Good Practices Manual

Green House Gases Emission Reduction

Chlor-alkali Sector

Prepared by

National Productivity Council

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PREFACE

It is now widely accepted that we have to limit the temperature rise to 2°C to mitigate effects of climate change. This requires changing the portfolio of energy basket from fossils to non-renewables, reduce energy use through energy efficiency and conservation and reduce GHG emissions.

The broad intent and its goals can only be achieved by coordinated actions at various level by society, business, industry and government. As part of its endeavour the Government of India is formulating policies, action plans to support and guide industry and entrusted National Productivity Council to prepare of Best Practices Manual for Reducing GHG Emissions in various sectors namely, **Thermal Power Plant, Chlor Alkali, Cement, Pulp and Paper and Iron and Steel**.

This manual is expected to serve as reference manual for

- Identifying sources of GHG emissions
- Assess and quantify emissions.
- Evaluate and assess potential to improve energy efficiency and reduce GHG emissions.
- Propose a menu of options which industry can consider for assessment and implementation.

The scope of this manual covers GHG emissions in the plant boundary and does not include transportation of raw materials, products and wastes to secured landfills, emissions from domestic waste treatment and emissions from sales and other offices.

It is hoped the manual will be handy reference and guide for all levels of engineers and managers working in the sector.

STUDY TEAM

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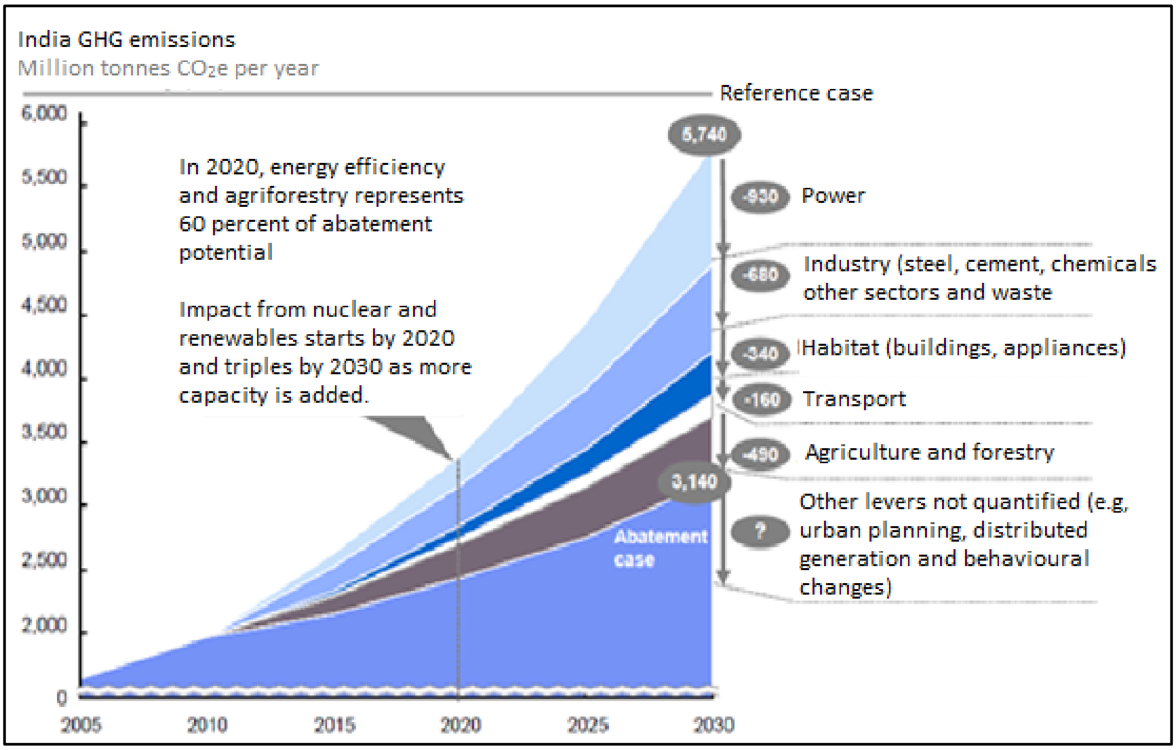
1. INTRODUCTION

1.1 BACKGROUND

Energy is a major driver of economy and the per capita consumption of energy is a lead indicator of its development. The fossil fuels, constituting 72.4% of the energy basket as of 2013[1], is the major contributor of GHG emissions and consequently global warming. The wider consensus that the temperature rise is to be limited to 2°C requires reducing GHG emissions by changing the portfolio of energy mix from fossil fuels to non-renewable sources, and reducing energy use through energy efficiency and conservation.

India is a net energy importing country and its GDP growth is one of the highest in the world. To maintain its growth rate as well as to ensure energy security and meet its committed GHG emission target reduction (30-35%) by 2030 from 2005 levels, India has been taking measures to shift its energy consumption towards renewable energy, besides adopting energy conservation and management measures. Studies indicate potential to reduce GHG emissions as shown in Figure 1.1.



In 2020, energy efficiency and agriforestry represents 60 percent of abatement potential

Impact from nuclear and renewables starts by 2020 and triples by 2030 as more capacity is added.

Figure 0.1 Indian GHG Emission Scenario (Past, Current & Projected)

Source: Pathways to lowcarbon_economy_Version2

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[1] http://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS

As can be seen, industrial sector's GHG reduction potential is about 680 million tonnes CO_2e per year. In line with these projections provided by various studies, Government of India has evolved policies, action plans and mission oriented programs to address the following objectives and issues.

- Energy security – to meet present and future needs
- Environmental impact-to address local emissions & global climate change
- Economic development – to create a sustainable development
- Ease of implementation

1.2 ABOUT THE PROJECT

To ensure effective translation of policy and implementation of action plans, Department of Industrial Policy & Promotion (DIPP), under Ministry of Commerce & Industry, Government of India has entrusted National Productivity Council of India (NPC) with the project titled "Preparation of Good Practices Manuals for Green House Gas Emission Reduction in Five Energy Intensive Industry Sectors in India" under the 12th Plan period (2012-2017).

The scope of the project is to conduct field and questionnaire survey in five selected energy intensive sectors (Thermal Power Plant, Chlor Alkali, Cement, Pulp and Paper and Iron and Steel) of Indian economy, and bringing out manuals on Good Practices for GHG Emission reduction in the selected energy intensive sectors. Out of these five energy intensive sectors, this manual highlights the best practices involved for reducing Green House Gases Emission Reduction in the chlor-alkali sector.

This manual brings out sources and trends driving India's greenhouse gas emissions in the chlor-alkali sector, outlining present situation and technologies that offer potential for significant emission reductions through enhanced energy efficiency that will put India on a sustained low-carbon path without sacrificing economic growth. It also highlights the Government of India policies and interventions that spur energy efficiency and GHG reduction activities in the sector eventually leading to improving energy security.

1.3 METHODOLOGY

For preparing this manual, the following methodology was adopted:

- Sector reports were prepared with inputs from questionnaire survey, detailed field visits and audits, workshops and guidance from steering committee.

- The synopses of the reports were extracted to prepare this manual for comprehensive presentation of information and provide guidelines for implementation of GHG emission reduction options.
- Feedback on the manual contents and the material was sought and received from industries, Alkali Manufacture’s Association, and other stakeholders and the same was incorporated in the final manual

1.4 GREENHOUSE GASES AND ITS IMPACT

Over the last 100 years, it has been found out that the earth is getting warmer and warmer, unlike previous 8000 years when temperatures have been relatively constant. The present temperature is 0.3–0.6 °C warmer than it was 100 years ago. The key greenhouse gas (GHG) causing global warming through human enhanced GHG effect is carbon dioxide.

The natural greenhouse effect is the process by which radiation from the earth's atmosphere warms its surface to a temperature above what it would be without its greenhouse gases naturally present in the atmosphere. The greenhouse gases naturally present in the atmosphere include carbon dioxide, water vapor, methane, nitrous oxide, and ozone.

Certain human activities add to the levels of most of the naturally occurring gases. For example, carbon dioxide is released to the atmosphere when fossil fuels such as oil, natural gas, coal, wood etc are burned. The enhanced greenhouse gas effect is the further rise in average earth’s temperature due to increase in the amount of carbon dioxide and other greenhouse gases in the earth's atmosphere due to human activities. Both these effects are depicted in Figure 1.2.

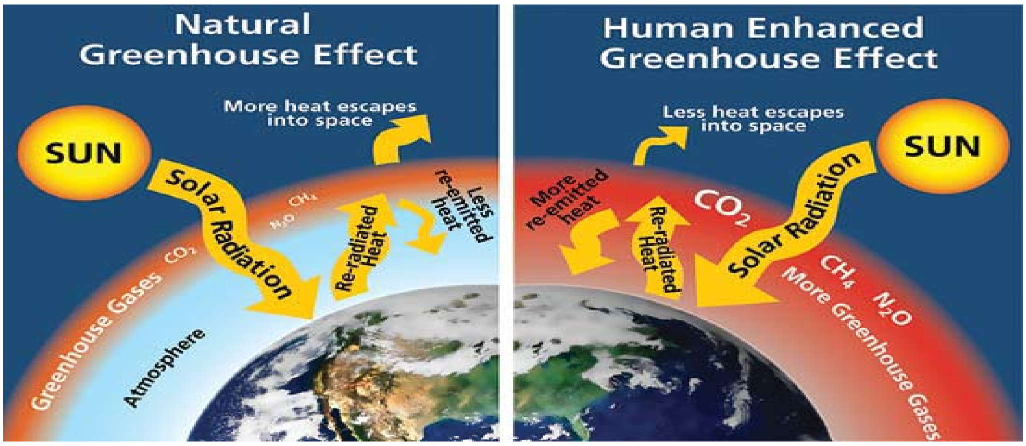


Figure 1.2 Natural and Human Enhanced Greenhouse Effect

Green House Gases (GHG) is of two types namely direct and indirect. Direct GHG contribute directly to the greenhouse effect in the atmosphere by trapping the infrared radiation near the earth’s surface. The major GHG gases identified by Intergovernmental Panel on Climatic Change (IPCC) are carbon dioxide, methane, nitrous oxide, hydrogen fluorocarbons, per fluorocarbons, sulphur hexafluoride.

Indirect GHG control the oxidising capacity of the troposphere by reducing the hydroxyl radical distribution thereby increasing the residence time of direct greenhouse gases, such as methane and ozone. Although there are a number of ways of measuring the strength of different greenhouse gases in the atmosphere, the Global Warming Potential (GWP) is the most used indicator.

GWP depends upon the greenhouse gas ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide. The GWPs for different GHGs are presented in Table 1.1.

Table 1.1 Direct and Indirect Green House Gases and its GWP

GHG	Name	Common Sources	Atmospheric Lifetime (years)*	Global Warming Potential
CO_2	Carbon Dioxide	Fossil fuel combustion, forest clearing, cement production etc.	50-200	1
CH_4	Methane	Landfills, production and distribution of natural gas and petroleum, fermentation from the digestive system of livestock, rice cultivation, fossil fuel combustion, etc.	12	21
N_2O	Nitrous Oxide	Fossil fuel combustion, fertilizers, nylon production, manure, etc.	150	310
HFC's	Hydro fluorocarbons	Refrigeration gases, aluminum smelting, semiconductor manufacturing, etc.	264	Up to 11,700
PFC's	Per fluorocarbons	Aluminum production, semiconductor industry, etc.	10,000	Up to 9200
H_2	Hydrogen	Chlor alkali production etc	100	5.8

The Figure 1.3 shows comparison of per capita CO_2 emission for the top five GHG emitting countries of the world and EU. India—owing to higher population—per capita CO_2 emission is the least. However, in terms of absolute emissions India is the third largest CO_2 emitting country, behind the US and China (2015) and contributing about 6 % (2.3 Gt CO_2) of global emissions (WEO 2015).

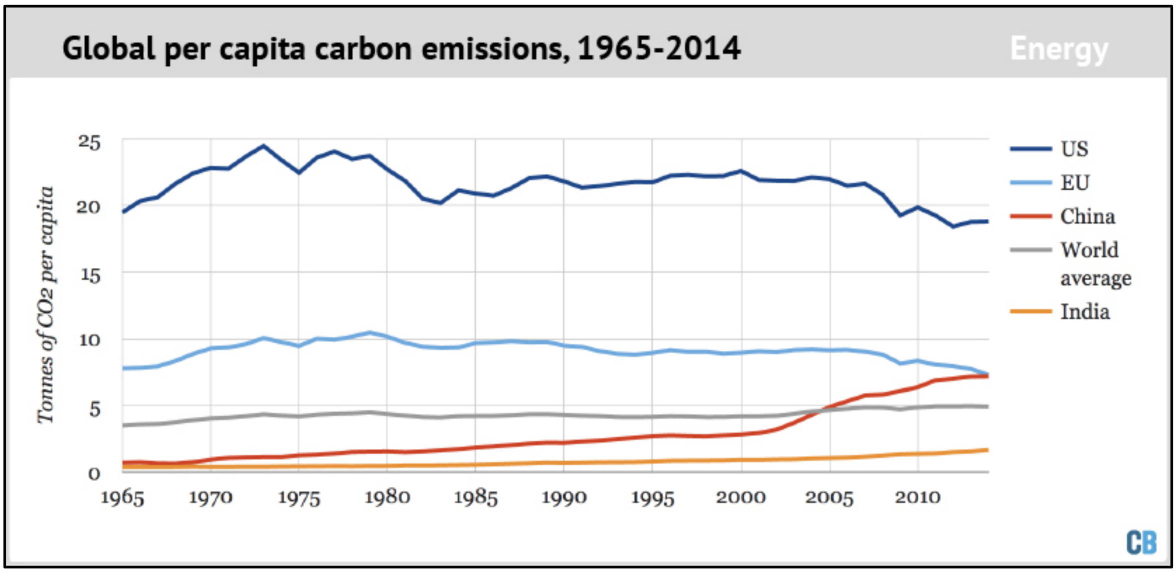


Figure 1.3 Per capita CO_2 Emissions

Impacts of Global Warming

Rise in Global Temperature

Observations show that global temperatures have risen by about 0.6 °C over the 20th century. There is strong evidence now that most of the observed warming over the last 50 years is caused by human activities. The various climate models predict that the global temperature will rise by about 6 °C by the year 2100.

Rise in Sea Level

In general, the faster the climatic change, the greater will be the risk of damage. The mean sea level is expected to rise 9–88 cm by the year 2100, causing flooding of low lying areas and other damages.

Food Shortages and Hunger

Water resources will be affected as precipitation and evaporation patterns change around the world. This will affect agricultural output. Food security is likely to be threatened and some regions are likely to experience severe food shortages and hunger.

Models also predict an average increase in temperature in India of 2.3–4.8^{o}C for the benchmark doubling of carbon dioxide scenario. It is estimated that 7 million people would be displaced, 5700 km^2 of land and 4200 km of road would be lost, and wheat yields could decrease significantly.

Due to rising energy demand, India's CO_2 emissions are expected to grow at the rate of 7% and surpass the present EU-28 emissions by 2020. As a part of mitigation effort, India is committed to increase its share of non-fossil energy sources from current 19% to 40% by 2030. However, combustion of fossil fuel will continue to be the single major contributor to the global warming in the coming years and hence the focus is on efforts to opt for renewable energy and enhance energy efficiency.

1.5 OUTLINE OF ENERGY SCENARIO IN INDIA

The energy mix of India for 2013 presented in the pie chart (Figure 1.4) indicates fossil fuel is the main stay of India's energy mix.

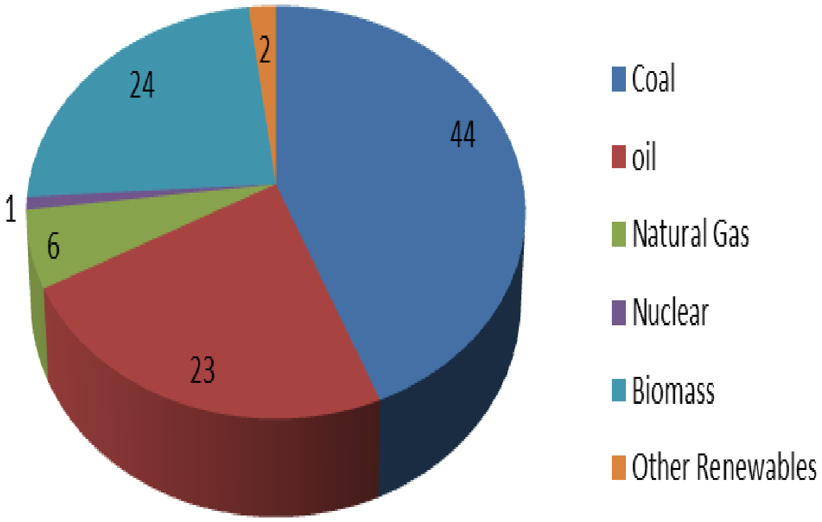


Figure 2.4 Primary Energy Demand in India for 775 MTOE
(Source : IEA, 2015)

Industrial energy demand has almost doubled over the 2000-2013 period, with strong growth from coal and electricity. Large expansion in the energy-intensive sectors is anticipated in the future. The present energy consumption in these energy intensive sectors in the country is high compared to the developed world. The major energy consuming sectors in the country are Iron & Steel, Chemicals, Textiles, Aluminium, Fertilizers, Cement & Paper. These sectors account for about 60% of the total energy consumption in industry. The energy consumption in manufacturing is relatively high in India which is reflected in the Specific Energy Consumption (SEC). This, therefore, provides an opportunity to reduce energy consumption and thereby GHG emissions. The typical SECs in different manufacturing sectors is presented in Table 1.2.

Table 1.2 Specific Energy consumption in Energy Intensive Industries

Sl. No.	Industrial Sector	Specific Energy Consumption (SEC)	
		India	World
1	Iron and Steel	6.5–7.0 GCal/Ton	4.5–5.5 GCal/Ton
2	Cement	80 kWh/T	110 kWh/T
3	Aluminium	4300 kWh/T (Refinery) 16500 kWh/T (Smelter)	3850 kWh/T (Refinery) 15250 kWh/T (Smelter)
4	Fertilizer	7.7 GCal/T of Urea	6.5 GCal/T of Urea
5	Paper and Pulp	8.4 Steam consumption/Ton	4.5 Steam consumption/Ton
6	Textile	7.1 GCal/Ton	3.1 GCal/Ton
7	Chlor Alkali	3.1 GCal/T (Soda ash) 2.1 GCal/T (Caustic Soda)	2.6 GCal/T (Soda ash) 1.8 GCal/T (Caustic Soda)

Energy Conservation and GHG Emission Reduction Initiatives by Government

The major policies that are currently promulgated and being implemented to meet the energy and climate challenge are summarized in Table 1.3.

Table 1.3: Government Policies and Initiatives for Energy Conservation

Policy /Initiative Statement	Key Features of the Policy
Energy Policies	
1. National Electricity Policy 2. National Rural Electrification Policy	• Access to Electricity - Available for all households in next five years • Availability of Power - Demand to be fully met by 2012. Energy and peaking shortages to be overcome and adequate spinning reserve to be available. • Supply of Reliable and Quality Power of specified standards in an efficient manner and at reasonable rates. • Per capita availability of electricity to be increased to over 1000 units.

Policy /Initiative Statement	**Key Features of the Policy**
3. National Tariff Policy 2006	• Minimum lifeline consumption of 1 unit/household/day. • Financial turnaround and commercial viability of electricity Sector. • Protection of consumers' interests.
Industrial Energy Efficiency Programs	
1. National Mission for Enhanced Energy Efficiency (NMEEE) (a) Market Transformation for Energy Efficiency (MTEE) (b) Energy Efficiency Financing Platform (EEFP) (c) Perform, Achieve, and Trade (PAT) Mechanism for Energy Efficiency	• Market-based approaches to unlock energy efficiency opportunities, estimated to be about Rs. 74,000 crores (2014-15) • Annual fuel savings in excess of 23 million toe • Cumulative avoided electricity capacity addition of 19,000 MW • CO_2 emission mitigation of 98 million tons per year
2. National Mission on Sustainable Habitat (NMSH)	Works on Municipal Solid Wastes, urban storm water & water mgmt. & energy efficiency
3. Energy efficiency Standards and Labelling Program	• BIS: formulations and implementations of national standards/production, quality and EMS certifications BEE : key thrust of EC Act, 2001
1. Capacity Building for Industrial Pollution Management	• Build capacity at the State and Central level, and develop a framework to address these issues in a comprehensive and systemic manner under an area-wide management approach. • The proposed project is aligned with the endeavour of the GoI to establish a National Program for Rehabilitation of Polluted Sites (NPRPS) as a framework for scaling up clean-up and rehabilitation of polluted sites and facilitate the reduction of environmental and health risks associated with legacy polluted sites.
Capping, Trading and Taxing	
1. Tax on Coal to Fund Clean Energy	All means to instil price signals to spur energy efficiency and using cleaner fuels

Policy /Initiative Statement	Key Features of the Policy
2. Renewable portfolio standards/obligation • Renewable Purchase Obligation (RPO) under the Electricity Act 2003 is mandated at the state level (discussed below in “National Policies Implemented at the State Level”)	• States can choose to apply the RPS requirement to all its utilities or only the investor owned utilities. • States can also define what technologies are eligible to count towards the RPS requirements.
3. RECS (Renewable Energy certificate System)	• Aimed at addressing the mismatch between availability of RE resources in state and the requirement of the obligated entities to meet the renewable purchase obligation (RPO) • Cost of electricity generation from renewable energy sources is classified as cost of electricity generation equivalent to conventional energy sources and the cost for environmental attributes. • Two categories of certificates, viz., solar certificates issued to eligible entities for generation of electricity based on solar as renewable Cost of Electricity Generation by Renewable Sources Cost Equivalent to Conventional Source Cost for Environmental Attributes energy source, and non-solar certificates issued to eligible entities for generation of electricity based on renewable energy sources other than solar
Subsidies for Energy Conservation	
1. Financial incentives through the Jawaharlal Nehru National Solar Mission	• Creating capacity in the area of solar, wind, bio-mass and other forms of renewal energy generation • Supports financially as well as technically to promote solar heater other solar applications widely in the country and particularly in the areas where conventional energy is not possible to supply • Long term energy security • Ecologically sustainable growth • Set target-20,000MW
2. Financial incentives by the Ministry of New and Renewable Energy through the Indian Renewable Energy Development Agency	
Energy Conservation in Buildings and Municipalities	
Energy Conservation Building Code	• Provide technical support to BEE to implement the ECBC in a rigorous manner • Develop reference material and documentation to support the Code

Policy /Initiative Statement	Key Features of the Policy
	• Develop ECBC Training material for workshops and training programs • Develop a road map for ECBC implementation
1. Municipal Demand-Side Management 2. State Energy Conservation Fund	Municipal Demand Side Management (MuDSM) is devised to take care of the most common and other issues which are seen as a hurdle by the Municipality to shift itself towards the energy efficient zone from the existing situation of high amount of energy consumption.
Energy Conservation in Agriculture and Forestry Activities	
Agriculture, forestry, and other land use policies 1. Agricultural Demand - Side Management (AgDSM) 2. National Mission for Sustainable Agriculture 3. National Mission for a Green India	• Consists of those activities, methodologies, awareness, policy and technologies that influence consumer (farmers) behaviour and changes their (farmers) consumption patterns. • The objective of the AgDSM programme is to reduce peak demand, shift the time during which electricity is consumed to off-peak hours and to reduce the total quantum of consumption.

1.6 GHG EMISSION FACTORS

The emission factors considered for calculations in this manual are tabulated in Table 1.4 (CEA, 2014).

Table 1.4 Typical GHG Emission Factors

No.	Parameter	Units	Factor
1	Grid Electricity	Kg CO_2/kWh	0.82
2	CPP Electricity		
a)	Coal Fired	Kg CO_2/kWh	1.03
b)	Diesel Fired	kg CO_2/kWh	0.62
c)	Gas Fired	kg CO_2/kWh	0.49
3	Coal (Sub-bituminous)	kg CO_2/kg	1.1
4	Diesel/Furnace oil	kg CO_2/kg	3.12

2. CHLOR ALKALI SECTOR PROFILE

2.1 INTRODUCTION

The chlor-alkali industry in India is around 60 years old. There are around 37 caustic soda units spread across India with total installed capacity of 3.20 MMT per annum with the top 10 chlor-alkali plants producing about 60% as shown in Table 1.1. Most of the units have a capacity under 100,000 MTPA with capacity utilisation in the range 79-85%. The Table 2.1 shows the number of plants in India along with their total capacity.

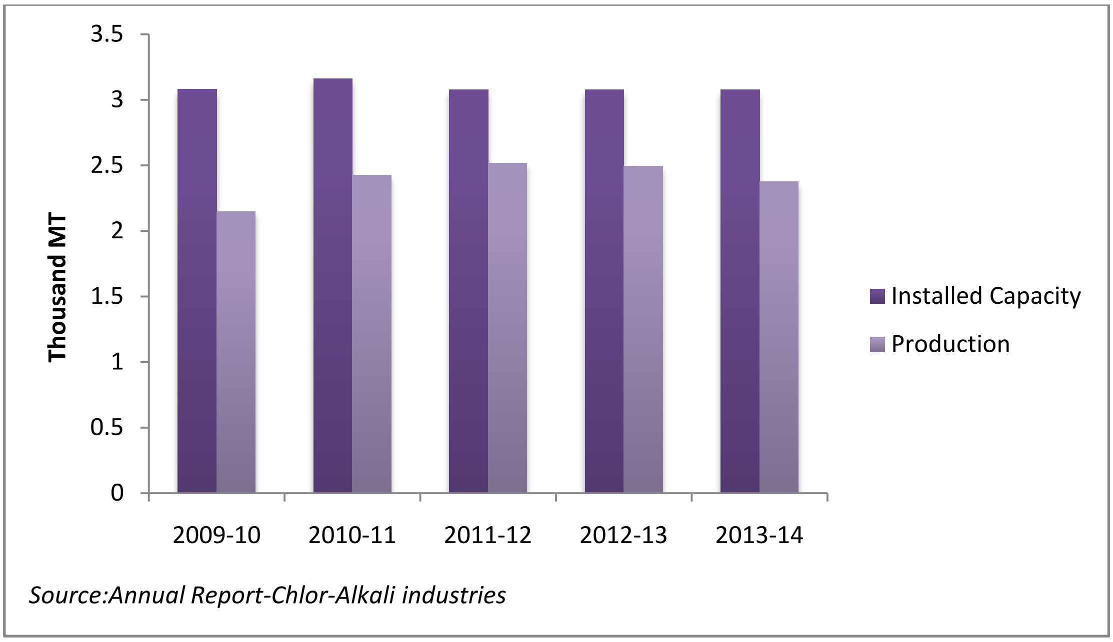
Table 2.1 Distribution of Chlor Alkali Plants in India

Region	No of plants	Capacity range TPD	Total Installed Capacity TPD	Installed Capacity Distribution (%)
East	8	40-365	1147	13
West	16	40-800	4615	52
North	4	235-335	1171	13
South	9	110-375	1943	22

As can be seen from Figure 2.3 more chlor-alkali industries are located in western Zone (54%) followed by South with 21%. This can be attributed to two factors namely, availability of salt, the main raw material for the industry and location of user industry in the area.

2.2 CAPACITY UTILIZATION

The average capacity utilization in the Indian industries is around 67.5 %.(2009-14) with installed capacity remaining stagnant since 2011-12 owing to economic downturn world over and reduced off-take from industries like aluminium. The Figure 2.1 shows production vs. capacity utilization for the period 2009-2014.



Source:Annual Report-Chlor-Alkali industries

Figure 2.1 Installed Production vs. Capacity (2009–2014)

Segregation of chlor-alkali plants is done based on scale of production is shown in Table 2.2. Since membrane process is the only used technology in India currently, classification is made based on this basis.

Table 2.2 Capacity Based Segregation (2013-14)

Process	<100 TPD	100-500 TPD[1]	>500 TPD[1]
Nos of units	5	21	6
Installed Capacities(TPY)	85675	19,05,610	12,33,500
Annual Energy Consumption range (TOE)	<12000	15000-90000	35000-1,12,000
Specific Energy Consumption (TOE/T)	NA	0.335-0.310	0.227-0.310
Annual GHG emission range, (Million Tons ofCO_2)	<0.129	0.162-1.047	0.408-1.302

NA= Not Available;   1= D

2.3 USES OF CAUSTIC AND CHLORINE

Sodium Hydroxide or caustic soda is an important chemical which is used in various sectors namely pulp & paper, alumina, soaps & detergents, inorganic chemicals, etc. About 25% of the production used for captive consumption while the rest is used for merchant trade.

The use of caustic sector-wise is shown in Table 2.3. The level of integration for chlorine in India is very low as compared to West Europe and North America, which have an integration level of about 86% and 52%, respectively. While plants outside India are **Chlorine** centric, plants in India are **Caustic** centric. These plants co-produce chlorine in the ratio of 1:0.89. All plants are running on state of the art energy efficient membrane cell technology.

Table 2.3 Breakup of Caustic Consumption in Different Industrial Sectors

Alumina	14%	Textiles	21%
Pulp and Paper	15%	Dyes & Inks	3%
Organics	12%	Water treatment	3%
Inorganics	8%	Pesticide	1%
Soap and Detergents	7%	Others	16%

Textile industry followed by pulp and paper and aluminum industries account for the largest share of caustic soda consumption. The different uses caustic soda and chlorine are given in Table 2.4.

Table 2.4 Uses of Caustic and Chlorine for Various Products/Applications

USE/INDUSTRY	PRODUCTS OR APPLICATIONS OF USE
Production of metals and resource	Alumina, propylene oxide, polycarbonate resin, epoxies, synthetic fibers, soaps, detergents, rayon and cellophane.
Pulp and paper industry	Caustic soda is used for pulping wood chips. Chlorine and its compounds are used to bleach wood pulp in the paper production.
Petroleum and natural gas	Caustic soda is used as a drilling fluid.
Manufacture of organic chemicals	Chlorine is used for making ethylene dichloride, glycerin, glycols, chlorinated solvents and chlorinated methane.
Plastic industry	Used for making plastics, most notably polyvinyl chloride (PVC), which is being used extensively in building and construction,

Pesticides	96 per cent of all pesticides are produced using chlorine
Industrial solvents	A variety of chlorinated compounds are used as industrial solvents, including the main ingredient used in dry cleaning.
Water treatment	Chlorine is used in 98 per cent of the water treatment plants in the world.
Pharmaceuticals	85 per cent of all pharmaceuticals use chlorine.
Other relevant applications	Domestic bleaches, flame-retardants, food additives, refrigerants, insulation, computer chip manufacturing and hospital disinfectants.

Chlor-alkali sector provides direct & indirect employment to about 1.5 lakh people. Nearly 50,000 people including contract labour work in the units manufacturing caustic soda and soda ash plants. In the XIIth Five Year Plan, the industry envisages employment increase to the extent of 5%.

2.4 EXPORTS AND IMPORTS

The Figure 2.2 shows the export and import trend over the period 2009-2014.

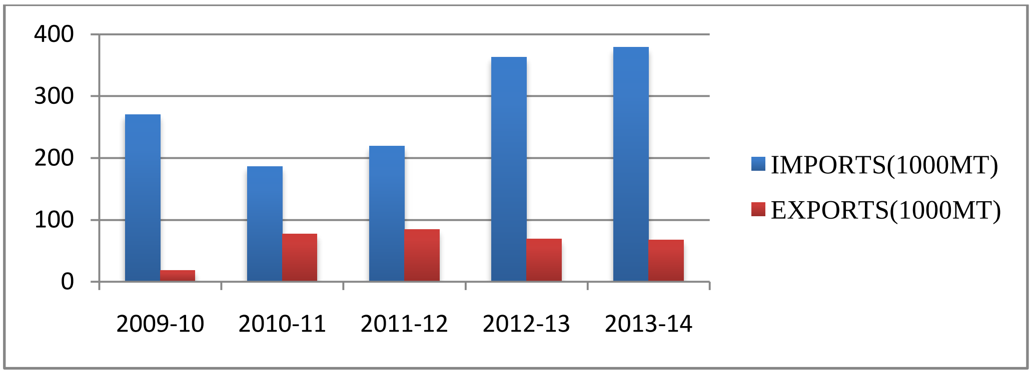


Figure 2.2 Indian Imports & Exports of Caustic Soda

2.5 PERFORMANCE AND PRODUCTIVITY INDICATORS

Labour Productivity

Labour productivity trend indicates production of 56-65 MT/quarter per employee as per DGFT reports shown in Table 2.5 which translates to 0.85-1 T NaOH/ employee. Some units during survey have indicated the labour productivity is 0.35 T NaOH/ employee. The labour productivity of European plants reported in BREF is 0.65 T NaOH/ employee.

Table 2.5 Labour Productivity

Productivity (Production/employee) MT per Quarter				
Quarter	**2006-07**	**2007-08**	**2008-09**	**2009-10**
Q1	56.03	59.67	65.16	63.30
Q2	57.46	62.54	66.77	65.14
Q3	60.25	63.15	59.97	-
Q4	62.11	65.17	62.28	-

From the above table, the labour productivity is showing increasing trend over the years. The variations in labour productivity may also be due to restriction in production due to difference in chlorine and caustic prices at global level.

Energy Consumption of Chlor-alkali Industry

The raw material involved in the production of caustic soda is salt and water. Electric energy is used in conversion of salt into caustic soda lye, chlorine and hydrogen gas. Thermal energy is used in brine preparation and preparing flakes from lye. In most units hydrogen generated is used as fuel to concentrate lye and produce caustic flakes. This is an energy intensive process where energy costs accounts for 50-60% of total production cost based on cost of power.

The electrolysis phase is the most energy intensive phase. This process involves conversion of AC power to DC power through a rectifier and involves electric conversion losses. Amongst the chlor alkali processes the membrane cell process produces30-35% NaOH concentration and thus the thermal energy required to concentrate the lye to the saleable product concentration is much less in membrane process compared to diaphragm process.

Specific Energy Consumption

Grid power cost in India ranges from Rs. 3.85 to Rs. 6.0 as compared to Rs. 0.8 in Middle East, Rs. 2.25 in USA and Rs. 1.98 in Europe making energy conservation and energy efficiency attractive in Indian chlor-alkali industries.

The specific energy consumption range for chlor-alkali process in relation to the scale of production is shown in Figure 2.3.

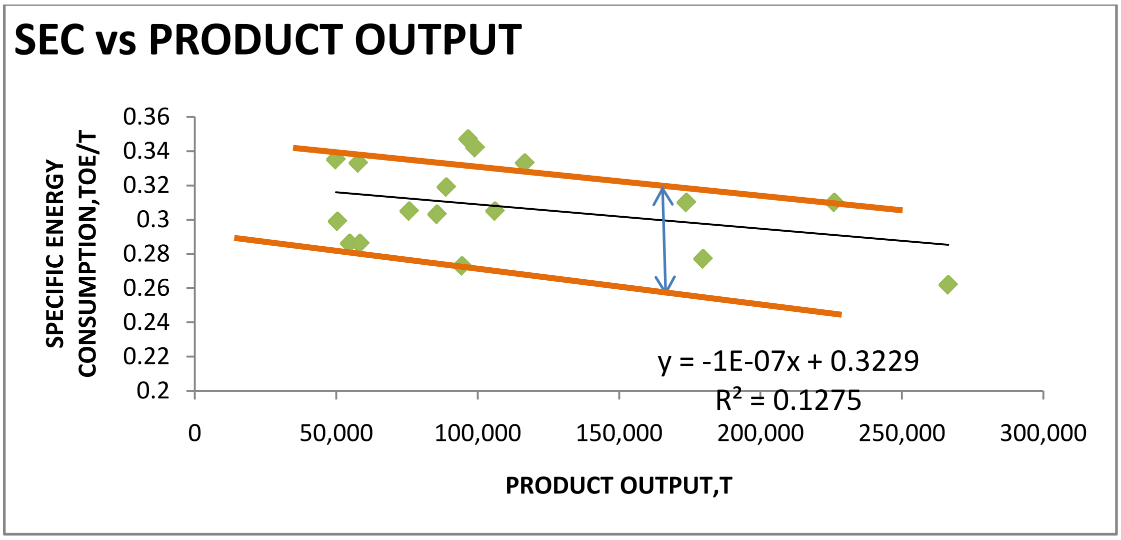


Figure 2.3 Specific Energy Consumption vs. Production

As can be seen the correlation of SEC with respect to scale of production is not strong. It is seen that an average of 5-11% savings in specific energy consumption can be achieved in 80% of the production units. The considered bandwidth comprises of the specific energy consumption variations between efficient and inefficient technologies.

The variations in specific energy consumption can be attributed to economies of scale, different cell generation technologies, improved rectifiers, adopting zero gap technology and ODC technology each of which represent options to conserve energy by units having higher specific energy consumption.

As per BEE PAT reports, specific energy consumption varies between 0.262 and 0.997 TOE/T of NaOH. Energy saving target of 0.054 MTOE/yr. which is 5% less than it was in 2008-09 was given by BEE under PAT scheme. This constitutes 0.81% of total national energy saving targets assessed under PAT. The section-wise breakup of energy consumed in chlor-alkali sector is shown in Table 2.6.

Table 2.6 Typical Section-wise Break-up of Energy Consumption

Section	**Energy kWh/T NaOH**	**%**
Primary & Secondary Brine plant	22.84	0.75
Membrane Cell plant	2784.47	90.91
Chlorine Treatment plant	84.52	2.76
Caustic Concentration unit	8.69	0.28
Caustic Evaporation unit	6.24	0.20
Waste water Treatment plant	5.01	0.16

Sodium Hypo plant	3.22	0.11
Utility plants	147.72	4.82
Total	**3062.72**	**100**

Energy Consumption Trend in Various Generations of Membrane Cells

The membrane cell has developed continuously since its broad scale implementation in the 1980s. The initial developments focused on anode and cathode coatings, membrane types, reduction of the cathode-membrane gap, electrolyte circulation in the cells, and gas release from electrodes and membranes.

In the 1990s, the electric resistance in the cell structure was decreased by gradually switching from monopolar to bipolar electrolyser configurations. Due to these developments, there was also an increase in the maximum current density which could be applied. The impact of these developments on the specific electricity consumption is shown in Figure 2.4.

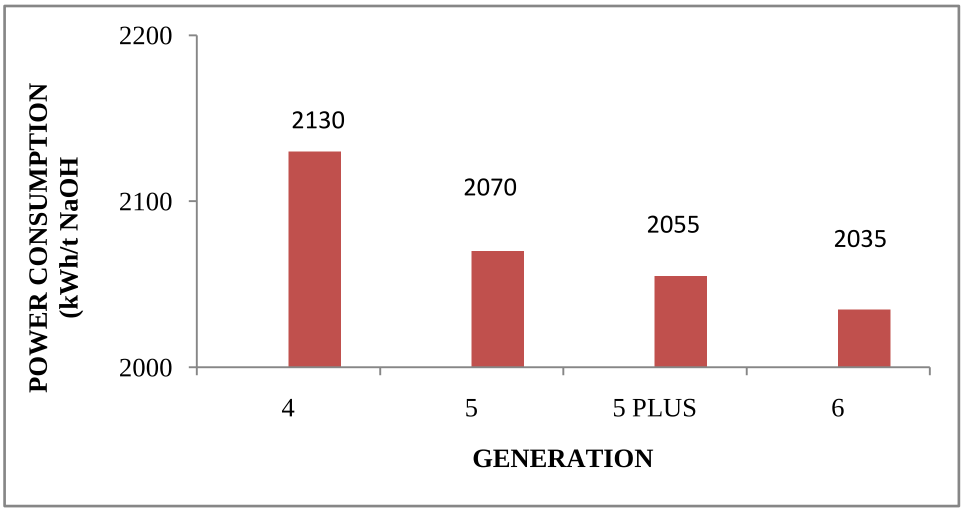


Figure 2.4 Power Consumption (kWh/t NaOH) Trend

2.6 BENCHMARKS FOR CHLOR-ALKALI INDUSTRY

Water conservation and benchmarking to world standards improves not only water productivity but also energy productivity due to lesser pumping and treatment costs. The best benchmarks cited are tabulated in Table 2.7.

Table 2.7 Best Benchmarks for Chlor-Alkali Industry

Section/ Process	**Comparable Benchmarks**
Labour productivity[3]	0.65-1.0 T NaOH per employee
#Total Water requirement	5.9 m^3/T NaOH (48% lye)
• Process water	2-2.25 m^3/T NaOH
• Cooling Water[6]	2.5-2.9 m^3/T NaOH
• Domestic Water[9]	0.045 m^3/T NaOH (45 lpcd)
Total Energy Requirement[8] (Low end of BEE target)	3040kWh/T NaOH(0.262 TOE/T NaOH)
Water treatment	1.3 kWh/T NaOH
Brine purification	2.5 kWh/T NaOH
Cell house (design stage)	kWh/T NaOH @ CD of 6.0 KA/m^2
• Mono-polar membrane	2550 (@CD of 4KA/m^2)
• Mono-polar – zero gap	2470 (@CD of 4KA/m^2)
• Bipolar 4th Gen zero gap	2130
• Bipolar 5th Gen zero gap	2070
• Bipolar 6th Gen zero gap	2020 - 2035
• ODC	1550
Caustic concentrator – Steam Economy (Steam to vapour ratio)	3 effect: 0.5-0.4 4 effect:0.29 5 effect: 0.23
Energy required for flaking[i]	95 kWh/ T NaOH (Best benchmark reported)
Chlorine liquefaction – Energy requirement for 98% liquefaction.	120-200 kWh/ T NaOH
Boiler efficiency	80%
Pump efficiency	65%
#Total water requirement assessment is based on the following 1 T lye (48%) produced, 97.5% Cl_2 generated is liquefied 2% of un-liquefied Cl_2 is converted to 33% HCl 0.5% of un-liquefied Cl_2 coming through vents is converted to 18% NaOCl 3-Stage	

3. CHLOR-ALKALI MANUFACTURING PROCESS

3.1 OVERVIEW OF CHLOR-ALKALI PRODUCTION

The schematic of chlor-alkali manufacturing process is shown in Figure 3.1. The main raw material for chlor-alkali production is brine. The brine (NaCl) is sent to electrolytic cell where it is electrolysed to form caustic soda (NaOH). Additionally chlorine and hydrogen gases are evolved. Chlorine is directly sold as a by-product after liquefaction. Hydrogen is partly used as fuel in the boiler and partly converted to HCl. Excess hydrogen is vented.

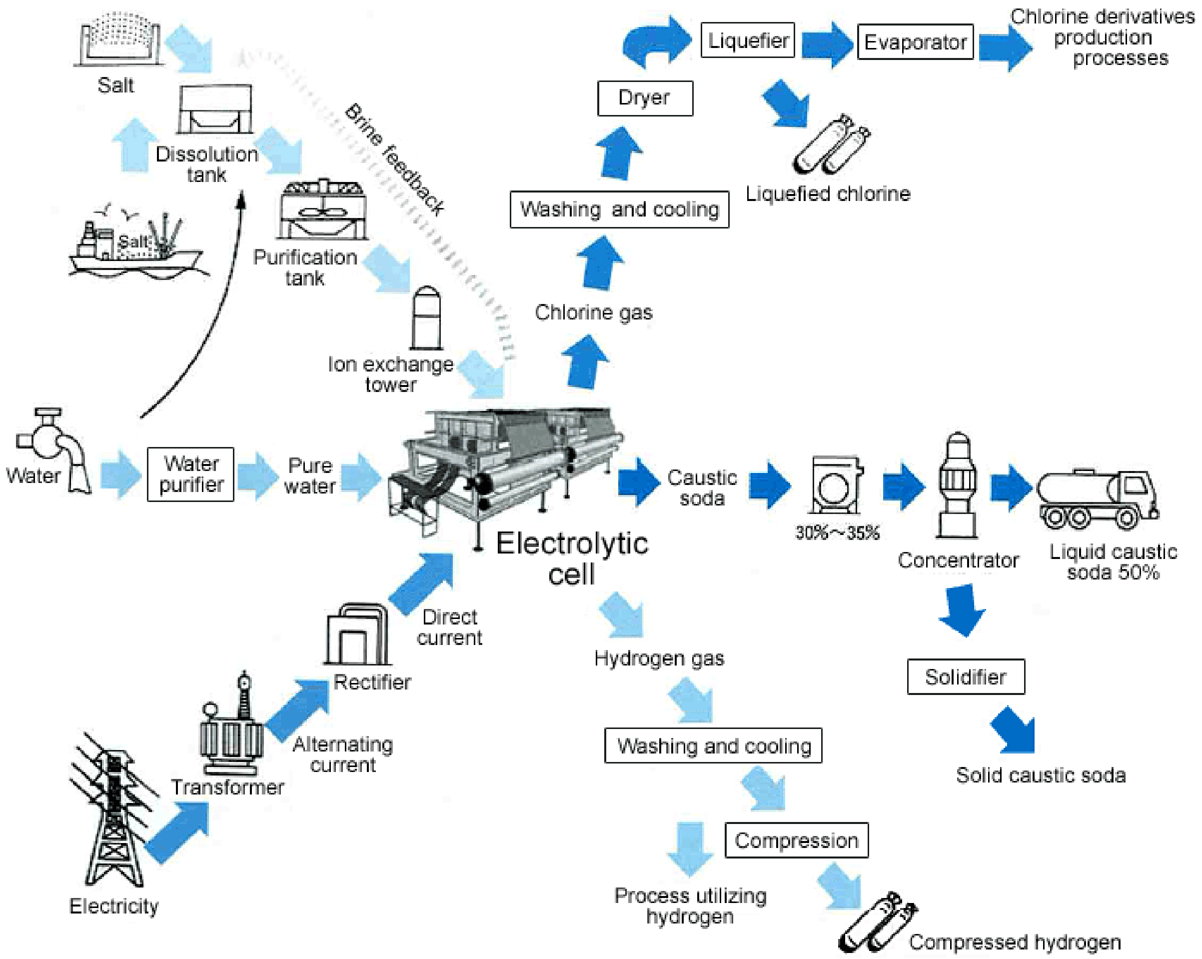


Figure 3.1 Schematic of Chlor-alkali Manufacturing Process

3.2 BRINE PREPARATION

Raw salt is mixed with treated water to prepare saturated brine solution (300-330 gpl) which is then purified to reduce the concentration of impurities (Ca, Mg, Ba, Sr, and metals) to the desired levels required for the electrolytic process.

The treatment is done in two steps, primary and secondary. In the primary treatment, Mg, Ca, Sr, SO_4 are removed and in the secondary treatment trace levels of the above impurities are removed to meet the purified brine quality requirements. The brine preparation and purification is shown in Figure 3.1.

Maintaining the efficacy of each treatment will reduce load on downstream treatment but also reduces energy requirements due to lesser brine depletion requirements and increased brine treatment requirements.

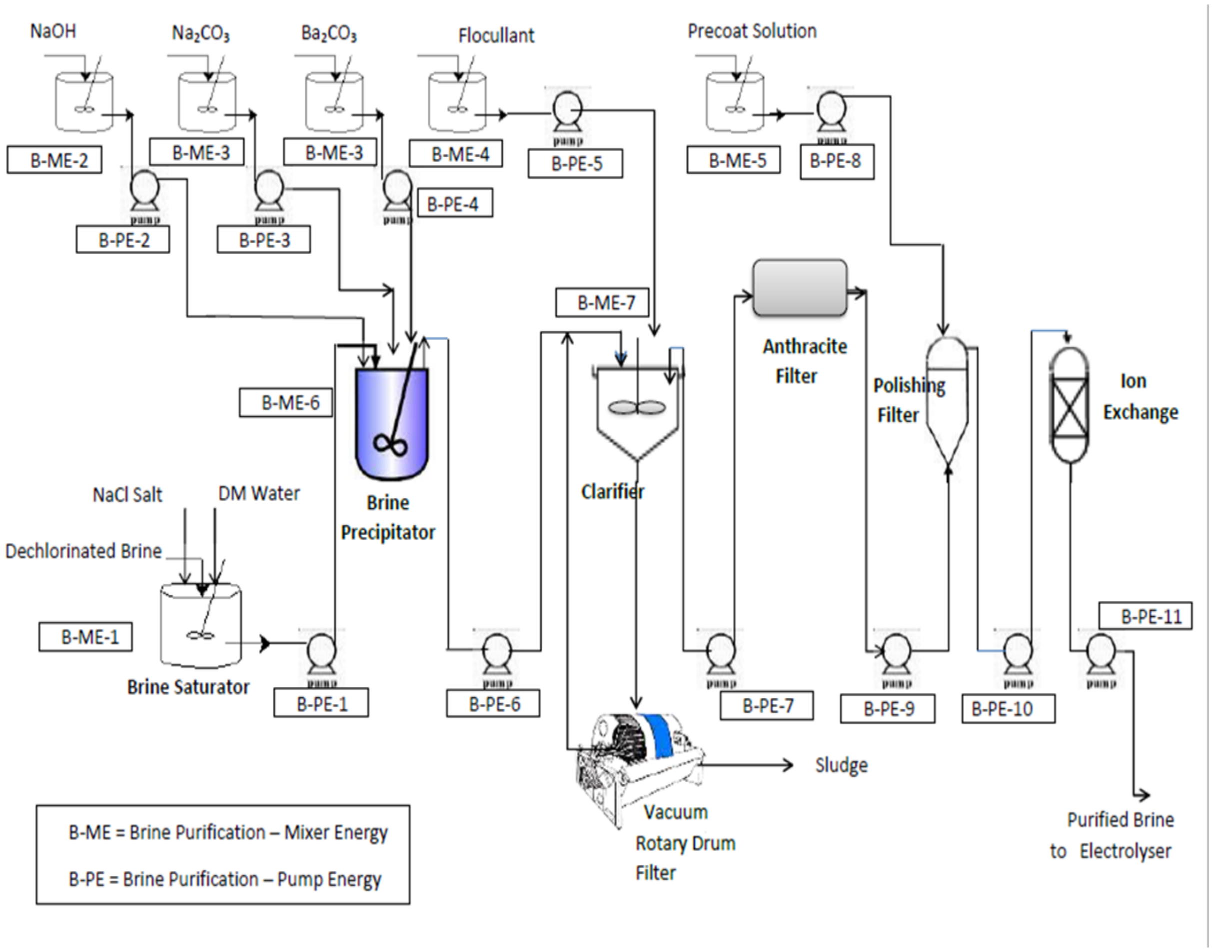


Figure 0.1 Brine Preparation and Purification

3.3 CELL HOUSE

The purified brine at 65-70ºC is fed into the electrolyser or cell house. The brine is decomposed mainly into caustic, chlorine and hydrogen. The side reactions cause release oxygen, chlorate, etc. The reactions involved are as follows:

Anode $\mathbf{Cl_{2(g)} + 2\,e^{-} \rightarrow 2Cl^{-}_{(aq)}}$
Cathode $\mathbf{Cl_{2(g)} + 2\,e^{-} \rightarrow 2Cl^{-}_{(aq)}}$
Overall reaction $\mathbf{2\,NaCl_{(aq)} + 2\,H_2O_{(l)} \rightarrow 2\,NaOH_{(aq)} + Cl_{2(g)} + H_{2\,(g)}}$

Energy supplied in AC form is transformed into DC form in rectiformer for decomposition of brine. Electrical energy losses and inefficiencies occur due to the following reasons.

- Rectiformer energy losses during conversion from AC to DC.
- Increasing energy consumption over time due to aging of membranes and electrodes.
- Energy losses due to undesirable side reactions.

The power consumption is reported as DC/AC kWh/ton of caustic in Indian Chlor-alkali plants whereas in European countries it is reported in DC/AC kWh/ton of chlorine.

The theoretical voltage requirement for decomposition of brine is 2.2V. In practice, the decomposition voltage requirement varies from 3.5V - 2.9V. The theoretical DC energy requirement is 1474 kWh/ton of caustic (100%) or 1663 kWh/ton of Cl_2 (100%).

The consumption of electricity is also influenced by current density, brine feed temperature, coating of electrode.

Relationship between Cell Voltage and Current density[2]

The operating cell voltage is a function of current density. At current densities above 1 KA/m^2, the operating cell voltage varies almost linearly with the current density. It can be expressed by the following relationship:

$$U_{cell} = U_o + k * i \text{ volts}$$

U_o denotes the cell decomposition voltage whereas i denotes the current density. The values of U_o and k depend on the different cell parameters and electrolysis conditions. The typical values for a bi-polar cell process are as follows:

$$U_o = 2.42 \text{ volts}, \quad k = 0.217 \text{ volts x m}^2 \text{/KA}$$

---

[2] Source: AMAI, Delhi

The effect of current density on cell voltage can be determined by the empirical equation as given by the following relation:

$$\mathbf{E = 2.41 + 0.329\ i + 0.24 \log i}$$

$$\boldsymbol{Actual\ DC\ Power\ Consumption = \frac{670 * \ Cell\, voltage}{Cell\, \mathrm{E}fficiency}}$$

Where,

E = Cell voltage (V)

I = Current density (kA/m^2)

Relationship between Life of Electrode and Power Consumption

The effect of coating of electrodes life on power consumption is given by the following relation:

$$\boldsymbol{Power\ Consumption\ (kWh/T\ NaOH) = First\ year\ power\ consumption\ (kWh/T\ NaOH) + 35}$$ [3]

Where, n= life of the membrane in years

Relationship between Brine Temperature and Power Consumption

Reduction in feed brine temperature will increase the specific energy consumption. The effect of brine feed temperature on power consumption is given by the following relation:

$$\boldsymbol{Power\ Consumption\ (kWh/T\ NaOH) = 1.3595\mathrm{T}^2 - 227.86T + 11670}$$

Where, T = Temperature of Brine feed in °C

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[3] The equation is based on best yearly cumulative value of power rise due to ageing of membranes. However, on an average the power rise is reported by AMAI is in the range of 40 – 60 kW/T/year

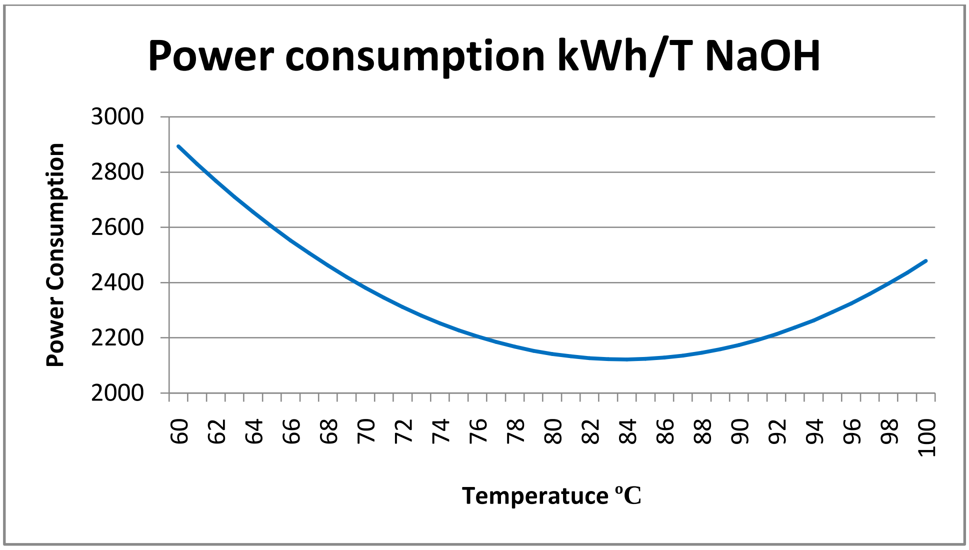

Figure 3.2 Graph on Brine Temperature v/s Power Consumption

Back migration of NaOH to Cathode causes formation of O_2, OCl^-, and ClO_3. The back migration and side reactions cause 3-7% loss of current efficiency with respect to caustic production. The reaction governing side reactions are given as follows:

$$HOCl \rightarrow OCl^- + H^+$$
$$2HOCl + OCl^- \rightarrow ClO_3 + 2H^+ + 2Cl^-$$
$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

Assessing Cell House Performance

Assessing the current efficiency of the cell house is important to operate the cell house efficiently and to determine the power consumption. The assessment can be made by direct or indirect method.

The direct method is the simplest method to calculate the current efficiency and it is based on the mass of product produced per unit of electrical input. However, the NaOH (100%) production of a cell house cannot be measured with sufficient accuracy to give meaningful results.

Direct Method

$$\eta_{Cathode}(\%) = \frac{Kg\ of\ NaOH_{actual}}{Kg\ of\ NaOH_{theoretical}} x100$$

To resolve this problem, the chlor-alkali industry uses indirect method which is an anodic balance approach, i.e., the compositions of the anode gas and the analyte. The formulae used for efficiency assessment and the model calculation are given below.

Indirect Method

$$\eta_{Cathode}\,(\%) = 100 - \eta_{ClO} - \eta_{ClO3} - \eta_{O2} - \eta_{alkali}$$

Where,

$$\eta_{ClO} = \frac{Kg\ of\ NaOH}{1.492\ x\ Q\ x\ Number\ of\ Cells} x100$$

$$\eta_{ClO} = \frac{1.042\ C_{ClO\ anolyte}\ V_{anolyte}}{Q\ x\ 2\ x\ Number\ of\ cells} x100$$

$$\eta_{ClO3} = \frac{1.97[(C_{ClO3\ anolyte}\ \ x\ V_{anolyte}\ ) - (C_{ClO3\ feed}\ \ x\ V_{feed}\ )]}{Q\ x\ Number\ of\ cells} x100$$

$$\eta_{O2} = \frac{2V_{O2}(100 - \eta_{ClO} - \eta_{ClO3})}{(V_{Cl2} + \ 2V_{O2})} x100$$

$$\eta_{alkali} = \frac{[C_{NaOH}\ + 0.7548\ C_{Na2CO3} +\ 0.4762\ C_{NaHCO3}]xV_{feed}\ \ x\ 100}{1.4923\ x\ Q\ x\ Number\ of\ cells} x100$$

Where,

$\eta_{ClO3,O2,ClO}$	Current efficiency loss due to chlorate, oxygen, ClO formation
$C_{ClO3,ClO\ anolyte\ ,ClO3\ feed}$	Concentration of ClO_3, ClO in the anolyte, feed brine (grams/ liter)
$V_{anolyte\ ,feed}$	Volumetric flow rate of the anolyte, feed brine (m^3/hr)
$V_{O2,\ \ Cl2}$	Volume of O_2, Cl_2 in the anode gas composition (%)
η_{alkali}	Current efficiency due to alkali (NaOH, $NaHCO_3$ and Na_2CO_3)
$C_{Na2CO3,NaHCO3,NaOH}$	Concentration of $NaCO_3$, $NaHCO_3$, NaOH in the feed brine (grams/litre)

Sample Calculation

Analysis Data		Field Data	
C_{Na2CO3}	0.212 gpl	V_{feed}	3 m^3/hr
C_{NaOH}	0.0005 gpl	$V_{anolyte}$	2.36 m^3/hr.
C_{NaHCO3}	5 gpl	Q	61.5 kA
$C_{ClO3\ anolyte}$	10.604 gpl	Number of cells	3
$C_{ClO3\ feed}$	7.6 gpl	Cell voltage	2.7 V

$$Actual\ DC\ Power\ Consumption = \frac{670 *\ \ Cell\ voltage}{Cell\ efficiency}$$

$$Actual\ AC\ Power\ Consumption = \frac{Actual\ DC\ Power\ Consumption}{Rectiformer\ efficiency}$$

Cell Current efficiencies are seen to range from 92% to 96% mainly variant with type of coatings deployed, condition and frequency/periodicity of recoating.

3.4 CAUSTIC CONCENTRATION

Electrolysis of brine yields 32% caustic. This is concentrated to 48% using 3 to 5 stage multiple effect evaporators or concentrated to 98% by further concentrating the 48% lye. In Indian chlor-alkali plants, 3-stage falling film evaporators are generally being used for evaporating the 32% caustic solution to 48% concentration as they have better heat transfer coeeficient and less fouling tendency. Low pressure steam is used for concentration in the evaporators.

This 48% lye is sold out or it is fed to the flaking unit to produce flakes using thermic fluid heaters. The concentrated high temperature anhydrous caustic soda is cooled in rotary flaker by cooling water and converted into caustic soda solid flakes at their fusing point temperature. The process flow diagram for concentrating 32% lye to 48% is shown in Figure 3.3 and the process of caustic fusion is shown in Figure 3.4.

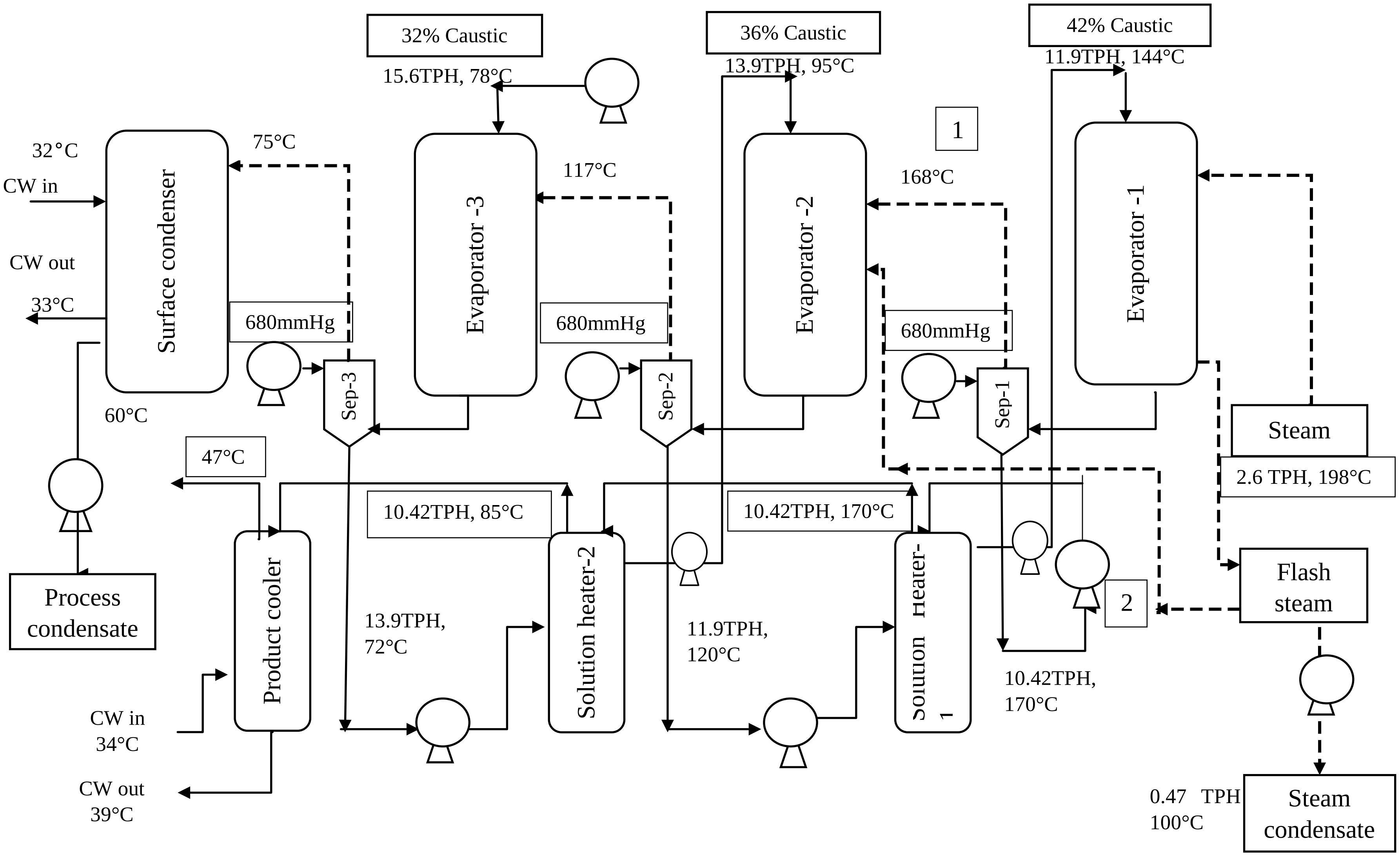

Figure 3.3 Process Flow Diagram for Caustic Concentration

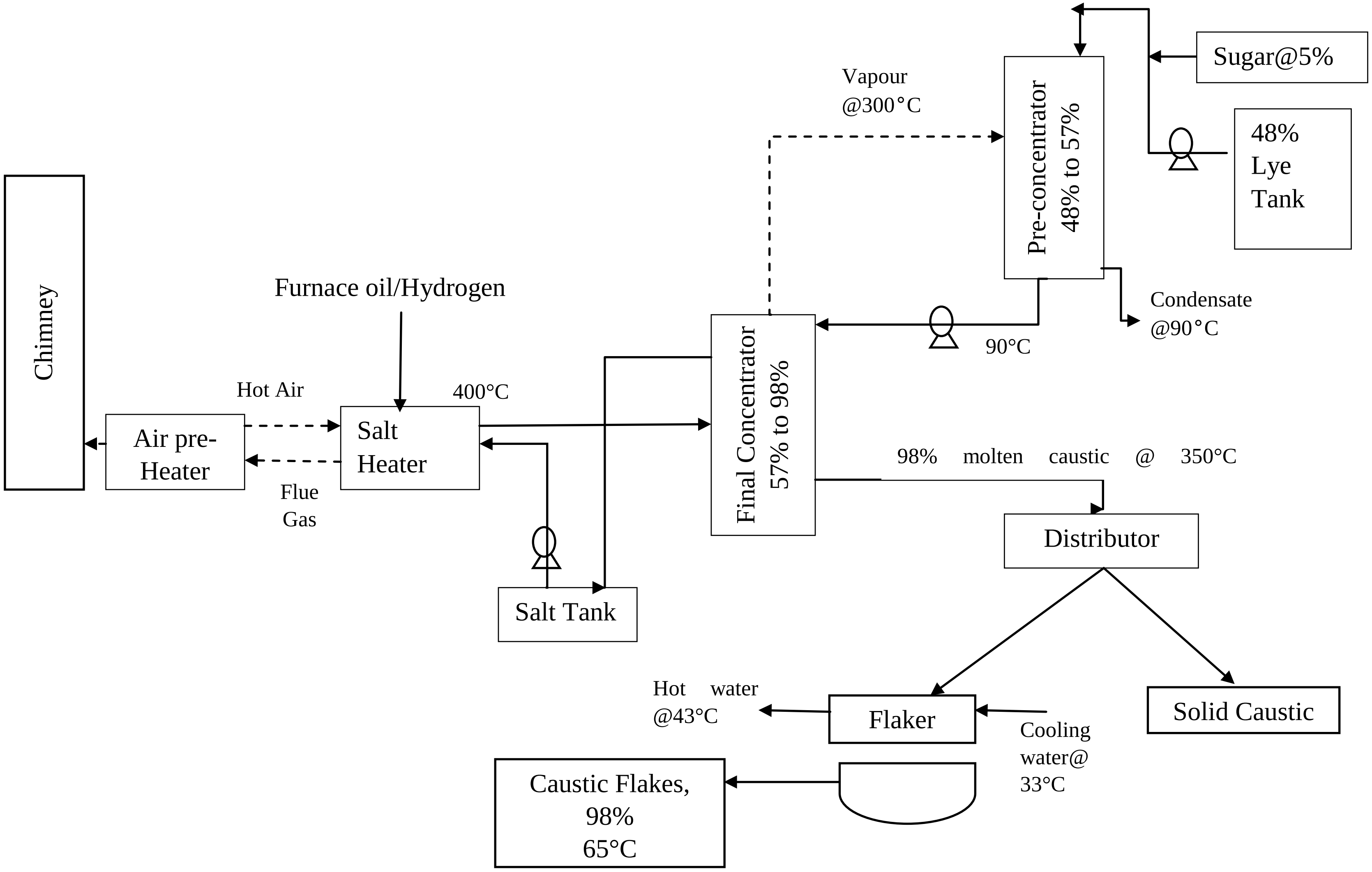

Figure 3.4 Process Flow Diagram of Caustic Fusion

Energy Consumption for Caustic Lye Concentration

Both steam and electricity is used for concentrating lye. The energy consumption in concentrating lye is given in the following Tables:

Table 3.1 Basis and Assumptions for Assessment of Electrical Energy Consumption For Caustic lye Concentration

Basis	TPD	Water to be evaporated	TPH	
Production 48% lye	250			
32%	375	41.67		
36%	333.33	47.62		
42%	285.71	35.71		
Total water evaporated		125		
Steam Requirement (assuming 3 stage MEE and Steam economy of 0.5)	62.5		2.6	
Flash steam (assuming 18%)	11.25		0.47	
Process and steam condensate recovery (assumed) %	0.95			
Process+ Flash steam condensate Recovery	176.25		7.34	
Process condensate loss	8.81			
Process condensate loss /T NaOH	0.04			
Formulae /Thumb-rule/ Constants				

$$P\ (kWhr) = \frac{Q(m^3/s)x\ Total\ head\ (hd - hs,\ m)x\ density\ (kg/m^3)x\ g\ (m/s^2)}{1000\ x\ \eta_{pump}\ x\ \eta_{Mot}}$$

$$Quantity\ of\ fuel\ required\ for\ salt\ heating\left(\frac{Kg}{hr}\right) = \frac{Heat\ energy\ needed\ for\ heating\ salt\ (KJ)}{calorific\ value\ of\ fuel\left(\frac{KJ}{Kg}\right)*\eta\ of\ furnace}$$

$$Delivery = W_{rev} = \frac{\gamma}{\gamma - 1}R(T_2 - T_1) = \frac{\gamma}{\gamma - 1}RT_1\left(\frac{T_2}{T_1} - 1\right) = \frac{\gamma}{\gamma - 1}RT_1\left(\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right)$$

g	9.81	m/s^2
LDO calorific value	9700 40740	kcal/Kg kJ/Kg
Cp (NaOH)	3.4	kJ/Kg. K
Cp (H_2O)	4.2	kJ/Kg. K
Assumptions:		
Pump efficiency factor	0.65	

Motor efficiency factor	0.95	IE4
Vacuum pump efficiency	0.72	
Boiler Efficiency factor	0.8	
3-Stage MEE	0.5	Kg steam/ Kg water evaporated/
4-Stage MEE	0.3	
5-stage MEE	0.25	
Thermic Fluid heater (Furnace) Efficiency	0.78	
Cp/Cv	1.4	
Mass rate of water vapour	186.86	Kg/hr

Table 3.2 Electrical Energy Requirement Assessment in Caustic Lye Concentration

Details	**Flow, Q**	**Head (hd-hs)**	**Density (ρ)**	**Energy Consumption, P**
	m^3/d	**m**	**kg/m^3**	**kW**
32% Feed Pump-1	286.26	30.00	1310	49.65
Process Condensate Pump-1	176.25	30.00	1000	23.33
Vacuum Pump-1				16.59
Condensate Steam Pump-1	11.25	30.00	1000	1.49
Separator Pump-36%	245.64	30.00	1357	44.13
36% Feed Pump	238.10	30.00	1400	44.13
Vacuum Pump-2				16.59
42% Feed Pump	195.69	30.00	1460	37.83
Separator Pump-42%	195.69	30.00	1460	37.83
Vacuum Pump-3				16.59
48% Lye Pump	166.00	30.00	1506	33.10
Total energy consumption, kWh/day				321.24
SEC for 250 TPD of NaOH				**1.28**
GHG emission in kg of CO_{2e} (1 kWh = 0.91 kg CO_2)				**1.17**

Table 3.3 Thermal Energy Requirement Assessment in Caustic Concentration (lye)

Steam required	T/250T NaOH	T/T NaOH
MEE	62.5	0.25
VAM	0.5	0.002
OTHERS	0	
Steam	63	0.252
Fuel used for steam generation	LDO	
Steam/Fuel	13	
Fuel used for steam generation	4.85	0.02
Fuel used for salt heating	18.27	0.07

Table 3.4 Electrical Energy Requirement Assessment in Caustic Concentration (flakes)

	Production (TPD)	Water to be evaporated (TPH)
48% Caustic Lye	250	
57% Caustic Lye	210.53	8.77
98% Caustic	122.45	5.10
Salt used for heating 57% lye	345.8	14.41

Formulae /Thumb-rule/ Constants

$$P\,(kWhr) = \frac{Q(m^3/s)\,x\,Total\ head\ (hd - hs,\ m)\,x\ density\ (kg/m^3)\,x\ g\ (m/s^2)}{1000\ x\ \eta_{pump}\ x\ \eta_{Mot}}$$

$$Heat\ Capacity, q(KJ) = m\left(\frac{kg}{hr}\right) * Cp\left(\frac{KJ}{Kg.K}\right) * \ \Delta T(K)$$

$$Blower\ Power, P(Hp) = \frac{Q(cfm\,)xPw\ (inch)}{6365\,x\ \mu}$$

	g	9.81	m/s^2
	Cp (HT Salt)	0.32	kJ/kg K
	Cp (HT Salt)	1.34	Kcal/kg ºC

Assumptions

Pump efficiency	0.65	
Motor efficiency	0.95	IE4

Details	Flow Q	Head (hd-hs)	Density (ρ)	Energy Consumption
	m^3/d	m	Kg/m^3	kW
48% feed pump	166.00	30	1506	33.10
57% feed pump	135.82	30	1550	27.87
Salt pump	192.53	30	1796	45.78
Flaker blower				2.20
Flaker cutter motor				1.50
Total energy consumption, KWh/day				110.45
SEC for 250 TPD of NaOH				**0.44**
GHG emission in kg of CO_{2e} (1 kWh = 0.91 kg CO_2)				**0.40**

Table 3.1 Thermal Energy Requirement Assessment in Caustic Concentration (flakes)	
Fuel for salt heating:	
Mass of 57% caustic, TPH	8.77
Temperature of heated salt To, °C	350.00
Temperature of caustic flakes Ti, °C	90.00
Difference in temperature, °C	260.00
Heat energy consumed in final concentrator	7754385.96
Fuel for salt heating (kg/hr)	244.02
Fuel for salt heating (T/250T NaOH)	5.86

Table 3.6 Heat Transfer Salt Requirement

Mass of NaOH	Cp of NaOH	Diff in temp (NaOH)	Mass of HT salt	Cp of HT salt	Diff in temp (HT salt)
Kg/hr.	KJ/Kg K	ºC	Kg/hr.	KJ/Kg K	ºC
8750	3.4	=(350-90)	**14408**	1.34	=(400-30)

3.5 CHLORINE

Chlorine generated in cell house is partially dissolved in return brine solution and the remaining is released as gas. Saturated chlorine is released from cell house at 80-90°C. It contains brine mist, impurities like N_2, H_2, O_2, CO_2 and traces of chlorinated hydrocarbons.

Chlorine is cooled to 18°C using chiller and dried using 96-98% H_2SO_4 to avoid downstream corrosion and minimise $Cl_2.nH_2O$ formation. Six–stage H_2SO_4 counter-current contact towers are used to reduce water content to 20 mg/m^3.

The dried Cl_2 is passed through demisters to remove H_2SO_4 droplets. The dried Cl_2 is compressed using centrifugal compressors by maintaining chlorine temperatures <120°C as dry chlorine at high temperature react uncontrollably with iron. The compressed gas is cooled to -13°C at 1 bar using any of the following liquefaction system (refer Table 3.7).

Table 3.7 Chlorine Gas Liquefaction

Liquefaction system	Refrigerant	Costs[1]
High pressure (7–16 bar) and High temperatures (~40°C)	Water	Low energy costs
Medium pressure (2–6 bar)and medium temperatures (between -10°C and -20ºC)	Water, HCFC/HFC or ammonia	Moderate energy costs
Normal pressure (~1 bar) and low temperatures (below -40ºC)	Mainly HCFC/HFC or ammonia	High energy costs

Along with chlorine gas, ingress air constituting non-condensable gases is also present. After liquefaction the non-condensable gases containing chlorine traces are scrubbed before venting out to meet the emission standards for chlorine. These gases termed as tail gases are absorbed in caustic solution to produce hypo or synthesized to produce other products like HCl, bleach and $FeCl_3$.

The process of chlorine liquefaction and scrubbing of tail gases is illustrated in Figure 3.5.

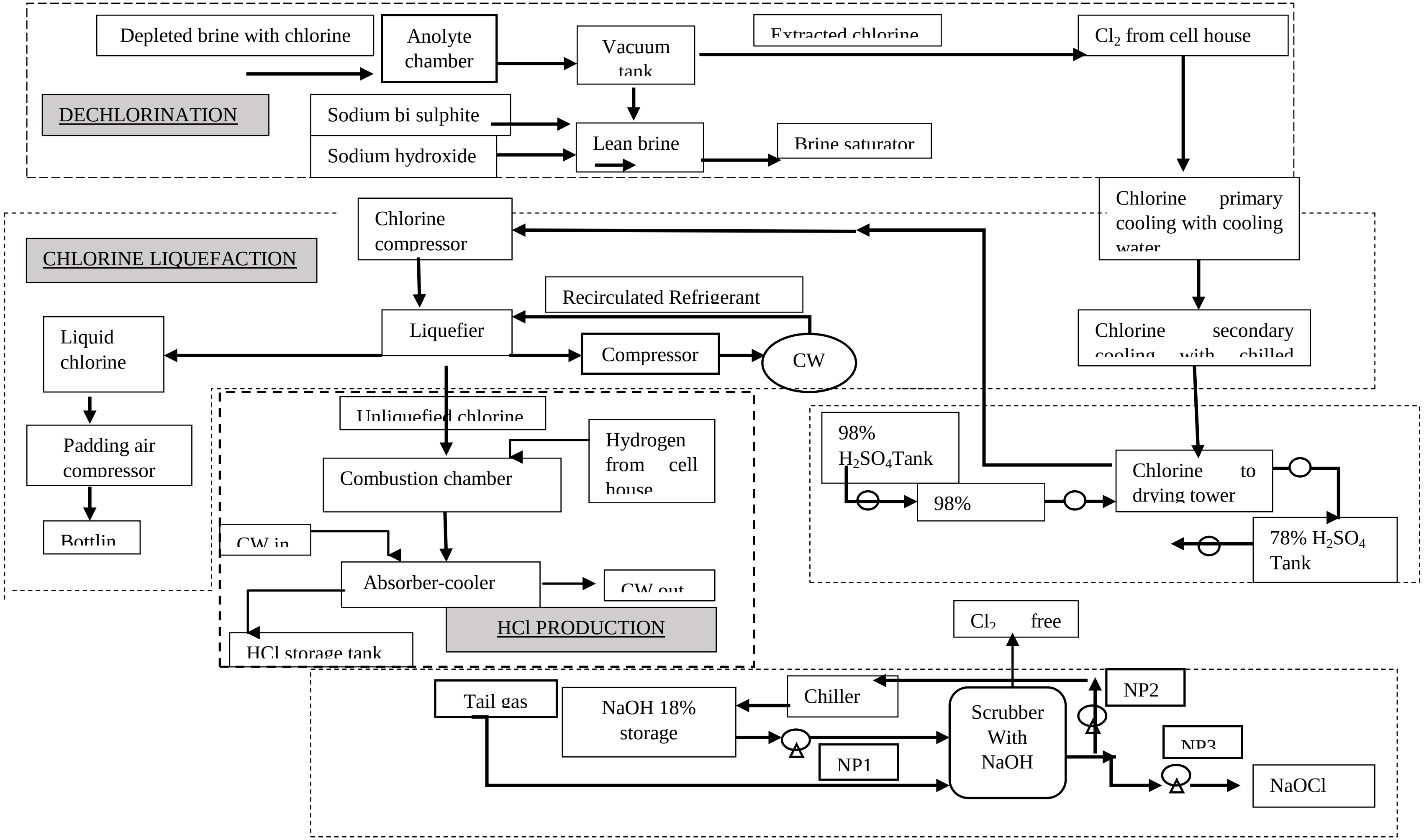

Figure 3.5 Process Flow Diagram for Chlorine Liquefaction

3.6 HYDROGEN GAS MANAGEMENT

During the caustic production in cell house, hydrogen is released along with chlorine. The produced hydrogen is used in the following ways:

- Steam generation (15%)
- HCl production (64%),
- Bottled (7%), based on the market requirement and balance hydrogen is vented out to atmosphere.

The percentage of vented hydrogen varies from plant to plant and averages about 14%.

3.7 UTILITIES

Water Treatment

Water is required mainly for brine operation. The number of water treatment steps depends on water treatment method selected. In chlor-alkali plants, the treatment is primarily focused to control calcium and magnesium. A typical water treatment system in a chlor-alkali plant is as follows:

Clarifier → MG-Filter → Strong Acid Cation unit → Degasser → Strong base Anion unit

Alternatively, water can be treated using RO with 75% throughput followed by mixed bed resin to reduce the chemical consumption. Considering the environmental effects of using chemicals and life cycle analysis of entire water treatment system, this choice is better despite higher energy consumption in RO treatment.

Since, most plants use ion exchange process for demineralisation, this manual covers aspects pertaining to this process only. The process flow diagram given in Figure 3.6 depicts a typical treatment system, commonly used in chlor-alkali industries along with energy usage areas in terms of pumping and mixing.

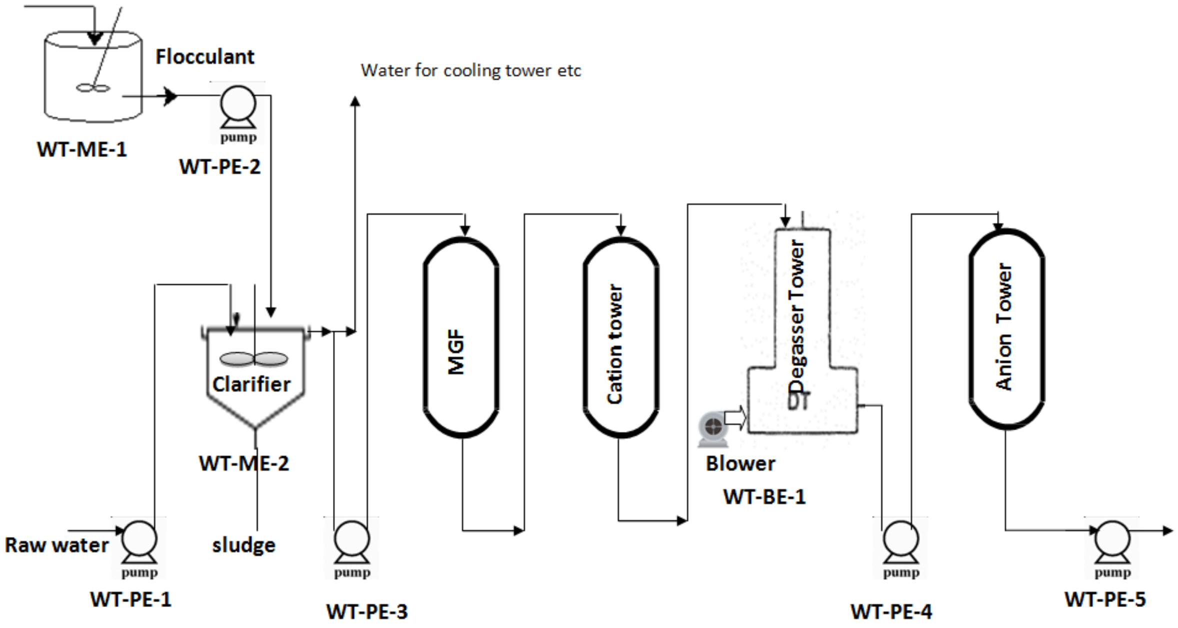

Figure 3.6 Water Treatment System Process Flow

Water Consumption

In chlor-alkali plants, water uses can be summarized as follows:

- Process water for brine preparation
- Preparation of reagents used for the brine purification
- Production of caustic in the cell house
- Dilution of the produced caustic in the caustic circuit
- Water for steam generation
- Cooling water for cooling tower water makeup, and
- Domestic use.

Reported specific water consumption for a chlor-alkali plant varies from 4-12 m^3/Ton of NaOH. The wide variation in water consumption could be due to the following:

- Raw water quality
- Caustic form (48% caustic lye vs. 98% caustic flakes)
- Amount of HCl and Hypo produced.
- Steam and process condensate recovery
- Reuse of alkaline waste brine generated during ion exchange column regeneration

An understanding of water uses and consumption will help conserve water and reduce energy consumed in treating and pumping water across the production chain.

Assessment of Water Consumption in Chlor-alkali Plant

Water required is the summation of:

- Water required for NaCl reaction.
- Water that goes with lye
- Steam and blow down losses
- Vapour losses during caustic concentration
- Water lost with water treatment and brine sludge cake
- Water lost through evaporation and blow-down in cooling towers
- Water used for preparing chemicals for tail gas scrubbing and others

Water balance for chlor-alkali plant considering brine preparation, steam, HCl production and tail gas treatment is shown in Table 3.8.

Table 3.8 Water Balance

A - PROCESS		
A1- For Brine preparation		
$2NaCl + 2H_2O \rightarrow 2NaOH + Cl_2 + H_2$		
117 + 36 → 80 + 71 + 2		
NaCl concentration	320	g/l
Water required for brine preparation as per NaCl concentration	3.2	m^3/T NaCl
1T NaCl	0.684	T NaOH
NaCl required	1.463	T/T NaOH
Water required for brine preparation	4.680	m^3/T NaOH
Water required based on stoichiometry	0.450	T/T NaOH
Water required for 48% lye	1.083	m^3/T NaOH Lye
Brine Treatment		
Assume, 0.2% impurities in NaCl	0.020	T/T NaCl
	0.029	T/T NaOH Lye
Moisture in cake assuming 30% solids content	0.068	T/T NaOH Lye
Water required for make-up brine preparation	1.639	T/T NaOH Lye
A-2: Steam		
Steam economy @ 2.19 T water evaporation/ T Steam	0.457	T Steam/T water
Water to be evaporated for Concentrating lye from 32-48%	0.500	T water/ T lye
Steam required for Concentrating lye from 32-48%	0.600[4]	T Steam/T Lye
Blow-down losses (2% of steam generated)	0.009	T/T NaOH Lye
Condensate recovery loss (95% recovery assumed)	0.023	T/T NaOH Lye

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Steam loss	0.032	T/T NaOH Lye
Process condensate loss (Assumed 5%)	0.031	m^3/T NaOH Lye
Steam and process condensate makeup water required	0.063	
A-3 HCl production* (It is assumed 2% of Cl_2 generated that is not liquefied is only converted to HCl. For additional HCl production adjustment according to calculations below needs to be made)		
$H_2 + Cl_2 \rightarrow 2\,HCl$		
$2 + 71 \rightarrow 73$		
Water required for diluting 1 T HCl to 33%	3.030	m^3/ T 100% HCl
HCl Production (2% liquefied Cl_2)	0.018	T 100% HCl/T NaOH
Water required for 33% HCl production	0.103	T/T NaOH Lye
HCl Production (33%)	0.086	T 33% HCl/ T NaOH
A-4 Tail Gas Treatment (It is assumed 0.5% of Cl2 generated comes out as tail gas that is converted to NaOCl. For additional NaOCl production adjustment according to calculations below needs to be made)		
$Cl_2 + 2\,NaOH \rightarrow 2\,NaOCl + H_2$		
$71 + 80 \rightarrow 149 + 2$		
Cl_2 in tail gas	0.0088	T/T NaOH Lye
NaOCl produced	0.0186	T/T NaOH Lye
NaOCl (18% produced)	0.1031	
Water required for 18% NaOCl (tail gas scrubbing)	0.0845	
FOR PROCESS [A-1 +A-2+ A-3+ A-4]	1.92	m^3/T NaOH Lye
B - Cooling		
Water required for cooling tower losses (Assumed)	2.9	m^3/T NaOH Lye
C- Domestic		
Labour productivity (0.3-1 is reported. Assumed 0.8 for Calculation)	0.8	
Domestic water requirement (45 Lit/ Person as per factories act)	0.036	m^3/T NaOH Lye
Total Primary and Secondary treated water required	**4.69**	m^3/T NaOH Lye
Assuming 5% water losses along with water treatment sludge		
Total Raw water required	**4.9**	m^3/T NaOH Lye

Energy Consumption for Water Treatment

Energy is consumed for

- Pumping water from one treatment stage to other.
- Supplying air in the degasser

- Mixing the chemicals

Energy consumption for a typical 250 TPD caustic plant (48% lye) consuming 1225 m^3/day (Specific Water consumption = 4.9 m^3/T NaOH) water will contribute only about 1.8 kg of CO_2 /T of NaOH.

Energy Consumption for Brine Purification

Energy is primarily consumed for mixing and dosing chemicals and pumping brine from one purification stage to another. Energy consumption and methodology of assessing GHG emissions in a typical brine purification plant considering a typical 250 TPD caustic plant consuming 410 m^3/day water is presented in Table 3.10.

Table 0.10 Assessment of Energy Requirement in Brine Purification

Production		250	TPD lye		
Formulae /Thumb-rule/ Constants					
$P\ (kWhr) = \frac{Q(m^3/s) x\ Total\ head\ (hd\text{-}hs,\ m) x\ density\ (kg/m^3) x\ g\ (m/s^2)}{1000\ x\ \eta_{pump}\ x\ \eta_{Mot}}$					
g		9.81	m/s^2		
Mixing power		10	W/m^3		
Assumptions:					
Pump efficiency		0.65			
Motor efficiency		0.95	IE4		
Equipment Number	**Details**	**Flow, Q**	**Head (hd-hs)**	**Density (ρ)**	**Energy Consumption**
		m^3/d	m	Kg/m^3	kW
B-PE-1	Brine saturator pump	481	30	1200	76.40
B-PE-6	Brine precipitator pump	481	30	1200	76.40
B-PE-7	Clarifier pump	481	30	1200	76.40
B-PE-9	Anthracite filter pump	481	30	1200	76.40
	Anthracite filter pump	481	30	1200	76.40
	Anthracite filter pump	481	30	1200	76.40
	Anthracite filter pump	481	30	1200	76.40
B-PE-10	Polishing filter pump	481	30	1200	76.40
B-PE-11	Ion-exchange pump	481	30	1200	76.40
B-PE-2	NaOH Pump	0.0020	10	1350	0.000119
B-PE-3	Na_2CO_3 pump	0.0013	10	1100	6.47E-05
B-PE-4	Ba_2CO_3 Pump	0.0013	10	1100	6.47E-05

B-PE-5	Flocculant pump	0.0013	10	1100	6.47E-05
B-PE-8	Precoat pump	0.0013	10	1100	6.47E-05
	Mixers				
B-ME-1	Brine Saturator Mixer	481			4.81
B-ME-7	Brine Precipitator Mixer	481			4.81
B-ME-8	Clarifier Mixer	481			4.81
B-ME-2	NaOH Mixer	481			4.81
B-ME-3	Na_2CO_3 mixer	481			4.81
B-ME-4	Ba_2CO_3 mixer	481			4.81
B-ME-5	Flocculant mixer	481			4.81
B-ME-6	Precoat solution mixer	481			4.81
	Total				726.05
SEC kW/T NaOH lye					**2.90**
GHG emission in kg of CO_{2e} (1 kW = 0.91 kg CO_2)					**2.64**

Steam Generation and Distribution

Steam is the primary source of thermal energy in a chlor-alkali plant constituting 6 % of total energy consumed. In chlor-alkali industry steam is primarily used for the following:

- Concentrating caustic lye from 30-32% to 48% in a triple effect back feed falling film evaporator. The heat carried by vapours generated by exchanging steam heat is used to concentrate caustic from 32-36-42-48% in succession.
- Used as mechanical energy in steam ejectors for creating vacuum,
- In Vapour-absorption refrigeration systems for liquefying chlorine in place of ammonia chillers.

The areas where steam is used and the quality of steam used is summarized in **Table 3.11.**

Table 3.11 Steam Consumption in Chlor-alkali Unit

Application	Pressure Level(s)	Remarks
Thermal Application		
Brine Processing		Brine to cell house is required at 65-70ºC and hence needs to be heated using LP steam.
Heating	L, M	
Anthracite regeneration	L,M	
Chlorine Processing		Vaporising liquid chlorine for downstream use. Tail gas chlorine recovery using a vapour-absorption refrigeration chilling plant.
Vaporization	L	
Tail gas stripping	L	
Condensate stripping	L	
Caustic processing		
Heating	L, M	
Evaporation	M, H	
Purification	M, H	

Application	Pressure Level(s)	Remarks
Plant-wide		Used for tracing leakages, purging of equipment during maintenance, cleaning, brine conditioning, etc.
Tracing	L	
General utility	L, M	
Purging (equipment and lines)	L	
Mechanical Application		
Ejectors	M, H	

***Legend (Steam Pressure)**: L =low (<900kPa), M= medium (900 kPa to 1800 kPa), H = High pressure (>1800 kPa)

Furnace oil or hydrogen generated in process is used to generate steam. The generation and distribution of steam on an average constitutes energy losses to the tune of 20-30%.

The steam condensate after recovering flash for use in 2nd effect evaporator is used as boiler feed. The process condensate along with flash steam condensate is used to makeup brine water.

Specific steam requirements in cell house vary from about 0.5–0.7 tons per ton of NaOH. This variation is due to varying multiple effects for concentration of caustic from 32% to 48% as shown in Table 3.12.

Table 3.12 Specific steam Consumption (Tons/Ton of NaOH)

3-Stage MEE	0.5
4-Stage MEE	0.3
5-stage MEE	0.25

For VAM chillers, steam consumption in terms of kg steam/TR for multiple stages is given in Table 3.13.

Table 3.13 Steam Economy of VAM(Kg Steam/TR)

1-Stage VAM	8 kg @2 bar
2-Stage VAM	4 kg @8 bar
3Stage VAM	3.5 kg @10 bar

The other steam efficiency measures include the following:

- Recovering heat from products (Cl_2 gas used to heat feed brine)
- Recovery of steam condensate
- Using MVR or TVR.

For a 250 TPD plant, major requirement is in caustic concentration which is about 80-90% of the total steam requirement. Hence, the steam requirement based on number of evaporator effects and their steam economy along with requirements in other sections can be calculated as follows:

For a 250 TPD caustic plant @ 0.7 tons steam/Ton NaOH @ 178°C and 10 bar

Steam required	=175 TPD
	= 7.3 TPH
Assuming boiler efficiency of 80%, boiler capacity	= 9.11 TPH
Boiler capacity required	= 10 TPH

Based on steam requirement it can be considered a boiler of around 10 TPH is suitable for a 250 TPD caustic plant. The steam generated is used for evaporation in a closed cycle.

Compressors

In chlor-alkali plants, compressors—reciprocating/rotary and centrifugal compressors for various applications such as,

- Supplying instrumentation air.
- Chlorine displacement by padding compressor.
- For compressing dry chlorine before liquefaction.

Benchmarks considered for energy consumption for generating compressed air are:

Compressor type	Benchmarks (kWh/Nm^3/min)
Centrifugal	0.07
Reciprocating	0.11
Screw	0.09

Benchmarks considered for chlorine liquefaction are:

Chiller Compressor using Freon /NH_3	Benchmarks (kWh/TR)
Centrifugal	0.6
Reciprocating	0.9
Screw	0.75

VAM chillers are increasingly used for reducing/ or optimising energy usage.

Energy Consumption for Cl_2 Liquefaction

Assuming centrifugal compressors being used for compression of chlorine,
For a 250 TPD caustic plant @ 222 TPD of Cl_2, produced,

1T NaOH = 0.8875 T Cl_2
887.5 kg Cl_2 = 280.175 m^3 Cl_2 @ STP
= 341 m^3 Cl_2 @ 60°C and 1 atm.
For 250 TPD = 222 T of Cl_2 is produced
= 75,700 m^3 Cl_2/day
= 52.57 $m^3 Cl_2$/min (@60ºC)
= 47 Nm^3 Cl_2/min

Energy required for compressing Cl_2 using centrifugal compressor @ 0.07 kwh./Nm^3/min.

Total energy = 0.07* 47
= 3.29 KWh/ min
Amount of Cl_2 produced = 222/ (24*60)
= 0.15

Energy required /T Cl_2 = 3.29/0.15
= 21.93 kW/T NaOH

Energy Consumption for Instrumentation

Assumed that no. of instruments requiring air in the chlor alkali plant is 20.
Compressed air @ 5 Nm^3/instrument/ min = 20 x 5 x 24
= 2400 Nm^3/hr.

Power required for reciprocating compressor = 0.11 x 144000
= 15840 kWh/ 250 T NaOH
= 63.36 kWh/T NaOH

Transformers and Rectifiers

Two types of transformers namely power transformer and distribution transformer are used. Power transformers are high voltage step-down transformer used in the range of 132 KV/11KV, 33KV/11KV to bring the power to the plant. Distribution transformer used are in the range 125 kVA to distributed the power to the utilities.

Transformer efficiency varies in the range of 93% old- 97% energy efficient. Rectiformers used in the plant is the combination of step-down transformer and rectifier which converts AC to DC. The different types of rectiformers used in chlor-alkali plants are

- Oil forced water forced(OFWF) cooling
- Oil natural air natural(ONAN) cooling
- Oil forced water flow(OFW) cooling

Rectiformer efficiency various from 91% (old –diode based) to 98% new-thyristor based.

Energy Losses in Transformer and Rectiformer

AC power consumption required for the production of caustic efficiency of the transformer is assessed by direct and indirect method. Direct method is simple output by input of the transformer. Indirect method various heat losses occurred in the transformer is considered and efficiency is computed.

Performance Assessment of Transformer

Direct Method:

$$\eta_{Transformer}\ (\%) = \frac{T_{Output}}{T_{Input}} x100$$

Indirect Method:

$$\eta_{Transformer}\ (\%) = \frac{T_{Input} - Loss_{Iron} - Loss_{Copper}}{T_{Input}} x100$$

Formula Used:

$$Loss_{\ Copper} = \left(\frac{Load\ kVA}{Rated\ KVA}\right)^2\ x\ full\ load\ losses$$

Where,

T_{Input}	Input to the transformer (kW)
T_{Output}	Output from the transformer (kW)
$Loss_{Copper}$	Copper Losses at operational load (kW)
$Loss_{Iron}$	Iron Losses or No load losses (kW)
$\eta_{Transformer}$	Efficiency of Transformer (%)
$Loss_{No\ Load}$	No load losses in the transformer
$Loss_{Full\ Load}$	Full load losses in the transformer

Performance Assessment of Rectiformer

Direct Method

$$\eta_{Rectiformer}\ (\%) = \frac{RF_{Output}}{RF_{Input}} \times 100$$

Indirect Method

$$\eta_{Rectiformer}\ (\%) = \eta_{RF\_Transformer}\ (\%)\ x\ \eta_{RF\_Rectifier}\ (\%)$$

Formulae Used:

$$\eta_{RF\_transformer}\ (\%) = \frac{RF_{Input}\ - Loss_{iron}\ - Loss_{Copper}}{RF_{Input}}$$

$$\eta_{RF_{transformer}}\ (\%) = \frac{RF_{Input}\ - m_{tc}C_{tc}(T_{tc\_in}\ -\ T_{tc\_out})}{RF_{Input}}$$

$$Loss_{\,Copper}\ = \left(\frac{Load\ kVA}{Rated\ KVA}\right)^2\ x\ full\ load\ losses$$

$$\eta_{RF\_rectifier}\ (\%) = \frac{\{RF_{Input}\ - Loss_{iron}\ - Loss_{iron}\ \} - m_t C_p(T_{in}\ -\ T_{out})}{RF_{Input}\ - Loss_{iron}\ - Loss_{Copper}}$$

$$\eta_{RF_{rectifier}}\ (\%) = \frac{\{RF_{Input}\ -\ m_{tc}C_{tc}(T_{tc\_in}\ -\ T_{tc\_out})\} - m_{rc}C_{rc}(T_{rc\_in}\ -\ T_{rc\_out})}{RF_{Input}\ - Loss_{iron}\ - Loss_{Copper}}.$$

Where,

RF_{Input}	Input to the Rectiformer (kW)
RF_{Output}	Output from the Rectiformer (kW)
$Loss_{Copper}$	Transformer Copper Losses at operational load (kW)
$Loss_{Iron}$	Transformer Iron Losses or No load losses (kW)
$\eta_{\text{RF\_transformer}}$	Efficiency of Transformer of Rectiformer (%)
$Loss_{Noload}$	No load losses in the transformer of rectiformer
$Loss_{Fullload}$	Full load losses in the transformer of rectiformer
m_{rc}	Mass flow rate of rectifier coolant (kg)
C_{rc}	Specific heat of rectifier coolant
T_{rc_in}	Input Temperature of rectifier coolant (℃)
T_{rc_out}	Output Temperature of rectifier coolant (℃)
m_{tc}	Mass flow rate of transformer coolant (kg)
C_{tc}	Specific heat of transformer coolant
T_{tc_in}	Input Temperature of transformer coolant (℃)
T_{tc_out}	Output Temperature of transformer coolant (℃)

The Table 3.14 shows methodology of calculation of energy loss in Transformer and its cooling water requirement.

Table 3.14 Energy Loss in Transformers		
BASIS	250	TPD 48% lye
Energy consumption in DC kW/T of NaOH	2390	Assumed 5th Gen Bi-polar
DC power required	597500	kW/day
AC to DC conversion Efficiency	97.5	%
Energy loss	15320	kW/day
Energy loss per hr.	638	KWh.
Energy loss	548985	kcal
Assumed rectiformer type: Oil Forced Water Forced Cooling type		
Consider,		
Cp oil	0.85	kcal/kg ºC
Temp difference of oil	3	ºC
Mass of oil	215288.3	kg/hr.
Cooling water required	26229.58	kg/hr.
CT water flow rate required	26.23	m^3/hr.

For a typical set of cooling towers in a chlor- alkali industry, the parameters measured are given in table 3.15.

Table 3.15 Assessment of Energy Requirements for Cooling Needs		
Production: 250 TPD lye		
Formulae /Thumb-rule/ Constants		
$P\ (kWhr) = \dfrac{Q(m^3/s) x\ Total\ head\ (hd - hs,\ m) x\ density\ (kg/m^3) x\ g\ (m/s^2)}{1000\ x\ \eta_{pump}\ x\ \eta_{Mot}}$		
Evaporation Loss (m^3/hr.)= $0.00085 * 1.8 * circulation\ rate(m^3/hr) * (T_1 - T_2)$		
Blow down= $\dfrac{Evaporation\ \ Loss}{COC-1}$		
CT Losses, $(m3/hr)$ = Evaporation Loss + drift loss + Blowdown loss+COC		
Total cooling water required,(m^3/hr)=Quantity of cooling water required (m^3/hr)+CT Losses(m^3/hr)		
g	9.81	m/s^2
Pump Efficiency	0.65	
Motor Efficiency	0.95	
Cp Cl_2	0.48	kJ/kg K
Cp NaOH	3.4	kJ/kg K
Cp HCl 33%	4.18	kJ/kg K
Cp H_2O	4.18	kJ/kg K

Cp H_2SO_4	1.38	kJ/kg K
Energy released due to NaOCl formation	1463	kJ/Kg of Cl_2 gas
Latent heat of vaporization of water	2319	kJ/kg
Heat of fusion of NaOH	209.2	kJ/kg
Assumption		
Head	10	m
Density	1000	kg/m^3
Density Freon	3660	kg/m^3
Pump efficiency	0.65	
Motor efficiency	0.95	
Drift Loss	2%	
COC	4	

Energy requirement for pumps used for cooling is given in Table 3.16.

Table 3.16 Energy Requirement Assessment for Pumps Used for Cooling Needs

Process unit	**Q**		**P**		**SEC**
	m^3/hr.	**m^3/s**	**kWh/day**	**kWh/day**	**kWh/ T NaOH lye**
Caustic Concentration					
Process Condensate	1480.36	0.41	1567.9	1567.9	13.13
Product Cooling	69.73	0.019	73.85	73.85	
Caustic Flaking					
Process Condensate	5.71	0.002	6.05	6.05	0.27
Flaking Drum	26.53	0.007	28.10	28.10	
Chlorine Liquefaction					
Chlorine Cooling	4.35	0.001	4.61	4.61	4.35
HCl Cooling	54.70	0.015	57.94	57.94	
Transformers	27.02	0.008	28.62	28.62	
Freon chiller			298.8		
Miscellaneous	32.78	0.009	34.72	34.72	
VAM					90.57
Total					**108.32**
GHG emission in kg of CO_{2e} (1 kWh = 0.91 kg CO_2)					**98.57**

4. BEST PRACTICES

This section includes area-wise best practices including energy efficiency and conservation measures in the chlor alkali plant.

4.1 CELL HOUSE

The energy losses in the cell house can be broadly classified as follows:

- Energy losses due to side reactions in the cell
- Energy losses due to voltage drop across different sections of the cell

Reducing Energy Losses due to Side Reactions

The Table 4.1 shows energy efficiency potential by controlling side reactions in cell.

Table 0.1 Energy Efficiency Potential by Controlling Side Reactions in Cell

Side Reaction	Typical Reduction in Efficiency (%)	Parameters for Improvement
$HOCl \rightarrow OCl^- + H^+$	1.3	• The partial pressure of chlorine. • The concentration of Cl^- ions, i.e. the concentration of salt in anolyte. • O_2 and ClO_3^- can be depressed by selecting anode coating with suitable characteristics and/or by decreasing the pH in anode compartment. Acidifying brine to pH<6 before feeding to membranes to increase life of anode coating, reduce formation of O_2, OCl^-, ClO_3.
$2HOCl + OCl^- \rightarrow ClO_3 + 2H^+ + 2Cl^-$	2.3	
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$	4.1	

Frequency of Analysis

The frequency of analysis of various streams entering and leaving the cell room is given in Table 4.2.

Table 4.2 Recommended Analysis Frequencies

Stream	**Analysis**	**Frequency**
Cell room feed and exit brine	gpl NaCl	2 hr.
Cell room feed brine	ppm Ca, Mg	4 hr.
Electrolyser feed and exit brine	pH	2 hr.
Cell room exit caustic	% NaOH	2 hr.
Electrolyser exit caustic	% NaOH	2 hr
Cell room chlorine gas	% O_2, H_2	8 hr.
Electrolyser chlorine gas	% O_2, H_2	Daily

Source: AMAI, Delhi

Reducing Voltage Drop in Cells

The Table 4.3 shows various components of cell voltage and possible solutions.

Table 4.3 Energy Losses in Cell House and Possible Solutions

Components of Cell Voltage	Factors for Improvement	Design Consideration	Operation & Maintenance Measures
Membrane IR drop	Mechanical strength and resistance	High performance membrane like improved mechanical strength, reduced resistance etc.	Regular replacement of membrane at the recommended period (3-5 years) to maintain the designed voltage drop. Every year due to membrane aging effect power consumption increases by 35 kWh/MT of caustic production
Cathode and anode over potential	Cathodic and anodic coating, feed water quality, brine purity	Research on different alloys of coating, catalytic cathode	Recoating of anode and cathode at the recommended period (8 years) to maintain the designed voltage drop.
Electrolyte IR drop	Brine purity, gap between anode and cathode, brine feed temperature	Reducing the gap between anode and cathode	Maintaining low impurities level in the brine system. Stringent brine quality check, Automatic control the feed brine temperature

Reducing Energy Consumption by Operating at Lower Current Density through Addition of Cell Elements

The energy consumption in electrolysis varies linearly with the cell operating current density. The energy consumption can be reduced by operating the cells at lower current density. This can be achieved by increasing the number of cell elements and operating the cell elements at lower current density without sacrificing the level of production. The cost incurred on adding the cell elements can be recovered by way of decrease in energy consumption while maintaining the same level of production. The payback period varies from 3 to 4 years.

Reducing Membrane Voltage Drop

The energy consumption on account of voltage drop across the membranes can be controlled by regularly monitoring the condition of membranes for energy performance and replacing them when limit prescribed by the supplier is exceeded.

Apart from the replacement of membranes, the anode and cathode pans are required to recoated and repaired as and when their condition deteriorates. This will keep cell voltage within the prescribed level and prevent damage and premature failure of the membranes.
The purity of aqueous sodium chloride fed into the cell elements for electrolysis should be maintained by removing calcium and magnesium impurities before being fed into the cell. The presence of calcium and magnesium impurities reduces the current efficiency of the membranes and causes accelerated ageing. The recommended limit for calcium and magnesium impurities is 20 ppb.

Structural and Contact Voltage Drop

The records of structural and contract voltage drops at the commissioning stage of the plant should be maintained as a benchmark for periodic monitoring and control.

Electrolyte Concentration

The cell voltage varies with electrolyte concentration—.increase is approximately of 20 mV per percent increase in NaOH concentration.

Electrolyte Temperature

The electrolysis should be carried out at optimum temperature to minimize energy consumption. The cell voltage varies with electrolyte temperature. Cell voltage decreases by 5 to 10 mV per degree increase in electrolyte temperature.

Energy Savings with Improved Membrane Technology

Over the years, there have been continuous improvements in membrane technology in terms of energy performance and GHG emission reduction in Tons of CO2 equivalent per T of NaOH Production. The Table 4,4 summarizes the development and commercialization of different technologies to reduce the energy consumption through voltage drop reduction in different areas.

Table 4.4 GHG Emission Reduction for Various Combinations of Technology Conversions

Technologies	Mono-polar zero gap	2nd generation Bi-polar	3rd generation Bi-polar	4th generation Bi-polar	5th generation Bi-polar	6th generation Bi-polar zero gap	Oxygen Depletion Cathode (ODC)
Mono-polar	0.07	0.14	0.35	0.39	0.45	0.49	0.93
Mono-polar zero gap	X	0.06	0.28	0.32	0.37	0.42	0.85
2nd generation Bi-polar	X	X	0.21	0.25	0.31	0.35	0.79
3rd generation Bi-polar	X	X	X	0.04	0.09	0.14	0.58
4th generation Bi-polar	X	X	X	X	0.06	0.10	0.54
5th generation Bi-polar	X	X	X	X	X	0.05	0.48
6th generation Bi-polar zero gap	X	X	X	X	X	X	0.44

Rectifiers

The rectifiers convert AC to DC and supply DC for the process of electrolysis. Therefore, they occupy a significant role as regards continuity, reliability and energy efficiency of the operation.

The efficiency of rectifiers may be defined as the ratio of DC power output at rectifier terminals to the AC power input at rectifier transformer terminals. The efficiency of rectifiers may vary from a low 94% to a high 97% or more. Since the volume of power handled by the rectifiers in chlor-alkali plants is large, even 1% change in efficiency results in significant energy losses/savings.

The rectifier efficiency depends upon the designed DC output voltage. The present trend is to deploy rectifier units with higher DC output voltage. The operating efficiency of the rectifier units also depends upon their loading. The low loading of the rectifiers reduces poor power factor and increases harmonic distortion. The I^2R losses increases which lead to poor energy efficiency.

The present trend is to replace conventional rectifiers with high DC output voltage diode based rectifiers or thyristor based rectifiers.

Installation of Harmonic Filter Banks/Power Factor improvement Capacitors

The rectifier loads constitutes more than 80% of the total plant load. Being non-linear load, they are major source of harmonics generation. The power factor of rectifier can be low as 0.85 depending upon the loading of rectifier transformers. The reduced power factor results in higher line distribution losses, poor voltage regulation and increased KVA loading of transformers and generators.

However, the losses generated due to harmonics can be reduced by carrying out the study of harmonics present in an electrical system and installing suitably designed harmonic filter banks. The harmonic filter banks apart from mitigating the harmful effects of harmonics are also used for power factor improvement. The benefits of installing the harmonic filter banks/power factor improvement capacitors are as follows:

- The line/distribution losses (I^2R losses) are reduced.
- The harmful effects arising from harmonics in the system are reduced.
- The voltage regulation at the load end is improved.
- The KVA loadings of the transformers, generators and cables etc are reduced, creating scope for further useful loading (KW loading) of the transformers, generators and cables.

Some electric supply companies offer monetary incentives to consumers for improvement in power factor. The payback period on installation of capacitors for power factor improvement can be as low as 6 months.

They also mandate Total Harmonic Distortion (THD) to be maintained below a specified limit and levy penalties in case of THD value exceeding the limit.

4.2 CHLORINE LIQUEFACTION AND TAIL GAS TREATMENT

Chillers/Liquefaction Units

- Efficiency of refrigeration increases as temperatures of the liquid before flashing becomes lower. The process is carried out by sub-cooling using the plant cooling water. If sub-cooling is inadequate with the available cooling water, use of economizers will help to evaporate and cool the remaining liquid.
- Multi staging provides marginal energy savings as well as improves safety as compressed gas temperature is reduced.
- The refrigerants with higher boiling points are recommended. The lower boiling refrigerants require more energy for refrigeration—they require higher compression pressures for condensation by cooling water.
- Operation of steam–based vapour absorption machine (VAM) in place of vapor compression chillers for energy savings if feasible.
- Application of VFDs in refrigeration compressors operating on variable loads.

Scrubber (Tail Gas Handling)

The various factors influencing scrubber performance are as follows:

- Inlet Cl_2 concentration
- Inlet air flow rate
- Recirculation rate
- Packing height
- Capacity of the scrubbing liquor for absorption of chlorine

About 1-8% of Cl_2 produced ends up as tail gas. The chlorine absorption unit is sized based on the gas flow and not on chlorine production capacity of the plant. The gas flow is based on the flow of inert gas injected to keep the hydrogen concentration below the explosivity limits. The majority of the plants work with gas flows in the range 2000–8000 m^3/h.

The commonly used scrubber is spray type scrubber which is simple in design and cost-effective. Pressure drop is low and consequently power consumption is only 0.5-2 HP/1000 CFM. The operating efficiency is about 90% for a particle size of +8µm.

4.3 HYDROGEN GAS MANAGEMENT

Thermal Energy Conservation by using Hydrogen as Fuel in Boiler

The existing oil-fired burner can be modified to handle hydrogen as a fuel. In most plants about 15% of hydrogen is used as fuel along with furnace oil. Combustion of one kg of hydrogen releases 28922 kcal/kg of heat.

Table 4.4 GHG Emission Reduction with Hydrogen as Fuel in Boiler

No.	Parameters	Units		Value	Basis
1	Hydrogen generation factor	Kg H_2/Ton NaOH	=	25	
2	Average H_2 used as fuel for process heating of total H_2 generated	%	=	15	
3	Average H_2used as fuel of total H_2 generated	kg H_2 /Ton of NaOH	=	3.75	
4	Combustion Calorific value of H_2	Kcal/ kg of H_2	=	28922	
6	Annual H_2 production for 250 TPD (considering 320 working days)	H_2 kg /yr.	=	$20x\ 10^5$	25x250x320
7	Hydrogen used as fuel	kg H_2/yr.	=	225000	$20\ x\ 10^5\ x\ 0.15\ x\ 0.75$
8	Heat availability (assuming 80% combustion efficiency)	kCal/yr.	=	$52059\ x\ 10^6$	(225000 x 231377 x.08)
9	Annual FO usage if H_2 is not used (considering 10,000 kcal/l and combustion efficiency of 65%	Kl /yr.		859	$(1.65x\ 52059\ x\ 10^6{}_)/(10000x1000)$
10	Annual GHG reduction for a typical 250 TPD plant (1 kl furnace oil = 3.24 t CO_2)	T CO_2/yr.		2783	(859 x 3.24)

Electrical Energy Conservation by Using Hydrogen as Fuel in Fuel Cells

Average reported flaring of H_2—which is a waste of energy—is about 14%. This energy can be potentially recovered by deploying fuel cells. Based on this equivalent power generation and reduction in GHG emissions by recovering energy from vented hydrogen for a typical 250 TPD plant is assessed and presented in Table 4.5.

Table 4.5 Captive PEM Fuel cell based Power Generation

S. No	Parameters	Units		Value	Rationale
1	Hydrogen generation factor	Kg H_2/Ton NaOH	=	25	
2	Average H_2 vented of total H_2 generated	%	=	14	
3	Average H_2 vented of total H_2 generated	kg H_2 vented /Ton of NaOH	=	3.5	0.14 x 25
4	Specific hydrogen consumption in PEM fuel cell	Kg H_2/kWh	=	0.06	At 50% conversion efficiency in Proton Exchange Membrane fuel cell.
5	Specific energy generation from PEM fuel cell using hydrogen	kWh/Kg H_2	=	16.67	1/0.06
6	Annual H_2 production for 250 TPD (considering 320 working days)	H_2 kg /year	=	$20x\ 10^5$	25x250x320
8	Hydrogen available for Fuel Cells (75% of 14% vented)	kg H_2/year	=	210000	$20 \times 10^5 \times 0.14 \times 0.75$
9	Potential captive electricity generation using Hydrogen PEM fuel cells.	kWh/yr.	=	3.5×10^6	(16.67 x 210000)
10	Annual GHG reduction for a typical 250 TPD plant (1 kWh = 0.91 kg CO_2)	T CO_2/yr.		3185.6	$3.5 \times 10^6 \times 0.91$
11	Savings from energy generated H_2 (@Rs 5/kWh)	Crore Rs/yr.	=	1.75	$(120.82 \times 10^6 \times 6.5)/10^7$

4.3.1 CAUSTIC CONCENTRATION

Energy efficiency techniques include the following:

- Flashing of condensate to produce steam for use in later effect operating at low pressure
- Increasing number of effects in evaporator—multiple effect evaporator— to reduce steam consumption.
- Reducing losses in process and steam condensate.

For a multiple effect evaporator steam consumption varies from 0.5-0.25 kg steam/ kg water evaporated depending on the number of effects. The measured steam consumption less than design indicate scope for improvement. The following factors affect evaporator performance:

- Scaling
- Improper vacuum supply
- Required steam pressure
- condensate evacuation issues
- Tube corrosion leading to puncture
- Performance of heat exchanger before evaporator (If applicable)

These issues can be addressed by choosing the right type of evaporator and adopting best operation and maintenance practices as follows:

Selecting an Evaporator

Whenever the evaporation rate is above 1,350 kg/h, multi-effect evaporation should be considered. In a double effect evaporator, evaporation is approximately 2 kg of water from the product for each kg of steam supply. In chlor-alkali industries, 3-stage falling film evaporator is preferred.

Using retrofits life TVR and MVR

Thermo Vapour Recompression (TVR)

When steam is available at pressures in excess of 3 bar(g) and preferably over 7 bar(g), thermo vapour recompression can be adopted. In this operation, a portion of the steam evaporated from the product is recompressed by a steam jet venturi and returned to the steam chest of the evaporator. Steam efficiency depends on the steam pressure and the number of effects over which TVR is applied. TVR can be used along with multi-effect to provide even larger steam efficiencies.

Mechanical Vapour Recompression (MVR)

This process takes the vapour that has been evaporated from the product, compresses the vapour mechanically and then uses the higher pressure vapour in the steam chest. The energy supplied to the compressor is drawn from an electrical motor/ steam turbine/gas turbine/internal combustion engine.

4.4 STEAM GENERATION AND DISTRIBUTION

Typical losses reported in steam generation and distribution is presented in Table 4.9.

Table 4.9 Losses in Steam Generation and Distribution

Heat Loss Areas	**%**
Steam Generation Losses	
Heat Loss in flue gas	15
Radiation and Convection Heat Loss	3
Boiler Blow-down	2
Steam Distribution losses	
Insulation (Steam and condensate)	6.4
Steam trap station failure	3.6
Condensate losses	3.8
Total	38.8

The various energy efficiency opportunities are as follows:

Recovery of Seam and Process Condensate

As against potential condensate recovery of about 90%, average recovery observed in industries is in the range 70-80% indicating saving potential of 0.6% of thermal energy.

Reducing Boiler Blowdown

By managing and treating boiler feed and condensate water to desired quality, blow-down losses can be maintained at 2%.

Effective Insulation of Boiler and Steam Distribution System

Through effective insulation, radiation and convection losses can be minimised to 3% in boiler and 6.4% in steam distribution.

Selection, Periodic Monitoring and Repair of Steam Traps

Suitable steam traps shall be selected and maintained for removal of condensate.

By adopting the best practices summarized above, the losses in steam generation and distribution can be brought down to 39% to 30%. Considering steam generation and distribution constitutes 6% of total energy used in the sector, a 10% reduction in thermal energy consumption amounts to 0.6% of total energy saved.

Other Energy Efficiency Opportunities include the following

- Avoiding steam leaks
- Utilising steam at the lowest acceptable pressure

- Increasing number of effects in multiple effect evaporator (95%)
- Using thermo-compressor to reuse low pressure steam

4.5 ENERGY EFFICIENCY IN PUMPING SYSTEM

Typical energy efficiency measures in pumping system include avoiding throttling for flow control, adopting multiple pump arrangement, and applying variable frequency drives for variable flows, replacing pump or motor or both and periodic preventive maintenance.

Avoiding Throttling Operation

This is the common method of controlling the flow from a pump. Throttle valves control flow by

- By increasing the upstream backpressure
- By increasing the backpressure on a pump

Multiple-pump arrangement

Multiple pumps operation comprises several smaller pumps in combination (series or parallel). It is adopted when a single pump is unable to operate close to its best efficiency because of wide variation in flow requirements.

The advantages in using combinations of smaller pumps rather than a single large pump are:

- Operating flexibility
- Redundancy in case of a pump failure
- Lower maintenance requirements due to pumps operating near their BEP
- Higher efficiency.

Variable frequency drives (VFD)

They are the preferred option when pumps operate for at least 2000 hours per year and process flow rate requirements vary by 30% or more over time. VFD eliminates the need for throttling valves and motor starters. VFD saves energy by varying the pump rotational speed as power is proportional to the cube of motor speed.

Motor Replacement

Right motor ratings, efficiency and motor loading influence energy consumption. Oversized as well as undersized motors, result with increased energy losses. Ideally motors should operate at 75-100% load. When motors are operated under lightly loaded conditions, power factor is reduced.

Some commonly encountered problems and measures to improve energy efficiency that can be used to address them are summarised in Table 4.10.

Table 4.10 Common Problems in Pump and Measures to Improve Energy Efficiency

S. No	Common Problem	Potential Measures to Improve Efficiency
1	Unnecessary water demand on pumping system	Reduce water demand on system through flow and water balance studies
2	Pump throttling	Adopt variable speed drive
3	Oversized pump	• Select pump that operates near to Best Efficiency Point (BEP) • Change impeller • Trim impeller
4	Inefficient piping configuration	Reconfigure during maintenance.
5	Oversized/ inefficient motor	Adopt energy efficient motor

Potential savings with energy efficiency measures are given in Table 4.11.

Table 4.11 Potential Savings with Energy Efficiency Measures

S. No	Energy Savings opportunities	Potential Savings
1	Replace throttling valve with speed control	10%
2	Install parallel pumping system for highly variable loads	10%
3	Replace motor with energy-efficient motor	1–3%
4	Replace old pump with a more efficient pump	10–20%

4.6 ENERGY EFFICIENCY IN TRANSFORMERS AND RECTIFIERS

Following are the best practices followed in the plant to conserve energy in transformer and rectiformer.

Optimization of Loading of Transformer

- By locating transformer close to the load center, considering other features like centralized control, operational flexibility etc, will bring down the distribution loss in cables.
- Under fluctuating loads, transformers should be used in parallel so that load is shared and transformers operate close to the maximum efficiency range.

Replacing existing Transformer with Energy Efficient Transformers

- By using energy efficient transformers, efficiency improves from 95–97%.
- By using amorphous transformers efficiency improves to 97–98.5%.

Energy Conservation Measures in Rectiformer

Energy loss in AC to DC conversion ranges from 5- 10%. Design rectifier efficiencies range from 91-94% (old diode type) to 97-98% (thyristor type), while the operational efficiencies are typically 0.5 to 1.0 % less than design. The options are:

- Apart from clean contacts, cooling, ventilation, actual loading on the rectifier system influences efficiency.
- Replacement of older thyristor controlled rectifiers with more efficient diode rectiformers increases the rectiformer efficiency to about 4-6% and saves about 5% of the total connected load. For a 250 TPD plant annual energy reduction is 930400 kWh and GHG reduction of 8466 Tons of CO_2 equivalent.

4.7 ENERGY EFFICIENCY IN LIGHTING SYSTEM

The various energy efficiency options in lighting system include the following:

- Use separate transformer for lighting to have better control over voltage.
- Replace HPMV & MH lights with LED lights
- Adopt lighting controls to eliminate unnecessary lighting
- Install lighting occupancy sensors
- Use day lighting.

5. CASE STUDIES

5.1 RE-COATING OF ANODE AND CATHODE WITH MEMBRANE CHANGE

Case Study-1: Re-coating of anode and cathode with membrane change		
Description	**Value**	**Remarks**
Energy saving due to recoating of anode and cathode (kWh/T of caustic)	20	Cell voltage increases by 31 mv per year =20 kW/T NaOH i.e; (31/1000 x 670)
Energy Saving due to membrane change (kWh/T of caustic)	35	Increase in power consumption by 35 kWh/T
Cost saving (Rs/T of caustic)(5 x (20+35)) Cost saving/ annum for 250 TPD plant operating for 280 days	275 1,92,50,000	@ Rs 5 /kWh
Investment required for recoating for 250 TPD caustic plant	12,50,00,000	
Simple Pay-back period in Years (12,50,00,000/1,92,50,000)	6.5	
GHG reduction by recoating and membrane change (kg CO_{2e}/ T of caustic)(20+35)*0.91	50	GHG factor of 0.91Kg CO_2/kWh
Annual GHG saving (kg CO_{2e})	35,00,000	280 days basis @ 250 TPD caustic

Courtesy: The Andhra Sugars Ltd

5.2 FULLY AUTOMATIC CONTROL OF BRINE FEED TEMPERATURE

Case Study-2: Replacement of semi-automatic control of brine feed temperature with fully automatic system		
Description	**Value**	**Remarks**
Energy saving due to control of brine feed temperature within the range of 1 degree Centigrade (90 – 89)(kWh/T of caustic)	14.5	$1.3595T^2 - 227.86T + 11670$
$(\mathbf{1.3595 * 90^2 - 227.86 * 90 + 11670}) - (\mathbf{1.3595 * 89^2 - 227.86 * 89 + 11670}) = 14.5$		
Cost saving (Rs/T of caustic) (5 x (14.5)) Cost saving/annum for 250 TPD plant operating for 280 days	72.5 5075000	@ Rs 5 /kWh
Investment	1000000	Rs 1 crore investment for 250 TPD plant
Simple Pay-back period in Years 10000000/5075000	1.97 years	

GHG reduction by recoating and membrane change (kg CO_{2e}/ T of caustic)(14.5)*0.91	13.2	GHG factor of 0.91Kg CO_2/kWh
Annual GHG saving (kg CO_{2e})	924000	280 days basis @ 250 TPD caustic

Courtesy: The Andhra Sugars Ltd

5.3 PREHEATING OF FEED BRINE USING CHLORINE IN RECUPERATOR

Case Study-3: Pre heating of feed brine from 60°C to 68°C using chlorine gas coming out of electrolyser at 80°C in recuperator

Description	**Value**	**Remarks**
Steam required to heat brine from 60-90°C (kg of steam / T of caustic)	397	36300 MT of steam requirement for brine heating from 60-90°C for 250 TPD
Steam required to heat brine from 68-90°C (kg of steam / T of caustic)	145	23100 MT of steam requirement for brine heating from 68-90°C for 250 TPD
Cost of steam saving by pre heating of feed brine from 60°C to 68°C using chlorine gas coming out of electrolyser at 80°C using recuperator saving (Rs./T of caustic) (397-145)/1000 * 2002 Savings in Rs./yr operating 280 days/yr	184.2 1,28,94,000	@ Rs 2002 / MT of Steam
Investment Rs.	1,20,00,000	
Simple Pay-back period in Years (Rs. 1.29 cr /Rs. 1.2 cr)	0.93	
GHG reduction by preheating brine (kg CO_{2e}/ T of caustic) (397-145)*(660/860)*0.91	176.6	GHG factor of 0.91 Kg CO_2/kWh, Steam caloric value 660kcal/kg
Annual GHG saving (kg CO_{2e})	12362000	280 days basis @ 250 TPD caustic

Courtesy: The Travancore – Cochin Chemicals (TCC) Ltd

5.4 CONVERSION OF CAUSTIC CONCENTRATION PLANT FROM DOUBLE EFFECT TO TRIPLE EFFECT

Case Study-4: Conversion of caustic concentration plant from double effect to triple effect.

Description	Value	Remarks
Steam requirement in MT for double effect evaporator for 1MT of caustic concentrated	1	1MT of steam / MT of caustic concentrated
Steam requirement in MT for triple effect evaporator for 1 MT of caustic concentrated	0.55	
Annual cost saving of steam (Rs./T of caustic) (1-0.55) * 600*360 Savings in Rs./yr operating 360 days/yr	97200	@ Rs 600 / MT of Steam
Cost saving/ annum for 250 TPD plant operating (97200*250)	243 lakhs	
Investment required for 250 TPD caustic plant	300 lakhs	
Simple Pay-back period in Years (300/243)	1.23	
GHG reduction (kg CO_2e/ T of caustic) (1-0.55)*1000*(660/860)*0.91	314	GHG factor of 0.91 Kg CO_2/kWh, Steam calorific value 660kcal/kg
Annual GHG saving (kg CO_{2e}) (0.314*250*360) for 250 TPD caustic	282.8 lakhs	

Courtesy: M/s. Sree Rayalaseema Alkalies and Allied Chemicals Ltd.

5.5 REPLACING RECIPROCATING COMPRESSOR WITH FREON SCREW COMPRESSOR FOR CHLORINE LIQUEFACTION

Case Study-5: Conversion of reciprocating compressor with Freon screw compressors for chlorine liquefaction

Description	Value	Remarks
The power reduction for the conversion of reciprocating compressor with Freon Screw	12 kWh / MT of chlorine	
For 250 TPD caustic production the expected chlorine	222 MT	
The Annual power reduction for the conversion of reciprocating compressor with Freon Screw for 250 TPD Caustic (222x12x280 days)	7.45 lakhs	
Annual cost saving in lakhs (7.45 lakhs x 5)	37.25	@ Rs 5 /kWh
Investment on Freon compressor	120 lakhs	
Simple Pay-back period in Years	3.2	

(120/37.25)		
Annual GHG saving (kg CO_{2e}) (7.45 lakhs*0.91) for 250 TPD caustic	6.8 lakhs	GHG factor of 0.91 Kg CO_2/kWh,

Courtesy: M/s. Sree Rayalaseema Alkalies and Allied Chemicals Ltd.

5.6 CONVERSION OF HOT WATER FIRED SINGLE EFEECT VAM MACHINE WITH DOUBLE EFFECT VAM MACHINE

Case Study-6: Conversion of hot water fired single effect vapour absorption machine (VAM) machine with double effect VAM

Description	Value	Remarks
The steam consumption for single effect VAM	8.16 kg/TR	
The steam consumption for double effect VAM	3.88 kg/TR	
Annual cost saving of steam (Rs./TR) (8.16-3.88) * 280*600/1000 Savings in Rs./yr operating 280 days/yr	5319	@ Rs 600 / MT of Steam
For a 250 TPD caustic plant TR required	345	
Cost saving/ annum for 250 TPD plant operating (5319* 345)	18.35 lakhs	
Investment required for 345 TR	52 lakhs	
Simple Pay-back period in Years (52/18.35)	2.83	
GHG reduction (kg CO2e/ T of caustic) (8.16-3.88)*(660/860)*0.91 *(345/250)	4.13	GHG factor of 0.91 Kg CO_2/kWh, Steam caloric value 660kcal/kg
Annual GHG saving (kg CO_{2e}) (4.13*250*280) for 250 TPD caustic	2.9 lakhs	

Courtesy: M/s. Sree Rayalaseema Alkalies and Allied Chemicals Ltd.

5.7 IMPROVEMENT OF POWER FACTOR BY ADDING CAPACITOR

Case Study-7: Improvement of power factor from 0.96 to 0.99 by adding capacitor in the existing capacitor banks. The average loading of transformer is 16000 kVA

Present kW load (KVA*PF)	= 16000 *0. 96 =15360
kVAr required = kW [tan φ1 – tan φ2]	=15360{(tan ($\cos^{-1}PF_1$) – tan ($\cos^{-1}PF_2$) } = 15360{(tan ($\cos^{-1}$0.96) – tan ($\cos^{-1}$0.99) } =15360*0.108 =1658.8 kVAr
New kVA = (old PF/New PF)*old kVA	= (0.96/0.99) * 16000 =15515.2

Annual cost savings in Rs due to reduction in kVA (@ Rs. 150 per kVA)= (old kVA – New kVA) * 12 * 150	= (16000– 15515.2)*12*150 = 8.72 lakhs
Cost of capacitor in Rs. taking Rs.1200/ kVAr for 1658.8 kVAr	=1658.8 * 1200 =19.9 lakhs
Payback period in yrs (19.7/8.72)	2.26

Courtesy: M/s. Sree Rayalaseema Alkalies and Allied Chemicals Ltd.

5.8 REPLACEMENT OF OLD LOW EFFICIENCY TRANSFORMER WITH NEW ENERGY EFFICICENT TRANSFORMER

Case Study-8: Replacement of old low efficiency transformer with new energy efficient transformer for 250 TPD plant			
Basis	250	TPD Caustic	
SEC	2500	kWh/ T NaOH lye	
Annual working days	320		
DC Energy consumption/ year	200000000	kWh/ year	
Rectiformer efficiency	97	%	
AC	206185567	kWh	
Power	26847.07904	kWh	
KVA @0.9 PF	29830.08782		
MVA assuming 10% factor of safety	32.8130966	Say 35 MVA	
	Unit	Old transformer	Energy efficient transformer
Loading		75%	75%
Efficiency		97	99
Transformer rating	MVA	20	20
Rated no-load loss	kW	18	15
Rated load loss	kW	107	100
Total loss	kW	78.1875	71.25
Annual Operation	Hrs.	8000	8000
Annual Energy Loss	kWh	625500	570000
Annual Energy Saving	kWh		55500
Total annual saving in Rs @ Rs 5/kwh	Lakhs		3
CO_2 emission @ 0.91 kg/kWh	ton/annum		51
Purchase price difference	lakhs		10

Payback period	Yrs.		3.6
GHG emission reduction for 250 TPD of 35 MVA transformer (51/20)*35	Ton/annum		89.30

Courtesy: The Travancore – Cochin Chemicals (TCC) Ltd

5.9 REPLACEMENT OF CONVENTIONAL MAGNETIC CHOKES WITH ELECTRONIC CHOKES

Case Study-9: Replacement of conventional magnetic chokes with energy saving electronic chokes (1500 nos.) for electrical energy savings and reduction of failure of tube rods.	
Electrical energy saved in kWh by replacing with electronic choke (saving is 56.5 kWh/choke/year @ 4200 burning hours)	=1500 * 56.5 = 0.85 lakhs
GHG emission reduction (0.85 *0.91) in Tons of CO_2 eq./annum	77.350
Electrical energy saved @ Rs. 5 / kWh	=0.85 * 5 = Rs 4.25 lakhs
Investment @ Rs. 200/electronic choke	=200*1500=3 lakhs
Pay back period in Yrs. (3/4.25)	0.7

Courtesy: The Travancore – Cochin Chemicals (TCC) Ltd

6. INTERNET OF THINGS (IOT)

6.1 OVERVIEW

As the world's expendable energy resources deplete and the industrial sector is being asked to deliver more to a growing population, energy efficiency has taken center stage to ensure the longevity of these energy resources, and the Internet of Things can play a crucial role. The emergence of the Internet of Things (IoT) almost certainly is the most important single development in the long evolution of energy management. The insight derived from data collected from new Internet-connected devices can be used to develop new services, enhance productivity and efficiency, improve real-time decision making, solve critical problems, and create new and innovative experiences.

Traditionally, many plants do not have the technology in place to track and measure energy use. On top of that, information on a plant's energy production and consumption is not consolidated into a single place. Energy production and consumption data is often not visible in real time and is not presented at a level granular enough to reflect how changes in behaviour affect energy use. With limited information at their disposal, energy managers can have a difficult time finding the places where energy use could improve. To develop a clear energy-saving strategy and drive energy-saving behaviour, managers need to boost monitoring capabilities and this data needs to be coordinated into a single system.

The Internet of Things (IoT) captures information seamlessly from the sensors and machines that monitor all aspects of the manufacturing process. The information it returns offer greater visibility into actionable data that can result in significant energy savings. Network sensors track energy performance, monitor for leaks and flag any subpar operating situations. Adding Internet of Things sensor technology to a plant allows for real-time alerts that notify energy managers about wasteful situations. Energy managers can then take timely action before their operation loses large amounts of money. Further, the Internet of Things gets the right information to the right expert– whether that person is an onsite manager, an off-site facility specialist, or a third party expert—when they need it, so they can make the best decisions to improve energy performance.

6.2 APPLICATIONS OF IOT IN CHLOR-ALKALI PLANTS

Few applications of IOT are presented as follows:

Chlorine Electro-Chemical Process Optimization

A process optimizer balances the current efficiency across cells to optimize performance and to identify and diagnose faults. The software can be operated with any DCS platform. Data is interpreted and performance variability in oxygen, hydrogen and chlorine is determined. It improves cell performance, product quality, membrane life and production.

Rectifier Control

Application specific control features include:

- Constant current control
- Power factor regulation
- Ampere-hours regulation
- Active compensation of DC current over swing due to tap changing
- Trending

PVC Reaction Process Optimisation

PVC is one of the product manufactured using chlorine generated from cell house. Operating and controlling PVC reactors is a key area for better product quality, productivity and cost reduction.

Off-line tool has model calibrated with historical data and enables “what if” scenarios to be carried out for maximizing output, minimizing cost and improving product quality.

On-line tool can be used to support batch optimization and characterization. The model supports on-line real-time parameterization to predict, control and optimize such items as initiator charge and reactor temperature profile. As a result, reaction times are optimized; plant throughput increases and coarse out-of-specification batches are detected earlier.

Predictive Asset Management

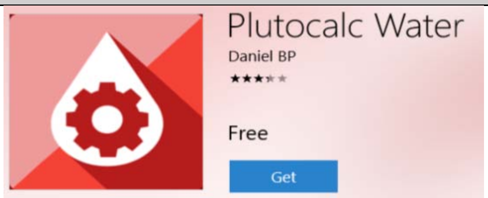
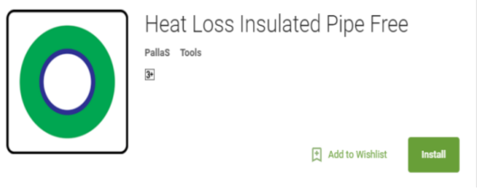
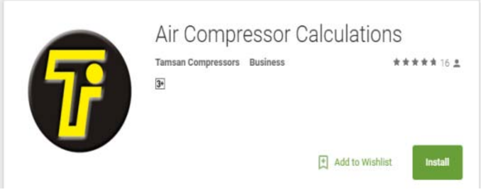
Predictive asset management tool determine the operating conditions of manufacturing assets without the use of dedicated asset monitoring equipment. Using existing sensor data and known fault conditions, predictive asset management tools determine the operating conditions of manufacturing assets without the use of dedicated asset monitoring equipment. This approach is particularly beneficial in areas of the plant where operating conditions make it difficult to take specific measurements. It will reduce planned and unplanned maintenance costs.

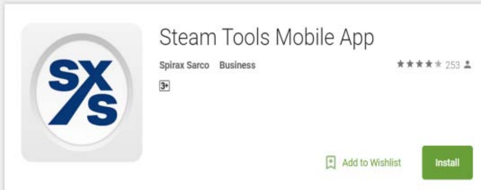
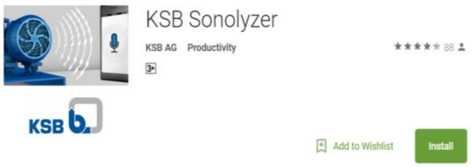
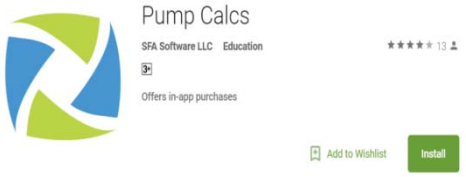
6.3 APPS FOR PRODUCTIVITY ASSESSMENT AND IMPROVEMENT

This section lists various Apps available free of cost online which can be installed in smart phones and used on daily basis for

1. Process improvement
2. Resource optimisation
3. Troubleshooting

Few apps are listed below for reference.

S. No.	App Logo	Description
1		Plutocalc is problem solver suite for water treatemnt, wastewater, hydraulics, environmental chemistry and unit conversions.
2		The Association of Water Technologies (AWT) calculations app allows water treaters to do basic water treatment calculations on their mobile device. The app allows you to determine your boiler system conditions, conduct a cooling tower survey, calculate dealkalizer capacity and determine energy savings.
3		The Heat Exchanger calculator is based on Effectiveness – NTU method.
4		User can calculate heat loss and outside surface temperature of an insulated pipe and a bare pipe to surroundings.
5		Helps user to calculate some basic technical values about air compressors.
6		It is for persons who need to install a compressor. Includes calculations for: • Buffer capacity • Pipe diameter • Pressure drop

S. No.	App Logo	Description
		• Cooling air required • Unit conversion • Leakage calculations • Condesate formed
7	 Gas Compressor At Work Rio Solutions Ltda Business Offers in-app purchases 	It helps to calculate gas compressor requirements such as actual flow, head and power. Produces output reports.
8	 SteamHUB Forbes Marshall Education 	It is ideal steam application tool. Calculations involved from steam generation to condensate loop. Equipped with steam tables and unit conversions.
9	 Steam Tools Mobile App Spirax Sarco Business 	Gives access to steam table and saturated steam pipe sizing tool without internet.
10	 KSB Sonolyzer KSB AG Productivity 	Allows check efficiency of pumps and other rotating equipment.
11	 Pump Calcs SFA Software LLC Education Offers in-app purchases 	Can be used for design and selection of centrifugal pumps, positive displacement pumps, electric motors, machinery components.
12	 Field Process Calculator Free R Tech Productivity 	App provides calculation for volume, surface area, flash steam calculation, pump shaft power, pipe flow calculation, cooling tower process calculation, etc.
13	 Bajaj Lighting App Bajaj Electricals Ltd Business 	User can get lighting design for commercial and industrial lighting. User can create own lighting solutions through app.
14	 Respirator Protection Resource 3M Company Productivity 	This app is intended for use as a quick reference guide for identifying types of workplace respiratory protection that may be appropriate for use when handling certain types of chemicals.

S. No.	App Logo	Description
15		This Indian Red Cross Society First Aid application provides you first aid guidelines to handle day-to-day emergencies. The information included is updated using the latest international guidelines for first aid (2015-2016).

ABBREVIATIONS

AMAI	Alkali manufacturer association of India
BAT	Best available technology
BCM	Billion cubic meters
CD	Current density
CE	Current efficiency
CFL	Compact fluorescence light
CIL	Coal India Ltd
EPDM	Ethylene propylene dinene monomer
ETP	Effluent treatment plant
FEB	Fluorinated ethylene propylene
GHE	Greenhouse emissions
gpl	Gram per litre
HCL	Hydro chloric acid
LED	Light emitting diode
lpm	Liters per minute
Mn	Million
MT	Metric Ton
MTOE	Million tons of oil equivalent
MW	Mega watts
NaClO	Sodium hypochlorite
$NaClO_3$	Sodium chlorate
PEM	Polymer electrolyte membrane
PPb	Parts per billion
ppm	Parts per million
PTFE	Poly tetra fluro ethylene
RO	Reverse osmosis
SCCL	Singareni collieries company Ltd
T	Tons
TPD	Tons per day
VFD	Variable frequency drive

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