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CARBON CAPTURE AND STORAGE PROGRAM

WP2 Task 2.1.3

STATUS REPORT
FUNDING PERIOD 2

Technical pre-feasibility study of South-West Finland´s district heating system´s multifuel CHP plant based on oxy-fuel fired circulating fluidized bed (CFB) boiler

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1 GENERAL

1.1 Background information and project objective

This project is a part of CCS-program by Cleen Oy. The aim is to develop an optimized CHP plant with oxy-fuel CFB based carbon capture concept for plants using large quantities of biomass. In addition, the aim is to utilize oxygen combustion data Fortum has earlier collected in collaboration with BHK / Hitachi. As part of this project also appropriate tools for plant concept design and cost assessment were studied.

The project result will be a feasibility study of a oxy-CFB CHP plant using varying mixtures of different fuels, a preliminary cost estimation and a proposal for a business concept. Also a proposal for the next phase of study and research topics will be presented.

2 DESIGN BASIS

2.1 Model scope and design data

The whole idea of the feasibility study was to use the new CHP-plant being planned to the north-western part of Finland (Naantali) as the base of the design.

In the first phase during the first quarter of the FP2 the base for the plant design was selected from the EIA-report from 2011 (case 1). The planned CHP-plant was a 450 MW_{th} CFB-boiler producing 300 MW's of process steam and district heat. Steam turbine plant was based on a condensing type turbine with several extractions for preheaters, district heaters and process steam. Main design concept and production values are presented in figure 1.

In the second phase during the last quarter of the FP2 the plant concept was changed to correspond the environmental permit applied by Turun Seudun Maakaasu ja Energiantuotanto (TSME) (case 2). CFB boiler size was reduced to 440 MW_{th} and steam turbine design was changed to back pressure type to meet the environmental permit. Main design concept and production values are presented in figure 2.

2.2 Boiler and flue gas treatment

The boiler was chosen to be a Foster Wheeler's so-called "oxyready" concept (Flexi-Burn), which made both air and oxygen combustion concept evaluation possible.

For the first case (case 1) fuel mixture was selected according to discussions with Fortum Heat. The mixture contains 30% coal and 70% of forest residues. More detailed information of the fuel used is presented in Appendix 1.

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For the second case (case 2) fuel ratio was changed to meet the TSME's environmental permit application. It consisted 57% coal, 35% of biofuels, 8% of peat and small amounts of refinery gas.

At this stage of the project the boiler was modeled as a simplified balance model according to DIN 1942 standard. Some assumptions had to be made during the modeling e.g. the flue gas temperature after the economizer. At a later stage of the project these assumptions, as well as air/oxygen and flue gas design will be modeled with detailed data provided by the boiler manufacturer Foster Wheeler.

The knowledge from the Fortum's previous Meri-Pori oxy-fuel project (FINNCAP) was used in designing of the oxygen feeding and flue gas recirculation system. The main principle for modeling the circulating flue gas was to prevent water vapor enriching in the flue gas and keeping the flue gas temperature about 20°C above dew point in the circulating gas and air / oxygen ducts. As a result it was necessary to remove most of the water from the flue gas with flue gas condenser. The energy from the flue gas condenser was used in the district heating system.

When flue gas humidity is close to the dew point, the flue gas dust becomes sticky, causing interference to the function of the electrostatic precipitator and the corrosion of the whole flue gas duct. The flue gas temperature before the electrostatic precipitator should remain about 10 - 15 ° C above the dew point of the gas (the water and acid dew point).

As the flue gas is saturated (at dew point) after the flue gas condenser it has to be reheated before the electrostatic precipitator and the circulating gas line. Hot flue gas before the flue gas condenser will be used to reheat the flue gas after the condenser to about 20 ° C above dew point.

Since one of the fuels is coal that contains sulphur also the acid dew point and the removal of sulfur had to be considered. Traditionally, the Flexi-Burn boilers desulphurization (SO_2) is done with limestone injection to the boiler. SO_3 of the flue gases condense to the dust particles at about 90 °C which will be removed in the electrostatic precipitator.

The recirculation gas will be taken after the electrostatic precipitator before the desulphurization plant. The amount of the circulating gas will be about 2/3 of the total gas volume. The oxygen is fed to the recirculating gas before the air preheaters so that the total oxygen content after the mixing is about 28 vol-%. There should be no significant risk of ignition involved if proper mixing of oxygen to the recirculation flow is taken care of.

The oxygen is preheated up to 80 to 90 °C with flue gases going to CPU and then mixed with recirculation gas. After mixing, the oxygen-flue gas mixture is preheated normally with the air preheaters and then supplied to the boiler as primary and secondary air.

2.3 Turbine and preheating

In the first case turbine was modeled as condensing type to maximize the electricity production. Live and reheat steam parameters were selected based on the boiler design. Turbine was equipped with extractions to condensate and feed water preheaters and process steam (20 bar ja 5 bar) consumers. The preheaters and the district heaters were also modeled.

The condensing mode operation was estimated based on the production data of the existing Naantali power plant and the used capacity for the modeling was agreed with the steering group of this project.

Steam turbine efficiencies were estimated based on the knowledge from the latest turbine projects.

In the second case steam turbine was changed to correspond the turbine described in the environmental permit of the TSME project.

As the turbine in the environmental permit was back pressure type, condenser and some of the low pressure preheaters were removed from the model. Live steam and reheat steam parameters were taken directly from the environmental permit, as well as the high pressure preheaters design. The low pressure preheaters were estimated on the basis of the structure of the turbine because these were not described in detail in the environmental permit.

Steam consumers were kept unchanged but district heating exchangers were redesigned to meet the environmental permit. In order to make the plant more flexible on minimum load an auxiliary cooler was added in parallel to district heat consumer.

2.4 Process steam and district heating

The modeled plant includes 20 bar and 5 bar process steam consumers (maximum 50 MW) and district heat production. Heat production amounts and consistency curves were collected from the actual production information of Naantali power plant.

2.5 Air separation and CO2 purification unit

Air separation unit (ASU)

ASU unit was modeled by using SOLVO power plant simulator ASU-component. Component consists compressor stages, coolers, molecular sieve and a distillation column. By implementing ASU component to model it is possible to approximate the electricity and cooling consumptions of this unit with different loads of the oxy-fuel plant.

The process values of ASU have been adapted from the previous studies. The purity of the end product, oxygen, was chosen to be at 95 vol-% as in the previous studies. At this stage of the project only the ASU's electricity consumption has been taken into account and the utilization of the warmed coolant flows (heat recovery) will be discussed later during the project.

CO_2 purification unit (CPU)

At this stage of the project CPU's electricity consumption has been approximated by using a constant energy for purifying certain amount of CO_2. This constant has been adopted from a Foster Wheeler study [1].

Modeling CPU in SOLVO is at the moment in development in a separate project which is done in co-operation with Aalto university. Later on the CPU can be modeled in more detail in SOLVO simulator. Further details such as CO_2's purity after CPU will be determined later on.

3 FINDINGS AND FURTHER ACTIONS

Findings

A simulation model was made from the design basis described in the previous chapter. The simulations were made with Fortum's power plant simulator SOLVO.

The plant performance (case 2) was calculated with nominal load in air combustion mode with the following main results: Plant's net electricity output was approximately 130 MW's while the net power to heat ratio of the plant was approximately 0.8. Net efficiency of the plant was on the level of 91 %.

When the simulation model was changed to oxygen combustion the change was dramatic. The net electricity of the plant decreased to the level of 70 MW's due to the high auxiliary power consumption of ASU and CPU. The consumption of these components together was approximately 53 MW's. The change in the district heat production was contrary to electricity's. This was because a flue gas condenser was taken into use in order to reduce the moisture in the recirculation gas. The effect on DH production was massive (increased by 55 MW) much because the flue gas recirculation cumulates the moisture in the flue gases. The net efficiency of the plant was similar to air combustion but the power to heat ratio of the plant was on the level of 0.4.

A rough approximation was made on the production economics to the simulated plant in air and in oxygen combustion. The prices of fuels, electricity, steam and district heat were approximated and no investment costs were taken into account. Under the assumptions that all the extra district heat could be utilized and there would be no CO_2 emissions from the oxygen combustion production-wise the plants would be equally economical when **the price of the CO_2 emissions would be on the level of 10 €/t_{CO2}.**

Further actions

There are still open questions which should be clarified during the next financial period. Boiler should be modeled in more detail including the heat surface modeling. The effects of oxygen purity and temperature before the boiler should be analyzed and the optimum solutions selected.

The design of the flue gas condenser should involve an analysis of the reasonable size, operation with air and oxy-modes and with different fuels and loads. During summer at minimum loads condenser cooling may need sea water instead of district heat water due to the low district heat demand. It could also be worth of analyzing the possibility of using some of the flue gas condenser's heat to fuel drying.

It should also be clarified what are the main differences in air and oxy-modes in process values, construction, operation and safety aspects.

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Air separation unit (ASU) is very energy consuming unit and options to reduce the used energy should be analyzed roughly. Could it be possible to use steam compressors and how much the O_2-purity affects the energy consumption and in part to the whole process?

Also ASU and CPU cooling energy should be recovered and integrated to the process if possible. With the back pressure plant this low temperature energy is more difficult to recover to the process than with the condensing plant.

Finally case 2 will be changed to a condensing plant to figure out the effects to the process and the prize of the condensing electricity with different fuels in air and oxy-modes.

REFERENCES

1. Selzer, A., Fan, Z., Hack, H., "Oxyfuel Coal Combustion Power Plant System Optimization"

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APPENDIX1: Properties of the fuels used in simulations

	Case 1: Biofuel 70 %, Coal 30 %		Case 2: Coal 57 %, Biofuel 35 %, Peat 8 %		
(w-%, dry)	Biofuel	Coal	Coal	Biofuel	Peat
C:	51,70	70,57	70,57	51,70	55,00
H	5,80	4,79	4,79	5,80	5,50
N	0,40	2,00	2,00	0,40	1,70
S	0,02	0,45	0,45	0,02	0,20
O	40,10	9,19	9,19	40,10	32,60
Ash	2,00	13,00	13,00	2,00	5,00
Water	50,0	11,4	11,4	50,0	50,0
LHV (kJ/kg), dry	19400	28240	28240	19400	20800

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Figure 1 Basic flow diagram of the case 2