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APPLICATION OF SUPPLY CONSERVATION CURVES TO STEAM SYSTEMS IN PULP AND PAPER INDUSTRY

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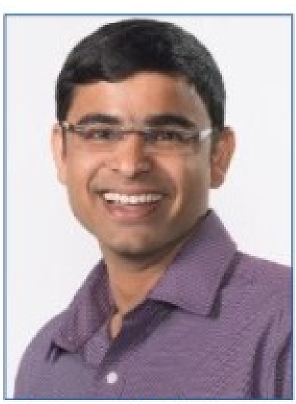

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ABSTRACT

The pulp and paper industry is a large consumer of energy and energy costs account for over 25% of all manufacturing costs. In the light of the PAT scheme in India, several mills in India have been conducting baseline audits and find that there are several areas where energy can be saved in a situation where the auditor makes several recommendations, which ones to take on first and which ones to do later becomes a dilemma.This is an attempt in providing the scientific and systematic answer to the dilemma of selection & prioritization of the available measures for implementation also to put a perspective on whether all the available measures are worth implementing or not. The objective is to go beyond the simple payback calculations & discount rates and integrate the technology with the financial models to make this process of measures implementation more robust. Typical Case study shows that out of available 55 measures 20 measures are not worth implementing at all, even though some of them have shorter payback, and vice versa.*A similar model of a 3 step prioritization model was put forth some years back in terms of Stop wastage , Improved efficiency and then next practice and coupled with the proposed conservation supply curves, we can make the selection process of recommendations more robust.*

1. Introduction

Steam Conservation Supply Curves (SCSC) are used as a tool to investigate the potential and economics of an energy conservation idea. It not only summarizes the economic feasibility of the idea but also provide the guideline for the sequence of measures you should be following while implementing. SCSC are widely used in industries with energy intensive practices and covers wide variety of energy conservation measures from small to big and then comparing the cost of implementing the same against the cost energy of average industrial standard for the sector. Objective is to make it an investment schedule over a period of time.

Please refer the following curve for a broader understanding of supply conservation curves,

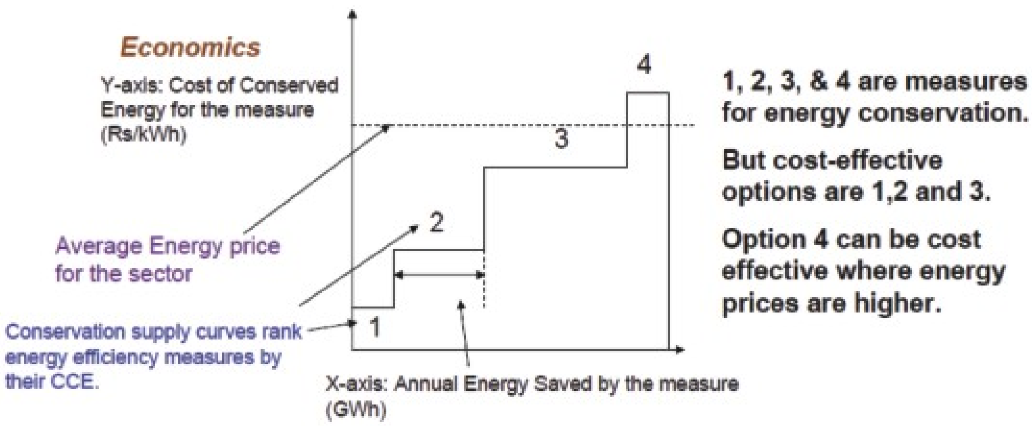

Fig.1 : Generic SCSC

The terminology used in plotting the CSC is explained as follows,

Cost of Conserved Energy (CCE)

$$CCE = \frac{\text{Annualized Investment + Annual Change in O\&M Costs}}{\text{Annual Energy Savings}}$$

$$\textbf{Annualised Investment} = \frac{\text{Capital Cost x d}}{(1-(1+d)^{-n})}$$

where

d is the discount rate

n is the lifetime of the conservation measure

Thus basically it is a plot of cost of conserved energy on Y-axis and amount of energy that will be saved by the measure in the life span and then taking the on-date energy cost as the reference value compare weather the energy conservation measure is worthimplementing. We can make it more realistic by adding accuracy to our calculations by taking the actual prices for the measure, operation and maintenance cost, different discount rate, overall life span of the measures, accuracy in energy saving calculations and other parameters.

2. Case Study-1-An integrated pulp & paper mill

For making the SCSC concept more realistic and test the potential available in providing insights in the investment schedule, we decided to apply it to a large size integrated pulp and paper industry in India.

We conducted a detailed audit with an objective of improving the overall efficiency of System, through auditing the steam and condensate system of five paper machines & Pulp Mill, RDH Area, SRP Area and CPP looking into the operational parameters and means to increase in efficiency at distribution, utilization, condensate & flash steam recovery.

Capacity of the Plant = 1, 33,488 tones/annum.

The present steam consumption = 3092 TPD

Fuel- Coal   Steam: fuel ratio = 6.77   The current cost of steam is INR 650 /ton of steam

In the Table 1 below,the findings and recommendations have been enlisted with investments and a simple payback calculation.

Area	Measure	Steam Savings	Expected annual Savings	Investement	Payback
		TPD	Rs	Rs	Months
PM-1	Rebuild thermal groups with proper measurement and control-PM1	4.3	973000	600000	7.8
	saturated steam for paper machine				
	steam flow meter correction				
	check and correct the syphon clearance of identified cylinders				
	Have Steam box for PM1	6.45	2662000	5000000	22.5
PM-2	Rebuild thermal groups with complete automation PM2	6.3	1435000	600000	5.0
	saturated steam for paper machine				
	Thermocompresor system for MG				
	steam flow meter correction				
	check and correct the syphon clearance of identified cylinders				
	Install steam box	9.45	3900000	5100000	15.7
	Utilize flash steam in for air preheating for MG Hood with proper control on MP steam heater.	2.33	741000	300000	4.9
PM-3	PM3 Rebuilding Yankee S&C and Hood system	4.36	2731000	3400000	14.9
	steam flow meter correction				
	PM-3 steam system rebuild with thermocompressor				
	Yankee hood MP steam flash steam recovery using flash vessel and air preheater for hood	2.3			
PM-4	To rebuild Steam and condensate system of PM4	18.9	4100000	6600000	19.3
	check and correct the syphon clearance of identified cylinders				
	PM4 Flash steam recovery to pre heat Hood PV air with temperature control on LP steam heater.	2	429000	500000	14.0
	Install steam box	9.6	3795000	5100000	16.1
	Moisture control post size press MF2	3.84	749000	1075000	17.2
	Condensate Recovery system for PM-1-4	12.2	2760000	3500000	15.2
PM-5	PM5 Restore Condensate and Flash network	6	1347000	400000	3.6
	Change the siphons joints on PM5 for Driers 18-42	20	4296000	4100000	11.5
	Close Hood Revamp with complete automation to optimize the performance and energy.	3.2	687000	1600000	27.9
	Nansulate coating of Dryer ends of MF3 to minimize radiation & convection losses	4	860000	700000	9.8

Table 1. Table of recommendations

Table 1. Table of recommendations *(Contd.)*

Area	Measure	Steam Savings	Expected annual Savings	Investement	Payback
		TPD	Rs	Rs	Months
Coating machine	Install temp. control to coater air heater with steam line acesories for improvement of steam quality	1.282	200000	1900000	114.0
Old Pulp Mill	Optimize Steam Pressure in Heater Mixer to avoid Steam Loss	1.3	300000	600000	24.0
	Digestor Out Liq. Heat Recovery for preheating White Liq. To Digestor Heat Recovery from WBL sent to SRP	7.3	1800000	4900000	32.7
	Preheating of WL using LP Steam to Reduce MP Steam Consumption	8	400000	1300000	39.0
	Monitor & Control Bagasse Moisture Entry to Digestor	4	1000000	200000	2.4
	Avoid Washer-4 Water Dilution for Optimum Steam Consumption in D0	1	1200000	100000	1.0
	Reduce Digestor Heat Loss by Proper Insulation	1	200000	100000	6.0
	Digestor Pipe Line Routing Optimization	0.1	20000	10000	6.0
	Arrest Hot Water Pump Gland Leaks	0.2	100000	10000	1.2
	Reduce Direct Heat Loss from Not having Insulation of Steam/Hot Lines	1.9	460000	540000	14.1
RDH	Condensate & Flash Steam Recovery from WL/C2 Steam Heaters	3.5	800000	2100000	31.5
	Restore WL/BL Heat Ex. & Have Correct Sized Cond. Lines & Heat Ex. Duty for WL Heater	30.3	7400000	7500000	12.2
	Optimize MP Steam Consumption in ODL Steam Sparger by utilizing LP Steam in Heater	15.1	600000	500000	12.2
	Arrest/Attend ODL Standpipe Steam Vent	0.4	100000	10000	1.2
	Arrest Hot Water Pump Gland Leaks	0.5	200000	10000	0.6
	Insulation of Liq. Heaters & Steam/Hot Water Lines In RDH Area	7.1	1730000	1480000	10.3
	Insulation of Chiller Lines/Steam & Cond. Lines in CLO2 Plant	1.9	450000	320000	8.5
	Vaccum Generation Using Vacc. Pump Instead of Steam Ejector in Clo2 Plant	21.6	4200000	2500000	7.1
	Condensate Recovery from Clo2 Plant to Boiler House	3.2	900000	400000	5.3
	Arrest Direct Steam Leaks & Ensure Steam Line Traps are INLINE	1.3	300000	100000	4.0
SRP area	Utilize Flash steam and condensate in Primary and secondary APH	48	11600000	3500000	3.6
	Insulate Process Condensate line to HWT	9	2000000	300000	1.8
	Insulate the Hot water Supply line	25	4400000	900000	2.5
	Insulation of Green Liq. Lines	4	800000	600000	9.0
	Condensate Preheating by Heat Recovery from WBL sent to SRP	6	1400000	5700000	48.9
	Arrest Steam Leakages	0.3	60000	21000	4.2
	Utilise Flash steam and condensate in Primary and secondary APH	48	11600000	3500000	3.6

Table 1. Table of recommendations *(Contd.)*

Area	Measure	Steam Savings	Expected annual Savings	Investement	Payback
		TPD	Rs	Rs	Months
	Blow Down Flash Steam Recovery	2.6	610000	900000	17.7
	Optimizing Steam Temperatures after DSH with Insulated Piping & Correct Steam	53.9	12400000	6000000	5.8
	Condensate Recovery from Main Line Traps	0.7	210000	470000	26.9
	Avoiding Parallel Lines for Interconnecting 21MW LP Hdr to 3MW Hdr	1	240000	300000	15.0
	Optimum Pipe Routing for MF-II	6.6	1560000	3020000	23.2
	Online Conductivity Monitoring to avoid Draining of Condensate	0.7	220000	630000	34.4
	Attending/Avoiding DSH pump Leaks	0.4	170000	30000	2.1
	Avoiding Direct Heat Loss having hot Steam/Condensate piping Insulated	6	1460000	1540000	12.7
	Attending Steam Leaks & Ensuring Line Traps INLINE	2.1	490000	80000	2.0

Since we know now the measures, energy savings associated with them as well as the cost of modification, we are now in position to plot the SCSC for the same.

We assumed the life span of the measures to be same, discount rate to be same and the annual operation and maintenance cost is also neglected for simplification and thus the installation cost is itself is the annualized cost in this case.

We calculated the annual energy saving by the implementation of the measure by using the steam data available with us (I.e. cost of steam, S: F etc.)

Cost of conserved energy is calculated for each measure and thus is a representative of how a measure is placed in implementation sequence.

Cost of coal is INR 4.5 /kg and thus we can calculate the average cost of energy for today which turns out to be ~ 197 INR/GJ, (on GCV basis).

Thus any measure which has CCE value less than 197 is OK to be implemented and the sequence for those measures lies with increasing order of their CCE and thus the measure with least CCE to be implemented first.

Regarding the measures which has higher CCE values than 197, are not implementable in the current format, either they need to come down on the cost or need the relook on the energy saved by them since the cost of conserved energy for those measures is more than the average cost of energy as of now for the plant, and thus it is costly saving for them.

Also the significance of the curve is that it states the measure which has maximum energy conservation may not be implemented first, neither did one measure which has least cost of modification, also only good payback doesn't guarantee you the same as payback doesn't consider the performance after payback, and thus all these aspects covered in SCSC is giving us more comprehensive approach.

Area	Measures	Steam Savings	Annual energy saved	Investement	Payback	CCE
		TPD	GJ	INR	Months	INR/GJ
RDH	Arrest Hot Water Pump Gland Leaks	0.5	591	10000	0.6	16.916
RDH	Arrest/Attend ODL Standpipe Steam Vent	0.4	473	10000	1.2	21.145
RDH	Optimize MP Steam Consumption in ODL Steam Sparger by Utilizing LP Steam in Heater Mixer	15.1	17853	500000	12.2	28.0063
SRP	Insulate Process Condensate line to HWT	9	10641	300000	1.8	28.1932
SRP	Insulate the Hot water Supply line	23	27193	900000	2.5	33.096
PULP MILL	Arrest Hot Water Pump Gland Leaks	0.2	236	10000	1.2	42.290
PULP MILL	Monitor & Control Bagasse Moisture Entry to Digestor	4	4729	200000	2.4	42.290
PM5	PM5 Restore Condensate and Flash network	6	7094	400000	3.6	56.388
SRP	Arrest Steam Leakages	0.3	355	21000	4.2	59.206
SRP	Utilize Flash steam and condensate in Primary and secondary APH	48	56751	3500000	3.6	61.673
SRP	Utilise Flash steam and condensate in Primary and secondary APH	48	56751	3500000	3.6	61.673
CPP	Attending/Avoiding OSH pump Leaks	0.4	473	30000	2.1	63.435
RDH	Arrest Direct Steam Leaks & Ensure Steam Line Traps are INLINE	1.3	1537	100000	4.0	65.061
PM2	Rebuild thermal groups with complete automation PM2 saturated steam for paper machine Thermocompresor system for MG steam flow meter correction check and correct the syphon clearance of identified cylinders	6.3	7449	600000	5.0	80.552
PULP MILL	Avoid Washer-4 Water Dilution for Optimum Steam Consumption in O0	1	1182	100000	1.0	84.580
PULP MILL	Reduce Digestor Heat Loss by Proper Insulation	1	1182	100000	6.0	84.580
PULP MILL	Digestor Pipe Line Routing Optimization	0.1	118	10000	6.0	84.580
CPP	Optimizing Steam Temperatures after DSH with insulated Piping & Correct Steam Trapping System	53.9	63727	6000000	5.8	94.152
RDH	Vaccum Generation Using Vacc. Pump instead of Steam Ejector in Clo2 Plant	21.6	25538	2500000	7.1	97.893
RDH	Condensate Recovery from Clo2 Plant to Boiler House	3.2	3783	400000	5.3	105.725
PM2	Utilize flash steam in for air preheating for MG Hood with proper control on MP steam heater.	2.33	2755	300000	4.9	108.901
PM1	Rebuild thermal groups with proper measurement and control-PM1 saturated steam for paper machine steam flow meter correction check and correct the syphon clearance of identified cylinders	4.3	5080	600000	7.8	118.103
SRP	Insulation of Green Liq. Lines	4	4729	600000	9.0	126.869
PULP MILL	Preheating of WL using LP Steam to Reduce MP Steam Consumption	8	9459	1300000	39.0	137.442
RDH	Insulation of Chiller Lines/Steam & Cond. Lines in CL02 Plant	1.9	2246	320000	8.5	142.490
PM-5	Insulate coating of Dryer ends of MF3 to minimize radiation & convection losses	4	4729	700000	9.8	148.014
PM-5	Change the siphons joints on PM5 for Driers 18-42	20	23646	4100000	11.5	173.388
RDH	Insulation of Liq. Heaters & Steam/Hot Water Lines in RDH Area	7.1	8394	1480000	10.3	176.307

Table 2 : (Continued)-CCE and Paybacks

Table 2 : (Continued)-CCE and Paybacks *(Contd.)*

Area	Measures	Steam Savings	Annual energy saved	Investement	Payback	CCE
		TPD	GJ	INR	Months	INR/GJ
RDH	Restore WL/BL Heat Ex. & Have Correct Sized Cond. Lines & Heat Ex. Duty for WL Heater	30.3	35824	7500000	12.2	209.356
PM4	PM4 Flash steam recovery to pre heat Hood PV air with temperature control on LP steam heater.	2	2365	500000	14.0	211.449
CPP	Avoiding Direct Heat Loss having hot Steam/Condensate piping Insulated	6	7094	1540000	12.7	217.088
PM-4	Moisture control post size press MF2	3.84	4540	1075000	17.2	236.779
PULP MILL	Reduce Direct Heat Loss from Not having Insulation of Steam/Hot Lines	1.9	2246	540000	14.1	240.384
	Condensate Recovery system for PM-1-4	12.2	14424	3500000	15.2	242.647
CPP	Avoiding Parallel Lines for Interconnecting 21MW LP Hdr to 3MW Hdr	1	1182	300000	15.0	253.739
CPP	Blow Down Flash Steam Recovery	2.6	3074	900000	17.7	292.776
PM-4	To rebuild Steam and condensate system of PM4 check and correct the syphon clearance of identified cylinders	18.9	22346	6600000	19.3	295.358
CPP	Optimum Pipe Routing for MF-II	6.6	7803	3020000	23.2	387.016
PULP MILL	Optimize Steam Pressure in Heater Mixer to avoid Steam Loss	1.3	1537	600000	24.0	390.368
PM-5	Close Hood Revamp with complete automation to optimize the performance and energy.	3.2	3783	1600000	27.9	422.898
PM-3	PM3 Rebuilding Yankee S&C and Hood system steam flow meter correction PM-3 steam system rebuild with thermocompressor	4.36	5155	3400000	14.9	431.788
PM-3	Yankee hood MP steam flash steam recovery using flash vessel and air preheater for hood	2.3	2719			
PM-4	Install steam box	9.6	11350	5100000	16.1	449.329
PM-2	Install steam box	9.45	11173	5100000	15.7	456.462
RDH	Condensate & Flash Steam Recovery from WL/C2 Steam Heaters	3.5	4138	2100000	31.5	507.478
PULP MILL	Digestor Out Liq. Heat Recovery for preheating White Liq. To Digestor Heat Recovery from WBL sent to SRP	7.3	8631	4900000	32.7	567.7265
CPP	Condensate Recovery from Main Line Traps	0.7	828	470000	26.9	567.8920
PM-1	Have Steam box for PM1	6.45	7626	5000000	22.5	655.656
CPP	Online Conductivity Monitoring to avoid Draining of Condensate	0.7	828	630000	34.4	761.217
SRP	Condensate Preheating by Heat Recovery from WBL sent to SRP	6	7094	5700000	48.9	803.507
Coating machine	Install temp. control to coater air heater with steam line aceesories for improvement of steam quality	1.282	1516	1900000	114.0	1253.521

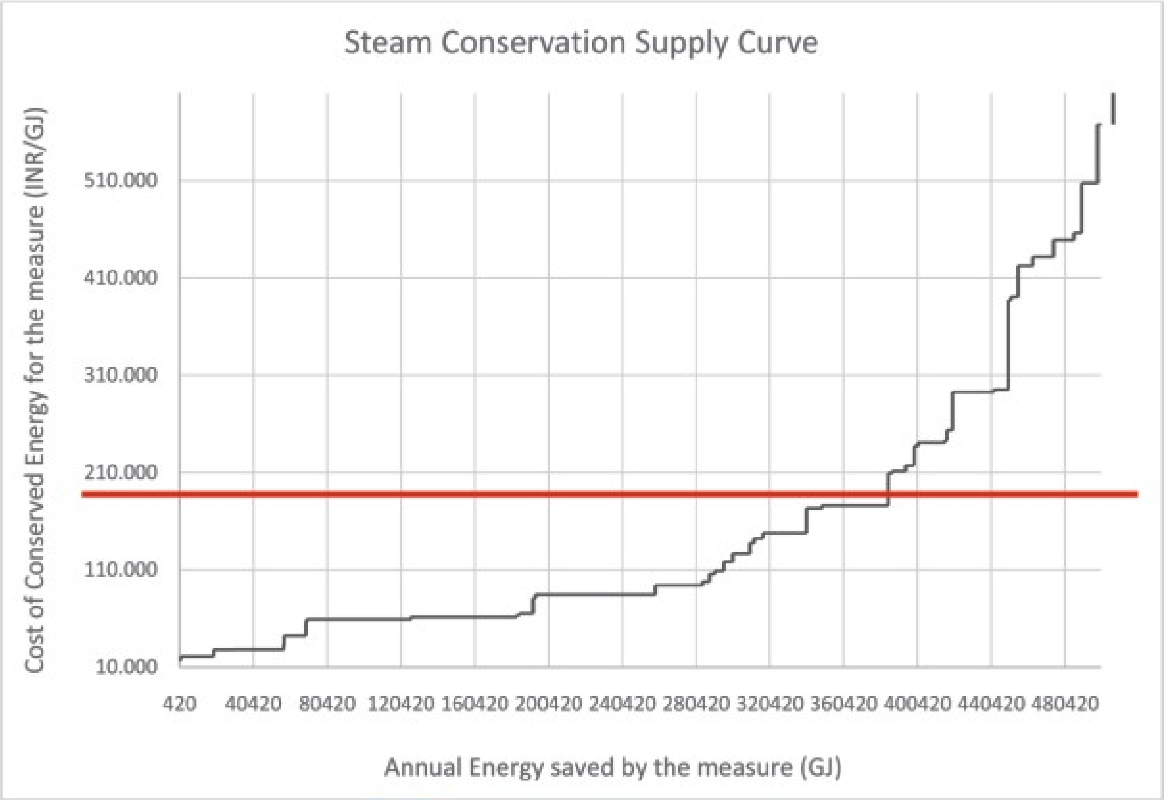

Fig. 2 : SCSC for industry in case study-1

Curve Characteristics:

- Steam conservation supply curve could be a very effective tool in solving the dilemma for selecting & prioritizing the energy conservation method.
- It is to be treated as a investment schedule and after implementation of each measure it is to be updated to know what is Specific steam consumption (SSC)
- Similar to steam same type of conservation supply curves can be plotted for air, electricity and other utilities.

3. Case Study-2- A waste paper based mill

We decided to apply the concept to a waste paper mill, which is relatively simple to understand and to operate so that we can drill down deeper on various points.

We used the same methodology as before by conducting brief audit at the plant and gathering the true parameters about energy and utilities also specific about the processes.

- Industry – Paper Mill (Duplex Board)
- Plant Capacity – 150 TPD paper production
- Production – Plant operates 24 hrs with production ranges between 100 to 150 TPD. An average production is 115 TPD
- Steam generation – Plant is operating by 12 TPH boiler to cater the steam demand of the plant
- Fuel – Lignite and Imported Coal
- Average fuel consumption – 54 TPD
- Annual Fuel Bill – Rs 520 Lacs
- Average Steam Demand – 220 TPD
- Steam to fuel ratio of 3.86

Please find the Findings and recommendations based on it, also we have the cost associated with the modification of the same.

ENCON NO	Title	Saving	Investment	Payback
		Lacs Rs	Lacs Rs	month
1.1	Boiler Efficiency Monitoring and control	28.25	13.8	5.87
1.2	Blow-down optimization and heat recovery			
2.1	Arresting leakages and Attending un-insulations	7.15	4.32	7.25
2.2	Good engineering practices	--	0.61	--
3.1	Thermo-compressor cum cascade based steam and condensate system	152.32	96.96	8.1
3.2	Temperature control valve for air blower	0.218	0.226	12.4
4	Steam Trap management	3.62	2.76	9.15
5	Improvement in Condensate and flash steam recovery	20.91	6.71	3.83

Table 3 : Table of Recommendations for case study-2

Since we know now the measures, energy savings associated with them as well as the cost of modification, we are now in position to plot the SCSC for the same.

We assumed the life span of the measures to be same, discount rate to be same and the annual operation and maintenance cost is also neglected for simplification and thus the installation cost is itself is the annualized cost in this case.

We calculated the annual energy saving by the implementation of the measure by using the steam data available with us (I.e. cost of steam, S:F etc.)

Cost of conserved energy is calculated for each measure and thus is a representive of how a measure is placed in implementation sequence.

Cost of coal is INR 2.8 /kg and thus we can calculate the average cost of energy for today which turns out to be ~ 217 INR/GJ, (on GCV basis).

Thus any measure which has CCE value less than 217 is OK to be implemented and the sequence for those measures lies with increasing order of their CCE and thus the measure with least CCE to be implemented first.

Regarding the measures which has higher CCE values than 217, are not implementable in the current format, either they need to come down on the cost or need the relook on the energy saved by them since the cost of conserved energy for those measures is more than the average cost of energy as of now for the plant, and thus it is costly saving for them.

Also the significance of the curve is that it states the measure which has maximum energy conservation may not be implemented first, neither did one measure which has least cost of modification, also only good payback doesn't guarantee you the same as payback doesn't consider the performance after payback, and thus all these aspects covered in SCSC is giving us more comprehensive approach.

ENCON NO	Title	Annual energy saved	Saving	Investment	Payback	CCE
		GJ	Lacs Rs	Lacs Rs	month	
5	Improvement in Condensate and flash steam recovery	9499	20.91	671000	3.83	71
1.1	Boiler Efficiency Monitoring and control	12975	28.25	1380000	5.87	106
2.1	Arresting leakages and Attending un-insulations	3248	7.15	432000	7.25	133
3.1	Thermo-compressor cum cascade based steam and condensate system	69197	152.32	9696000	8.1	140
4	Steam Trap management	1645	3.62	276000	9.15	168
3.2	Temperature control valve for air blower	99	0.218	22600	12.4	228

Table 4 : CCE and Paybacks

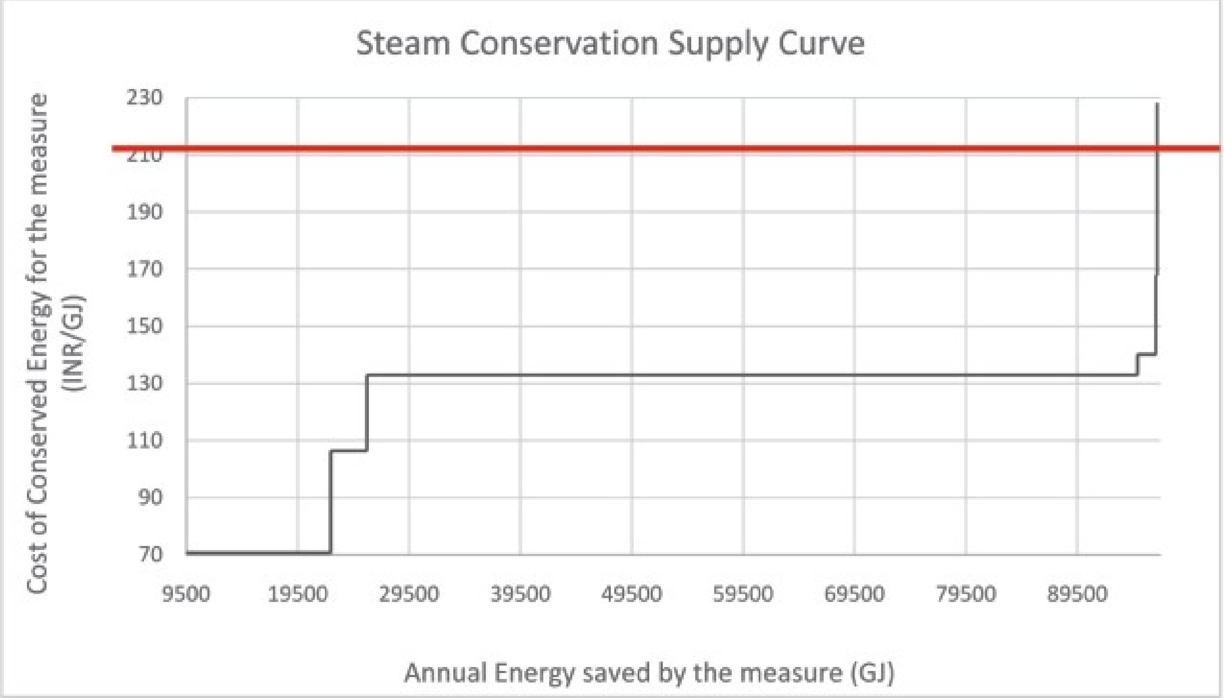

Fig. 3 : SCSC for industry in case study-1

4. Conclusion

- Steam conservation supply curve could be a very effective tool in solving the dilemma for selecting & prioritizing the energy conservation method.
- It is to be treated as a investment schedule and after implementation of each measure it is to be updated to know what is Specific steam consumption (SSC)
- Similar to steam same type of conservation supply curves can be plotted for air, electricity and other utilities.

5. References

2.1 Books

- Energy Efficiency Improvement and CarbonDioxide Emission Reduction in Thai Pulp and Paper Industry - Naphasorn wiriyaphong and Athikom Bangviwat
- Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry-N. Martin, N. Anglani, D. Einstein, M. Khrushch, E. Worrell, and L.K. Price
- Characterizing Emerging Industrial Technologies in Energy Models – John.A

2.2 Web references

I. http://www.energy.go.th/sites/all/files/annual_report2009.pdf

II. https://www.unido.org/fileadmin/import/userfiles/puffk/**paper**.pdf

III. www.iiasa.ac.at/web/home/research/Flagship.../GEA_Chapter8.pdf

6. Further work

- As of now SCSC have shown great potential to be used as investment schedule for the industry.
- It also has the potential at a broad level to be used as a tool in policy making for the industries.
- The best operating industries will set the trends for BAT/BPT.
- There is strong need to put efforts and make the SCSC more practical and closer to the real life scenario so that it becomes the true decision making tool.

7. List of Abbreviations

Acronym	Definition
S:F	Steam to Fuel ratio
SCSC	Steam Conservation Supply Curve
CCE	Cost of conserved Energy

8. List of Figures

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