Level 1:

a) Installation of Variable Frequency Drive for centrifugal equipments

b) Preventive maintenance

c) Energy Efficiency improvements in Captive Power Plant

d) Reduce "mv" drop in the electrolysers bus bar joints

Level 2:

a) Replacement of old motors with new energy efficient motors

b) Reduction in furnace oil consumption in auxiliary boiler by process modification.

c) Replace steam ejector with water ring vacuum pump for brine dechlorination

d) Replace exhaust blower with new energy efficient blower

e) Installing Economizer in boiler to increase boiler feed temperature by using hot flue gas stream

f) Replacement of old rectiformer's with thyrister based rectiformers

g) Install intermediate controller for the compressed air system

h) Replace existing reciprocating refrigeration compressors by energy efficient (screw) compressor

Level 3:

a) Low energy consumption in Chlor-Alkali cells using oxygen reduction electrodes

b) Install adaptive control system and minimize variation in feed temperature

c) Install hydrogen fired vapour absorption machine (VAM)

d) Recoating of electrodes reduces the specific power consumption of caustic soda production

e) Install commercial co-generation system for Chlor – Alkali industry

Table 6 : Table for Prioritizing the Technical Proposals

Sl. No.	**Opportunities**	**Ease of implementation**				**Priority of activity**		
		Easy	**Moderate**	**Difficult**		**Short**	**Medium**	**Long**
1	*Mercury to membrane cell technology*	*X*						*X*
2	VFD for the brine pumps	X				x		
3	Provide VFD for one chlorine compressor and avoid bypass control during load variation		X				X	
4	Replace steam ejector with water ring vacuum pump for brine dechlorination		X				X	
5	Low energy consumption in Chlor-Alkali cells using oxygen reduction electrodes			X				X

6	Install adaptive control system and minimize variation in feed temperature			X				X
7	Install intermediate controller for the compressed air system		X				X	
8	Replace exhaust blower with new energy efficient blower		X			X		
9	Install thermocompressor and utilise flash steam in the I- effect heat exchanger			X				X
10	Replace existing reciprocating refrigeration compressors by energy efficient compressor		X				X	
11	Install commercial co-generation system for Chlor–Alkali industry			X				X
12	Reduction in furnace oil consumption in auxiliary boiler by process modification.		X					X
13	Increase the operating parameters of hydrogen boiler and install a micro back pressure steam turbine to generate steam and power			X				X
14	Install hydrogen fired vapour absorption machine (VAM)		X				X	
15	Reduce MV drop in MCC-1 Electrolyzers bus bar joint	X				X		
16	Replace old rectifier (diode based) with thyrister based rectifier		X					X
17	Recoating of electrodes reduces the specific power consumption of caustic soda production		X				X	

6.0 COST ABATEMENT CURVE

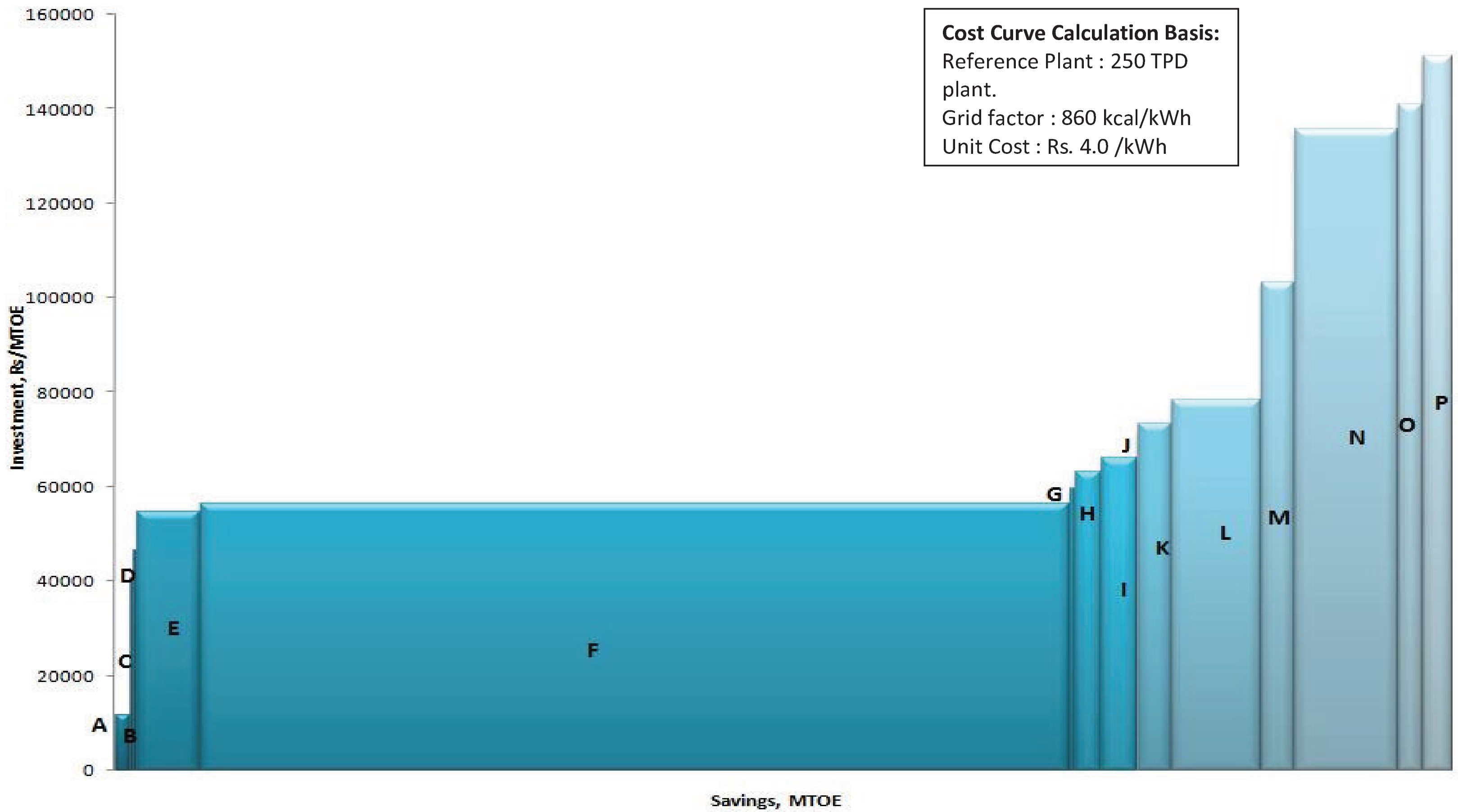


Figure 19 : Cost Abatement Curve

Table 7: Representation of all Proposals as per Cost Abatement Curve & MTOE savings for each technical proposal

A	Reduce MV drop in MCC-1 Electrolyzers bus bar joint, 6.8 MTOE
B	Reduction in furnace oil consumption in auxiliary boiler by process modification, 43 MTOE
C	Replace steam ejector with water ring vacuum pump for brine dechlorination, 8.0 MTOE
D	Replace exhaust blower with new energy efficient blower, 8.0 MTOE
E	Increase the operating parameters of hydrogen boiler and install a micro back pressure steam turbine to generate steam and power, 182 MTOE
F	Low energy consumption in Chlor-Alkali cells using oxygen reduction electrodes, 2483 MTOE
G	Provide VFD for one chlorine compressor and avoid bypass control during load variation, 15 MTOE
H	Install thermocompressor and utilise flash steam in the i- effect heat exchanger, 75 MTOE
I	VFD for the brine pumps, 102 MTOE
J	Install intermediate controller for the compressed air system, 2.5 MTOE
K	Replace existing reciprocating refrigeration compressors by energy efficient (screw) compressor, 95 MTOE
L	Replace old rectifier (diode based) with thyrister based rectifier, 255 MTOE
M	Install hydrogen fired vapour absorption machine (VAM), 96 MTOE
N	Recoating of electrodes reduces the specific power consumption of caustic soda production, 294 MTOE
O	Install adaptive control system and minimize variation in feed temperature, 70MTOE
P	Install commercial co-generation system for Chlor – Alkali industry, 85 MTOE

7.0 CONCLUSION

The Chlor-Alkali sector is an energy intensive sector where energy represents approximately 65% of total production cost. In a country like India, where the cost of industrial electricity is high, industries using large quantities of electricity such as the caustic soda industry have been focusing more attention on reducing energy consumption. Hence some caustic soda companies are closely monitoring their energy consumption, resulting in overall moderate specific energy consumption. Internationally, India compares positively with a substantial share of membrane cell technology.

The technologies and best practices presented here is only small effort to help the designated consumers to achieve their PAT targets. Apart for this, several activities like regular efficiency testing of pumps, fans, compressors, motors, maintenance of anodes & cathodes, can result in enormous energy savings. Effective utilization of by product gases, instead of flaring, is another step towards saving of usage of conventional energy sources.

Indian Chlor-Alkali sector is bound to grow for the next few decades, thanks to the strong demand from the domestic and international market. On the flip side, it would place a huge burden on the energy market. World is now a fast track proving all predictions on longevity of availability of conventional energy sources. In this scenario, working towards energy efficient world class levels reduces the Specific Energy Consumption of the Chlor-Alkali sector.

This compendium is an effort towards this direction discussing not only on the efficient use of energy but also the utilization of World Class Energy Efficient practices. This "Technology Compendium" would help designated consumers in achieving their PAT targets set by BEE.

Reduction in resource intensity along with improved operational efficiency will be one of the key drivers for the industry to grow at a steady pace and thereby being global competitive.

ANNEXURE 1: GHG INVENTORIZATION & TREND ANALYSIS:

Present status

Major raw materials used in the Chlor-Alkali Industry are salt and water which are not expensive. A major portion of the total cost of production consists of energy cost. Caustic soda is produced by the electrolysis process and electricity costs account for about 60% of the total production cost, which is much higher compared to competing nations. Nearly 85- 90% electricity is consumed in the electrolysis process and the remaining 10-15% in auxiliary consumption to run the plant.

On an average the present specific energy consumption of the Chlor – Alkali sector is 2400 – 2500 kWh / Tonn of caustic soda production. As per the PAT targets given by BEE & extrapolating the values to the entire Indian Chlor-Alkali sector, the calculated annual MTOE consumption comes to be 1.18 mMTOE and this contributes 12.48 million TCO_2[29] emissions releasing into the atmosphere.

Table 8 : List of Technical Proposals

Sl. No.	Project Description	Investment, Rs/MTOE	savings, MTOE	Tons of CO_2[30]
A	Reduce MV drop in MCC-1 Electrolyzers bus bar joint	0.00	6.8	72
B	Reduction in furnace oil consumption in auxiliary boiler by process modification.	3680.53	43	455
C	Replace steam ejector with water ring vacuum pump for brine dechlorination	12881.85	8.0	91
D	Replace exhaust blower with new energy efficient blower	14722.12	8.0	91
E	Increase the operating parameters of hydrogen boiler and install a micro back pressure steam turbine to generate steam	17320.14	182.75	1933

[29] 1 kWh = 0.91 kg of CO_2 – As per CO_2 Baseline Database for the Indian Power Sector, Version 6.0

[30] GHG savings indicated is calculated only for the reference plant of 250 TPD. Projects explained in this compendium should be seen individually for its applicability in a particular plant. The reader is advised not to sum up individual GHG emission savings and extrapolate for the sector as it might be misleading.

	and power			
F	Low energy consumption in Chlor-Alkali cells using oxygen reduction electrodes	17844.99	2483.25	26276
G	Provide VFD for one chlorine compressor and avoid bypass control during load variation	18928.44	15.05	159
H	Install thermocompressor and utilise flash steam in the I- effect heat exchanger	19980.02	75.25	796
I	VFD for the brine pumps	20912.10	102.168	1081
J	Install intermediate controller for the compressed air system	22649.42	2.795	29
K	Replace existing reciprocating refrigeration compressors by energy efficient (screw) compressor	23235.67	95.3568	1009
L	Replace old rectifier (diode based) with thyrister based rectifier	24784.71	255.42	2702[31]
M	Install hydrogen fired vapour absorption machine (VAM)	32715.82	96.75	1023
N	Recoating of electrodes reduces the specific power consumption of caustic soda production	42939.51	294.8572	3120
O	Install adaptive control system and minimize variation in feed temperature	44612.48	70.95	750
P	Install commercial co-generation system for Chlor–Alkali industry	47846.89	85	910

Future Emissions Scenario

The growth in Chlor – Alkali industry is projected to reach new heights. As per CII estimate, Caustic soda production will reach 4 million Tons in 2020 and would be 6 million Tons in 2030. The emission from Chlor – Alkali industry would also increase with respect to the increase in production and estimated figures are 22 million tCO_2 and 33 million tCO_2 of GHG emissions in the years 2020 and 2030 respectively.

[31] Refer Annexure 2 for model calculation

ANNEXURE 2 – BASIS OF SAVING ESTIMATION / SAMPLE CALCULATION

Sample Calculation:

The model calculation is given for the technology option "*Replace old rectifier (diode based) with thyrister based rectifier*"

Basis for calculation:

Operating hours of the plant	=	8000 hrs
Annual operating days	=	330 days
Reference Plant size	=	250 TPD
Cost of electrical energy	=	Rs. 4.00 / kWh
1 kWh	=	860 kcal
1 KWh	=	0.91 kg of CO_2
1 MTOE value	=	Rs. 10,154

Savings without PAT

Energy saved	=	36 kWh / Ton of Caustic Soda
Annual savings	=	36 kWh X 250 TPD X 330 days X
	=	X Rs. 4.00 / kWh
	=	Rs. 11.80 million / annum
Investment	=	Rs. 20.00 million
Payback	=	Rs. 20.00 million / Rs. 11.80 million X 12 months
	=	21 months

Savings with PAT

Energy saved	=	36 kWh / Ton of Caustic Soda
Annual savings in kWh	=	36 kWh X 250 TPD X 330 days

	=	2.97 million kWh
Annual savings	=	36 kWh X 250 TPD X 330 days X
	=	X Rs. 4.00 / kWh
	=	Rs. 11.80 million / annum
MTOE saved	=	2970000 kWh X 860 kcal/kWh
		10000000
	=	255 MTOE
MTOE savings in Rs	=	255 MTOE X Rs. 10,154 / MTOE
	=	Rs 2.59 million
Total savings	=	Rs. 11.80 million + Rs. 2.59 million
	=	Rs. 14.40 million
Investment	=	Rs. 20.00 million
Payback	=	Rs. 20.00 million X 12 months
		Rs. 14.40 million
	=	17 months

Calculation of GHG emissions:

Energy saved	=	36 kWh / Ton of Caustic Soda
Annual savings in kWh	=	36 kWh X 250 TPD X 330 days
	=	2.97 million kWh

As per CO_2 Baseline Database for the Indian Power Sector, Version 6.0, the CO_2 emission for 1 kWh of electricity consumption emits 0.91 kg of CO_2.

CO_2	=	2970000 kWh X 0.91 kg of CO_2
	=	1000
	=	2702 Tons of CO_2

ANNEXURE 3 – LIST OF EQUIPMENT / TECHNOLOGY SUPPLIERS

The details of the Supplier who plays an important role in providing the newer energy efficient technologies are given below:

1. ThyssenKrupp Uhde GmbH, Germany — www.uhde.eu
2. INEOS Technologies, ICL, UK — http://www.ineostechnologies.com/
3. UHDENORA S.p.A, Milan, Italy — http://www.uhdenora.com
4. Lurgi GmbH, Frankfurt, Germany — http://www.lurgi.com
5. Asahi Kasei Chemicals Corp., Japan — http://www.asahi-kasei.co.jp/chemicals/en/
6. Asahi Glass Co., Ltd., Tokyo, Japan — https://www.agc.com/english/index.html
7. De Nora Permelec SpA, Milan, Italy — http://www.denora.it/
8. Chlorine Engineers Co., Ltd., Japan — http://www.chlorine-eng.co.jp/en/
9. ABB — www.abb.co.in
10. Larsen & Toubro Electrical & Automation — www.larsentoubro.com
11. Siemens India Limited — www.siemens.co.in
12. ABB India Limited — www.abb.co.in
13. Schneider Electric — www.schneider-electric.com
14. Danfoss India — www.danfoss.com
15. Bharat Bijlee Ltd. — www.bharatbijlee.com
16. Kirloskar Electric Company Ltd. — www.kirloskar-electric.com
17. Crompton Greaves Ltd. — www.cgglobal.com
18. Nash — www.gdnash.com
19. Kakati Karshak Industries Pvt. Ltd.
20. Kirloskar Pumps — www.kirloskarpumps.com
21. Transparent Energy Systems Private Limited — www.heatrecovery-system.com

22. Dalian East Energy Project corporation limited www.dleast.cc

23. Siemens AG www.siemens.com

24. Thermax www.thermaxindia.com

ABBREVIATIONS

AKCC - Asahi Kasei Chemicals Corporation

AMAI - Alkali Manufacturers' Association of India

BASF - Badische Anilin-und-Soda Fabrik

BEE – Bureau of Energy Efficiency

BFP – Boiler Feed Water Pump

CEP – Condensate Extraction Pump

CII – Confederation of Indian Industry

Cl_2 – Chlorine

COC – Cycles of Concentration

CSA - Chloro Sulphonic Acid

CSF - Caustic Soda Flake

CST – Central Service Tax

CT – Cooling Tower

DC – Designated Consumers

DCM - DCM Shriram Consolidated Limited

DCS - Distributed Control System

FD fan – Forced Draft fan

FICCI - Federation of Indian Chambers of Commerce and Industry

FRP - Fibre Reinforced Plastic

GACL - Gujarat Alkalies and Chemicals Limited

GBC – Green Business Centre

H_2 – Hydrogen

H_2O – Water

H_2SO_4 – Sulphuric Acid

HCL - Hydrogen Chloride

HER - Hydrogen Evolution Reaction

Hg – Mercury

HPMV lamps - High Pressure Mercury Vapour Lamps

ICL Chemicals - Industrial Chemicals Limited

ID fan – Induced Draft fan

IPPC	– Integrated Pollution Prevention and Control
KTH	- Royal Institute of Technology
KWh	– Unit of Energy
Lakh	– One hundred Thousand
MCC	– Master Control Center
mMTOE	- Million Metric Tonne of Oil Equivalent
MT	– Metric Tonne
MTOE	- Metric tonne of oil equivalent
MTPA	– Metric Tonne per Annum
mv	– Medium Voltage
MW	– Mega Watt
Na_2SO_4	– Sodium Sulfate
Nacl	– Sodium Chloride
NaOH	– Sodium Hydroxide
NAPCC	- National Action Plan on Climate Change
NMEEE	- National Mission on Enhanced Energy Efficiency
O_2	– Oxygen
ODC	- oxygen depolarized cathodes
OEM	– Original Equipment manufacturer
ORR	- Oxygen Reduction Reaction
PA fan	– Primary Air Fan
PAC	- Poly Aluminium Chloride
PAT	- Perform, Achieve & Trade scheme
Ppb	– Parts Per Billion
Ppm	– Parts Per Million
PVC	- Polyvinyl Chloride
RIL	- Reliance Industries Limited
SBP	-Stable Bleaching Plant
SEC	- Specific Energy Consumption

SSEF - Shakti Sustainable Energy Foundation

TERI - The Energy and Resources Institute

TPD – Tonnes Per Day

TPH – Tonnes Per Hour

TR – Tonnes of Refrigeration

UK – United Kingdom

VAM - Vapour Absorption Machine

VFD – Variable Frequency Drive

WCC – World Chlorine Council

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