Finnish Recovery Boiler Committee SkyRec

Utilization of Pyrolysis Gases from the Recovery Boiler Preliminary studies

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Introduction

There is an interest to replace fossil fuels in pulp mills. One theoretical possibility is to extract gases from the lower part of the recovery boiler. These gases potentially have a heating value high enough to be used in, e.g. the lime kiln. In addition, gas extraction can also potentially increase the recovery boiler capacity.

This work was carried out to study possibilities for extracting gases from the lower part of a recovery boiler, to be used in the lime kiln. The extracted amount should be such that it would cover the need of a lime kiln with 30 MW thermal input, typical at a 500 000 – 550 000 ADt pulp mill. The study consisted of the following tasks:

- equilibrium calculations of gas composition as function of air factor at 900°C;
- ii) analysis of gas composition in the lower furnace in two recovery boilers using existing CFD results; and
- iii) estimation of the minimum and maximum dust content of the lower furnace gas.

It should be noted that the original project title refers to "Pyrolysis Gases". However, this work was not restricted to only considering the gases released from black liquor during the pyrolysis stage of combustion. Instead, the "gas" that is referred to in this report is the flue gas from black liquor combustion at various air factors.

Equilibrium calculations

The fuel analysis of a typical Finnish liquor was used as basis for the equilibrium calculations. For the calculations the liquor was assumed to consist of two parts: (i) smelt and (ii) moisture + combustibles. Only the fraction consisting of moisture and combustibles was considered in the equilibrium calculations.

The elements in the liquor dry solids were first assumed to form smelt consisting of Na₂S and Na₂CO₃. By difference the carbon and oxygen not bound in smelt were considered combustible. In addition, all hydrogen in liquor dry solids was assumed combustible. Thus, the input to the calculations concerning mass consisted of the amounts of black liquor moisture and combustible carbon, hydrogen, and oxygen. The black liquor heating value, excluding heat from sulfide oxidation, was used in calculation of the adiabatic flame temperature. The gas phase chemical species CH_4 , CO, CO_2 , H_2 , H_2O , O_2 , and N_2 and solid carbon (soot) were included in the calculations.

Two different equilibrium calculations of black liquor combustion with varying air factor were carried out:

- (i) considering the adiabatic flame temperature, which varies with the air factor and
- (ii) at a fixed temperature of 900°C.

Figure 1 presents the shares of gas phase species and solid carbon at the adiabatic temperature (T_{ad}) as function of air factor. The adiabatic temperature increases with the air factor, reaching 900°C at an air factor of about 0.45. The adiabatic temperature shown in Figure 1 was calculated assuming that black liquor and combustion air have an initial temperature of 25°C. Assuming an initial temperature of 200°C resulted in the adiabatic temperature reaching 900°C at an air factor of about 0.4.

Due to heat transfer inside the recovery furnace, it is motivated to assume that a gas, regardless of its adiabatic temperature, could have a temperature of 900°C when extracted from the recovery boiler.

Figure 2 presents the equilibrium gas composition as function of air factor at 900°C. The region of air factors which would result in adiabatic temperatures below 900°C is indicated. In addition, the region of zero heating value gas due to overstoichiometric combustion is indicated. Methane and solid carbon are not stable at 900°C and are therefore not included in Figure 2.



Figure 1. Equilibrium calculations: Shares of gas phase species and solid carbon at adiabatic temperature (T_{ad}) as function of air factor.



Figure 2. Equilibrium calculations: Gas composition as function of air factor at 900°C. Region of air factors which would result in adiabatic temperatures below 900°C also indicated, as well as the region of zero heating value gas due to overstoichiometric combustion.

Figure 3 presents the heating value of the gas as function of air factor corresponding to the composition presented in Figure 2 (chemical equilibrium at 900°C). The amount of gas to be extracted to cover 30 MW is indicated for two cases. The sensible enthalpy is excluded in calculation of the amount of gas needed. In addition to the heating value, the gas would contain some energy because of its temperature. Taking zero degrees Celsius as the reference temperature, in the case of 10kg/s extracted, the gas would contain 30 MW as heating value and about 9 MW as sensible enthalpy; the sensible enthalpy being 30% compared to the heating value of the gas. In the case of 3 kg/s extracted, there would be about 3 MW sensible enthalpy, which is 10% compared to the heating value.





CFD simulations

Results from existing CFD simulations of two recovery furnaces were analyzed for the local gas composition in the lower furnace. The recovery boilers A and B have rated capacities of 3150 tds/d and 4450 tds/d, respectively.

Figure 4 presents the gas heating value in recovery furnaces A and B. The heating value of the gas is highest in those locations which have a high fuel-to-air ratio (low air factor).

In Furnace A, black liquor droplets hitting the back wall create a zone near the back wall between secondary and tertiary air levels with a gas heating value of about 3 MJ/kg. The location could be suitable for gas extraction.

In Furnace B, the spray is directed to a greater extent towards the char bed, resulting in the high-heating-value zones located above the bed. For each furnace (A and B), the simulated char bed as a whole was close to a balanced situation, i.e., the overall char bed burning rate closely matched the overall input rate of combustible matter. However, in Furnace B the high-heating-value zones above the char bed are associated with local carbon accumulation in the char bed, indicating bed growth in these locations. It is uncertain if Furnace B could be operated continuously in this manner.



Figure 4. Gas heating values in the lower furnace of two recovery boilers, as predicted by CFD simulations. Heating values shown above the char bed, close to the furnace back wall, and on the front-to-back center plane of the furnace.

The CFD simulations do not take into consideration gas extraction from the furnace, which could potentially affect the gas composition inside the recovery furnace. In addition, modifications to the operation or design of the recovery furnace could possibly be made to increase the gas extraction potential. However, these considerations are outside the scope of this work.

Dust content

Estimates for the minimum and maximum dust content of the lower furnace gas are based on the dust content in the ESP being typically about 20 g/Nm^{3 (1,2)}. Taking into consideration the share of combustion air introduced at different air levels, the dust load inside the recovery furnace can be estimated as presented in Figure 5; with the range of dust load being 20-80 g/Nm³.

¹ Tarja Tamminen, Continuous Monitoring of Dust Concentration and Composition in Kraft Recovery Boilers, Licentiate Thesis, Report 01-07, Combustion and Materials Chemistry Åbo Akademi University, 2007.

² Adams (ed), Kraft Recovery Boilers, TAPPI PRESS, 1997.

Release of dust-forming elements has been observed to occur mainly (>90%) during in-flight combustion of black liquor droplets¹. In Figure 5, the estimated dust load between the primary and secondary air levels (80 g/Nm³) assumes that all dust formation has taken place in that zone. However, it is perhaps more realistic to estimate that the lower furnace dust content would be in the range 30-80 g/Nm³, given by the estimated dust contents in the two zones below the tertiary air level (see Figure 5).



Figure 5. Estimated dust load in different locations of the recovery furnace due to split of combustion air.

Summary and conclusions

Preliminary studies were carried out to investigate the potential for extracting gases from the lower furnace of the recovery boiler to be used in the lime kiln.

The following conclusions are made:

- Extraction of gas with a heating value of 3 MJ/kg could be feasible with normal recovery boiler operation.
- Existence of suitable location for gas extraction depends on recovery boiler operation. A high fuel-to-air ratio, for example, close to a furnace wall would be desirable.
- Dust load is estimated to be in the range 30-80 g/Nm³.
- Factors not included in this study, but which could be relevant to consider include: modifications to recovery boiler operation to maximize gas heating value; gas extraction; and removal of dust from the extracted gas.