MATERIAL ASPECTS OF A 700°C - POWER PLANT

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1. Introduction

An effective way to reduce CO_2-emissions and protect our resources is to increase the efficiency of coal fired power plants. The application of CCS (Carbon Capture Storage) - Technologies as a technology to achieve near zero emissions leads to an efficiency reduction of 8 -12 % points. For the oxyfuel process for example the efficiency drop is caused by the additional power demand for air separation and compression of CO_2. This needs to be at least partly compensated by an increase of the efficiency of the power plant integrated in to a future CCS-concept. One possibility for efficiency increase is the operation of power plants with higher steam parameters.

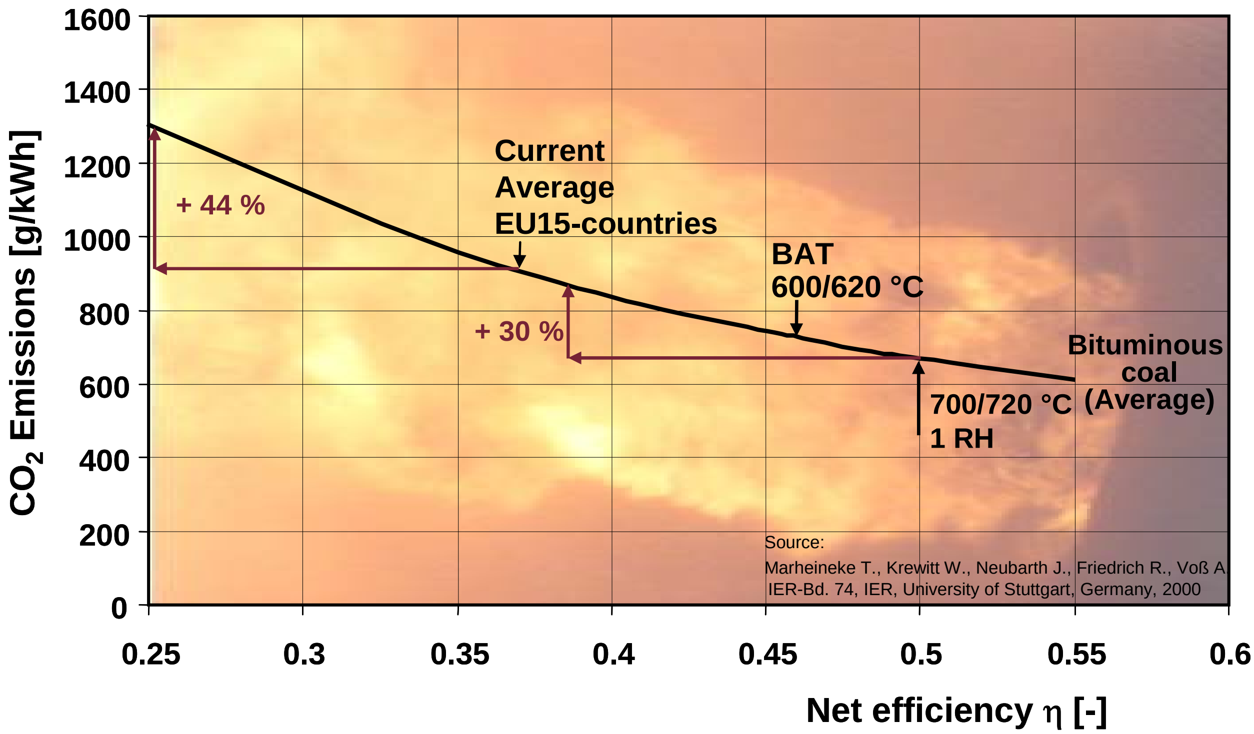

Figure 1-1: CO_2 Emissions increase of Power Plants with Bituminous coal by applying CCS

Illustrated in figure 1-1 is the increase in CO_2-production caused by the reduction of efficiency when implementing CCS-Technologies on bituminous coal fired power plants. Applying CCS in a power station with 37 % net efficiency leads to an efficiency drop of 12 %. With the new overall efficiency of 25 % the steam generator produces 44 % more CO_2 and consumes 48 % more coal. By combining CCS-Technologies and a 700 °C-Power Plant, with an efficiency of 50 % (net), the increase of CO_2-production can be limited to 30 %. Since the mid 90s European companies have been developing the 700 °C, 350 bar-Technology with the aim of applying new materials and adequate manufacturing and testing methods. Commissioning of a first 500 MW_{el} demonstration plant is scheduled for 2014.

2. New materials for the 700 °C - Technology

2.1 Need for new materials

The steam parameters of a 700 °C-Power Plant are significantly higher than those of a conventional coal fired power plant. The elevated steam pressure of about 350 bar in comparison to the 285 bar of a conventional power plant leads to higher stresses in all components of the high pressure part of the boiler. In combination with material temperatures over 700 °C new materials with adequate strength in these high temperature regions need to be applied. Figure 2-1 illustrates this need for new materials. The austenitic materials TP 347H FG, Super 304H and HR3C provide sufficient high values for creep strength in a temperature region common for 600 °C-Power Plants. For higher temperatures the creep strength of these materials is lower than 100 MPa for 100,000 h. The wall thicknesses of high temperature components of a 700 °C-Power Plant would be too high for fabrication and would lead to high pressure losses. Therefore the use of materials with higher creep strength like the new austenitic material Sanicro 25 or the modified version of the nickel base alloy Alloy 617 is necessary.

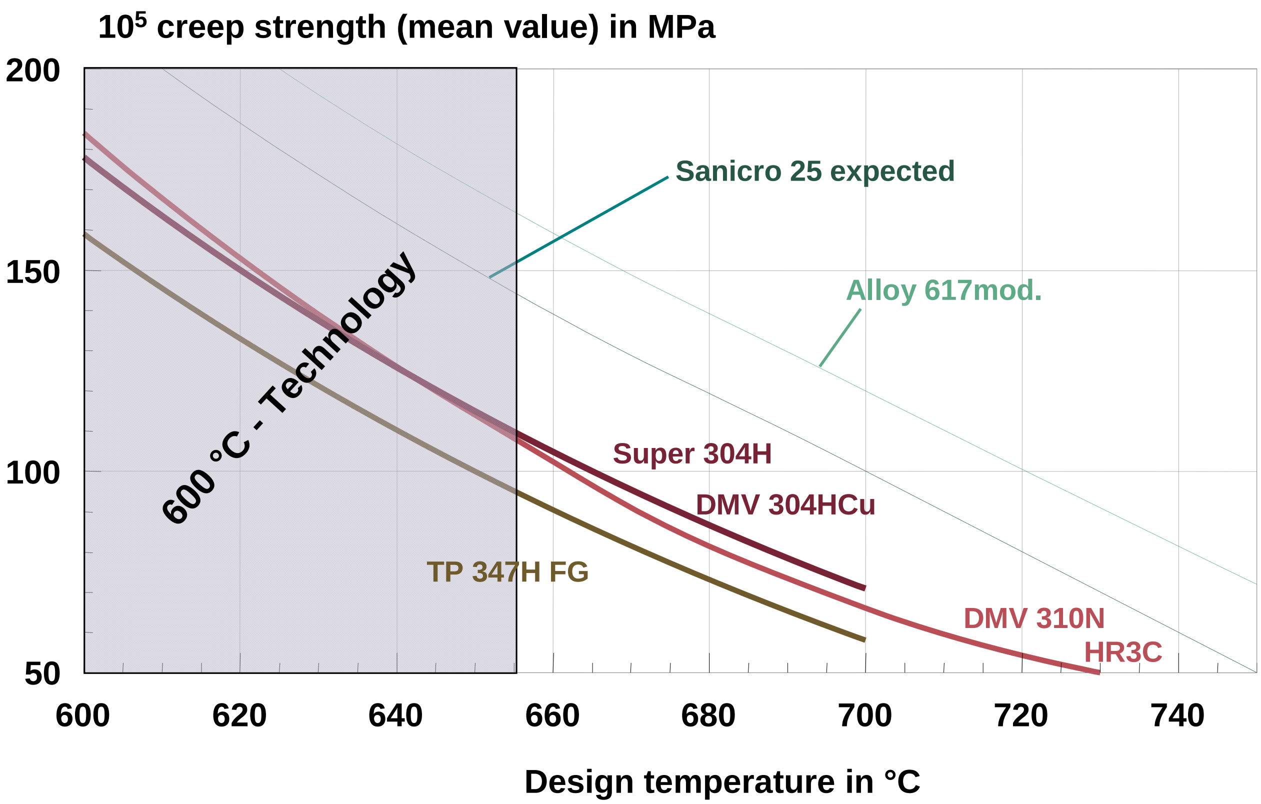

Figure 2-1: Creep strength of austenitic materials and nickel base alloys

The higher material temperatures of a 700 °C-Power Plant do not only make the use of materials with higher creep strength necessary. More over these materials need better corrosion and oxidation resistance compared to the austenitic materials. Figure 2-2 shows the influence of material and flue gas temperature on the fire side corrosion of superheater tubes build of austenitic materials with 18 % chromium. The corrosion rate increases with increasing flue gas and material temperature. For material temperatures higher than 650 °C, which are common for 700 °C-Power Plants, the corrosion rate exceeds the area of 0,3 to 0,4 mm/10,000 h at common flue gas temperatures of 1000 to 1200 °C. This area can be regarded as a maximum allowable corrosion rate for achieving a life time of 200,000 h with suitable wall thicknesses regarding pressure loss and manufacturing. New materials for higher temperatures need to have similar corrosion resistance but in the high temperature range they will be used for.

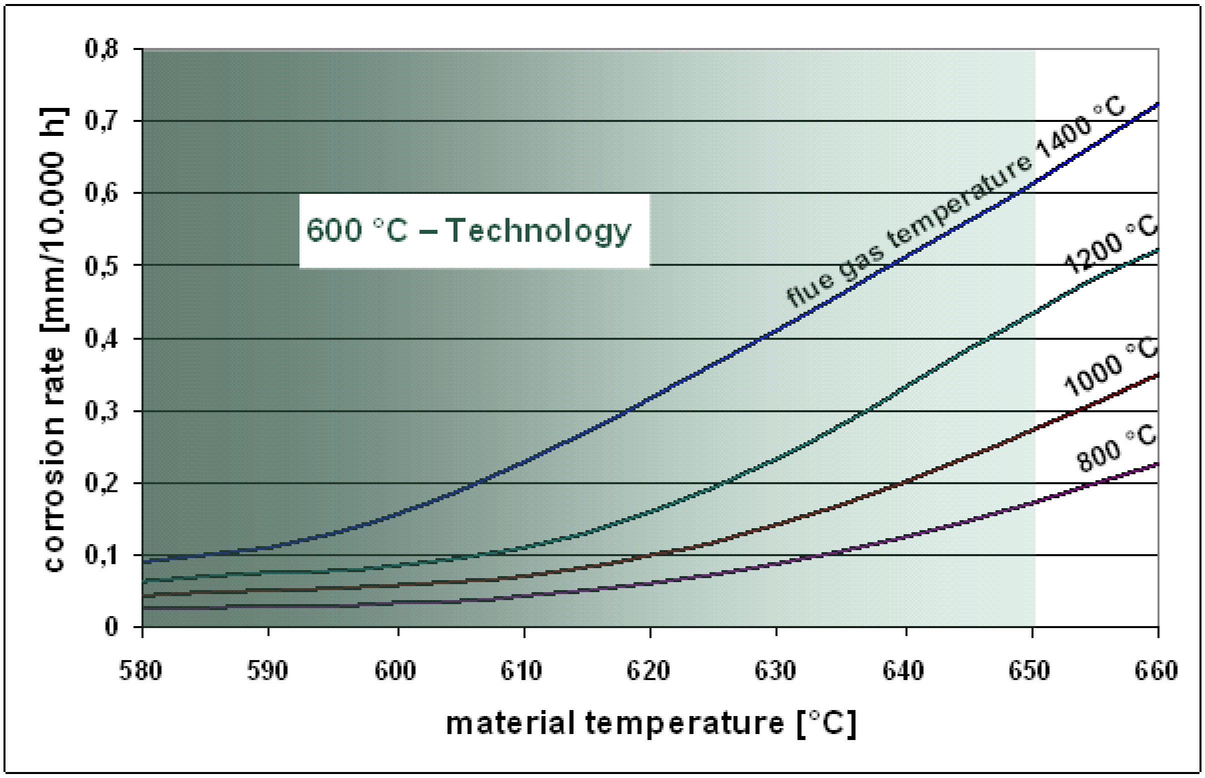

Figure 2-2: Corrosion rate of austenitic materials with 18 % chromium [Source: Cutler, A.J.B., Flatley, T and Hay, K.A.: Fire-side corrosion in power-station boilers. Combustion (Dez. 1980) S. 17-25]

2.2 Possible new materials

Preferred materials with high creep strength and high resistance against corrosion and oxidation are nickel base alloys. These alloys are new materials for large coal fired steam generators and partly still under investigation. Some materials already used in large steam generators will probably be applied to areas of the steam generator where they have not been used before.

Materials for membrane walls

For state of the art steam generators with steam temperatures of about 600 °C, ferritic materials like 7 CrMoVTiB10-10 (T24) can be used for the membrane walls. With material temperatures of

550 °C at the membrane walls however the limits of ferritic materials are reached. For the higher material temperatures of a 700 °C-steam generator martensitic materials like VM 12 and X10CrWMoVNb9-2 (T 92) are possible answers. But the relatively low chromium content of the martensites may create high steam side oxidation. For temperatures exceeding the range of application of these martensites, which is fixed by the oxidation behaviour and strength of these materials nickel base alloys like Alloy 617 (modified.) have to be used. The manufacturing process for membrane walls of both martensitic materials and nickel base alloys still has to be qualified. This includes the qualification of the welding materials, non destructive testing of the welds and bending tests of a membrane panel. The application of martensitic materials for membrane walls requires heat treatment after welding during fabrication, erection and after repair work. A suitable process for the heat treatment of the large membrane panels has to be developed. For the nickel base alloy Alloy 617 (mod.) heat treatment after welding is not necessary. From a manufacturing point of view this makes the use of Alloy 617 (mod.) for the membrane walls additionally to the ferritic materials favored.

Materials for superheater and reheater tubes

In the low temperature ranges of the superheater tubes the same ferritic materials as for the membrane walls can be used. Additionally at material temperatures higher than 550 °C martensitic materials like VM12 and X20CrMoV12-1 will be applied in 600 °C-steam generators. For the final stages of the superheaters, where the material temperature exceeds the maximum allowable temperature for martensites of 600 °C, austenitic materials like Super304H or HR3C need to be used. In a 700 °C-Power Plant the material temperatures at the final stages of the superheaters of more than 700 °C are too high for the common austenitic materials. The newly developed austenitic material Sanicro 25 extends the range of application of these materials to about 680 °C. For the remaining temperature range up to above 700 °C materials with higher strength are necessary. Possible new materials for this temperature range are nickel base alloys like the modified Alloy 617, Alloy 740 and Alloy 263 and the newly developed Japanese austenitic material HR6W. For these new superheater materials the qualification of the base material, creep tests across the weld and bending tests have to be carried out. The qualification of the base material which is a fundamental step on the way to a marketable product for most of the above mentioned new materials is still ongoing. Only the qualification of the base material of the modified Alloy 617 is completed, which makes it presently the preferred material.

Materials for headers and pipes

The common materials for headers and pipes are martensitic materials like X20CrMoV12-1, X10CrMoVNb9-1 (T91) or X10CrWMoVNb9-2 (T92). With steam temperatures of about 600 °C the use of martensitic materials has reached its limit. For the high temperature headers and pipes of a 700 °C-Power Plant materials with higher strengths are necessary. Possible new materials are the nickel base alloys Alloy 617 (mod.) and Alloy 263 or HR6W. For these new header and pipe materials, similar qualification and testing programs have to be carried out as for the superheater tubes. Additionally methods for non destructive testing of welds by ultrasonic testing and/or x-ray have to be tested for headers and pipes of these materials.

Materials for supporting tubes and screen

The screen as the first convective heating surface above the furnace and the supporting tubes are in the state of the art power plants built of ferritic or martensitic materials like 7 CrMoV-TiB10-10 (T24) or X10CrMoVNb9-1 (T91) and VM 12 in the screen. The material temperature of the screen in a 700 °C-Power Plant is so high that martensitic materials like the VM12 can not be used anymore. The screen has to be built of Alloy 617 (mod.). In order to avoid dissimilar welds in tubes in the flue gas path the supporting tubes which form the screen have to be manufactured of Alloy 617 (mod.) as well.

3. Investment costs of a 700 °C - Power Plant

As illustrated in the preceding chapter, nickel base alloys like the modified Alloy 617 are the preferred materials for the 700 °C-Technology. They have a sufficient high strength and high resistance to steam side oxidation and fire side corrosion. Alloy 617 (mod.) showed in testrigs considerably better resistance to corrosion and oxidation than austenitic materials. The specific costs of nickel base alloys however are about 5 to 8 times higher than those of conventional austenitic materials. The use of these materials at the high temperature heating surfaces and partly at the membrane wall raises the investment costs of a 700 °C-Power Plant significantly. The investment costs of a 700 °C–Power Plant are expected to be about 15 % to 25 % higher than those of a conventional power plant with the same power output. Other cost raising factors besides the necessary use of nickel base alloys are the increased heating surface due to the about 100 K higher steam temperatures at the boiler outlet, the potentially larger wall thicknesses due to the higher steam pressure and the partly higher manufacturing effort of the new materials. For widely spread commercial application of the 700°C-Technology a reduction of the investment costs is necessary. A very promising way to do so is the application of alternative material concepts for different parts of the boiler.

3.1 Membrane walls

Possible new materials for the membrane walls as already stated are Alloy 617 (mod.) and the martensitic materials VM 12 and X10CrWMoVNb9-2 (T92). Regarding manufacturing aspects, like the necessary heat treatment after welding, the sole use of Alloy 617 (mod.) for the membrane wall additionally to the ferritic materials is preferred. To reduce the investment costs the substitution of part of the Alloy 617 (mod.) in the membrane wall with VM12 or T92 is a very promising measure. The price difference between these martensitic materials and a nickel base alloy can reach up to 60.000 € per ton. To make the use of the martensitc materials possible a special manufacturing concept has to be developed, which considers the necessary heat treatment after welding. It could be possible that due to thick oxide layers repeated acid cleaning of the evaporator tubes during the life time of the boiler may be necessary. A possible way to completely avoid the use of the new materials Alloy 671 (mod.), VM12 and T92 in the membrane wall is to restrict the steam temperature at the exit of the membrane wall and to lower the operating steam pressure. The membrane wall exit temperature can be lowered by increasing the furnace gas exit temperature as low as the slagging behaviour of the coal allows it. This leads to a reduction of the furnace height. The lower steam temperature and pressure allows the use of ferritic materials (7CrMoVTiB10-10, T24) for the entire membrane wall. With the lower operating steam pressure however the plant efficiency decreases.

3.2 Superheater and reheater tubes

As already stated for most of the new superheater tube materials the qualification of the base material is not yet completed. Alloy 617 (mod.) however is widely qualified, which makes it presently the favoured material for the high temperature parts of the superheaters and reheaters. One possible way to reduce the investment costs of a 700 °C–Power Plant is to substitute the Alloy 617 (mod.) with Sanicro25, Alloy 263, Alloy 740 or HR6W. Sanicro25 and HR6W make a reduction of the investment costs possible, because their price is expected to be lower than that of Alloy 617 (mod.). Alloy 263 and Alloy 740 will probably have similar prices as Alloy 617 (mod.), but they have a higher strength which reduces the wall thickness needed for the superheater tubes. To get the benefit from the shown potentials for the reduction of the investment costs the qualification of the base material of these new materials has to be promoted and on a fast track completed. Another possibility to reduce the investment costs for the superheaters and reheaters is to raise the flue gas temperature in the convective path of the boiler by raising the furnace gas exit temperature. This leads to smaller heating surfaces due to the higher temperature difference. To optimize the final superheater and reheater stages regarding their heating surface it is important that they are placed directly behind the screen. Future potential for further optimization lies in the arrangement in counter flow instead of the now common parallel flow for the final stages. But this arrangement with higher material temperatures and increased corrosion potential can only be applied after additional corrosion investigations.

3.3 Headers and pipes

Similar to the membrane wall and superheater tubes, the substitution of Alloy 617 (mod.) by other materials is a possible way to reduce the investment costs for the headers and pipes. The material costs of the newly developed austenitic material HR6W are expected to be lower than those of Alloy 617 (mod.) which makes its use very promising. Alloy 263 enables the reduction of the investment costs due to its higher strength compared to Alloy 617 (mod.). A smaller amount of this material is needed for approximately the same material costs as Alloy 617 (mod.). As already stated, before these alternative materials can be used this qualification has to be continued and completed.

4. Conclusion

The improvement of the efficiency of coal fired power plants by operation of power plants with higher steam parameters is a fast and reasonable step towards the necessary reduction of CO_2-emmissions. For the oncoming application of CCS-Technologies to achieve near zero emissions the higher efficiency of a 700 °C-Power Plant is a perfect foundation. The reduction of the efficiency for a power plant with CCS-Technologies of 8 – 12 % points can at least partly be compensated by the higher efficiency of a 700 °C-Power Plant. Caused by the significantly higher steam parameters of a 700 °C-Power Plant new materials with adequate strength and resistance to oxidation and corrosion need to be applied. The qualification of some of the new materials is not yet completed and will have to be continued in the coming years.