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EXPERIENCE THE EXCELLENCE

PRESENTATION

ON

ENERGY EFFICIENCY CASE STUDIES IN CHLOR-ALKALI SECTOR

By

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Electrical Research & Development Association

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- Established in 1974
- Spread over 25 acres at Vadodara, Gujarat, India
- Total laboratory build up area of more than 14,000 sq.m.
- Customer base of more than 10,000

Chlor Alkali Plant

- Electrolyzer
- Compression
- Evaporation Unit
- Concentration Unit

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Case Studies

Usage of Steam to it’s maximum potential

Case Study : Steam System

High Grade Energy of process steam is destroyed in Let down process (pressure and temperature) at PRDS

Observation:

- Pressure reduction and De-superheating cause loss of useful energy
- Destruction of Exergy occurred in PRDS

Data Collected:

Steam and process side historical and current data were collected i.e. Pressure, temperature, steam flow, variation in parameters etc.

Case Study : Steam System

Micro Turbine

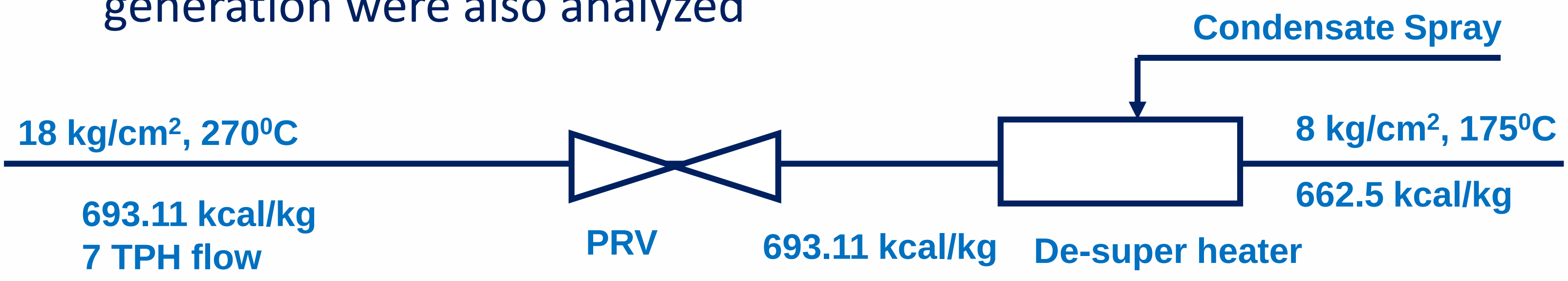
Case Study : Steam System

- The medium pressure steam is used for other process purpose.
- The MP steam is used for process heating at lower temperature and hence, its pressure is reduced to 8 kg/cm^2g and de-superheated to 175^0C.
- This causes a severe drop in energy occurring due to loss of pressure. This energy loss can be reduced by installing backpressure micro turbine.
- Thus, installation of Back pressure turbine in parallel with present PRDS System will allow the energy of super-heated steam to be converted into electrical power.

Case Study : Steam System

Analysis:

- Observing field data potential for electrical energy conversion were analyzed.
- Reliability and consistency in steam parameters and power generation were also analyzed



Counter Measure Identified: Installation of Back Pressure Turbine of 160 kW capacity to use the energy lost in de-super heating.

Steam System

Parameters		Unit of Measurement	Value
Inlet			
1	Steam Flow	TPH	7
2	Temperature	^0C	270.00
3	Pressure	kg/cm^2	18.00
4	Specific Enthalpy	kcal/kg	693.112
Extraction			
1	Steam Flow	TPH	7
2	Temperature	^0C	175
3	Pressure	kg/cm^2	8
4	Specific Enthalpy	kcal/kg	662.5
Steam Power			
1	Inlet	kW	5641.55
2	Extraction	kW	5392.38
Theoretical Power Generation		MW	0.249
Combined Efficiency (Assumed)		%	70
Net Power Generation		MW	0.175

Savings

- The savings can be thus calculated as:
- Power saving opportunity = 175 kW
- Energy saving opportunity =13,86,000 kWh
- (Considering 24 hours operation for 330 days a year)
- Cost of Energy = Rs. 4.5/kWh
- Amount that can be saved = Rs. 62.4 Lakh
- Approximate Investment required = Rs. 50 Lakh
- Simple Payback = 10 Months

Usage Of Best Available Medium For Heat Exchange

Hydrogen pre cooling system

- The hydrogen generated at cell is available at 90 ^{0}C. This hydrogen is required to be compressed before it is sent to other process plants. For Hydrogen to be compressed, it is required to be at nearby ambient temperature.
- For this, a system is provided wherein, the hydrogen is first cooled by DM water in DM water heat exchanger, and then it is cooled by chilled water to around 20-30 ^{0}C.
- However, even though the heat exchanger is provided, due to various technical problems, it is not possible to cool the H2 gas by DM water. Hence, it is suggested to cool the gas by passing Cooling Water instead of DM Water in the heat exchanger. This will reduce the cooling load required by the chiller.

Hydrogen pre cooling system

		Present System	Proposed System
DM Water Heat Exchanger			
Temperature of H_2 at Inlet	^0C	90	90
Temperature of H_2 at Outlet	^0C	90	40
Reduction in Heat Load in H2	kcal/kg	0	171.69
Chilled Water Heat Exchanger			
Temperature of H_2 at Inlet	^0C	90	40
Temperature of H_2 at Outlet	^0C	25	25
Reduction of Heat Load in H_2	kCal/kg	223.45	51.75

Savings

- Thus, the reduction in chilled water load can be given as (223.45-51.75) kcal/kg of hydrogen.
- This equals to 171.7 kcal/kg of H_2 gas.
- Now, the flow of H2 gas at compressor inlet is around 3700 Nm^3/hr. Considering the density of H_2 gas being 0.08375 kg/m^3; the flow of H2 can be around 310 kg/hr.
- Thus, the reduction of load on chilled water system will be: 53205 kcal/hr.
- This is equivalent to 17.59 TR of chilled water requirement.
- The average specific steam consumption of Chillers is around 10 kg/TR. Thus, the steam consumption can be reduced by 175.9 kg of steam per hour.

Savings

➢ Cost of steam	= Rs. 900/MT
➢ Thus, considering the operation for 330 days at 24 hours per annum, the total amount that can be saved be given by:	
➢ Steam can be saved per year	= 1393 MT/year
➢ Sp. Enthalpy of LP Steam	=675 kcal/kg
➢ (Average as per Year 2021-22)	
➢ Average Boiler Efficiency	=87.42%
➢ (As per the boiler efficiency calculated by indirect method during Energy Audit)	
➢ Reduction in input Energy from Coal	=1075.58 GCal
➢ Average GCV of Coal	=5900 kcal/kg
➢ (As received basis on 17/09/2022)	
➢ Amount of coal that can be saved per annum	=182.30 MT
➢ Cost of Coal	=Rs. 6850/MT
➢ Total Amount that can be saved	=Rs. 12.5 Lakh
➢ Investment	= Nil
➢ Simple payback	Immediate

Rectiformer Case Studies

Rectiformer Cooling System (Case Study)

- During the audit, it was observed that chilled water is being used to cool the DM Water used for the cooling of Rectifier Circuit Elements. It is recommended to install additional heat exchanger to first cool the DM water with normal cooling water and then further cool it with Chilled Water. Temperature control 3-way valve can be utilized for the new cooling circuit.
- The present parameters of the cooling system are as follows:
- DM Water Flow 16.75 m^3/hr
- DM Water Inlet temperature to cooling circuit 41^{0}C
- DM Water Outlet temperature from cooling circuit 35.5^{0}C
- Heat Rejected 30.5 TR
- Chilled Water Inlet Temperature 14^{0}C
- Chilled Water Outlet Temperature 27.5^{0}C
- Chilled Water Flow 6.8 m^3/hr

Savings

- Utilizing Cooling Water with 31^{0}C temperature, the complete heat load of 30.5 TR per rectiformer on chiller can be eliminated. Additionally the current system can be utilized in series with the cooling water system.
- Considering the specific energy consumption of chiller 0.75 kW/TR
- Power saving opportunity 22.88 kW

(for 01 Rectiformer)

- Total Power Saving opportunity 91.5 kW

(for 04 rectiformer)

- Energy saving opportunity 7,24,680 kWh
- Amount that can be saved Rs. 43.5 Lakh
- Approximate Investment Rs. 20 Lakh
- Simple payback 6 Months

Rectiformer Cooling System (Case Study)

- It should be noted that the temperature of DM Water must not go below 31^0C in any case and hence, temperature controlled valves must be utilized.
- Also, it is to be noted that since, the cooling water has substantial amount of Dissolved solids compared to chilled water, instead of normal Plate Heat Exchangers, Steel Plate Heat Exchangers used in Dairies must be used. In Dairies, the quality of milk is the most important thing and most prioritized.
- Hence, for pasteurization process, when cooling water is utilized, to ensure that water does not get mixed with milk, specialized steel PHEs are used.
- Similar PHEs can be used here to ensure cooling water does not mix with DM Water

Energy Consumption by Electrolytic Cells (Rectiformers)

There are two rectiformers (rectifier transformers) transforming supplying DC power to 12 Electrolysers for electrolysis of brine. Each Electrolysers has 12 cells, thus totalling to 144 cells.

- **Rectiformer 01:**

	Voltage (kV)	Current (A)	Power Factor	Active Power (MW)
R	33.61	364.2	0.9333	19.806
Y	33.21	364.3	0.9524	
B	33.00	364.1	0.9455	
avg	33.273	364.2	0.9437	
	Energy (01 hour)	19909 kWh		

Energy Consumption by Electrolytic Cells (Rectiformers)

- **Rectiformer 02:**

	Voltage (kV)	Current (A)	Power Factor	Active Power (MW)
R	33.64	444.2	0.9166	23.871
Y	33.30	447.6	0.9289	
B	33.13	448.4	0.9293	
avg	33.357	446.73	0.9249	
	Energy (01 hour)	23798 kWh		

Energy Consumption by Electrolytic Cells (Rectiformers)

During Energy audit it was observed that the flow of brine was around 18.5 to 19.5 m^3/hr per cell for rectiformer 2, while that of rectiformer 1 was also same.

Looking at the stark difference in power consumption by both the rectiformers, it was observed that the membranes of the Electrolysers of rectiformer 2 were new, while that of rectiformer 1 were old.

Hence, it is suggested to install new membranes on every cells of Electrolysers of rectiformer 1.

Savings

Replacing the membrane of Electrolyser D & E

During energy audit, it was found that the membranes of 02 Electrolysers from electrolysers A to F i.e. D & E also needs replacement.

The Electrolysers were consuming around 49.3 kW power higher than the re-membraned Electrolysers, which had new and better membranes.

Hence, it is suggested to change the membranes of the Electrolysers.

No. of cells of Electrolysers:	12
Electrolysers for re-membraning	02
Power saving opportunity:	49.3 x 2 kW
Energy saving opportunity:	851904 kWh
(Considering 360 days for 24 hours)	
Amount that can be saved:	Rs. 35.8 Lakh
Approximate investment for 1 element:	Rs. 1.1 Lakh
Total No. of elements per electrolysers:	111
Approximate investment:	Rs. 244.2 Lakh
Simple Payback:	7 Years

Making Best Usage Of Available Equipment – Cooling Tower

Cooling System (Case Study)

	UOM	RCC Cooling Tower	PVC Cooling Tower
Operating Parameters			
Dry Bulb Temperature	^0C	29	29
Wet Bulb Temperature	^0C	26.9	26.9
Hot Water Temperature	^0C	41.66	30.62
Cold Water Temperature	^0C	34.92	28.29
Cooling Water Flow	m^3/hr	1685	96.5
Calculated Parameters			
Heat Load	TR	3756	74
Range	^0C	6.74	2.33
Approach	^0C	8.02	1.39
Effectiveness	%	46	63

Recommendation

- ❖ Both the cooling towers of plant are connected with common basin and common return line. RCC cooling tower of plant is utilized to supply cooling water to Vacuum system, Process Air Compressors. Whereas, PVC Cooling tower is utilized to supply cooling water to Heat Exchangers E02, E002 and E004.
- ❖ The hot water basin of cooling tower had valves throttled to less than 50% open.
- ❖ The water line to PVC cooling tower has very little flow compared to RCC Tower around 6%. The return line has provision for interconnection between the two cooling towers.
- ❖ Hence, it is recommended to utilize only one cooling tower (RCC) for all the purposes. The Pump of PVC cooling tower can be utilized separately.
- ❖ This will reduce the power consumed by one cell (15 kW rating) at-least.

Savings

- The energy saving opportunity can be calculated as:
- Power Consumption by CT Fan 11 kW
- Energy Consumption by CT Fan 87120 kWh
- (Considering 330 days operation for 24 hours)
- Amount that can be saved Rs. 5.22 Lakh annually
- Also it is recommended to check and clean the cooling tower from any vegetation growth and other algae growth and replace the damaged fills and nozzles during annual maintenance activities.
- It is also recommended to carry out canopy fitting on the water distribution area.

Case Study – Waste Heat Utilization

Performance of Gas Fired Furnaces of Caustic Concentration Units

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The analysis of CCU Furnaces is as follows:

Sr. No.	Parameters	Unit	Value	
			CCU3	CCU2
1	Fuel		Hydrogen and Natural Gas	
2	Hydrogen Flow	Nm^3/hr	894	489.9
3	Natural Gas Flow	Nm^3/hr	74.5	270
4	Combustion Air Flow	Nm^3/hr	3818.81	51000
5	Ambient Air Temperature	^0C	33	36.9
6	Ambient Wet Bulb Temperature	^0C	28	36.9
7	Air Inlet Temperature to Furnace	^0C	294	36.9
8	Oxygen in Flue Gas	%	16.17	
9	Furnace Temperature	^0C	456.89	458
10	Salt Inlet Temperature	^0C	398.13	386.3
11	Salt Outlet Temperature	^0C	456	430.6
12	Specific Heat of Salt	kcal/kgK	0.33	0.33
13	Calorific Value of Hydrogen	$kcal/Sm^3$	3048	3048
14	Calorific Value of Natural Gas	$kcal/Sm^3$	9168	9168
15	Salt Flow	TPH	236.25	114.86
16	Flue Gas Exit Temperature	^0C	248	398.3

Performance of Gas Fired Furnaces

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Calculated Parameters				
1	Excess Air	%	334.78	0
2	Heat Gained by Salt	kcal/hr	1384677	741987.7
3	Heat Gained by Air	kcal/hr	328894.1	0
4	Heat supplied by Hydrogen	kcal/hr	2682961	1470227
5	Heat Supplied by NG	kcal/hr	227225	823500
6	Heat Supplied	kcal/hr	2950280	2304485
7	Direct Efficiency	%	58.08%	32.20%

Observation

- During the audit, following points were observed:
- The furnace can operate on both Hydrogen and Natural Gas.
- Hydrogen, being produced in-house from electrolysis, is mostly preferred for the combustion process. Natural gas is only used when hydrogen generation is low or when there are issues with b
- Even after installation of Air Pre-heater (APH) in CCU – 3; the temperature of flue gas remains significantly high.
- The APH of CCU-2 is not operating and a new APH is being procured.
- The excess air supplied in the furnace is also significantly high.
- This excess air and excess temperature at flue gas exit causes significant amount of heat loss into atmosphere.

Recommendation

- Hence, it is recommended to:
- Install flue gas analyser and control the damper of combustion air blower based on the feedback provided by oxygen reading of the analyser.
- Normally, the oxygen at the flue gas exit shall be around 2% for gas firing furnaces. However, a second feedback of furnace draught must be given to accurately control the damper opening.
- This will not only reduce the excess air and heat loss caused by excess air, but also it will reduce the electrical energy consumption.
- The savings by installation of feedback based damper control for combustion blower for CCU#3 can be calculated as follows:
- At current condition, the dry flue gas loss amounts to 35% of total heat input.
- Reducing oxygen to 5% on conservative basis from current 16%,

Recommendation

- The heating system for CCU#3 can be described as follows:
- The caustic with 48% concentration is first heated in steam chamber from 80^0C to 97.6 ^{0}C in vacuum.
- The caustic with volumetric flow rate of 2.56 m^3/hr and 48% concentration at 4.74 bar (g) pressure is allowed to pass through Evaporator in having vacuum pressure -649.76 mm H_2O(g); where it is heated through steam which gets condensed in shell.
- However, at present the steam is not allowed to flow(and heating is done by the water vapour and condensate of the next stage), and the solution is directly subjected to vacuum, where it loses water content and the concentration is boosted to 50-52%. The temperature of the caustic solution (48%) is also increased to around 98^0C due to heat of the water vapours of next stage. The 50% concentrated caustic solution is then passed through another evaporation tank where it is heated with salt. The salt at 427.37^0C heats the caustic solution from 97.6^0C to 354.46^0C and thus, the caustic losses it's water content and gets concentrated upto 98.5%. The water vapour thus released in this heat exchanger is allowed to pass through previous evaporator.

Savings

• Reduction in dry flue gas loss	25%
• Reduction in heat loss	737570 kcal/hr
• Reduction in consumption of Hydrogen	246 Sm^3/hr
	20.58 kg/hr
• Market cost of Hydrogen	Rs. 30/kg
• Approximate Savings	Rs. 617/hr
• Annual Energy Savings	5841.55 Gcal
• (Considering 330 days of operation for 24 hours)	
• Annual Hydrogen Savings	162.99 MT
• Annual monitory Savings (Fuel Side)	Rs. 48.8 Lakh
• Approximate investment for Flue Gas Analyser	Rs. 8 Lakh
• Approximate investment for control system	Rs. 5 Lakh
• Approximate total investment	Rs. 13 Lakh
• Simple Payback	03 Months

Recommendation

- Additionally, instead of Damper Control System, VFD may also be provided for the CA Blower with feedback from Furnace draught and oxygen reading from the flue gas analyser. This will reduce the power consumption of CA Fan from the present 11 kW to 5 kW leading to energy savings of 47520 kWh annually; leading to additional savings of Rs. 2.85 Lakh per annum. However, the response time of VFD and valve to be checked and decision can be taken based on the past experiences with VFD in CCU plant.

Recommendation

- Since, even after control of excess air, around 14% of the total heat supplied remains in the flue gases. This can be utilized for pre-heating of the caustic.
- This pre-heating can be calculated as follows:
- Considering the new exit gas temperature to be 120^0C;
- Remaining heat that can be utilized 6.87% of the supplied heat
- Remaining heat that can be utilized 202684 kcal/hr
- Amount of Hydrogen gas that can be saved 67.56 m^3/hr
- Temperature of 48% caustic can be raised from 80^0C to 110.4^0C
- Concentration of 48% caustic can be increased to 53.9%
- Amount of Hydrogen that can be saved 535075 sm^3 44.76 MT
- Amount that can be saved annually Rs. 13.4 Lakh
- Approximate Investment required Rs. 30 Lakh
- Simple payback 2.3 Years

Recommendation

The data considered for calculation of temperature is as follows:

	NAOH(l) In				H2O(l) In	
	1.5	TPH			1.5	TPH
	80	^{0}C			80	^{0}C
	Liquid Mixture					
Heat available in Water					80.01641	kcal/kg
Total Heat available in water					120.0246	Mcal/hr
	Heat Exchanger					
	$NAOH_{(l)}$ Out		$H_2O_{(l)}$ Out		$H_2O_{(g)}$ Out	
	1.5	TPH	1.27978	TPH	0.220148	TPH
	110.391	^{0}C	110.391	^{0}C	110.391	^{0}C
	Liquid Mixture				Vapour Exhaust	
	0.868371	kcal/kgK	110.6113	kcal/kg	643.0151	kcal/kg
Total Heat gained	39.58596	Mcal/hr	39.15485	Mcal/hr	123.9432	Mcal/hr
Total Heat Gained	202.68 Mcal/hr					

Case Study – Regular observation of operating parameters

Observation

The operating parameters of the Caustic Evaporation Units are as follows:

CEU	Material	Material Flow (m^3/hr)	Vacuum (mmHg)	Steam Pressure (kg/cm^2g)	CW Flow (m^3/hr)	Steam Condensate Flow (m^3/hr)	Total Steam Required
1	NAOH	22	-698.4	8.09	233.5	3.1	12.01 TPH
2	NAOH	19.56	-652	8.00	195	4.05	
3	KOH	7.8	-516	6.30	214.5	3.23	
4	KOH	4.5	-676	4.81	97.3	1.63	

Observation

- It is observed that vacuum of the condenser of CEU 1 is the best while the vacuum of the similarly designed CEU 2 is little poor. It is also observed that the water flow entering into CEU 2 condenser is lesser than that of CEU 1. Also, material flow of CEU 1 is more than material flow in CEU 2, and the steam consumption of CEU 1 is less than that of CEU 2.

Recommendation

- Hence, it is recommended to check and clean the condenser during shutdown period.
- Similarly, it is recommended to check and clean the condenser of CEU 3 during the shutdown period. Since, the vacuum has direct impact on steam consumption of CEU.

Case Study – Regular Maintenance

RCC-B Cooling Tower Pumps

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	Parameters	Unit	RCC CT Pump 5	RCC CT Pump 6
1	Rated Flow	m^3/hr	900	900
2	Rated Head	M	40	40
	Mechanical Parameters			
3	Flow	m^3/hr	505	725
4	Suction head	M	2.2	2.2
5	Discharge pressure	kg/cm^2	3.7	4.05
6	Head	M	34.8	38.3
	Electrical Parameters			
7	Voltage	V	415	415
8	Current	A	320	215
9	Power Factor		0.86	0.86
10	Electric Input power	kW	197.81	132.90
11	Motor Efficiency (assumed)	%	92	92
	Calculated Parameters			
12	Hydraulic power	kW	47.84	75.59
13	Power Input to pump	kW	181.98	122.27
14	Combined efficiency	%	24.19%	56.88%
15	Pump Efficiency	%	26.29%	61.82%

Recommendation

- The efficiency of RCC B Cooling Tower Pump 5 is significantly low compared to RCC B CT Pump 6. This is due to very low flow delivery and very low head. Hence, it is recommended to check the condition of impeller and carry out overhauling and maintenance of the said pump. The energy saving opportunity can be stated as follows:
- Power saving opportunity 20 kW
- Energy saving opportunity 79200 kWh
- (Considering 165 days of operation for 24 hours)
- Amount that can be saved Rs. 4.75 Lakh
- Approximate Investment Rs. 1 Lakh
- Simple payback 3 Months

Case Study - VFD

Performance Analysis of Hydrogen Blowers

	Parameters	Unit	371&571
1	Rated Flow	Nm^3/hr	2253
2	Rated Head	mmWC	1983
	Mechanical Parameters		
3	Flow Combined	Nm^3/hr	3888
4	Suction Pressure	mmWC	240
5	Discharge pressure	mmWC	2274
	Electrical Parameters		
6	Electric Input power	kW	61
7	Motor Efficiency (assumed)	%	92
	Calculated Parameters		
8	Hydraulic power	kW	21.54
9	Power Input to Blower	kW	56.12
10	Motor Blower Combo Efficiency	%	35.31%
11	Combined Blower Efficiency	%	38.38%

Recommendation

- During audit, it was observed that the bypass valve was open by 66%. Hence, it is recommended to install variable frequency drive for the blowers. The saving potential is as follows:
- Power saving opportunity on conservative basis 10 kW
- Energy saving opportunity 79,200 kWh
- (Considering 24 hours operation for 330 days)
- Amount that can be saved Rs.4.75 Lakh
- Approximate Investment Rs.2.8 Lakh
- (For four blowers)
- Simple Payback 7 Months

Thank You

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