Specification and Evaluation of Chemical Recovery Boilers

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Introduction

A specification is for identifying a product. The correctness of a specification is very much important in the selection of any equipment. More so, is the case, when the equipment happens to be like a recovery boiler involving huge capital investment and a number of auxiliary equipments. This paper delves the details of specifying the kraft liquor recovery boilers.

It is needless to emphasize the importance of a recovery boiler in the case of pulp and paper mills. Because of the huge investment the installation of a recovery boiler in a pulp/paper mill will be justified only if the plant capacity is considerable. The technological developments and the feed back data from the various units in operation make it possible to economically justify the installation of recovery boiler in mills of capacity above 80 tonnes/day. In Western countries the capacity of the pulp and paper mills have ever been increasing. The highest capacity recovery boiler designed so far is for a 1500 t/day pulp mill.

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"This paper gives some guidelines for the paper industry to precisely specify the requirements of the chemical recovery boiler and helps to choose the one which would give the best performance".

The various factors which influence the design/performance of a recovery boiler are listed below. All these information/data would be required during the initial stages for the design of the boiler.

	UNIT
1. Pulp production	: Tonnes/day
2. Dry solids from multiple effect evaporator	: Tonnes/day
3. Raw materials used	: %
4. Type of digester cook	:
5. Elemental analysis of dry solids	
Carbon	: %
Oxygen	: %
Sodium	: %
Hydrogen	: %
Sulphur	: %
Inerts	. %
Total	: % : 100
6. Higher heating value of dry solids	: Kcal/Kg.
7. Smelt sulphidity	: % TAPPI
8. Smelt reduction	: % TAPPI
9. Weight of make up salt cake	: Tonnes/day
10. Moisture in salt cake	: %
11. Black liquor solids concentration leaving multiple effect evaporator	: %
12. Black liquor temp. in storage tank	: °C
13. Liquor condition—oxidised	: Yes/No
14. Main steam pressure	: Kg/cm²
15. Main steam temperature	: °C
16. Steam temperature control range	: %MCR
17. Feedwater temperature	: °C
18. Ambient air temperature	: °C
19. Gas temperature leaving the unit	: °C
20. Plant elevation above sea level	: Meters
21. Space limitation	:
22. Type of dust collecting equpt. & efficiency	:
23. Provision for burning aux. fuel for load carrying	:

The significance of the above factors and the normal operating values are described below :

Pulp Production

This is to give a feel about the size of the unit to all concerned and could be specified for the bone-dry conditions of pulp

Dry Solids From M.E E.

This is the basic design data for sizing of the boiler. While fixing up the capacity of black liquor solids many factors have to be considered. The main ones are listed below :

1. The range of chemical requirement/ton of pulp for different species of raw materials anticipated.
2. Standby/load sharing, when an already existing boiler goes on a shut down.
3. Future possibilities of plant expansion that is a reasonable increase of the capacity.

The normal expected dry solids/tonne of unbleached pulp is 1.8 to 2.0 tonnes. Such a reasonable ratio could be used in fixing the total capacity of the boiler. Finalising a very high dry solids capacity than anticipated, would require auxiliary fuel stabilisation for a wider range of the part load operating condition. On the other hand specifying a smaller capacity with an intention to overload the boiler is also not correct. The technological developments have led almost all the recovery boiler manufacturers to tailor make the boiler depending upon the specific requirements. So, the present design of recovery boiler should not be compared with very old units in operation which were all designed with a lot of conservatism. Such designs cannot exist in the present day competitive market. In such process boilers by taking care of a few points, it is possible to design a boiler for overloading upto 30%. However, it is very much essential that the percentage of overloading desired be clearly brought out in the specification.

Raw materials used

The various raw materials used for pulp/paper making are hard woods, softwoods, bagasse, straw, grass etc. In many cases a varying proportion of the above materials are also used. This information would help the boiler designer to finalise the optimum concentration for firing and to choose proper handling equipment. Also with certain species of wood the smelting temperature is higher than normal. Hence, the idea about the raw materials would help the designer to some extent, to take care of such problems in the design.

Normally the heating value of hard-wood liquor is less than that of soft wood liquor. However, the recovery unit operation is not affected so long as the solids content to the furnace is kept sufficiently high. It shall be noted, that the same size recovery unit will match higher hardwood tonnage than soft-wood because less liquor is required for hardwood cooking.

Type of digester cook

There are a number of processes of cooking. However, this paper confines to the widely practised kraft (sulphate) process.

Elemental analysis of dry solids

The elemental analysis of black liquor is an extension of the ultimate analysis with the composition of the ash determined. This analysis of the black liquor varies widely with the different raw materials used. A fairly accurate analysis of the liquor would enable the determination of the quantities and compositions of the various material streams leaving the recovery unit so that the thermal efficiency of the boiler could be guaranteed. A typical analysis of black liquor dry solids is as follows :

		%
Carbon	:	40.0
Oxygen	:	34.0
Sodium	:	18.0
Hydrogen	:	3.5
Sulphur	:	3.5
Inerts	:	1.0
		100.0

Higher heating value of dry solids

The higher heating value (HHV) is the heat liberated in the formation of the black liquor products of combustion in the bomb calorimeter. This value varies from 3100 to 4000 Kcal/Kg and depends on the composition of the liquor, raw materials used and the ratio of the organic to the inorganic content. While furnishing this value for design, it is better to give an average value with the variation anticipated. It shall be noted that if the value is very low that is below 3300 kcal/kg. auxilliary fuel support will be required over a wider range of the part load operating condition. It will be very good from the furnace combustion conditions point of view if the actual HHV lies in the range of 3500 to 4000 kcal/Kg. However indicating a very high value than the actual has some drawbacks. The reduction efficiency of the unit will come down and also upset the combustion stability in the furnace. It should be clearly understood that indicating a very high HHV value alone will not increase the feasibility of over-loading the furnace.

Smelt sulphidity

The smelt sulphidity defined as the ratio of Na_2S to $Na_2S + Na_2CO_3$, for kraft process, varies from 20% to 28% depending upon the cooking conditions. Many mills operate at 25% sulphidity level. Choosing a higher value is conducive to the furnace water-wall corrosion.

Smelt reduction

The smelt reduction, defined as the ratio of Na_2S to $Na_2S + Na_2SO_4$, is a parameter chosen to control the inert chemieal recycling. This value has a bearing on the hearth bed temperature and depends on the boiler design. There is a feeling that good reduction cannot be obtained with hard-wood liquor. But there are mills using hardwood and operating at a reduction value in the high nineties. The operating values range from 90 to 96% with 92% in majority of the cases.

Weight of make up salt cake

This depends on the sulphidity required and the sulphur/sodium content in the liquor. Normally the salt cake requirement is around 4% by weight of dry solids. However, this ratio goes upto even 8% in some cases, given the liquor analysis, the composition of salt cake and the sulphidity required, the boiler designer would be in a position to predict the make up salt cake requirement.

Black liquor concentration leaving multiple effect evaporator :

This depends on the multiple effect evaporators envisaged. However, many variables influence the performance of these effects with the result, maintaining a particular solids concentration at all loads may not be possible. For the design of the boiler, it would be better to have the normal anticipated value, which lies between 45 to 50%. If the value slightly comes down from that indicated for the boiler design, in many cases, the boilers are provided with an economiser and a gas bypass arrangement which would allow the boiler to take up the lower concentration.

If the unit has to be odour free and the viscosity of liquor reasonable enabling the multiple effect evaporators to concentrate the liquor to a higher value, then a large economiser unit is considered. In such cases the liquor concentration leaving MEE would have to be in the range of 60 to 63% solids. The concentration, on the lower side of the above range would be safely acceptable only when the liquor has a HHV above 3500 kcal/Kg.

Where the raw material used is bagasse etc., there is a limitation in the concentration which could be achieved in the MEE. This is because of the silica content posing scaling problems and the high viscosity making the transfer of liquor from one effect to the other, increasingly difficult with the increasing concentration. In such cases the concentration leaving MEE would be between 30 to 40% only.

Black liquor temperature in storage tank.

This is the average temperature of strong black liquor in the storage tank. This depends on the storage capacity of the tank and the temperature of liquor leaving the MEE. This is normally in the range of 90 to 100°C This value is required for working out the heat balance to predict steam generation and to size the direct contact evaporator.

Liquor oxidation

The kraft mill is one of the sources for many odourous gases such as hydrogen sulphide (H_2S), alkylmercaptans (RSH)., alkyl sulphides (RSR), alkyl disulphides (RSSR), sulfur dioxide (SO_2), sulfur trioxide (SO_3) and others. The first four of the above are often referred to as total reduced sulfur (TRS) compounds. The recovery boiler quite significantly contributes to this odour level. The recovery boiler emission of TRS is predominently H_2S and the remaining alkyl groups are mostly methyl. The recovery unit emission is mainly from two areas, that is the gas contact evaporator and the recovery unit furnace.

In a conventional unit the strong black liquor of 45 to 50% solids is concentrated by direct contact with hot flue gas at a temperature of 300 to 350°C using a cascade evaporator or a cyclone evaporator. Under such conditions H_2S is formed by hydrolysis, as indicated below :

$$Na_2S + 2H_2O \rightarrow 2NaOH + H_2S$$

Also, the CO_2 in the flue gas reacts significantly to form H_2S, as follows :

$$Na_2S + CO_2 + H_2O \rightarrow Na_2CO_3 + H_2S$$

Test data from various mills indicate odour concentration of 70 to 1500 ppm from direct contact evaporator.

The odourous gas emission from the above source can be minimised by elimination of direct contact of the flue gas with unoxidised black liquor. The oxidisation is a treatment given to the black liquor before it enters the direct contact evaporator which converts the Na_2S in the black liquor to a more stable thiosulphite.

$$2Na_2S + SO_2 + H_2O \rightarrow Na_2S_2O_3 + 2NaOH$$

A number of mills have oxidation systems operating at 99% + efficiency. Black liquor oxidisation enables the use of all the historically well proven recovery boiler components. However, the performance of the unit is highly sensitive to the conversion of Na_2S without reversal of the reaction, as well as, trouble free operation of the oxidiser without foaming problems. The oxidizer performance requirement to have the minimum TRS emission is the liquor to the evaporator should have less than 0.2 grams/litre of Na_2S, pH value of 12 or higher and sodium to sulfur ratio higher than 4.

Main steam pressure and temperature

The chemical recovery boiler is the major source of steam pulp mill. In any process using steam, the lowest total energy cost will be obtained only when mechanical power is extracted and the remaining heat is used for process. The large demand of process steam at low/moderate energy levels in the pulp and paper mills provides good oppurtunity to obtain inexpensive mechanical power by generation of steam at high energy levels and extracting the resultant excess energy using steam turbines. However, the selection of steam parameters depends on the mill conditions such as the existing steam cycle and the total energy concept. The nominal steam conditions used throughout the paper industry for power generation is given in the table I.

Table I
Chemical Recovery Unit Steam Conditions.

Pressure Kg/Cm²	Temperature °C
30	300–400
45	400
70	400–450
90	480

The pressure and temperature conditions can only be established after a complete steam and power balance for the plant has been made.

There are a few conditions which limit the steam parameters for the recovery unit.

1. The maximum boiler design pressure is limited to 105 Kg/cm². This is because of the additional safety hazards of the furnace waterwall tubes, requiring extraordinary maintenance. This fire side corrosion of furnace tubes will be present in units having operating pressures of 65 Kg/cm² or higher.
2. The maximum superheated steam temperature is normally limited to about 480°C, with around 500°C in a few extraordinary cases. This is because the fouling tenndency of slag increases very rapidly with increasing temperature. In small capacity boilers, it may so happen that the boiler could not be designed for higher steam temperatures due to lack of space for accomodating the large superheater surface area required.

Quite a few mills, to start with, operate at a lower capacity during the initial years and after some time increase the plant capacity. In such cases, during the initial-period, the plant may find it economical to generate staturated steam for process alone, without investing on the turbine etc. for captive power generation. There may be a few high capacity paper mills coming up with project expansion. Because of the considerable size of the plant they may find it economical to have a higher level of steam conditions than the existing one. But due to various constraints they may not be able to straight away install a higher pressure cycle for power generation. In the above cases, it is possible to design the boiler to operate at lower steam parameters for some years and then with some minimum modification and down time covert the boiler to operate at higher parameters. It is beyond the scope of this paper to go into the detailed aspects of such conversion.

Steam temperature control range

The recovery boilers in pulp mills are normally operated at a constant load which is the 100% MCR. Under normal circumstances, during charging conditions of the digester, the boilers may be overloaded but otherwise the boilers would be operating at 100% MCR to generate power. Even if there is any fluctuation in the steam demand for the turbine, this is usually taken care of by the other power boilers in the mill, burning conventional fuels. From the above, it is obvious that the chances of continued operation of recovery units at part load, burning black liquor, is very remote. Normally, part load conditions would be encountered only during the regular startup and shut downs.

In order to efficiently use the turbine over a wide range of load, it is better to generate steam at a costant temperature. Normally, steam temperature control is provided over the range of 70 to 100% MCR. The range specified has direct implication on the superheater size, material and the internal fouling of superheater due to the spray water. A few engineers, fancy the specification for a recovery boiler asking for temperature control over a range of 50 to 100%. This may be because of their familiarity with the oil/gas fired VU60 or D type industrial boilers, or they feel that below the control range, the superheater steam/metal temperatures will shoot up resulting in tube failures. It has to be clearly understood that any boiler manufacturer, when specifying a range of steam temperature control means that the average predicted steam temperature over the remaining uncontrolled range will be below the controlled temperature. With radiant platen superheaters, the superheater materials may have to be selected for the worst condition that is at part load. Again, this part load metal temperature increase, in the radiant platen superheatersof recovery units should not be imagined to be in the same proportion as in the case of other boilers. because, this effect is dependent upon so many variables, like the type of fuel, and type of ash and the furnace configuration etc.

Feedwater temperature

This value is required for predicting the total steam generated from the recovery unit. There are very many published matters on the boiler feed water qualities for pulp mills. It is beyond the scope of this paper to go into the feedwater treatment process and operating controls. However, it should be noted, that in conventional fuel fired industrial boilers, the feed water not be demineralised if the boiler operating pressure is lower than 60 Kg/Kgm^2g (approx). However in the case of a recovery unit, a tube failure in the furnace leads to such a severe explosion due to smelt water reaction that all the boilers irrespective of the operating pressure should use demineralised and deaerated feedwater. The deaerators normally used operate at a pressure level slightly above atmospheric and result in a minimum feedwater temperature of 105°C. This temperature is acceptable in the case of conventional units. However, if the recovery unit is one of the odour free type, designed with a large economiser as the last heat recovery surface, the feedwater temperature should be a minimum of 140°C. Otherwise there is a risk of economiser corrosion.

Ambient air temperature

The value refered to, is the average ambient temperature which unless specified exactly, most of the boiler manufacturer would take as 26.7°C.

In the case of recovery units all the air required for combustion is heated to the desired temperature using steam airheater, Hence, an increase or decrease of the ambient temperature affects heat input of the steam airheater and the effect of this variation to the heat balance is not that significant. However it is better to check the sizing of FD fan with reference to the highest possible ambient temperture.

Gas temperature leaving the recovery unit

If there had been no constraints, everyones wish is to have the lowest temperature possible. The factors which influence the flue gas exist temperature are ;

1. The low temperature corrosion due to sulphur trioxide in the flue gas.
2. Corrosion due to the presence of sodium chloride in the flue gas.
3. The economy of providing additional heat recovery surface versus the heat absorbed from the low temperature gas.

In steam generating units, the low temperature corrosion normally occurs in the final heat recovery equipment and surfaces further down stream in the gas path. This is due to the condensation of SO_3 on metal surfaces when the metal temperatures are below the dew point. The factors influencing the formation of SO_3 when burning a fuel containing high sulfur are as follows :

1. Flame temperature
2. Residence time
3. Excess air
4. Fuel impurities and additives.

By maintaining all metal temperatures above the acid dew point, low temperature corrosion could be eliminated. It is important to know the acid dew point corresponding to the SO_3 concentration in the flue gas. As the SO_3 concentration is reduced, the acid dew point temperature is decreased resulting in higher efficiency without low temperature corrosion. However, in the case of recovery units, the high moisture content of the gas increases the magnitude of low temperature corrosion.

The presence of sodium chloride in the black liquor will cause some difficulties in the performance of the recovery unit. One of them being the corrosion of electrostatic precipitator collecting electrodes.

Considering all the above factors, it would be obvious that the boiler designer is the best person to decide this value. In many cases, the paper mill engineers are also well informed and they would be in a position to decide. Whoever, decides, the value has to be the same and shall be as follows:

(a) For blackliquor concentration of 45 to 50% in the conventional units, the optimum temperature would be 160°C.

(b) For large economiser units the optimum temperature is in the range of 200°C.

Plant elevation

It is an universal practice to find the volume of air and flue gas at standard barometric pressure. However, when sizing the fans and ducts they have to be sized for the actual volume to predict which the plant elevation should be known.

Space limitation

In a few existing mills, the space envisaged for the new recovery boiler may be fixed due to various conditions. In such cases, it is better to send these information in the form of a drawing, so that, the boiler designer could try to have an equipment layout which is best suited for this condition.

Type of dust collecting equipment and efficiency

The efficiency of dust collecting equipment is reqnired to make a perfect material balance. There are only two types of dust collecting equipments, suitable for recovery units, i.e. the Electrostatic Precipitator and the venturi scrubber. Of the two, the electrostatic precipitator is capable of giving very high dust collection efficiencies (99%+) and are best suited against air pollution codes. The venturi scrubber gives dust collection efficiencies in the range of 90 to 94%. This equipment is capable of operation at a lower flue gas temperature than the minimum temperature suitable for the electrostatic precipitator.

This means an increased thermal efficiency, of course, at the cost of increased emission of odourous gases. The selection of the equipment has to be based on techno-economical analysis comparing the capital cost, running cost, efficiency and pollution. The present trend of the many mills is to favour the electrostatic precipitator with a collection efficiency of 98% for the conventional unit and 99% for the large economizer unit.

Provision for burning auxiliary fuel for load carrying

Almost all the recovery boiler manufacturers could offer a boiler, with a marginal increase in the cost, capable of generating 100% MCR steam flow as in the case with black liquor, using oil or gas. If the customer is very much concerned about the initial capital investment he could ask the boiler manufacturers to design the ducts etc. suitable for burning auxiliary fuel to generate any amount upto 100% steam flow but not to include the load carrying burners and their controls. Should the purchaser find the necessity to generate steam in the recovery unit using auxiliary fuel, these burners and controls could be added to the system even at a later date.

Auxiliary power

The boiler designer would also like to know the various auxiliary power supplies available in the mill, such as, auxiliary steam conditions, compressed/instrument air conditions and electrical power supply. This would help him to propose the correct equipment in the initial offer itself. Many mills normally have the following auxiliary power supplies.

Steam	: 10.5 Kg/cm^2 saturated 3Kg/cm^2 saturated
Compressed air	: 5Kg/cm^2
Instrument air	: 3.5Kg/cm^2
Electrical	: 230V, 1 phase; 50Hz 415/440 V, 3 phase; 50Hz

If the auxiliary steam is avaialble at two different conditions as mentioned above, then the boiler designer will try to use the lower pressure steam for most of the steam airheaters (almost 75%) with only 25% of the heating elements, using the high pressure auxiliary steam. This way some better utilisation of energy could be effected. Similarly if the plant is already having a 11OV, single phase, 50Hz electrical supply then the boiler manufacturer may like to use this for his standardised instruments and controls.

All the above points so far explained is to help the paper mill engineers, to clearly bring out their requirements which in turn would help the boiler manufacturer to propose a best suited design. Much more important job is to evaluate the offers received from the various boiler manufacturers so that the contract could be finalised on the best suited offer. The evaluation of the various offers have to be carefully done considering the following points.

1. The total cost of the offer

In fact this would be the only factor in finalising the offers, had all the offers received, been equally good from the technical aspects and the extent of supply of various equipments. However, in practice no two offers can be identical in all the aspects and hence in all the cases a technological evaluation is invariably required. As everyone would be aware, it is not just the face value of an offer which is to be taken for evaluation.

2. Design of Boiler

There are only a few, basically different designs of recovery boilers marketted by various manufacturers of their licencees. Almost all the designs have well proven in operation. But there are always a few plus and minus points with every design. Also each design may be best suited for certain conditions.A better idea about these equipments could be obtained by having called on by the Sales Engineers of the respective companies.

A few points which the author feels, would be advantageous for the operation are as follows:

a) The refractory lining provided at the hearth bed gets worn out calling for frequent maintenance shut downs. In some cases, it may lead to smelt corrosion of furnace wall tubes. However, this problem could be overcome, if the design is envisaging a decanting type of hearth.

b) The recovery units handle dust laden gases. The dust particles are very much compared to the flue gas from burning conventional fuels and also have a sticky nature at certain conditions, resulting in fouling of the heat transfer surfaces, mainly the superheater surface. So, soot blowing is an important operation in the case of recovery units. However, the different types of commercial soot blowers have some limitation in cleaning. This is because the effective soot blowing depends to a greater extent on the configuration of surface and nature of the soot or deposit. It has been found that the platen type surfaces with tangent tube construction, has the maximum non-fouling tendency. Many of the boiler manufacturers offer such surfaces for the superheater and also the furnace screens. The furnace screens in the case of recovery unit provides an additional advantage. These screen surfaces to some extent have a control over the nature of deposits on the superheater. It is better to have atleast 500 mm deep screen so that the direct radiation from the furnace could be effectively filtered, to protect the superheater.

3. **Extent of equipment supply**

Not in all the cases a boiler manufacturer includes in his offer all the equipment required to make the system complete. This is due to various reasons, which in many cases could be monetarily advantageous to the Purchaser. But such a proposition leaves with him some responsibility to procure the correct equipment and match this equipment with the others in the system. However, during tender evaluation, it is very much essential to find out the extent of equipment included in every offer.

4. **Performance conditions (predicted and guaranteed)**

Normally no boiler manufacturer deviates the performance requirements indicated in the tender specification unless, it is to the advantage of the Purchaser. However, it is better to make sure by going through the predicted performance indicated. In some cases there could be some difference in the thermal efficiency.

Suitable credits have to be given for these variations when the offers are compared. The normal practice is to guarantee the following in the case of recovery units.

1. steam flow
2. steam pressure
3. steam temperature
4. black liquor rating
5. reduction efficiency.

Many manufacturers would be agreeable to guarantee of additional parameters. However, these have to be mutually agreed to between the Purchaser and the manufacturer.

5. **Auxiliary Power Consumption**

Another important aspect to be compared during tender evaluation is the auxiliary steam, electrical power and compressed air required by the various equipments for continued performance. These have a major influence in the overall plant efficiency. It is possbile to generate a higher steam flow with certain auxiliary equipment, for example, steam airheater, consuming more quantity of auxiliary steam. Also there are certain other equipments, which have a small capital cost and may require a very high electrical power consumption, during operation. In such cases unless proper capitalisation factors are accounted for, during the finalisation of the supplier, the plant may be losing considerably in the long run.

These are only a few major points which have been highlighted. However there are so many other factors which also influence the finalisation of a contract. It is beyond the scope of this paper to cover those aspects.

Conclusion

Specifying a recovery boiler is not a simple thing for which a definite specification could be written so that bidders prices are the final criteria and the award could be made to the lowest bidder, expecting quality products. Many factors which cannot be readily defined in a specification contribute to good boiler design.

Preparing a tight physical specification which spells out items such as furnace configuration, furnace heat loadinngs, intermediate gas temperatures, concentration of liquor to be sprayed into the furnace, number of soot blowers, drum sizes etc. cannot ensure the desired result. It would be obvious that a physical specification alone will not ensure the unit reliability and availability. A more realistic approach is to give the performance specification and let the boiler manufacturer offer a well proven design that will economically meet the performance requirements. Forcing the boiler supplier to change his standard design/manufacturing techniques, does not necessarily increase the reliability-but it does increase the cost.

The evaluation of the offers received is another important job which must be accomplished by someone with the knowledge of these boilers, who can review the design features of the various offers and select the one with the maximum reliability and availability.

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