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Date: 7.6.2011
Subscriber: Finnish recovery boiler committee

FURNACE TUBE TEST PROBE

The aim of this test was to expose selected materials to recovery boiler furnace conditions for longer period than 1000 hours that was used in previous tests so that the average material temperature (on furnace side surfaces) is 440°C ± 10°C. The total test period was now 2720 hours. Materials tested in this test were 3R12 (304L), San 67, carbon steel and HN52 ("N").

The test was started by installing the test probe in place on 2nd of February 2011 at noon. Set value for system pressure was set at 9,4 bar(a). The test began when pressure exceeded 8,0 bar(a) at 1:26 pm. The saturation temperature of heat transfer oil exceeded then 370°C according to thermocouple readings (and was about 20°C more than water saturation temperature at 170 bar pressure).

The test was completed on 6th of June 2011 at 8:48 am when the probe had been exposed to boiler furnace conditions for 2720 hours. During the whole 2720 hour test period the system pressure stayed above 8 bar(a) 2154 hours.

The calculated average temperature on the surface of the top test piece (3R12) was 435°C and 442°C on the surface of the lowest test piece ("N"). The total exposure time was 2720 hours of which the pressure stayed above 8 bar(a) 2154 hours, i.e. 79 % of the time.

As the estimated surface temperatures in all test pieces were reasonable close to the target value of 440°C for a significant portion of the test duration and there were no uncontrolled excursion of material temperatures, the test was carried out successfully.

Instrumentation of the test device

The test probe was equipped with four thermocouples, two of which installed vertically and horizontally in the middle of the top (3R12) and the lowest ("N") test pieces. Other two thermocouples were installed inside the tip, one measuring the cooling oil temperature and the other one inside surface temperature. The set value for system pressure was selected on the basis of the thermocouple readings and the data from previous tests. The pressure was adjusted with a cooling fan regulated by PI controller. When

the pressure was set at 9,4 bar(a) the upper thermocouple inside the test pieces gave readings around 420 °C and the lower one temperatures around 425 °C.

The probe was also equipped with two electric heating elements to make sure that the system pressure would not drop too low when the tip of the probe is sprayed by black liquor (the probe was installed in an empty liquor gun opening, i.e. close to operating liquor guns). The electric heating elements were automatically turned on/off when temperature of the test device dropped below/increased above the set point. The set point was selected so that the system pressure would remain above 5 bar(a) (with cooling oil saturation temperature more than 345°C) all the time the probe is installed.

Inner side surface temperature, cooling oil temperature and system pressure during the test

In figure 1 are shown the temperature on the inner side surface, cooling oil saturation temperature and system pressure between 4th of February and 10th of Mars.

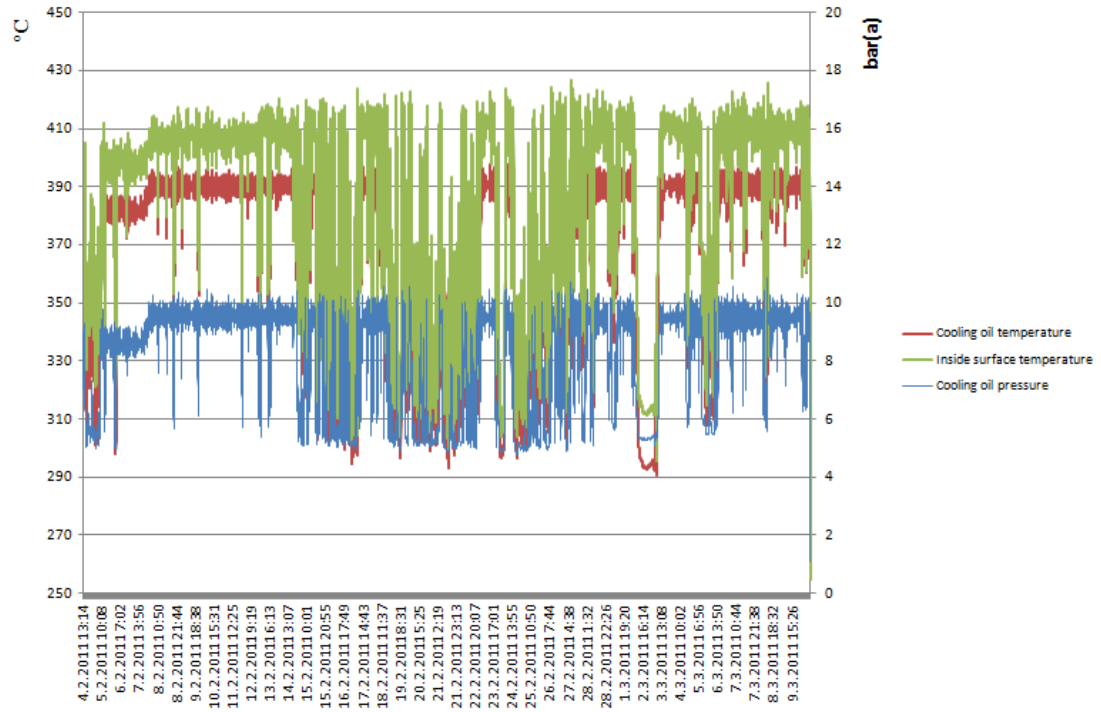

Figure 1. Inner side surface temperature, cooling oil saturation temperature and system pressure 4.2 – 10.3.2011.

During the first 814 hours of the test (4.2 – 10.3.2011) the black liquor guns were positioned some of the time in a manner that the tip got sprayed by black liquor and the heat flux wasn't strong enough to keep the cooling oil pressure constant. That can be seen in figure 1 as heavy fluctuation in cooling oil pressure and temperature.

In figure 2 are shown the temperatures in the middle of the top and the lowest test pieces 4.2 – 10.3.2011.

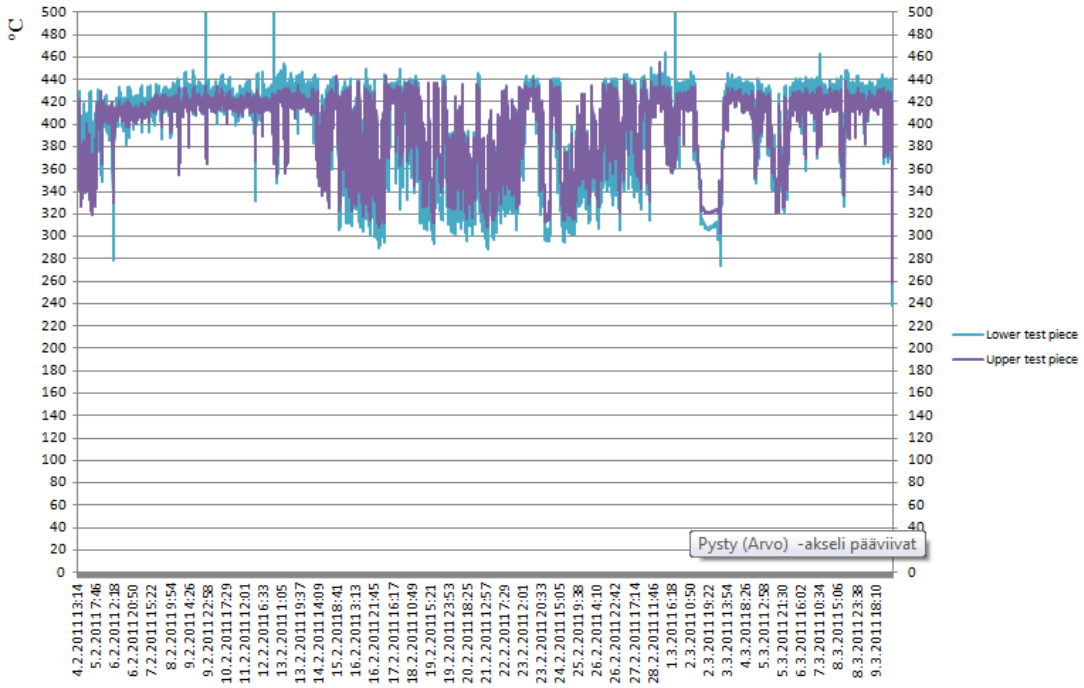

Figure 2. Temperatures in the middle of the top and the lowest test pieces 4.2 – 10.3.2011.

On 10th of Mars there was discovered a small leak in the test probe cooling oil system and the probe had to be drawn out of the liquor gun opening and cooled down for repairing the leak. The test probe was back in operation on next day.

In figure 3 are shown the temperature on the inner side surface, cooling oil saturation temperature and system pressure between 11th and 31th of Mars.

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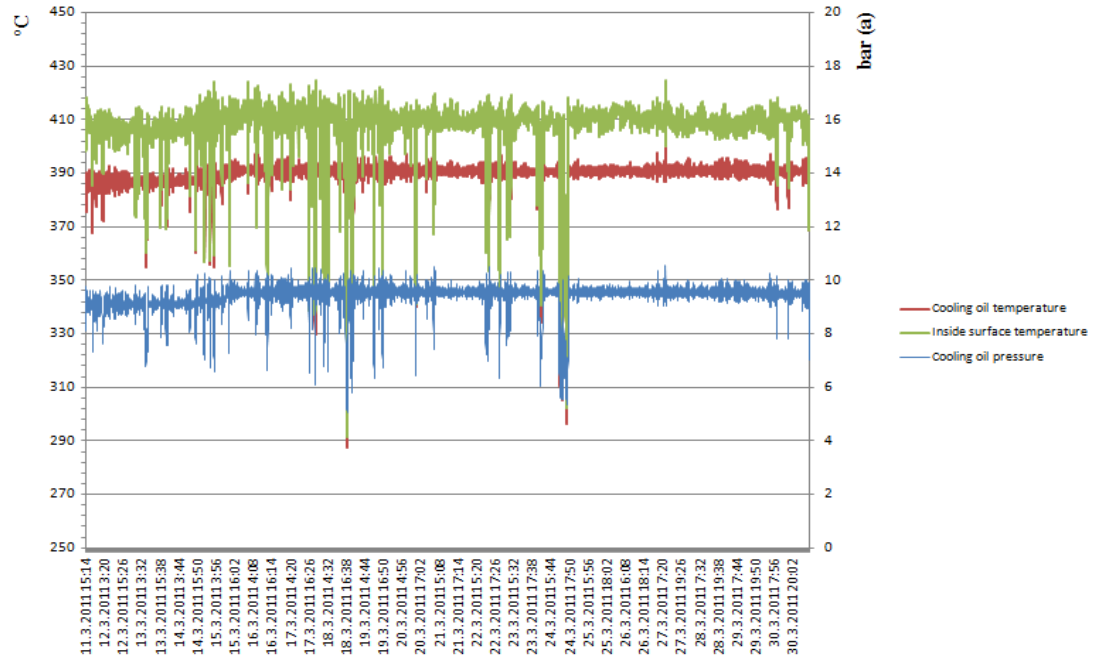

Figure 3. Inner side surface temperature, cooling oil saturation temperature and system pressure 11 – 31.3.2011.

Both thermocouples installed inside the test pieces broke down after installing the probe back on liquor gun opening after repairing the leak.

On 31th of Mars there was discovered again a small leak in the test probe cooling oil system and the probe had to be drawn out of the liquor gun opening and cooled down for repairing the leak. The test probe was back in operation on 4th of April.

In figure 4 are shown the temperature on the inner side surface, cooling oil saturation temperature and system pressure between 4th of April and 6th of June.

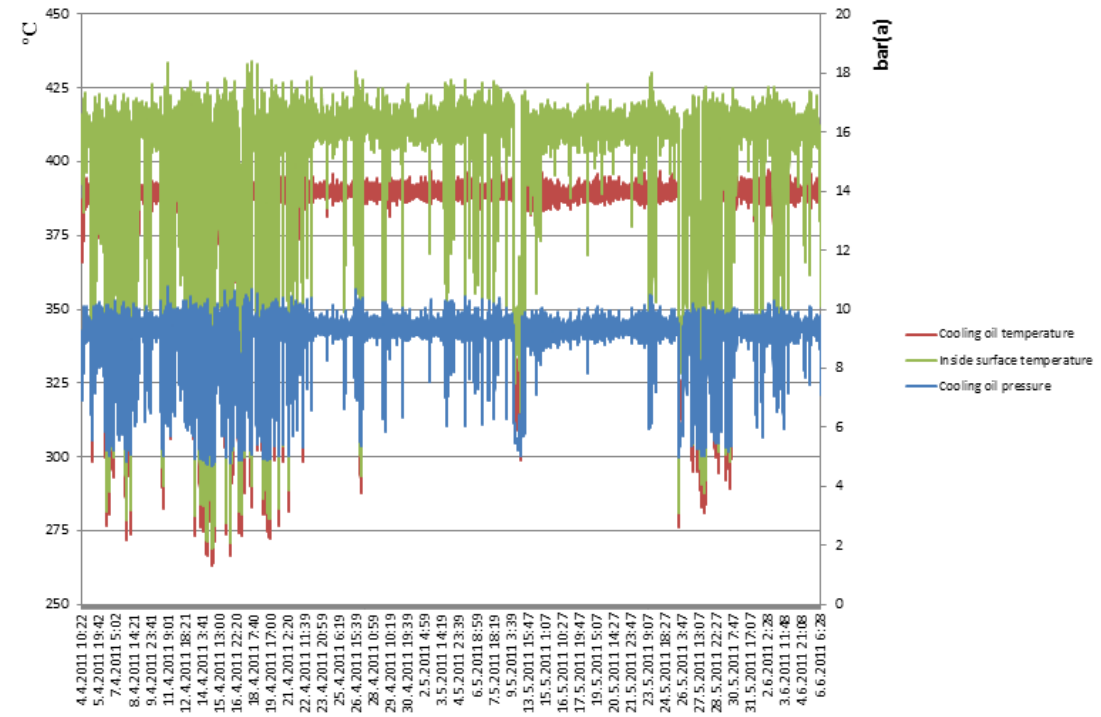

Figure 4. Inner side surface temperature, cooling oil saturation temperature and system pressure 4.4 – 6.6.2011.

During the whole 2720 hour test period the system pressure stayed above 8 bar(a) 2154 hours.

Material temperatures

Temperatures on test piece furnace side surfaces can be calculated by using average heat fluxes across the test pieces that can be calculated from the measured inner side surface temperature and the temperatures in the middle of the test pieces. When the thermocouples placed in the middle of the top and the lowest test pieces were still working (4.2 – 10.3.2011) and gave temperature readings between 400 – 445 °C, the measured temperature difference between the top test piece and probe inner side surface was 11,0 °C on average. At that time the average temperature on the probe inner side surface was 407,8 °C, i.e. the average temperature in the middle of the lowest test piece was 418,8 °C. The temperature difference for the lowest test piece and the inner side surface was accordingly 17,0 °C, i.e. the average temperature in the middle of the lowest test piece was 424,8 °C.

Heat transfer coefficient for 3R12 material (top test piece) at 400 °C is 22 W/m°C, 45,3 W/m°C for carbon steel at 400 °C and cladding thicknesses 1,65 mm for 3R12 material and 5,41 mm for carbon steel. Heat transfer coefficient for "N" material (lowest test piece) 400 °C is 18,5 W/m°C and material thickness 3,65 mm.

Average heat flux across the top test piece can now be calculated to be 142 kW/m^2 and 173 kW/m^2 across the lowest test piece. With these average heat fluxes the average surface temperature on the top test piece furnace side surface is 435 °C and 442 °C on the lowest test piece surface.

In figure 5 are illustrated the temperature distributions in the middle of the top and the lowest test pieces during 4.2 – 10.3.2011, when the thermo-couples were still working properly and the cooling oil pressure was close to set value (> 8 bar(a)).

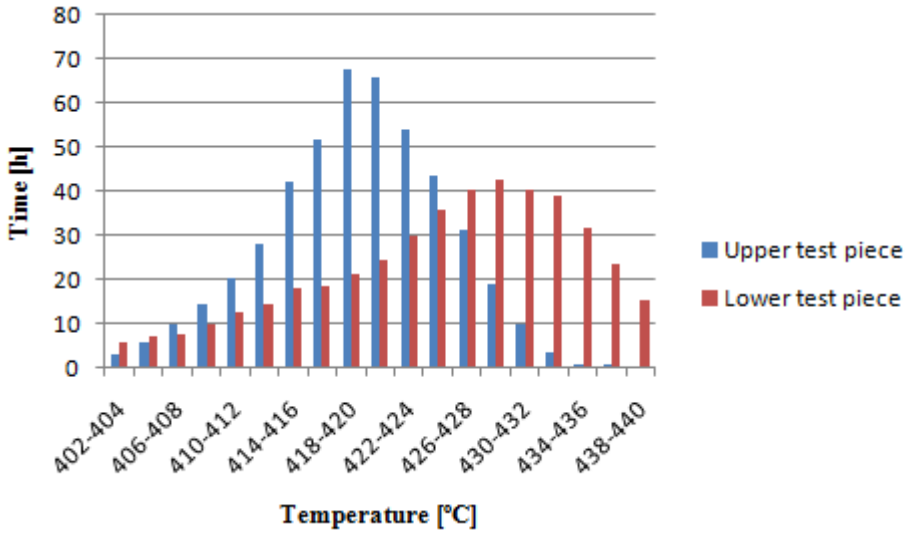

Figure 5. Temperature distributions in the middle of the top and the lowest test pieces 4.2 – 10.3.2011 when the cooling oil pressure was close to set value (> 8 bar(a)).

Summary

The calculated average temperature on the surface of the top test piece (3R12) was 435°C and 442°C on the surface of the lowest test piece ("N"). The total exposure time was 2720 hours of which the pressure stayed above 8 bar(a) 2154 hours, i.e. 79 % of the time.

The temperatures in other two test pieces were not measured, but there is no reason to believe that they would have been markedly different from those of the upper test piece.

As the estimated surface temperatures in all test pieces were reasonable close to the target value of 440°C for a significant portion of the test duration and there were no uncontrolled excursion of material temperatures, the test was carried out successfully.