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2-Heating Surface area Black liquor super concentrator and Waste flue gas heat capturing by Humidifier and dehumidifier

(Fuel feed and Residue management System of recovery Boiler)

Suraj Kumar
Director Technical
Henchmen Engineering Consultant Private Limited

Abstract: *Energy demand has been increasing rapidly from recovery boiler and in an average Indian mill recovery contributes 40%- 50% mill total steam demand. Typically, Black liquor solids generate HP steam 3.0 Mt/Mt BD black liquor solids fired having GCV-3000 kCal/kg and Boiler thermal efficiency 60-65%. Some of integrated Mill upgraded their evaporator plant to produce 72% Black liquor solids concentration which in turn produced HP steam 3.5 Mt/Mt Black liquor solids fired and been successful to bring recovery Boiler steam contribution to 53%. Still almost 30% energy is lost to environment. Achieving higher black liquor solids demand a special design of concentrator / super concentrator, especially when liquor has very high viscosity. Black liquor Solids having GCV-3000 kcal/kg can produce as high as 5.0 Mt HP steam at 100% bone dry solids at 100% thermal efficiency. Many Indonesian/ USA based mills has already achieved 4.0-4.2 Mt/Mt HP steam generation at 110 Bar steam pressure by firing black liquor solids at concentration at 85%. A "2-heating surface area super concentrator" is designed to produce 80-85% of any black liquor at prevailing viscosity and firing the same.*

Flue gas exiting the ESP has temperature 155-1750C along with water vapor that has enough energy and shall be captured. It also gives opportunity to paper industry to capture this energy at the same time after flue gas desulphurization with last stage unbleached pulp, which not only is effective to capture 99% SO2 and H2S. At the same time pH of pulp slurry and flue gas gets neutralized. This flue gas desulphurization by virtue of its high temperature leads to humidification and in turn evaporation. Now due to this Flue gas enthalpy increases and in turn gets condensed on successive finned tube evaporative dehumidifier by transferring its energy. Energy transfer to finned tube dehumidifier is used de-air DM water. All vapor generated in to finned tube evaporative deaerator is used regenerate low TDS water from wastewater by using 3 effect MEE or can be flashed into IV effect.

Following purpose gets solved 1. Higher black liquor solid firing, 2. Deaerator LP steam consumption reduction, 3. Unbleached pulp brightness increase by 2-3 ISO without pulp shrinkage (nominal), 4. Low TDS water from wastewater at very nominal costing, 5. Flue Gas desulphurization, 6. Coal or biomass reduction and many other.

Keywords: *2 heating surface area super concentrator, Humidifier, finned tube Dehumidifier, MEE, FGD (flue gas desulphurization), unbleached pulp brightness.*

1. Introduction

A Kraft Recovery Boiler is considered as main equipment of an integrated paper industry for two specific reasons:

- A recovery Boiler converts firing black liquor into smelt (Molten Salt/ Green liquor).i.e. mixture of sodium carbonate and sodium sulphate. Recovery Boiler upon combustion of firing black liquor (fig-1) produces HP steam, which is source to produce electricity and exhaust steam for heating.
- Integrated Pulp and paper mill regenerate cooking chemicals from Chemical recovery boiler. For this weak black liquor from pulp mill is evaporated in multiple falling film evaporator upto 65% solids at least from 15% solids. Produced HBL is stored in HBL tank as inventory.

Fig-1 (Heavy Black liquor sample)

Higher the Black liquor solids, higher will be the HP steam Generation (fig-2) & table-1.

Impact of Viscosity: Viscosity is the property of any fluid which creates the resistance to flow. While producing higher black liquor is one aspect, storing, extracting from the HBL tank, and firing the same without interruption in recovery boiler is another part. High viscosity of agro black liquor has imposed a limit on the Indian paper mill to attain a maximum of 65% solids concentration. Due to continuous evaporation from the HBL tank the viscosity of HBL increases as temperature drops further.

Why Solids concentration is Important:

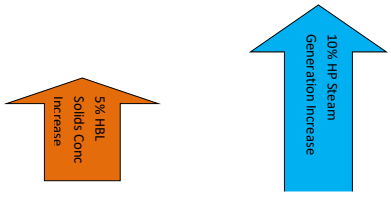

Fig-2 Black Liquor Solids Concentration vs. HP Steam Generation

Typically, an integrated paper mill meets 40% to 45% of the mill's total steam demand from recovery boiler and rest steam demand is fulfilled by CFBC/ FBC/other fossil fuel-based boilers. Typically, a recovery boiler produces High Pressure Steam, 2.8-3.0 Mt/Mt of black liquor solids fired, if solids concentration is 60-65%. Table 1 reveals the characteristics of firing black liquor affecting the performance of recovery boilers.

At very high Solids Concentration (>80%), Kraft recovery boiler has been observed to produce benchmarks steam generation of 4.0 Mt/Mt of solids. Dark Green shaded color in the table is the benchmark solids firing in larger recovery boilers operating internationally with at higher concentrations. Indian Recovery Boiler benchmark is shown by lower shade of green color and is indication of average Performance. Recirculation of such high concentration needs a pressurized tank, high temperature and high pumping requirement.

Black liquor Solids generation from Multiple effects evaporation depends on many factors. i.e.

At Very high Solids Concentration (>80%), Kraft recovery boiler has made benchmarks of steam generation of 4.0 Mt/Mt of solids. Dark Green shaded table is the benchmark of bigger recovery boilers operating internationally with higher concentration. Indian Recovery Boiler benchmark is shown by low shade of green color and is indication of avg Performance. Recirculation of such high concentration needs a pressurized tank, high temperature and high pumping requirement.

Black liquor Solids from Multiple effects evaporation depend on many factors. i.e.

1. Types of raw material mix
2. NPEs in Black liquor
3. Viscosity of Black liquor
4. Causticizing Efficiency
5. Na_2SO_4 to Na_2CO_3 Ratio in weak black liquor.
6. Most importantly Design of super concentrator body.

Most of agro based paper industry has achieve upto 50% black liquor solids from MEEs and 60-65% from cascade evaporators. Cascade utilizes flue gas heat to evaporate moisture from heavy black liquor before firing into Kraft recovery boiler. Generally a cascade evaporator is installed immediately after the boiler bank, where in flue gas of temperature 350-450^{0}C enters in and exit out at temperature 130-155^{0}C. A Cascade evaporator increases firing black liquor solids from 50% to 65% by direct contact evaporation but at the same time, sweep away organic content also along with exit flue gas. Due to direct contact with CO_2 firing black liquor becomes highly viscose. HP steam generation from such recovery Boiler become as low as 2.5 Mt/Mt of solids fired.

From table 1 & Fig-2 it is quite evident that as the solids concentration increases, HP steam generation increases with increase of NCV. GCV of fuel remain the same but net calorific value of the firing liquor increases due to increase of black liquor solids. Therefore, HP steam generation also increases which in turn causes boiler thermal efficiency to increase. But Poor MEEs design and high firing liquor viscosity makes it very difficult to pump the liquor.

At Such a high viscosity frictional loss in recirculation becomes as high as 2000 kJ/kg. Which triggers the need for a new innovative design of super concentrator to combat all these challenges.

It is evident and has been seen that temperature of 175^{0}C or above and retention more than 25 Minutes is enough to break down lignin-hemicellulose polymerization linkages of heavy black liquor resulting in viscosity reduction

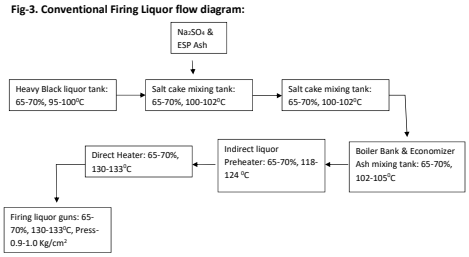

Fig-3. Conventional Firing Liquor flow diagram:

Table 1- – Black liquor firing solids characteristics affecting performance of recovery boilers.

S.Nos	Firing liquor Solids Conc (%)	Firing Liquor Water(%)	Steam Gen Mt/Mt	Gross Calorific Value kCal/Kg	Net Calorific Value kCal/Kg
1.	50	50	2.5	3000	2754
2.	60	40	3.0	3000	2803
3.	65	35	3.15	3000	2828
4.	70	30	3.4	3000	2852
5.	75	25	3.7	3000	2877
6.	80	20	3.9	3000	2901
7.	85	15	**4.1**	3000	2926
8.	90	10	4.5	3000	2950

Thermal efficiency Calculation:

For recovery boiler thermal efficiency, we must know the total enthalpy input and total enthalpy output.

Thermal efficiency= (Enthalpy of HP steam out-Enthalpy of feed water into Economizer)/ (Energy input by firing Black liquor solids)

Typically firing black liquor at temperature of 150-1800C for combustion, is achieved by use of air preheater having extended fins coil type arrangements. Also to fire higher black liquor solids its temperature shall be at least 130^{0}C. Typically boiler feed water temperature remains in the range of 130-135^{0}C from deaerator, depending upon running %MCR. This feed water temperature is maintained by in deaerator by using live LP steam contact with feed water. Usually feed water temperature to deaerator is 65-85^{0}C. A deaerator is always placed close to Kraft recovery boiler.

Total thermal efficiency:

(Total enthalpy HP Steam out- Total enthalpy of deareator feed water in) / (total energy input by black liquor solids + total heat in by hot air)

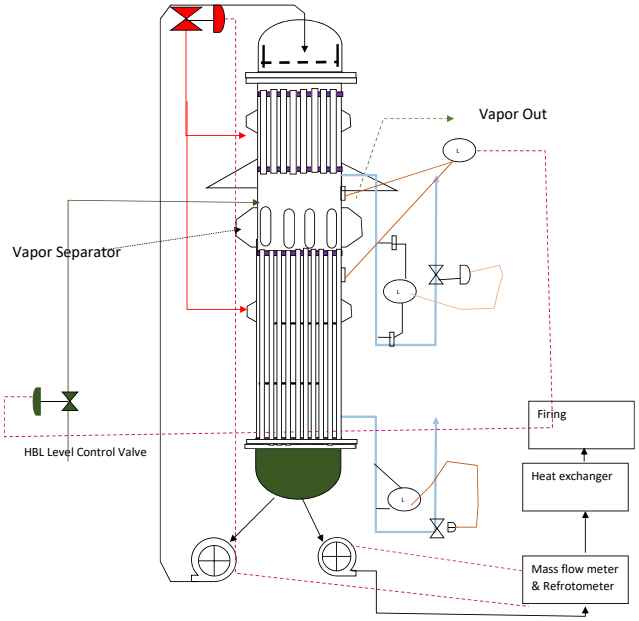

Fig-4: Recovery Boiler residue Management (Flue Heat capturing by Humidification and De humidification)

A. Fuel Feed Management (2-Heating Surface area Black liquor Super concentrator)

HBL from Conical HBL having solids concentration 55-70% is fed to **"2-heating surface area super concentrator"** (Fig-4), its solids concentration is raised till 80% and above at 1750C, utilizing indirect saturated MP steam, Due to aesthetic design friction losses remains nominal which facilitate proper wetting of tubes (an important factor for heat transfer and evaporation).High temperature keeps viscosity under control another important parameter for heat transfer and evaporation. Sump has enough inventories to supply liquor boiler for 2 hrs.

Before firing into recovery boiler its temperature is brought down by indirect cooling utilizing weak black liquor and control instrumentation, this hot weak black liquor is supplied back to MEEs which help in increasing steam economy.

Saturated Vapor, generated from **"2-heating surface heating area super concentrator"** is made to condense on heating surface area of shell and tube heat exchanger, which in turn transfers heat energy to raise WBL temperature.

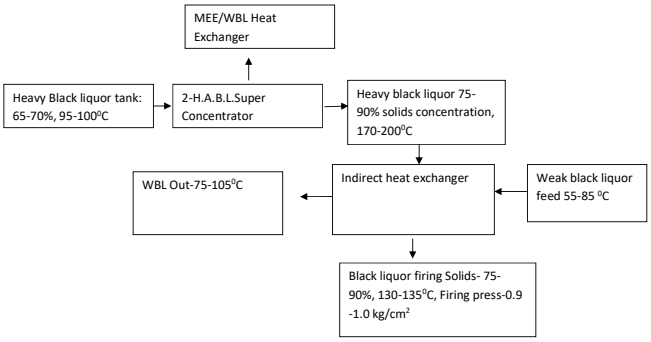

Fig-5 Proposed Heavy Black Liquor Handling

b. Flue Gas (Residue) management

1. Flue gas exiting the recovery usually has temperature 155 to 1650C with thermal efficiency of 60-70%. 30-40% of total energy feed to recovery boiler in India is lost to chimney. And in case of cascade-based recovery boiler, this efficiency will be 50%. Flue gases having H2S and SO2 is scrubbed with last brown stock washer unbleached slurry. High PH of Pulp as well as flue gas gets neutralized as it has excellent capability to scrub down flue gas. CO2 Gas has good capability to increase brightness without much shrinking of pulp when compared with O2/Ozone where from shrinkage more than 2% is observed at many places. Continuous excess slurry and washed water is returned to pulp mill. This stage of gas scrubbing is named as first humidifier. See table 2 & fig-6

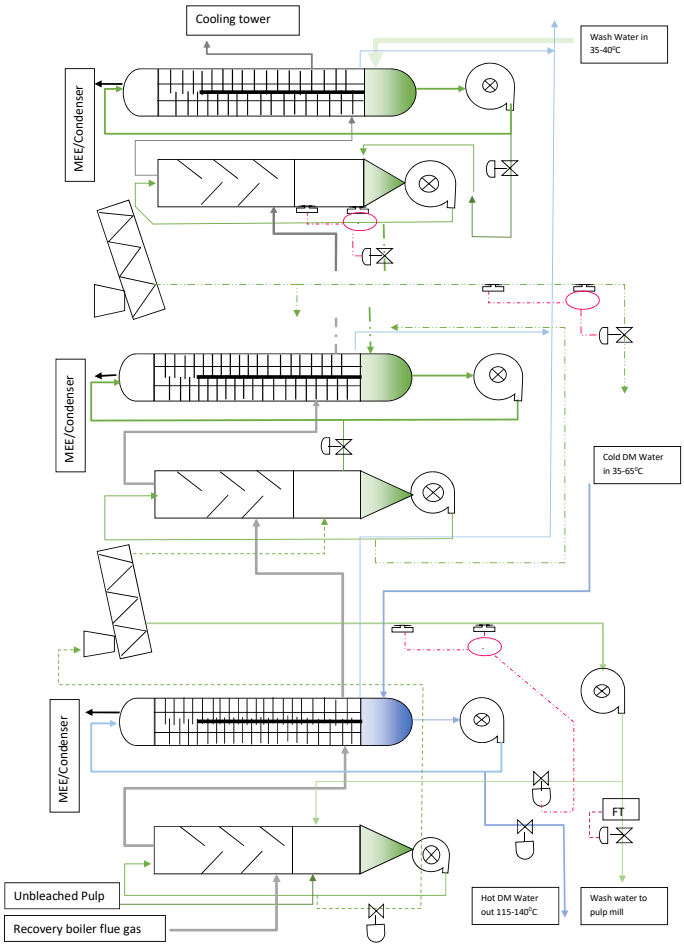

Fig-6 Recovery Boiler residue Management (Flue Heat capturing by Humidification and De humidification)

2. Evaporated water from first humidifier cum scrubber get condenses over dehumidifier-1 and transfers its latent heat to heating surface of finned tube dehumidifier-1. DM water circulating in dehumidier-1 generates low pressure steam which further evaporates water from wastewater via MEE.

3. This process of humidification and dehumidification continues until temperature flue gas reaches to 450C and finally fed to last humidifier called cooling tower. This cooling tower essentially shall be one which takes continuously waste water after filtration. This cooling tower does not reject any water like blow down.

4. Continuous high TDS wastewater from cooling tower is fed to 2nd last humidifier.

5. And from 2nd last humidifier water is fed to predecessor humidifier and so on.

6. In Nutshell boiler flue gases and wastewater remain in counter current action.

Methods & Material

a. HBL of 1000C and 65-75% solids of hard wood species from conical Storage tank is picked by HBL transfer pump as per level transmitter of 2-heating super area super concentrator via control valve, see Fig-4. This HBL concentration can be 50%, in case of agro pulping (Bagasse & wheat straw). A continuous mass flow is extracted from two heating surface area super concentrator via Refractors-meter as per firing requirement which measures the mass flow & running solids concentration. Running solids concentration gives signal to MP steam control valve to control the firing product density. At the same time this transmits signal to VFD of firing pump Motor. A dedicated PLC/DCS controls all the action.

Condensate from the shell is taken out by a proper condensate sealing mechanism, A small Amount Steam vent provision given.

Liquor of concentration of 80-90% solids concentration is drawn from 2 heating surface super concentrator and flows easily due to reduced viscosity at prevailing conditions. Highly concentrated HBL having temperature 175 -185^{0}C is allowed to pass through the HBL cooler to bring down firing temperature to 135^{0}C by indirectly exchanging heat to WBL.

Vapor, generated from the **"2-heating Surface area Super concentrator"** (fig-4) is allowed to condense on heating surface area of another standby "2-heating surface area super concentrator" or Heat Exchanger using WBL and Hot WBL transferred to WBL feed or can be directly used in MEE -1 first Effect.

After a week of use, standby **"2-heating surface area super Concentrator"** is taken in circuit and previously running **"2-heating surface area super concentrator"** is taken in wash mode.

b. Flue gas exiting ESP of temperature 165^{0}C is scrubbed by unbleached pulp slurry to remove SO_2 and H_2S, a slow bleaching takes place due to carbonic acid. Unbleached pulp has excellent quality to scrub 98% SO_2.

Table: 2 Water-Holding Capacity of Flue Gas at Different Temperatures

S.No.	Temperature (^{0}C)	Hot Flue Gas Water holding capacity (T/T)
1.	165	2.6
2.	150	2.5
3.	100	.622
4.	50	.083
5.	30	0.027

At such high prevailing temperature, almost 1.0 Mt water can be evaporated per1 Mt of dry flue gas at the same time can hold as high 2.6 Mt water/ ton air see table-2. Water so generated is made condensed on finned tube dehumidifiers heating surface area .First dehumidifier act as deareator (fig-6).

Dehumidified flue gas now again becomes ready to sweep away more water by evaporation from counter current action of flue gas and water. Process of humidification and dehumidification continue until finally flue gas temperature come down to 450C.

Finally flue is taken away from cooling tower. Low TDS so generated over dehumidifiers are collected and transferred for plant use & pulp washing.

Results and discussion

1. Black liquor firing solids can be increased from 65% to 85% from wood liquor as well as from 50% to 85% of agro based liquor.
2. Specific HP steam generation increased from 3.1 to 3.9 Mt/Mt for wood liquor and 2.4 Mt/Mt to 3.5 Mt/Mt of agro liquor.
3. Specific coal consumption can be reduced 0.25 Mt/Mt Paper.
4. Specific steam economy of evaporator plant increases by 0.25 Mt/Mt
5. Specific steam consumption in chemical recovery plant reduces by 0.5 Mt/MT
6. Now HP steam pressure as high 110 Bar in India can be designed
7. Specific Water consumption reduction is possible with just nominal expenses
8. Net Zero liquid discharge economically present
9. Climate change can be mitigated as only low temperature cold humid flue gases will be discharged
10. Bleaching chemical reduction by 0.5% at least can be achieved.
11. Pulp shrinkage can be avoided by 1.5%.
12. Deareator steam consumption can be reduced by 10% at least.

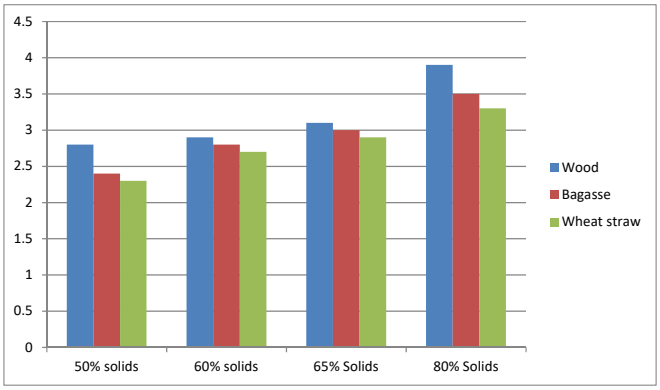

Fig-7 Black liquor Solids Vs HP Steam Generation ratio

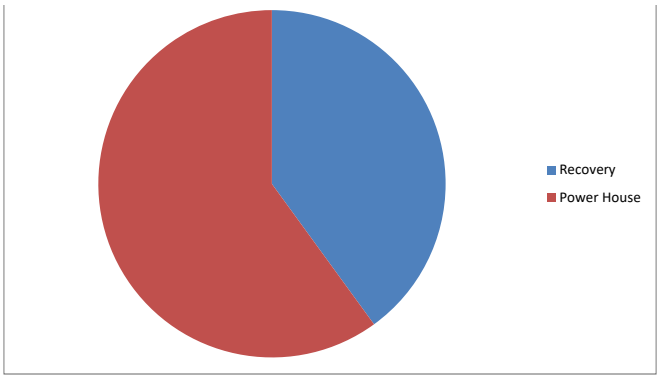

Fig-8 Recovery Boiler Vs Power Boiler contribution before at 65% solids

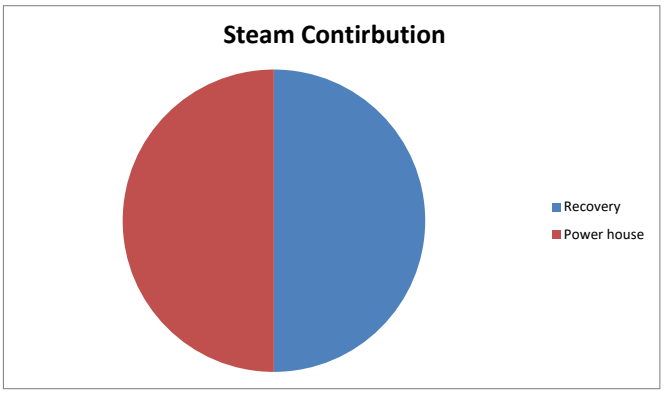

Fig-9 Recovery Boiler Vs Power Boiler contribution after at 75% solids

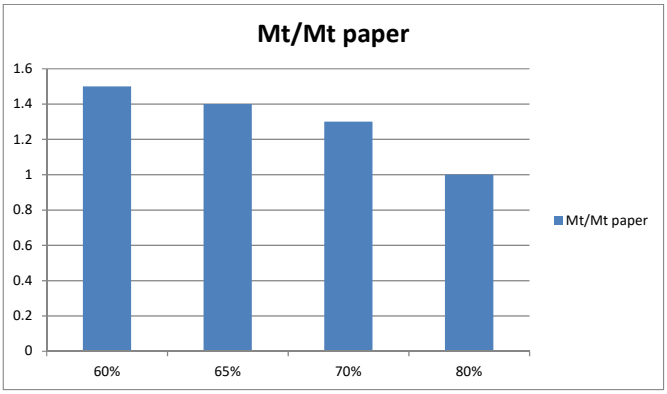

Fig-11 Coal Reduction vs HBL solids Concentration increase

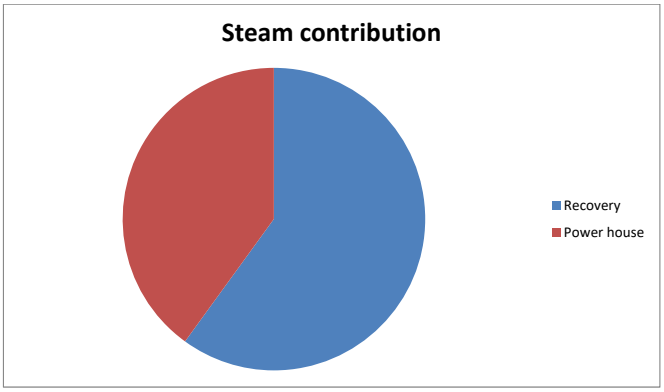

Fig-10 Recovery Boiler Vs Power Boiler contribution after at 80% solids

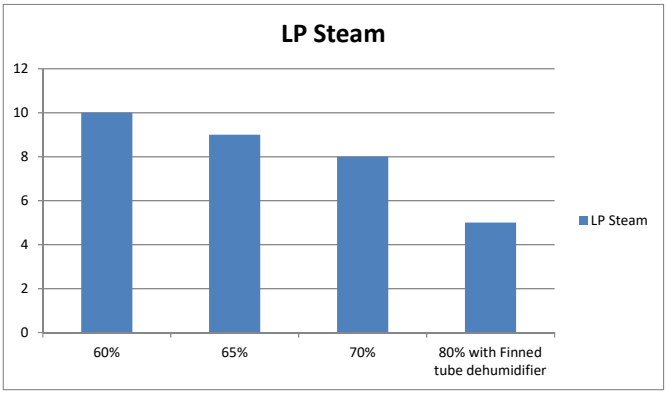

Fig-12 Deareator LP Steam Consumption with 80% Solids finned type dehumidifier

Table -3 (2-Heating Surface area Wood Black liquor Super concentrator)

S.No.	Particulars	UOM	Quantity	Rate (INR)	Value Cr INR
1.	MP Steam Consumption	Mt	70350	1,800	12.6
2.	Power Consumption	KWH	21,00,000	8	1.68
3.	Total Expenses				14.28 CR INR

Table-4 (Tentative benefits and gain of 2-heating surface area super Concentrator for wood black liquor)

S.No.	Particulars	UOM	Quantity	Rate (INR)	Value Cr INR
1.	Main HP Steam generation increase	Mt	1,22,500	2,000	24.5
2.	Coal Reduction	Mt	30,625	6,000	18.4
3.	RB Running days				
4.	Soot blowing steam reduction	Mt	3,500	2,000	0.7
5.	Black liquor evaporator Steam reduction	Mt	17,500	1,800	3.15
6.	Steam Saving for HBL heating as per conventional	Mt	17,500	1,800	3.15
7.	Total Saving				50 CR INR

(Table-5: 2-heating surface area super concentrator Agro Black liquor)

S.No.	Particulars	UOM	Quantity	Rate (INR)	Value Cr INR
1.	MP Steam Consumption	Mt	1,83,750	1,800	33.1
2.	Power Consumption	KWH	21,00,000	8	1.68
3.	Total Expense				34.78 CR INR

Tentative Capital Expenditure

1. **Tentative Capital Expenditure (2-Heating Surface area black liquor super concentrator for wood black liquor)**

Basis: 700 TDS (Black liquor Solids fired per day from 65% solids conc. to 80% conc.)

a. 10 Cr INR including all

b. Operating expenses per Annum (Tentative)

c. Gains/Year

d. ROI: (50-14.28) x100/10=357%

e. Payback Period : 1 Year Maximum

1. Basis: 700 TDS (Black liquor Solids fired per day from 50% solids conc. to 80% conc.)

a. 10 Cr INR including all

b. Operative Expenses

c. Gains/Year

d. ROI: (74.4-34.78) x100/10=396%

e. Payback Period : 1 Year Maximum

2. **Tentative Capital Expenditure (Humidification & dehumidification system to capture waste heat)**

Basis: 700 TDS (1650C to ambient)

a. 20 Cr INR including all

b. Operative Expenses per year

d. ROI: (64.97-15.68) x100/10=357%

f. Payback Period: 1 Year Maximum

Table-6 (Tentative benefits and gain of 2 heating surface area super Concentrator for Agro black liquor)

S.No.	Particulars	UOM	Quantity	Rate (INR)	Value Cr INR
1.	Main HP Steam generation increase	Mt	2,45,000	2,000	49
2.	Coal Reduction	Mt	61,250	6,000	18.4
3.	RB Running days				
4.	Soot blowing steam reduction	Mt	3,500	2,000	0.7
5.	Black liquor evaporator Steam reduction	Mt	17,500	1,800	3.15
6.	Steam Saving for HBL heating as per conventional	Mt	17,500	1,800	3.15
7.	Total Saving				74.4

Table-7: (Tentative operative expenses for Humidification and dehumidification system)

S.No.	Particulars	UOM	Quantity	Rate (INR)	Value Cr INR
1.	Power Consumption	KWH	1,96,00,000	8	15.68
2.	Total Expenses				15.68 CR INR

Table-8: Tentative gains and benefits

S.No.	Particulars	UOM	Quantity	Rate (INR)	Value Cr INR
1.	Low TDS water	Mt	39,20,000	100	39.2
2.	Deareator LP steam saving	Mt	33,600	1,800	6.05
3.	Zero Liquid discharge				
4.	Zero Emission discharge				
5.	Bleaching cost reduction	Mt		500	6.15
6.	Pulp Saving (shrinkages)	Mt	1225	25,000	3.1
7.	ETP Power Saving plus ground water Extraction cost	KWH	84,00,000	8	6.72
8.	ETP Chemical saving	Rs		50,000INR/Day	1.75
9.	Compliance expense				2
10.	Total Saving				64.97

Conclusion:

1. Clear, Integrated Paper Mills can reduce their Coal based energy contribution to 50% if firing black liquor solids reach 75% and at more than 85% this will be just 40% see table no.1 & fig-10, fig-12. In nutshell there will be scope to reduce costs by 4000 Rs/Mt paper
2. Integrated paper industry utilizes 60-75 Kg LP steam for every ton of feed water, Deareator steam can be made almost nil by utilizing flue gas residue management system. If integrated paper mill will have to recycles 10000 Mt/day feed water, this shall save at least 600 Mt/Day LP Steam. See fig-12
3. Almost TDS less water can be produced from Waste water & flue gases interaction at lowest possible cost 50 Rs/M3, which is expected to reduce ground water extraction by 30%. Typically 100 MT/Hr hot flue gas will generate 250 Mt/H of Low TDS water. The Humidification and dehumidification system is applicable to all types of boilers. Lesser moisture in fuel (coal, rice husk and others) makes hot flue gases carry away more water via evaporation, which is recycled back as low TDS water. See table no.2
4. Pulp shrinkage can be reduced by scrubbing RB flue gas with unbleached pulp slurry or IInd last Seal tank water.
5. One of biggest challenges is mixing recovery Boiler steam with CFBC & AFBC boiler due huge pressure differences. Usually, Recovery boilers in India are producing HP Steam at 65 Bar or lesser, Where as power boiler at 90 bar or above. By implementation of "2-heating surface area super concentrator", 110 Bar HP steam from Indian recovery boilers will also be possible, so both Recovery boilers and other fossil fuel fired boilers steam could added in single header before transferring to TG.
6. An integrated mill reduces 1100 Mt CO2 daily if its pulp production capacity is 600 ADT/Day which estimated to be 4, 01,500 Mt/Year.
7. Capex requirement of 2-heating super concentrator for wood black liquor shall be 10 Cr INR one time. Annual operating expenses shall be 14.28 Cr INR. Overall annual benefits shall be 50 Cr INR with 357% annual return on investment assumed 700 TDS wood black liquor solids fired recovery Boiler.
8. Specific Main HP steam generation shall increase from 3.1 Mt/Mt to 3.7 Mt/Mt wood black liquor solids. Table 4, Row no.1.
9. Due to contribution increase of wood liquor recovery boilers, Power house side steam load will reduce by same amount, which means reduction of specific coal by respective amount. Table-4, row no.2.
10. Capex requirement of 2-heating super concentrator for Agro black liquor shall be 10 Cr INR one time. Annual operating expenses shall be 34.78 Cr INR (table-5).Overall annual benefits shall be 74.40 Cr INR (table-6). Annual return on investment assumed 700 TDS Agro black liquor solids fired shall be 396%, as solids increases from 50% to 80%.
11. Specific Main HP steam generation will increase from 2.4 Mt/Mt to 3.7 Mt/Mt Agro black liquor solids Table 6, Row no.1.
12. Due to contribution increase of Agro liquor recovery boiler, Power house side steam load will reduce by same amount, which means reduction of specific coal. Table-6, row no.2.
13. Capex requirement for 700TDS recovery boiler flue gas management (humidification and dehumidification) shall be 20 Cr INR. Annual operating expenses shall be mainly power amounting 8 Cr INR (Table-7). Annual gain and benefits shall be 65 Cr INR (Table-8) and return on investment shall be 357%.
14. Almost all the mill's reject water can be recycled back along with precious salts.
15. Paper industry can safe guard itself from water extraction, discharge as well for emission claims. At the same time this industry can set example for climate change mitigation for other industries.