LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
FACULTY OF TECHNOLOGY
BIOENERGY TECHNOLOGY

MASTER'S THESIS

INFLUENCE OF MIXED FUELS COMBUSTION ON BOILER OPERATION

Supervisors and examiners: Professor, D.Sc. (Tech.) Esa Vakkilainen
Docent, D.Sc. (Tech.) Juha Kaikko

Lappeenranta, 2010

Vitaly Ovsyannikov

ABSTRACT

Lappeenranta University of Technology
Faculty of Technology
Master's Degree Program in Bioenergy Technology
Vitaly Ovsyannikov

Influence of mixed fuels combustion on boiler operation

Master's thesis

2010

87 pages, 33 figures, 6 tables and 3 appendixes

Examiners: Professor Esa Vakkilainen
Docent Juha Kaikko

Keywords:
Boiler, biomass, biofuel, mixed fuel, boiler efficiency, fuel properties, emissions, IPSEpro, operation, modeling.

The aim of this work is to study the effect of different fuel mixtures on the operation of circulating fluidized bed (CFB) boiler. The applicability of heat balance modeling software IPSEpro to simulate CFB boiler operation is also investigated. The work discusses various types of boilers and methods of boiler operation. The fuel properties and the possible fuel influence on the boiler efficiency are described. Various biofuel types that are possible to use in combination with other fuels are presented. Some examples of the fuel mixtures use are given. A CFB boiler model has been constructed using IPSEpro and applied to analyze boiler operation outside design conditions. In the simulations, the effect of different load levels and moisture contents for the fuel mixture has been studied.

ACKNOWLEDGMENTS

This Master's Thesis was carried out in the Lapeenranta University of Technology.

I want to express my gratitude to Professor Esa Vakkilainen and Professor Juha Kaikko, for their support during the learning process and assistance during this thesis writing. Thanks to them, I chose the right path and eventually wrote this work.

Also I want to thank Project Coordinator Julia Vauterin for help and support during my studies in LUT.

Thanks to the Saint Petersburg State Technological University of Plant Polymers and Lappeenranta University of Technology for the opportunity to get a good quality education.

I would like to thanks my supervisor from SPbSTUPP Ivanov Aleksandr Nikolaevich for guidance and advices. It was he who spotted it in my power to training in LUT and supported towards the training end. My sincere gratitude to Aleksandr Nikolaevich.

Special thanks for all those who supported me morally during my training in LUT. I thank my friends, relatives, family.

And I also thank you, reader, for that you hold my work in your hands. I hope you will find here what you are looking for and consider this work worthy.

I just thank
God for the soul.
I just thank
Friends for the friendship.
I just thank
My family, parents
For that they are,
Thank you.

Lappeenranta, May 2010

Vitaly Ovsyannikov

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ABBREVIATIONS

CFB	Circulating fluidized bed
UPM	United paper mills
daf	dry ash-free mass
d	Dry mass
m	Moist fuel
HHV	Higher heating value
LHV	Lower heating value
IT	Initial temperature
ST	Softening temperature
HT	Hemisphere temperature
FT	Final temperature
PVC	Polyvinyl chloride
RDF	Refuse-derived fuel
MSW	Municipal solid waste
CHP	Combined heat and power
MDK	Model development kit
PSE	Process simulation environment
MS	Microsoft
SH	Superheater

DSH	Desuperheater
SH I	First superheater
SH II	Second superheater
SS & RL	Solids separator and return leg

LIST OF SYMBOLS

A	Absorptive power of object	[-]
A_d	Ash content for dry fuel mass	[%]
A_m	Ash content for wet fuel mass	[%]
A_v	The absorption factor of the gas	[-]
B	Diameter of ashes cone	[m]
C^f	Fixed carbon content	[%]
C^f_{daf}	Fixed carbon content for dry ash-free fuel mass	[%]
C^f_d	Fixed carbon content for dry fuel mass	[%]
C^f_m	Fixed carbon content for wet fuel mass	[%]
H	Height of ashes cone	[m]
H_d	Hydrogen content in dry fuel	[%]
k	Overall heat transfer coefficient	[W/m^{2}K]
k_0	Design overall heat transfer coefficient	[W/m^{2}K]
m_1	Mass of wet fuel sample	[g]
m_2	Mass of dry fuel sample	[g]
Nu	Nusselt number	[-]
p	Pressure	[bar]
Pr	Prandtl number	[-]
q_{sf}	Heat-flow rate at surface,	[W/m^2]

q_m	Mass flow	[kg/s]
q_{m0}	Design mass flow	[kg/s]
Q^m	Heating value for wet fuel mass	[kJ/kg]
Q^d	Heating value for dry fuel mass	[kJ/kg]
Q^{daf}	Heating value for dry ash-free fuel mass	[kJ/kg]
Q_{eff}	Effective radiation	[W/m^2]
Q_{self}	Self-radiation	[W/m^2]
Q_{refl}	Reflected radiation	[W/m^2]
Q_{abs}	Absorbed radiation	[W/m^2]
Q_{inc}	Incident radiation	[W/m^2]
Re	Reynolds number	[-]
T	Temperature	[˚C]
T_0	Fluid temperature	[˚C]
T_{sf}	Surface temperature	[˚C]
T1	Temperature after air-sand separation	[˚C]
T2	Temperature after air heater	[˚C]
T_0	Design temperature	[˚C]
T_w	The surface temperature of the fouling layer	[K]
T_{cg}	The average temperature of the gas	[K]
V	Volatile content	[%]
V_d	Volatile content for dry fuel mass	[%]

V_{daf}	Volatile content for dry ash-free fuel mass	[%]
V_m	Volatile content for wet fuel mass	[%]
W	Fuel moisture	[%]
$\alpha_{hot.conv}$	Convective heat transfer coefficient for hot side	[W/m^2K]
$\alpha_{hot.conv0}$	Design convective heat transfer coefficient for hot side	[W/m^2K]
$\alpha_{hot.rad}$	Radiation heat transfer coefficient for hot side	[W/m^2K]
$\alpha_{hot.rad0}$	Design radiation heat transfer coefficient for hot side	[W/m^2K]
α_{cold}	Heat transfer coefficient for cold side	[W/m^2K]
α_{cold0}	Design heat transfer coefficient for cold side	[W/m^2K]
ε_w	The emissivity of the fouling layer	[-]
ε_{cg}	The emissivity of the gas	[-]
σ	The Stefan-Boltzmann constant	[W/m^2K^4]
λ	Thermal conductivity	[W/mK]
μ	Dynamic viscosity	[Ns/m^2]

1 INTRODUCTION

Today, no one can deny the fact that world is experiencing global climate change. Warming caused by greenhouse gases is one of the major problems of mankind. Many countries try to reduce greenhouse gas emissions. One way to reduce greenhouse gas emissions is to use biomass for energy production. Carbon dioxide released by the use of biomass does not increase the amount of greenhouse gases in the atmosphere. All the carbon dioxide released during the use of biomass takes part in the nature carbon cycle, and absorbed by plants in the vegetative period. Biomass harms the environment much less than the fossil fuels. Biomass is a renewable source of energy unlike fossil fuels, the amount of which is limited and decreases over time with increasing prices.

Currently, governments of many countries try to reduce emissions of greenhouse gases in the atmosphere. Therefore they increase percentage of renewable energy use, including biomass. One way to increase the percentage of biomass is to add available biofuels to the fossil fuels or waste burning processes. Also considered is a possibility to create a balanced biofuels mix that is available for individual regions.

The purpose of the master thesis is to examine the effects of biofuels mixtures on the boiler operation and its effectiveness. In the first part of the work various types of boilers and their operation conditions are considered, described the main components and equipment of boilers. Then the problems associated with boiler operation are explored. In the second part the boilers work is explained in details including the properties of fuels and the possible problems depended on the fuel composition. Described the main types of biofuels used in boilers. Than various biofuel mixtures are described and the problems that are arisen from the mixing of different fuels. Examples of fuels mixtures in use are described. The third part of the Master thesis briefly describes the program IPSEpro, its purpose and applications. In the fourth part of the work a CFB boiler model is described. The boiler model was set up in the program IPSEpro. Series of experiments for the boilers model for assessing the effects of different biofuels on main operation parameters and efficiency of the boiler are made. The analysis of the experiments and conclusions are conducted.

2 BOILERS

Boiler is constructively combined device into one complex for produce steam or hot water by burning fuel. The main boiler parts are furnace chamber and flue gas duct. Heating surfaces are placed in the furnace and flues, which perceive the heat of the combustion products. Elements of the boiler are based on the frame. Brickwork and isolation protects boiler from heat loss. The boiler design depends on its destination, type of used fuel, combustion method, steam production unit, pressure and temperature produced steam.

Boilers can be classified into boilers for hot water production and steam production. In turn, steam boilers can be classified according to different parameters:

1. steam parameters
   - Boilers for saturated steam: Often in the steam generator does not include superheater because there is no need to produce superheated steam.
   - Boilers for superheated steam: Saturated steam is sent to the superheater, where it is further heated to superheated steam.

2 pressure of the working medium

Steam boilers are divided into boilers subcritical and supercritical pressure.

3 hydraulic circuit
   - Once-through steam generator: Heat carrier passes only once through the heat exchange surface.
   - Drum type steam generator: Heat carrier circulates many times in the evaporator circuit formed by the furnace waterwall and downcomers.
   - Steam boilers with multiple circulations, in turn, are divided into boilers with natural and forced circulation.

4 type of pipes
   - Gas-tube boiler: Boilers, in which the high-temperature gases go inside tubes, giving heat to the water surrounding the pipe. Gas-tube boilers are based on the sidewalls of the furnace.
   - Water-tube boiler: Heated water flows inside pipes, and the furnace gas is outside pipes in water-tube boilers. Water tube boilers are usually hung on a special frame or frame of the building.

The most common methods of burning biofuels are grate firing and fluidized bed firing.

Figure 1. Circulating fluidized bed boiler. (FBS,2010)

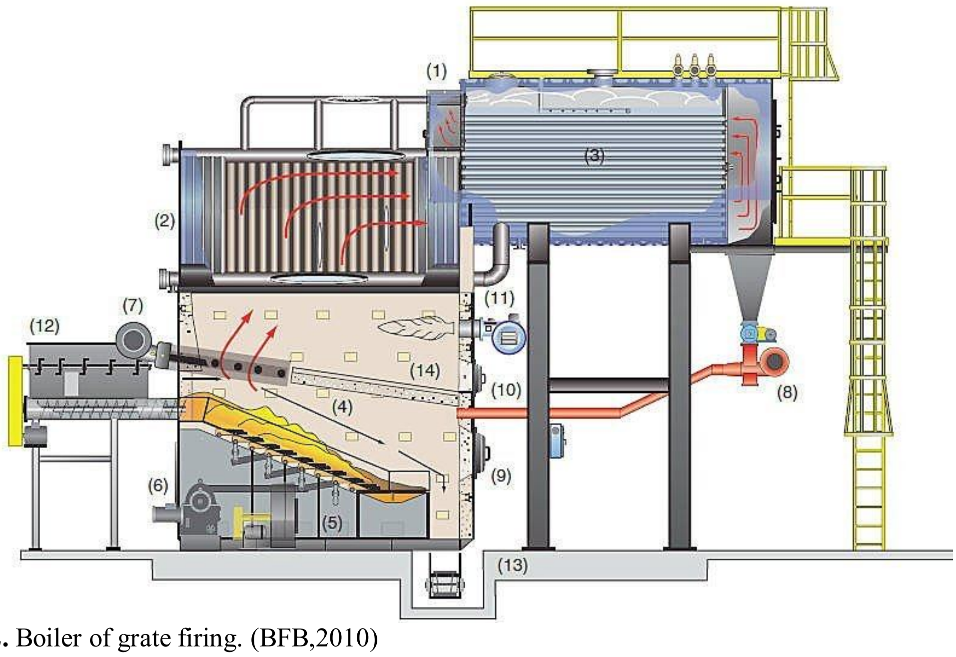


Figure 2. Boiler of grate firing. (BFB,2010)

2.1 Fluidized bed boilers

In considering the prospects for the use of biofuels, in particular to power a new generation, one of the main issues is its efficient combustion. Under combustion efficiency primarily refers to fulfill two requirements: combustion must be complete, i.e.

economical, and it should not lead to large emissions of pollutants (primarily sulfur oxides and nitrogen).

For a long time to burn biofuels used bed firing, in which the biofuel is fed onto the grate, often moving, through which enters the hot air, which is carried out and the burning of biofuels as a source of radiation and thermal energy for heating the working fluid. To fulfill the above requirements was developed and put into practice a number of sensitive and meaningful activities that are, nevertheless, can not solve the problem entirely. Therefore, the last time begin to use more environmentally friendly combustion technologies for a wide range of biofuels. Among these technologies is the technology of burning solid fuels in circulating fluidized bed.

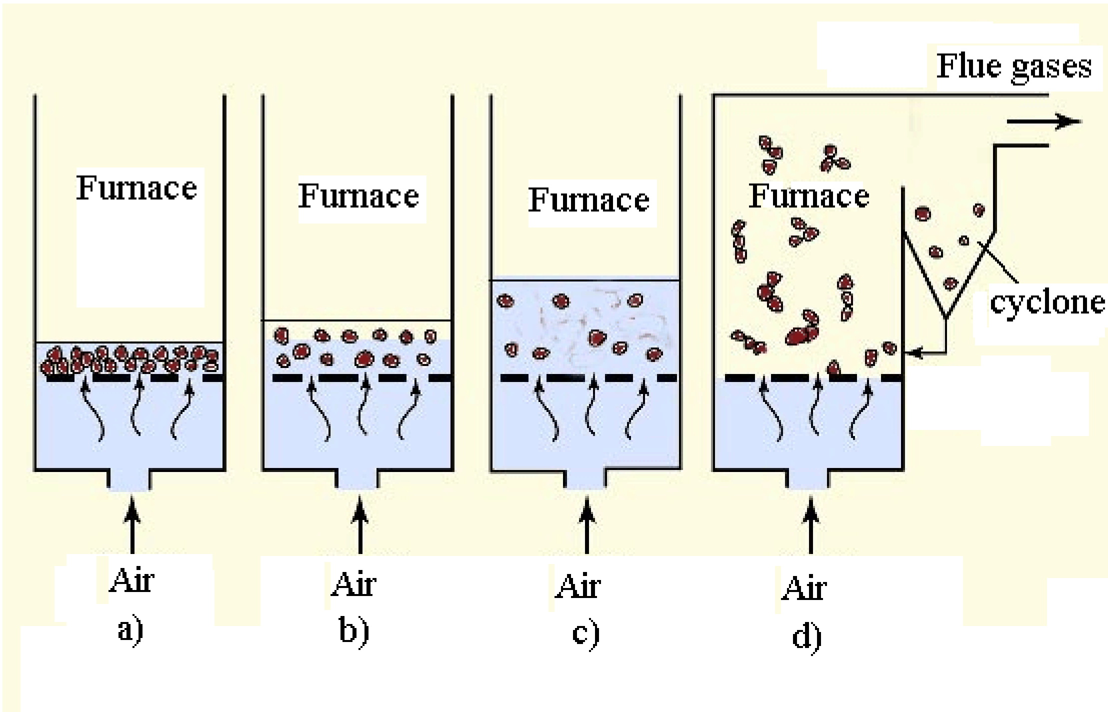


Figure 3. Change of the fluidized bed with different amounts of air supplied for combustion. (Energocon,2010)

The theoretical basis of CFB boilers is operation of the fluidized bed. If a certain cell (see Fig. 3, a) set the grid on which to place a layer of solid fuel, and submit to the grate in a small amount of air after preheating layer begins burning fuel from the surface with the release of gaseous products of combustion. When filling the burning fuel on the grid will be supported by fixed layer burning. Beds of solid fuel combustion occurs. If you increase the flow of air under the grate, then the fuel particles located on the grid, will operate the velocity pressure, which will counteract the force of gravity acting on each particle of fuel. At a certain velocity of air particles of fuel will be suspended in the lifting air flow, and the thickness of the burning layer will increase.(see Fig. 3, b) With further increase in speed in a layer of individual air bubbles appear (see Fig. 3, c), and the thickness of the layer increases more. This so-called bubble fluidized bed. He behaves like a boiling liquid, hence the name of the method - fluidized bed combustion.

At still high cost of air lift force acting on a particle of fuel is so great that they do not have time to burn and break out of a fluidized bed. With further increase air flow visible layer disappears and is burning accumulations of fuel particles in the whole volume of the chamber with intensive stirring.(see Fig. 3, d) The higher number of fuel particles do not have time for burn and is removed from the chamber. Here, on their way to establish cyclone. Cyclone - cylindrical vessel in which the combustion products are separated from the unburned particles. Combustion products(flue gases) are directed into the second part of the boiler, convective shaft, for heating the working medium (water and steam). Unburned particles move in a swirling flow, are discarded to the walls, falling down, and again sent to the combustion chamber. This is the circulated fluidized bed. Its main feature is that the circulating material is hundreds of times greater than the amount of air supplied for combustion.

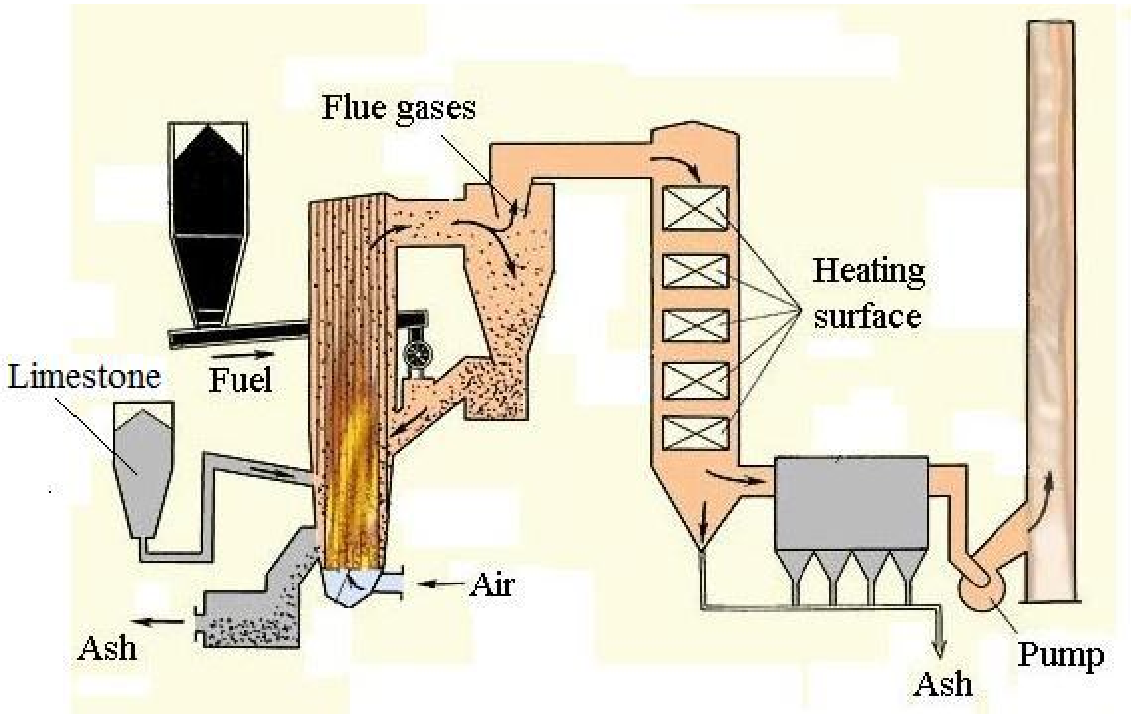


Figure 4. Scheme of circulating fluidized bed boiler. (Energocon,2010)

There are a number of schemes, realizing the technology of CFB. Consider one of them, shown in Figure 4. Solid fuel from the hopper suction is sent to the furnace grate, under which the combustion hot air is directed. It also comes from another bunker limestone, which reacts with sulfur, connects it to continue with the dry ash is discharged from the boiler. Thus, it's to prevent the ingress of sulfur in the flue gases and then into the air. The resultant fluidized bed heat transfer part of its working medium, moving in the screens that lined the walls of the furnace. From the top of the furnace a mixture of products of combustion bed material, and fuel particles, not burnt in a fluidized bed is sent to the cyclone, where there is a separation of solid particles from the combustion products. Unburned hot particles are mixed with particles of fresh fuel and this mixture enters the fluidized bed burning furnace. The combustion products enter the convective shaft, which houses other surface heating of the working medium: convective primary and intermediate superheaters, economizer, air heater. At the exit of the convective shaft the products of combustion fly ash is removed. Then they come in electrostatic precipitators for removing residues of fly ash. After which they are sent to the chimney to disperse in the upper atmosphere. One of the basic ideas implemented in CFB boilers is the fact that the temperature of the fluidized bed is low - at 820-900 ° C. At such temperatures, the formation of oxides of nitrogen is very slow. Another important idea - repeated circulation of the hot mixture of bed material, ash, limestone and a relatively small amount of forward fresh fuel. This provides not only good desulphurization of flue gases, but also greatly intensifies the combustion process. (Energocon,2010)

2.2 Heating surfaces and heat transfer

Heating surfaces of boilers are a variety of heat exchangers. Heat exchanger is a device in which the heat exchange between two or more heat-transfer agents or between the coolant and the solid surface. The process of transferring heat from one fluid to another is one of the most important and frequently used in engineering processes. For example, steam boiler operation is based on the heat transfer between the combustion products of fuels and water. According to the working principle, heat exchangers are divided into recuperators, regenerators and mixing heat exchangers. There are also heat exchangers, in which the heating of the fluid is carried by the "internal" source of heat. Recuperative heat exchangers are devices, in which two moving fluids at different temperatures are separated by a solid wall. Heat transfer occurs by convection between the fluid and the wall, and by radiant heat transfer, if at least one of the fluids is emitting gas. Figure 5 given some constructions recuperative heat exchangers.

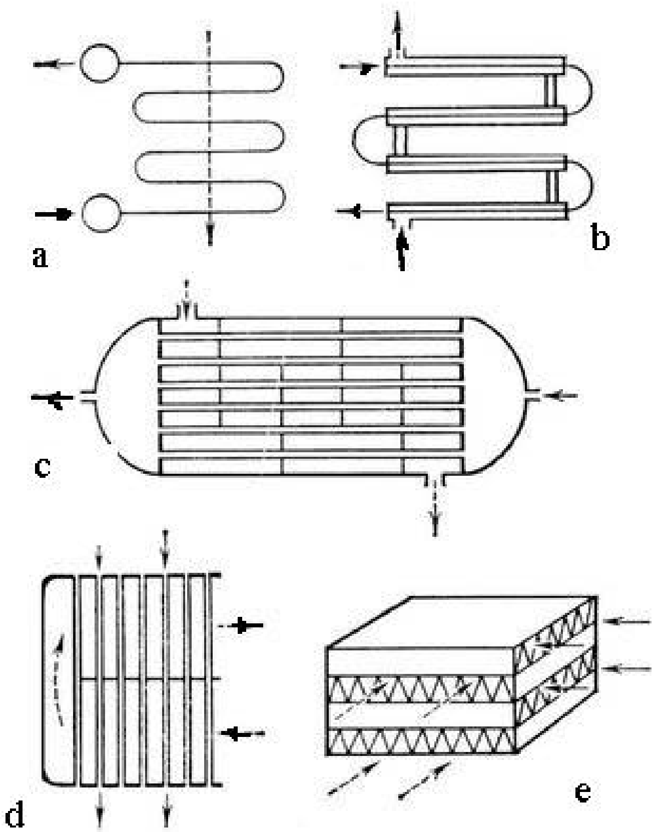


Figure 5. Reinforced recuperative heat exchangers a) coil, b) type "pipe in pipe" c) shell-and-tube d) tubular air heater e) plate-type. (Kichigin,1955)

Regenerative heat exchangers have the same heating surface periodically washed by the hot, then cold fluid. That is first selects the surface of the heat and warms up, and then gives the heat and cooled. A typical example of regenerators is regenerative air preheater. Since in the recuperative and regenerative heat exchangers heat transfer is carried out through solid surface, they are surface heat exchanger. In direct-contact heat exchangers heat transfer takes place in direct contact on the fluids. The heat exchanger of this type is a cooling tower in which water is cooled by atmospheric air. In the heat exchangers with an internal source of heat is only one fluid. (Kichigin,1955)

2.2.1 Radiation heat transfer

Radiant heat exchange is carried out by the processes of transformation of the internal energy of matter into radiation energy, the energy transfer in the form of radiation and its absorption of the substance. Processes radiant heat exchange is determined by the relative positions in the space of bodies exchanging heat, properties of the medium separating the bodies. The essential difference between radiant heat exchange from other types of heat transfer is that it can proceed in the absence of a material medium that separates the heat transfer surfaces, as performed by the proliferation of electromagnetic radiation. Radiant energy falling in the process of radiant heat exchange on the surface of an opaque body and is characterized by the value of the incident radiation flux Q_{inc}, partially absorbed by the body, and partly reflected from its surface.

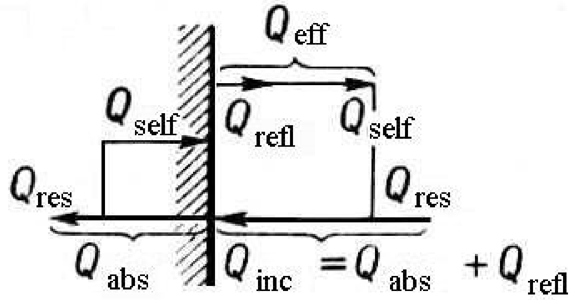


Figure 6. Schematic image of the radiation fluxes in the radiant heat exchange. (Bloch,1962)

The flow of absorbed radiation Q_{abs} is determined by the following relation

$$Q_{abs} = A \cdot Q_{inc} \tag{2.1}$$

where A is absorptive power of object [-].

Due to the fact that for an opaque body:

$$Q_{inc} = Q_{abs} + Q_{refl} \tag{2.2}$$

where Q_{refl} flux reflected from the surface of the body [W/m^2].

The flux of the reflected radiation is calculated by the following equation:

$$Q_{refl} = (1 - A)Q_{inc} \tag{2.3}$$

where $1 - A = R$ is reflectance of object [-].

If the absorptive power of object is equal to 1, and consequently, its reflectance is equal to 0, that is the body absorbs all incident radiation, then it is called a blackbody.

The surface of any body, included in the radiant heat exchange system emits streams of reflected radiation Q_{refl} and self-radiation Q_{self}. The total amount of energy, stretching from the surface of the body, called the flow of effective radiation Q_{eff}. Effective radiation is determined by the following equation:

$$Q_{eff} = Q_{refl} + Q_{self} \tag{2.4}$$

Part of the energy absorbed by the body returns to the system in the form of self radiation. Therefore, the result of radiant heat exchange can be represented as the difference between the threads of its self and absorbed radiation. The next value is called the flux of the resulting radiation:

$$Q_{res} = Q_{self} - Q_{abs} \tag{2.5}$$

The flux of the resulting radiation shows how much energy per unit area gets or loses the body in unit time as a result of radiant heat exchange. Radiant heat exchange plays a significant role in the processes of heat transfer occurring at temperatures around 1000 °C and above.(Bloch,1962)

Assuming the combustion gas to be an isothermal and homogeneous mixture, the net rate of radiant heat transfer between gas and surrounding walls(furnace water walls, for instance) is given by(VDI,2002)

$$\Phi = A\sigma \frac{\varepsilon_w}{1-(1-\varepsilon_w)(1-A_v)}(\varepsilon_{cg}T_{cg}^4 - A_v T_w^4) \tag{2.6}$$

where ε_w is the emissivity of the fouling layer [-]

ε_{cg} is the emissivity of the gas[-]

A_v is the absorption factor of the gas [-]

T_w is the surface temperature of the fouling layer [K]

T_{cg} is the average temperature of the gas. [K]

σ is the Stefan-Boltzmann constant.[W/m^{2}K^4]

Assuming all radiation parameters ε_w, A_v and ε_{cg} constant as well as ε_{cg} and A_v equal, the variation of the radiative heat transfer coefficient outside design conditions can be represented by the following equation:

$$\frac{\alpha_{cg}}{\alpha_{cg,0}} = \frac{T_{cg}^4 - T_w^4}{\left(T_{cg}^4 - T_w^4\right)_0} \frac{\left(T_{cg} - T_w\right)_0}{T_{cg} - T_w} \tag{2.7}$$

In the equation, the design values are denoted with subscript 0.

2.2.2 Convection heat transfer

Convective heat transfer is the process of heat transfer that occurs between moving fluids. Convective heat exchange takes place due to the combined action of two mechanisms of heat transfer. There are the actual convection and thermal conductivity. In the case of convective heat exchange distribution of heat in space is due to the heat transfer in moving fluid from a region of higher temperature to the region with lower temperature and due to the thermal motion of micro particles and the exchange of kinetic energy between them. Due to the fact that for a non-conducting medium, the intensity of convective transport is very large compared to the thermal conductivity, the latter in laminar flow plays a role only for heat transfer in a direction transverse to the flow of the medium. The role of heat conduction for convective heat exchange is more significant with the motion of electrically conducting media (eg, liquid metals). In this case, the thermal conductivity significantly affects the heat transfer in the direction of motion. In turbulent flow the main role in the process of heat transfer across the flow is pulsating movement of turbulent eddies across the fluid flow. Participation of thermal conductivity in the process of convective heat exchange leads to the fact that these processes depend significantly on the thermophysical properties of the medium: coefficient of thermal conductivity, heat capacity, density.

This is a process of two convective heat transfer occurring at the interface of two phases. In this calculation problem is to find the heat flux at the interface. That is the value that shows how much heat gets or gives a unit of the interface per unit time. Density of heat flow also depends on the shape and size of object, surface roughness and surface temperatures.

Convective heat transfer between the fluid and surface can be described using the following equation, also known as Newton's cooling law. (Eckert,1961)

$$q_{sf} = \alpha(T_0 - T_{sf}) \tag{2.8}$$

where q_{sf} is heat-flux [W/m^2]

$\alpha$is convection heat-transfer coefficient [W/m^{2o}C]

T_0 is fluid temperature [^{o}C]

T_{sf} is surface temperature [^{o}C].

The flow across the tube banks with 10 or more rows convective heat transfer coefficient outside the tubes can be determined from a correlation for the Nusselt number as a function of Reynolds and Prandtl.(Incropera,1996)

$$Nu = C \,\mathrm{Re}^m \,\mathrm{Pr}^{1/3} \tag{2.9}$$

where Nu is Nusselt number [-]

Re is Reynolds number [-]

Pr is Prandtl number [-]

C is constant [-]

m is constant [-]

In the equation, C and m depend on the geometry. Typically, a value of 0,6 is applied for m.

Bearing in mind the definition of the Reynolds number, the variation of the convective heat transfer coefficient can be calculated by equation (Kaikko,2007)

$$\frac{\alpha_{cg}}{\alpha_{cg,0}} = \frac{\lambda_{cg}}{\lambda_{cg,0}} \left(\frac{\mu_{cg,0}}{\mu_{cg}} \frac{q_{m,cg}}{q_{m,cg,0}} \right)^{0.6} \tag{2.10}$$

where λ is thermal conductivity [W/mK]

μ is dynamic viscosity [Ns/m2]

For the flow inside the tubes convection heat transfer can be estimated from a correlation for fully developed turbulent flow in rough tubes(Incropera, 1996)

$$Nu = C' \operatorname{Re} \Pr^{1/3} \tag{2.11}$$

where C′ is constant [-].

In the equation C′ depends on the roughness of the tube.

The variation of the convection heat transfer coefficient can be developed into (Kaikko,2007)

$$\frac{\alpha_{a}}{\alpha_{a,0}} = \frac{\lambda_{a}}{\lambda_{a,0}} \frac{\mu_{a,0}}{\mu_{a}} \frac{q_{m,a}}{q_{m,a,0}} \tag{2.12}$$

Heating surfaces in boilers with fluidized bed can be immersed in fluidized bed. In this case, a number of features of the location and the influence of additional factors on heat transfer must be taken into account. The orientation of the heat exchanger can be horizontal, vertical or inclined. The horizontal arrangement of pipes in fluidized bed is more advantageous compared to the vertical, so less pressure drop across the resistance of the boiling layer. Also on heat transfer in fluidized bed affects: pressure layer, temperature layer, superficial velocity of gases, particle size and design of heat exchanger. The heat exchanger immersed in the fluidized bed is more susceptible to wear and corrosion, and therefore it should be made from more durable materials. (Eckert,1961)

2.2.3 Furnace waterwall, superheater, economizer and airheater.

In the furnace tube boilers often include radiation screens. Furnace waterwall can increase the heat in the furnace at a lower heat load on her wall, thereby decreasing the time spent on maintenance and increased efficiency of boiler, in addition, significantly reduces the requirements for thermal insulation of the walls. Waterwalls performe as part of a pipe which passes boiler water. Steam formed in the tubes is directed to the steam drum. These screens are usually protected of the wall boiler plant. Pipes can be smooth, with spacers, fin, studded with refractory coating.

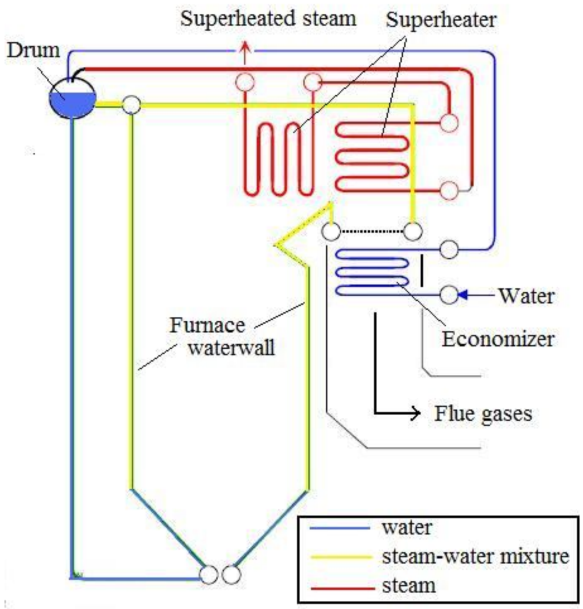


Figure 7. Scheme of water-steam system.

Superheater is a heat exchanger, designed to raise the temperature of steam above the normal boiling point. High-temperature superheated steam enhances efficiency of steam engines and turbines, since the consumption of steam is reduced to about 1% with an increase in the overheating at 5 °C. The upper limit temperature is determined by a thermal resistance of mechanical equipment and materials. Large power plants operate at temperatures of superheated steam to that exceed 600°C.

Superheaters are made of steel tubes, forming a heating surface for passing on him steam. Saturated steam from the boiler goes in at one end of the tube and is heated to the desired output temperature by the warm flue gas supplied to its outer surface. Heating surface superheaters is about half the surface area of the boiler at moderate temperatures of steam and twice - at high. Superheater can be made in the form attached to the boiler of a separate unit with its own firebox. As a rule, superheaters built into the system of steam generator. Built superheaters are of two types: radiation and convection. Radiation superheater surface is located so that it perceives the radiant heat from the combustion zone in the furnace of the steam generator. Radiation superheater surface passes a pair of 2-3 times more heat than the same surface by convection. Convection superheater located in areas of high gas passes boilers.

Economizer heats the feed water prior to its entering into the boiler through the heat of flue gas from the furnace. Economizers are divided into boiling and non-boilin type. The design of boiling and non-boiling economizers is essentially the same. Water is boiling at the exit (it is desirable that steam content does not exceed 25%) in the boiling economizer.

Most often economizers are made of tubes bent in the vertical coils and arranged in packages. For ease of maintenance and repair of the surface the economizer is divided into packets up to 1 m, making the gaps between 65-80 cm. Economizers location pipe is usually chess; hallway location in terms of heat transfer inadvisable. Before entering the boiler in thermal power plant, the feed water is heated in the regenerative cycle due to the extraction of steam from the turbine to 215-270 °C, which reduces required the surface of the economizer and increases thermal exciting of the steam cycle.

Air heater is a heat exchanger for heating air passing through it. Air heaters are widely used in boilers of thermal power plants and industrial, in industry furnace (for instance metallurgy, oil refining), air heating systems, fresh air ventilation and air conditioning.

Hot combustion gases are used for heating the air. Air heaters are divided into recuperative and regenerative based on the principle of operation. In recuperators air heater heat exchange takes place through the wall that separates the fluids. In the regenerative air heater heat exchange is carried out alternately heating and cooling fixed or rotary mass (metal or ceramic) that is alternately exposed to hotter and colder fluid. In thermal power plants mainly recuperative types of tubular air heaters are used.

2.3 Fuel system

In the world there is a variety fuels suitable for boiler: fossil fuels, peat, wood, agricultural waste, as such. Certain type of fuel corresponds to a certain type of boilers. Initially, the fuel can be divided into gaseous, liquid and solid.

Fluidized bed boilers can use different types of solid fuels. Fluidized bed boilers are often used for the burning of biofuels, because these types of furnaces are well suited for fuels with high moisture content in these furnaces can achieve big reductions SO_x and NO_x.

Fuel in CFB boilers is burned in a fluidized bed, which contributes significantly to the access of oxygen to the fuel in the combustion process, and as a consequence of intensifying the combustion and heat transfer to the heating surfaces, as well as more complete combustion. These factors can reduce the size of combustion chamber, and hence metal for boiler.

Fluidized bed is a collection of polydisperse particles, through which air is blown fluidize at a certain speed, sufficient for liquefaction and not exceeding the rate of entrainment of fuel particles from the furnace, if air velocity exceeds the speed of entrainment of particles after the cyclone furnace installed and this layer is called a circulating fluidized bed. In this case the particles of fuel are in a suspended state and intensively mixed in terms of firing, it helps increase air flow to all the particles of fuel and the combustion process. The fuel in the furnace is fed from the fuel bunker with "feeder". Feeders may be different by type. Moreover, the composition of fuel should be fine-grained, which follows from the conditions of a fluidized bed. The required composition of fuel is ensured through the use of the crusher or site dropout stage of fuel preparation and into the fuel tank enters the fuel with fine-grained fraction.

Ash is removed from the ash hopper to the conveyor belt deashing, for example, using the rocker-type unloader. It consists of a table with holes for sifting ashes, crank mechanism, gearbox and electric motor.

Stable and trouble-free operation of fluidized bed combustion chamber is influenced by characteristics and properties of solid fuels such as moisture, ash, fusibility of ash, fractional composition and volatiles.

Fuel moisture has little effect on the process of burning in a fluidized bed. However, sometimes the fuel may have restrictions on the moisture condition for efficiency spreader. In addition, the high moisture compounded throw fuel due to sticking it in the bunker.

Ash content of the fuels can range from 15 to 80%. The value of ash content below 15% may lead to a decrease in the number of inert filler and, therefore, violate the combustion process in fluidized bed.

Fusibility of the ash has a significant impact on the stability of the furnace with a fluidized bed, because from the beginning of the softening temperature of the ash depends on temperature in the layer on its upper control limit.

Fractional composition of fuel shod not very too much. However, large numbers of small fractions (0-1 mm) increase heat loss from carbon loss.

Volatile content affects the ignition temperature of fuel. The high yield of volatiles provides a lower ignition temperature of fuel, reducing the consumption of liquid fuel during ignition.

One of the advantages of fluidized bed furnaces is that they can be used for the incineration of many types of fuels for produce energy, or as a device for the destruction of combustible waste, in some cases, beneficial use of heat and in all cases with the simplification of the problem of harmful emissions.

Examples of fuels for fluidized bed boiler are all kinds of coal, waste treatment processes of coal, coal-water slurry, oil, shale oil, sludge oil, peat, wood chips, sawdust, gas, domestic waste, paint waste, waste fuel origin, worn tires (crushed),such as.

However, for each fuel a special design is required.

The efficiency of combustion of fuels in the furnaces of fluidized bed is affected by the following factors: excess air coefficient, the temperature in the layer, fluidizing air velocity, residence time of fuel particles, fractional composition of fuel.

The temperature in the layer is an important factor influencing the efficiency of combustion. However, this temperature should be restricted to 950^{o}C. The increase in temperature from 800 to 900^{o}C leads to improved combustion efficiency by about 3% with excess air of 25%.

Increasing the speed of fluidizing air increases the entrainment of unburned fuel particles from the combustion zone. In addition, turbulence is increased in the layer and this improves the mixing of fuel in the whole volume. For normal working conditions influence the rate of liquefaction slightly.

The total residence time of fuel particles in the combustion zone (at a sufficiently high temperature) is essential for the completeness of combustion. For boilers with fluidized-bed residence time depends on the thickness (height) of the fluidized bed and the thickness ratio to the height of free space in the furnace. To increase the residence time and thereby improve the combustion efficiency, increasing the height of free space is preferred over than the thickness of the layer. For boilers with circulating fluidized bed the same results can be achieved by setting the cyclone combustor for the free zone. An alternative is the use of recycled ash from the return of fly ash with unburned fuel in the fluidized bed. Since the particles are returned after a brief heating fuel in a fluidized bed to burn in space over bed. Temperature should be maintained at a high enough level to ensure a degree of post-combustion.

Fractional composition of fuel is important only for certain types of fuels, when not in use recycled ash. Effect of fractional composition of fuel on combustion efficiency depends on the behavior of different particles of fuel in a fluidized bed.

2.4 Water-steam system

Boilers can be divided into two subgroups according to the criterion of water circulation in the steam system: boilers with natural circulation and forced circulation boilers. In boilers with forced circulation pumps are installed. The water in the boiler is circulated by the pressure difference created by pumps.

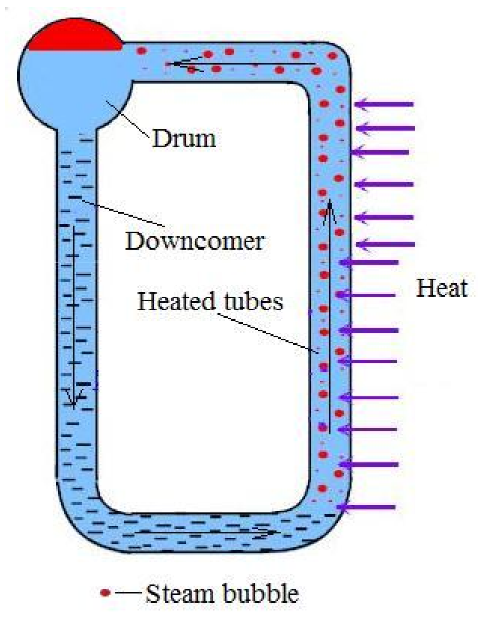


Figure 8. Schematic image of the natural circulation.

In boilers with natural circulation water moves by natural means. The circulation arises from the difference in the density (hence a pressure difference) of downcomers and heated tubes. Difference in densities arises from the fact that, in heated tubes with steam-water mixture density is loses than the density of water in downcomers.

In CFB boiler feed water is first directed to the economizer for heating. After the economizer heated water is taken to the drum, where it mixes with water situated therein. Then the water is sent to the screen tube, which partially evaporates turning into vapor. Then the resulting steam is sent to the superheater for superheating and achieve the desired temperature. After the steam superheater with the required parameters is sent to the turbine compartment. In the steam turbine compartment held its duty cycle in all the turbines. After the turbine compartment, the steam is sent to the condenser. Water used to condense the steam from a nearby reservoir. Throughout the cycle, are possible and there is loss of water. Therefore, after the capacitor eventually condense into water, add more water held water treatment, to replenish the losses. The water then goes to the economizer and etc.

Water treatment is an integral part of any boiler. From water treatment depends largely the life of boiler. Depending on the source of water different level of attention must be paid to the selection of proper water treatment systems. Quality water treatment equipment and its proper maintenance of industrial boilers provide long service life. An important part of water treatment process is deaeration. There are two basic types of deaeration: the chemical and thermal. Both types have than advantages and are used under certain conditions. Chemical deaerator is a compact device that contains a water treatment system and thereby simplifies the process of service. Thermal deaerator is a receptacle that can combine a deaerator and condensate tank.

2.5 Air-gas system

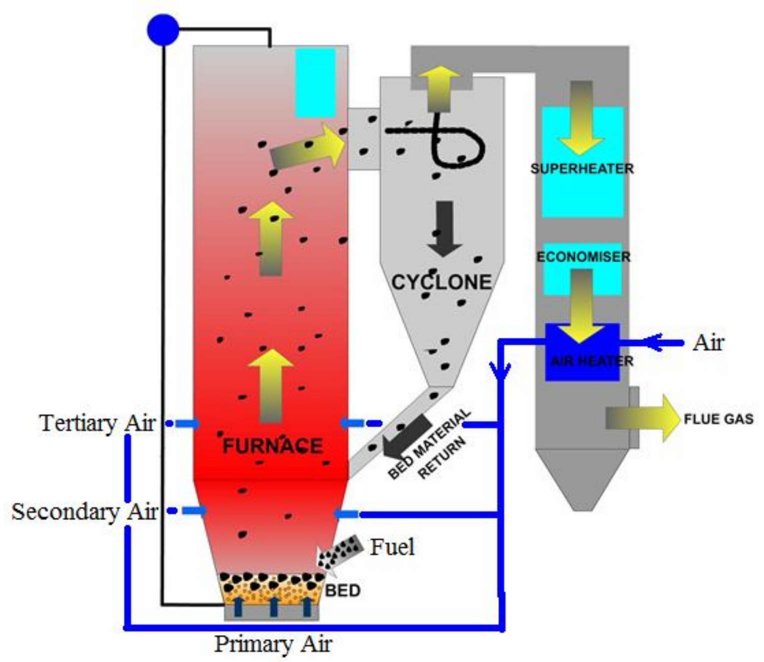


Figure 9. Scheme of air-gas system.

The proper functioning of the air-gas system depends on efficiency and service life of the boiler. Knowing the amount of fuel supplied to the boiler theoretically amount of air for complete combustion can be calculated. But in the boiler is fed more air because of imperfections in the furnace, because of all the possible losses, in the case of CFB boilers, and in order that a well-managed working material circulation furnace. All supplied air can be divided into three categories: Primary air, secondary air and tertiary air. (See Figure 9)

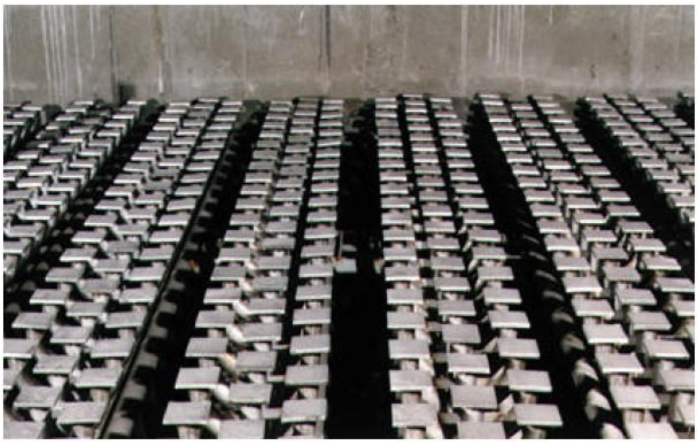


Figure 10. Grate of CFB boiler. (Salmenoja,2002)

Primary air is supplied through a special grate (see Figure 10) located at the bottom of the furnace. The air is supplied at high pressure, for circulation of the bed material.

Secondary and tertiary air streams are used for better control and completeness of combustion.

The air is fed into the furnace is taken from the atmosphere. The air goes to mechanical filters in the beginning, and then sent to the air heater. Air heater can be recuperative or regenerative type. After air heater air is distributed to the furnace and as a result on combustion. Flue gases are formed in the furnace. Flue gases are heating working medium in the boiler. After the furnace flue gases pass cyclone, where particles are released from the working environment, unburned fuel and ash. After the cyclone the flue gases are sent to the chimney. At the beginning of the flue is installed superheater, because at the beginning of the flue gases have the maximum temperature. After passing through the superheater flue gases pass economizer, air heater, and are then further directed to a system of flue gas cleaning exhaust gas to and smokestack.

2.6 Damage to heating surfaces

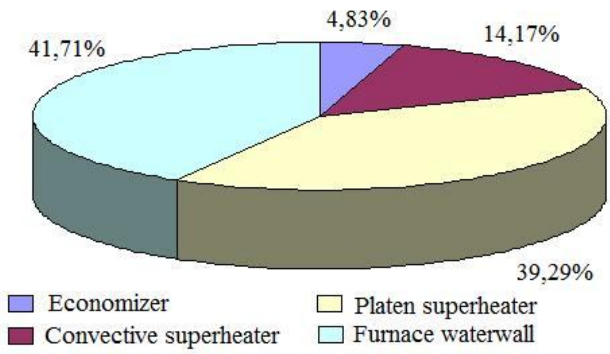


Figure 11. Statistics damage boiler unit on the elements. Data from (Yanov,2006).

The total length of pipes in modern boilers reaches tens of kilometers. Most minor damage to any parts of pipes can lead to fistulas or broken, causing an emergency stop of the boiler. Experience shows that maintenance and repair of power about 30-40% of failures units accounted for boilers and boiler auxiliary equipment. In turn, the main cause of failure is damage to the boiler heating surfaces. Approximately 50% of unplanned shutdowns is to the damage of the heating surfaces. Statistics show (see Figure 11) that about 50% of damages are accounted for semi-radiative and convective heating surfaces. Of these, 70% are accounted for platen superheaters. This statistics is typical for all types of boilers burning solid fossil fuels.

In practice offers the following characteristic damage of boiler piping system:

a) The increase in pipe diameter. Diameter of the screen tube is increased as a result of overheating in violation of the circulation of boiler water or sediment on the inner surface of scum and sludge. The circulation is disturbed due to clogged pipes.

With a weak circulation of water in the pipes is deposited sludge, further slowing or completely stopping its motion. When slowing down the circulation of water in the tube formed by the vapor bag. Steam to a much lesser extent, removes heat from the pipes than water, resulting in a wall overheats, the yield strength of the metal decreases and the tube is inflated by a pressure.

b) Wear (abrasion) of pipe walls. By an increased rate of dusty gas flow tube wall are subjected to abrasive wear and become thinner. Depreciation tubes occur mainly in the convective heating surfaces - on heating pipes and water economizer coils. The walls of the tubes are worn under the influence of the jet or stream, do not contain dust particles. The jets of steam or its mixture with water, pull up by the high velocity of the fistula or cracks in any one tube, often leave traces on the adjacent tubes. The walls of the tubes wear out from exposure to a fraction, used for cleaning the heating surface.

c) Warping and bending pipes. Some tubes from waterwall in the operation bend and protrude from the total number of tubes. The reason for this is often gripe individual tubes when passing them through the lining, leaving no gaps for thermal expansion of pipes. The pipes are bent and warped and because of excessive or uneven cold oversize, with the installation of the precipice of their attachment or violations of the normal circulation of water in the boiler.

d) Corrosion of tubes.

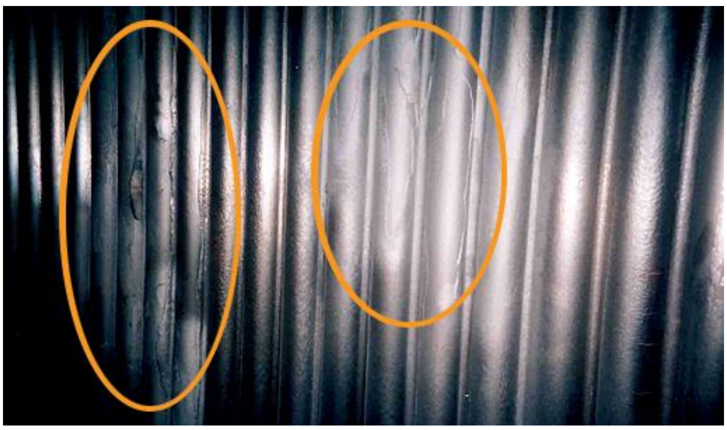
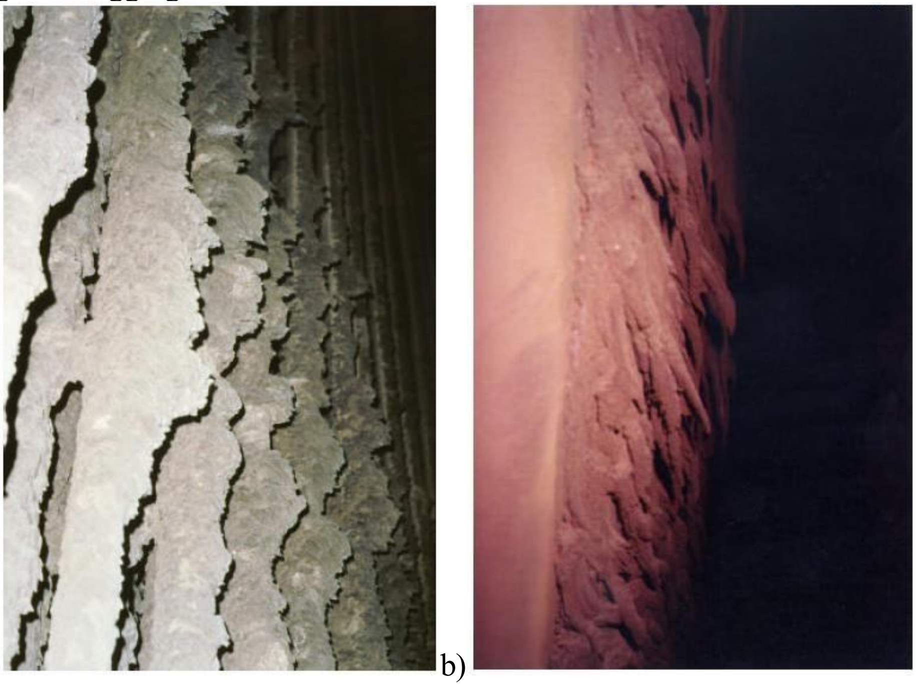


Figure 12. Corrosion of waterwalls tubes. (Salmenoja,2002)

On the outer and inner surfaces of pipes as a result of corrosion processes appear pockmarks and sinks, which can be converted to fistula. Corrosion on the outer surface of the pipe appears most often by burning sulfur fuel. Corrosion on the inner surface of pipes comes from exposure to the metal oxygen and carbon dioxide contained in the feed water. Chemical processes are enhanced with increasing pressure and temperature.

e) Fouling and slagging tubes



a) b)

Figure 13. a) Fouling and b) Slagging. (Salmenoja,2002)

The substances contained in exhaust gases can condense and stay on the heating surfaces, thus forming stable compounds, partially or completely solder between a pipe and block the passage of flue gases. The formation depends on:

- Temperature of flue gases;
- Coolant temperature;
- Tube material;
- Velocity of gas;
- Orientation of tube;
- Properties of fuel.

Especially the process drossing tube boilers are prone to fouling and slagging when using biofuels.

Deposits accumulate on heat transfer surfaces mainly by five different means: (EUBIONET, 2003)

1. Inertial impaction, where the bulk of fly ash cannot follow the stream lines of the gas flow and hit the heat transfer surfaces. The particle size is usually greater that 10μm.

2. Thermophoresis due to temperature difference in the gas. When the thickness of a deposit layer increases, the effect of thermophoresis is reduced as the temperature on the surface of the deposit layer approaches the gas temperature.

3. Condensation of vaporised compounds occurs after reaching heat transfer surfaces of sufficiently low temperature. This mechanism is pronounced in biofuel combustion.

4. Diffusion, an important deposition mechanism especially for vapours and particles smaller than 1μm.

5. Chemical reactions within the deposit layer and between gaseous and solid compounds.

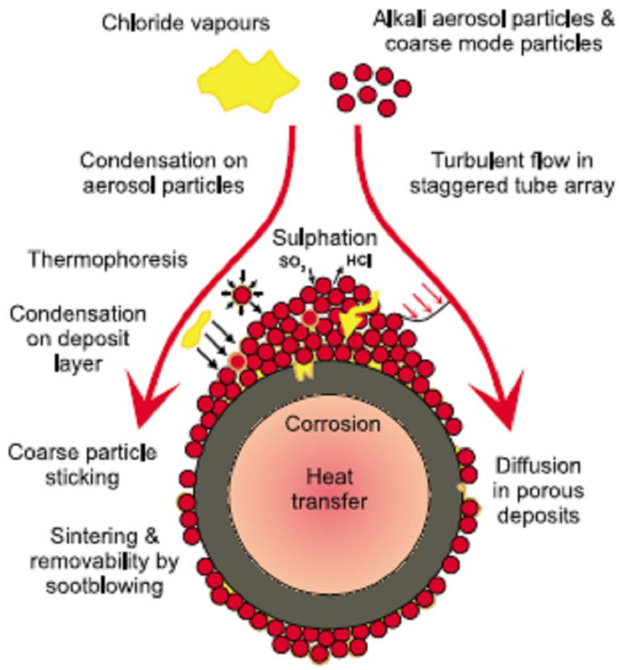


Figure 14. Schematic illustration of deposit formation and condensation of inorganic vapours on a superheater tube surface. (EUBIONET, 2003)

According to statistics, the causes of damage to one of the main causes of failures of boilers burning solid fuel is intense drossing and contamination of the heating surfaces (39%) or drossing caused by overheating of metal pipes. The reason for the large number of damage caused by drossing is the lack of information from operational staff on the intensity of drossing or contamination of each of the heating surfaces to date. Typically operational staff judged the intensity of drossing and contamination of the heating surfaces only on indirect indicators, analyzing the testimony of staff supervision.

Currently, there are several ways to combat the intense drossing and pollution of the heating surfaces of boiler:

-Modernization platen and convective heating surfaces;

-Security actions;

-The introduction of cleaning the heating surfaces;

-Complex technical boilers diagnostics.

Of these methods the most rational way to improve the reliability and efficiency of the boiler unit is supplying the steam boiler systems with technical diagnostics of the main and auxiliary equipment. Introduction of complex technical diagnostics to determine the optimal mode of operation of the boiler unit to ensure high reliability and efficiency of all its key elements in real time. It is also possible to implement automatic operation diagnosis of contamination and cleaning of heating surfaces.

It is possible damage to pipes during repairs due to accidental impact of a tool, details of collapsible metal scaffolding. Based on the analysis of the conditions of the metal and causes damage to the company executives exploiting developing activities to prevent damage to pipes of the heating surfaces. The residual deformation of heating surfaces pipes is convenient to check templates. Measurements are made in the zone of maximum temperatures in the same locations as indicated on the form. The results of measurements to be replaced:

-Tubes of carbon steel - at a value of residual deformation of 3.5% or more;

-Tubes of stainless steel - at a value of residual deformation of 2.5% or more;

-Tubes of waterwall - at a value of residual deformation of 2,0% or more.

Residual strain is defined with respect to the nominal outside diameter. The growth of the residual deformation of pipes of heating surfaces may be due to either overheating the metal or its creep. Damaged pipes may also be the result of corrosion wear (both external and internal surfaces), ash wear or deterioration from exposure to a jet of steam from blowing apparatus. To prevent damage to pipes of the heating surfaces, caused by corrosive wear is important to ensure proper working conditions of the metal. During overhaul the boiler to the state of devices, protecting tube from the local abrasive wear of fly ash and make measurements and record the amount of ash, shot and corrosive wear tube wall on the outside. If you suspect that excessive wear of pipe walls to keep a clipping of samples and measurements of the thinned part. The degree of internal corrosion control during the inspection of samples of tubes, carved at the sites, which were observed corrosion damage. Frequency of clippings set taking into account the corrosive action of water, but in any case not less than once every 5 years. If you wear exceeding adopted an increase to the calculated wall thickness, pipe or part to be replaced. In addition to these causes damage to the heating surfaces may occur due to work hardening shot, workmanship, external mechanical damage and corrosion fatigue, caused by the presence of variables, the sign of stress and corrosion. Warping heating surfaces pipes affects the aerodynamics of the boiler, causes uneven distribution of the flow of stack gases may lead to local overheating and damage to tubes. Warping waterwalls tubes called lack of freedom of thermal movement caused by jamming collectors, drums or individual tubes, mounting the steep, uneven heating and other causes.

3 FUELS

3.1 Energy classification

Energy [Greek. Energeia-activity] is the measure of motion of matter.

By the use of energy is classified into: thermal, mechanical, electrical, nuclear.

Sources of energy that can be used on Earth can be classified as:

- from outside, i.e. from space;
- located on the Earth and in its depths.

1. The external source is the energy of the sun and moon.
2. Sources on the Earth are the energy contained in fossil fuels, geothermal and nuclear energy.

External sources of energy form the Earth flow of air and water flows, temperature gradients, electric energy as lightning. Evaporation of water forms clouds, resulting in the formation water flows, from which you can get hydroelectric energy. Wind itself is a source of energy, and cause waves, which can also be transformed into electrical energy. The first plant to use the temperature gradient was established in 1926 in Cuba. Plant capacity - 40 Watts. For heat working medium used warm upper layers of the ocean, and for cooling - the deep layers.

The gravitational energy of the moon causes tides, the difference of water level reaches a few tens of centimeters up to 9 meters. This can be seen in the Americas in Passamaquoddy Bay between Maino in the U.S. and Brunswick, Canada. Tidal stations were installed in Russia in place of «kislaya guba» - 2 MW of electricity, in Canada - 20 MW and 240 MW in France. Believed that the potential of tides in the world is 64 thousand megawatts of electricity.

Geothermal energy is hot water and steam from the bowels of the Earth, as well as hot ground. In 1904 in Italy in place Larderello was drilled borehole, from which get the pairs. At present, this source of energy work station with a capacity of 400 MW of electricity. Fossil energy sources are uranium ore, coal, oil, gas and slate coal.

The result of solar energy is also the organic matter (biomass). The variety of organic energy resources will be described below.

Energy Resources of the Earth can also be divided into two broad groups:

- Renewable sources of energy;

- non-renewable sources of energy.

Non-renewable sources of energy include fossil fuels.(Erik Ravn,1999)

In accordance with Resolution № 33/148 UN General Assembly (1978) to non-traditional and renewable sources of energy include:

- peat
- biomass
- wind energy
- sun energy
- energy of water flows on land
- medium-and high-grade geothermal energy
- energy of the seas and oceans
- low-potential thermal energy

The peat is combustible fuel formed an accumulation of plant remains exposed to incomplete decomposition in swamps. Peat contains 50-60% carbon. Calorific value (max.) is 24 MJ / kg. World reserves of peat is 267 billion tons (1979).(Bulatov,1987)

Figure 15. Lump peat.

According to different estimates in the world from 250 to 500 billion tons of peat. It covers about 3% of the land. In Germany, the area of peat occupy 4,8% of territory, in Sweden 14%, in Finland - 30,6%. In Russia, the leader in peat, the employment share of the lands reaches 12,5%. The energy potential of peat in Russia is 49.5 billion tons of equivalent fuel. Also, there are large reserves of peat in Indonesia, Canada, Ireland, Great Britain and several U.S. states. If wood is within the carbon cycle, and extracting energy from it does not break this cycle, as well and peat is also within the same cycle. However, the ratio of peat is other than to wood. The author thinks it is relevant to the peat is absolutely not true. Because the EU does not regard it as quickly renewable source of energy, but considering how slowly renewable source of energy, peat does not cease to be biomass. And if we can get energy from peat, it is biofuels. Classification of peat in biofuels, which does not enjoy the benefits of the Kyoto Protocol does not make it to fossil fuels. We can assume that the EU's decision in respect of peat is political and economic direction, to create conditions for the development of forestry, agriculture, wind energy and other things. This is done to the detriment of some countries which use peat (Finland) and countries that have large reserves of peat (Russia, Canada).

Most EU countries do not have peat, perhaps for this reason to peat are not taken seriously.

Another surprising fact that the peat, as the true representative of organic matter, even mummified and partially decomposed, is not attributed to biomass, and allocated as a separate source of energy.

3.2 Biomass classification

Biomass energy can be divided into:

- Zoomass is the total number of living organisms;
- Phytomass is the total number of plants generated through photosynthesis.

Living organisms:

- Birds;
- Fish;
- Mollusks,
- Animals;
- Reptiles.

Energy from organic origin:

- Waste products of living organisms;
- Waste of cattle slaughter;
- Waste of bird slaughter;
- Waste from fish processing;
- Waste from loss of cattle and poultry;
- Shells of crustaceans and mollusks.

Institute of Chemical Engineering University of Technology, Vienna, Austria, biofuel is classified into 647 species, which, in turn, are divided into 8 groups.

This is:

- o Wood;
- o Straw;
- o Wood waste;
- o Bark;
- o Energy planting;
- o Shells, husks and skins, peelings, stones;
- o Grass;
- o Other (Sludge, pulp, seeds, paper).

Energy planting is planting fast-growing shrubs and trees on temporarily taken out of agricultural use land.

The shells, husks and skins, stones are a husk seeds, seeds in the production of cereals, shell nuts, peel of citrus fruits. If the processing industry these wastes are a problem, can be make from them pellets or briquettes. It should be noted that this material has very high calorific value.

Paper and cardboard, which are not used as a secondary raw material, can be used as a fuel and combusted in boilers or formed granules, and including mixtures with other fuels.

Others are for example, sludge, raw material is specific and is on treatment plants. In a mixture with other fuels Sludge can be used.

In trees and shrubs energy source is:

- Wood;
- Bark;
- Reproductive organs (buds);
- Fruit, pine needles, leaves, resin.

Wood is not only forests, but also fruit trees and shrubs. This includes wood, grown exclusively for energy. This energy planting is fast-growing species such as willow and poplar. However, breeding of fast growing species is not judicious in a small volume of annual timber growth or in the presence of millions of cubic meters of overmature wood. Wood is used directly in the form of firewood, wood chips, dust, granules, and for production other energy sources - coal, alcohols, flammable gas, liquid energy.

During of fruit processing producers waste for example orange peel or a grape seeds. Such wastes can be an environmental issue and a source of energy. In Brazil, waste of oranges processing used for production alcohol.

Grasses and herbaceous plants:

- Crops and grasses (wheat, rye, oats, canola, winter cress, alfalfa, etc.);
- Cereals (cane), sugar cane;
- Cyperaceae (cane, bamboo);
- Umbrella (cow parsnip);
- Field, prairie grass (canary);
- Algae, mosses, lichens.

Biofuels in this case are:

- Stems, roots;
- Fruits;
- Seeds

Grass, for example canary red from which can be produced pellets, unless other sources are exhausted. Biodiesel produce from seeds of bitter cress and canola. In the absence of intensive agriculture, a large amount of crop residues is not formed, but in some cases, they can create local problems. For example sunflower husks, rice husks. In the rural economy a significant amount of waste can be used as fuel for decentralized sources of electricity and heat, for example, through the gasification of energy. Calorific value of grasses and herbaceous plants not low and in some cases even higher than that of wood. However, wood is considered as a more reliable source of energy than grass. (Sendetsky)

3.3 Fuel properties

All considered wood, agricultural, and other biofuels, as well as peat, solid fuels are composed of combustible parts and ballast. Ballast form ash and moisture. The ash and combustible part (without water) form a dry mass of fuel.

In the elemental composition of bio-fuels is mainly dominated by five chemical components: carbon (C), hydrogen (H), sulfur (S), oxygen (O) and nitrogen (N). Carbon, hydrogen and sulfur are combustible elements and forms combustible part of fuel. The sulfur content in fuel is of interest primarily occurrence of sulfurous waste. However, high sulfur content can be occurred threat of low-temperature corrosion in breeching and smokestack. Chlorine can also cause corrosion of heating surfaces, it is important to know its content in fuel. Chlorine can create problems during combustion, such as softwood chips, if their share of the fuel is sufficiently high. Although the content of heavy metals in biofuels will not reach dangerous values in the case of stringent requirements for protection of the environment they should be considered, and especially the burning of industrial and domestic waste. Even different parts of the tree contain different proportions of small amounts of nickel, arsenic, cadmium, chromium, copper, mercury, lead and zinc.

The most important parameters of the fuel are direct ash, moisture, volatile and fixed carbon, as well as the heat of combustion.

Ash content, moisture, volatile and fixed carbon can be expressed in several ways (see Fig. 16):

- •% of dry mass (d);
- •% of moist fuel (m);
- •% of combustible mass– dry ash-free (daf).

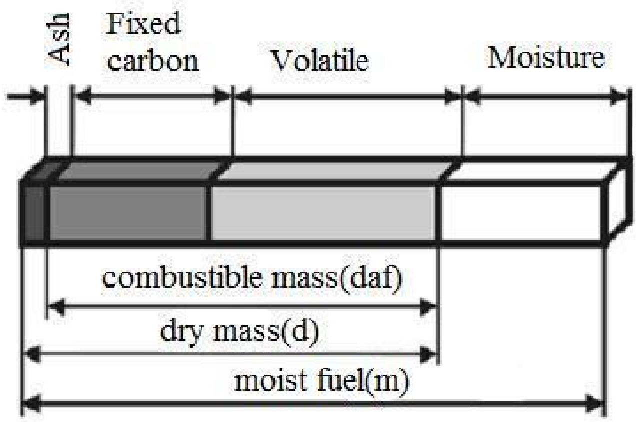


Figure 16. Components of solid fuels.

Moisture of fuels is a variable, so the table reference for ash content and volatile prefers to be in % of dry mass, but in practical boiler calculations it is used mainly in % of the working masses of moist fuel.

Between the ash content of dry mass and the ash content of working mass (moist fuel) there is the following relationship:

$$A_d = A_m 100/(100 - W_m), \qquad (3.1)$$

where A is ash content of fuel[%]

W – moisture content of fuel [%]

Fuel moisture is determined by drying a sample of fuel in the oven at 105 ± 2.C to constant weight:

$$W = (m_1 - m_2)/m_1 \cdot 100, \tag{3.2}$$

where W – fuel moisture [%]

m_1- mass of wet fuel sample [g]

m_2 - mass of dry fuel samples [g]

Measuring of moisture is an important procedure for acceptance of fuel, especially when the amount of fuel is measured by weighing.

Volatile measured by a standardized method, which involves heating the dry sample fuel without access to oxygen (900 ± 10) ° C for 7 minutes. Volatile(V) are found to change the masses, as in the determination of moisture content, and expressed as a percentage of dry (V_d) or a dry ash-free (V_{daf}) mass.

Value of carbon in the composition of volatile and fixed (C^f) determines the ratio of heat released in the plume (furnace volume) and the layer of burning fuel. Since volatile in many biofuel high (V_{daf} = 80 - 90%), most of the heat released when they are burned in the furnace volume.

Fixed carbon is a carbon remaining after the release of volatiles. Fixed carbon content of expressed as a percentage and calculated as a share of non-ash dry weight after the release of volatiles:

$$C_{daf}^{f} = 100 - V_{daf} \tag{3.3}$$

$$C_{d}^{f} = 100 - A_d - V_d \tag{3.4}$$

$$C_{m}^{f} = 100 - A_m - W - V_m \tag{3.5}$$

3.3.1 Heating value

Heat value is called the amount of heat released during combustion of unit of fuel mass. Measurement of heat value produced in the so-called “bomb calorimeter”. With heating value in a “bomb” expect higher heating value (HHV) and lower heating value (LHV) of fuel.

Higher heating value (HHV) is the amount of heat that is emitted in the complete combustion of substances, including the heat of condensation of water vapor in the cooling combustion products. Lower heating value (LHV) corresponds to the amount of heat that is emitted by complete combustion, without the heat of condensation of water vapor. Difference between higher and lower heating value of fuel greater, than higher moisture content of fuel and hydrogen content.

In most cases the flue gases leaving the boiler through smokestack at a temperature above 100 °C that is significantly above the dew point, and in these conditions the energy of condensation of water vapor is not used. In the case of so-called "clean fuels", in which virtually no sulfur and chlorine, for example natural gas and wood, can be cooled the flue gases to 40 - 60 °C and obtained from condensation of water vapor 15 - 20% additional heat. Thus, in the "normal" boilers used the lower heating value, in installations with condensation of water vapor from flue gases using higher heating value. In practice, adopted to calculate the efficiency of the boiler using lower heating value, that for boilers with condensation of water vapor leads to efficiency more 100%. Of course, this is not a violation of the law of conservation of energy, its tradition and agreement permit to compare of the efficiency of boilers of various types.

Heating value is usually expressed in MJ/kg or kJ / kg, with a basis can be adopted mass of wet, dry or dry ash-free fuel. Designating the hydrogen content in dry fuel - H_d, we obtain the following relations between low and high heating value (MJ / kg):

$$Q^{m}_{HHV} = Q^{d}_{HHV} \cdot (1 - W/100) \tag{3.6}$$

$$Q^{d}_{HHV} = Q^{daf}_{HHV} \cdot (1 - A_d/100) \tag{3.7}$$

$$Q^{d}_{LHV} = Q^{d}_{HHV} - 2{,}442 \cdot 8{,}936 \cdot H_d/100 \tag{3.8}$$

$$Q^{m}_{LHV} = Q^{d}_{LHV} \cdot (1 - W/100) - 2{,}442 \cdot W/100 \tag{3.9}$$

$$Q^{m}_{LHV} = Q^{m}_{HHV} - 2{,}442 \cdot \{8{,}936 \cdot H_d/100 \cdot (1 - W/100) + W/100\} \tag{3.10}$$

If heating value measured and reported in the references, mainly to unit mass, the boiler is often better to assign it to one unit, which calculates the number-incoming fuel. Such a unit in the case of wood chips can be, for example, volume in m^3. To link heating value per unit mass and volume, you need to know the specific weight (density) of fuel. In the main heating value is determined per unit mass of moist fuels, but humidity fluctuations that way of presenting data can lead to inaccuracies. Another possibility - include heat value of 1 kg dry fuel. For a typical range of moisture measurement errors biofuels influence of moisture on the magnitude of heating value of the dry portion is substantially lower than heat value amount of the working masses of wet fuel.

3.3.2 Ash characteristics

Although the ash content of wood fuel, as well as other solid biofuels, low (few percent), fusibility characteristics of ash directly affect the operation of the boiler. Ash fusion can cause drossing firebox and dense appearance deposits on convective heating surfaces. There are a number of standards to determine the characteristics of ash fusibility: ASTM D 1857, ISO 540 и DIN 51730.

According to ASTM standard measure change in cone shape of ash when it is heated in an oxidizing environment (see Fig. 17):

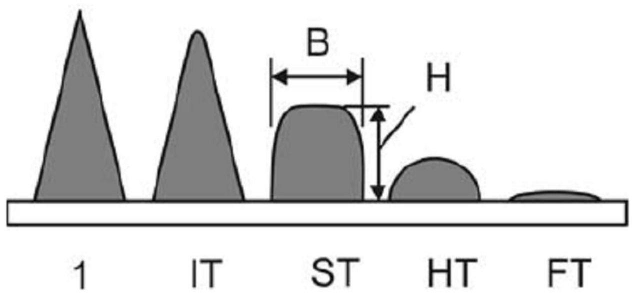


Figure 17. Changing form of standard cone on heating. (Alakangas,2000)

The notation used in the figure:

1 - Original state prior to heating cone has sharp tip;

IT - beginning of deformation, sharp tip rounded;

ST - softening temperature, ash cone is flattened, so that the height of the cone is reduced to a diameter (H = B);

HT - point of education hemisphere, cone converted to a hemisphere (H = B/ 2);

FT - point spreading, liquid ash spreads over surface.

Fusibility characteristics ash can vary widely depending on the type of biofuel, place of biofuels production, method of making/production biofuels, inclusions belonging to a fuel (e.g. from soil). Even ash varies in different parts of tree. According to published sources fusibility characteristics of wood ash vary within the following limits:

• Beginning of deformation IT = 1150 – 1490°C;

• Softening temperature ST = 1180 – 1525°C;

• Point of education hemisphere HT = 1230 – 1650°C;

• Point spreading FT = 1250 – 1650°C. (Alakangas,2000)

If bark softening temperature is usually quite high (above 1500 °C) and does not cause drossing firebox and grate, the ash from sawdust and wood chips is much lower, and to avoid problems drossing need to strictly maintain the combustion. Fusibility of ash depends on its mineral composition, and even small differences in the composition can significantly change fusibility characteristics. It is impossible to predict the fusibility of ash on fuel composition and ash composition.(Biedermann)

3.4 Use of mixed fuels

In the world there are many different types of biofuels and the properties of these biofuels are different. Properties of biofuels differ significantly from the properties of coal. For example, the yield of volatile from wood biofuels about 80%, while coal is usually about 30%, the same difference in chemical composition and properties of fuel ash. It is important to thoroughly and accurately know the properties of fuels are used in the pot together. Fuel used together to complement and enhance each other. The properties of fuel mixture should be chosen so that the effectiveness of their use in the boiler was maximal. And for this it is necessary to know the properties of biofuels separately. It is important to monitor the chemical composition of ash, and physical properties of ash, because ash properties affect drossing boiler. Weed of the heating surface usually alkali metals. In wood fuels alkali metals are in form of salts or organic compounds. In peat inorganic constituents are most commonly associated in the form of silicates, which are more stable at higher temperatures. It is important to monitor the chlorine and sulfur in the fuel. Even a little chlorine can lead to the formation of alkali and chlorine compounds. In turn, these compounds cause corrosion of the boiler heating surfaces. This phenomenon can be prevented with chlorinated fuel to use fuel containing silicate of aluminum. Some types of peat contain silicate of aluminum. Especially be careful when co-combustion to use various wastes, including wastes from wood production. Because this can significantly increase the emissions of harmful substances into the atmosphere, increase the intensity drossing, and cause corrosion, because it wastes contain many different elements. Waste timber production, such as waste from the production of fiberboard, particleboard, plywood, may contain various impurities and additives, from adhesives and treatment. But the price of this waste is much lower than the standard wood biofuels (pellets, briquettes).

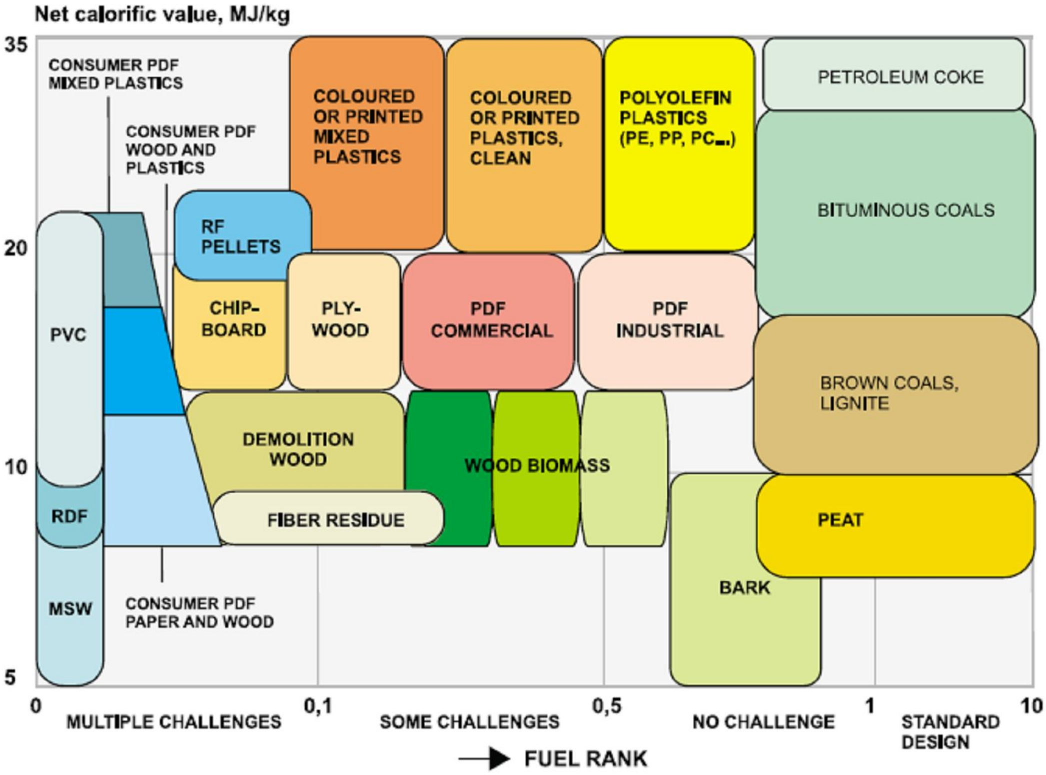


Figure 18. Influence of fuel characterisation to boiler design(EUBIONET,2003)

Table 1. Typical Properties of solid fuels. (EUBIONET,2003)
d=dry basis *-in ash

TYPICAL PROPERTIES OF SOLID FUELS									
Property	Coal	Peat	Wood without bark	Bark	Forest residues (coniferous tree with needles)	Willow	Straw	Reed canary grass (spring harvested)	Olive residues
Ash content (d)	8.5-10.9	4-7	0.4-0.5	2-3	1-3	1.1-4.0	5	6.2-7.5	2-7
Moisture content, w-%	6-10	40-55	5-60	45-65	50-60	50-60	17-25	15-20	60-70
Net calorific value, MJ/kg	26-28.3	20.9-21.3	18.5-20	18.5-23	18.5-20	18.4-19.2	17.4	17.1-17.5	17.5-19
C, % (d)	76-87	52-56	48-52	48-52	48-52	47-51	45-47	45.5-46.1	48-50
H, % (d)	3.5-5	5-6.5	6.2-6.4	5.7-6.8	6-6.2	5.8-6.7	5.8-6.0	5.7-5.8	5.5-6.5
N, % (d)	0.8-1.5	1-3	0.1-0.5	0.3-0.8	0.3-0.5	0.2-0.8	0.4-0.6	0.65-1.04	0.5-1.5
O, % (d)	2.8-11.3	30-40	38-42	24.3-40.2	40-44	40-46	40-46	44	34
S, % (d)	0.5-3.1	<0.05-0.3	<0.05	<0.05	<0.05	0.02-0.10	0.05-0.2	0.08-0.13	0.07-0.17
Cl, % (d)	<0.1	0.02-0.06	0.01-0.03	0.01-0.03	0.01-0.04	0.01-0.05	0.14-0.97	0.09	0.1*
K, % (d)	0.003	0.8-5.8	0.02-0.05	0.1-0.4	0.1-0.4	0.2-0.5	0.69-1.3	0.3-0.5	30*
Ca, % (d)	4-12	0.05-0.1	0.1-1.5	0.02-0.08	0.2-0.9	0.2-0.7	0.1-0.6	9	

There are many different biofuels suitable for co-combustion, properties of some of them displayed in the table 1. By co-combustion are well suited different types of wood fuel. Boilers with fluidized bed and grate boilers can use a wide range of biofuels. Pulverized fuel boilers able to use fewer types of biofuels and has more stringent standards for fuels. Co-firing coal and wood are widely distributed in Europe and USA. Often wood biofuels added in small quantities, only 5-10% of the total mixture. This amount of biofuels does not reduce the efficiency of boiler, but significantly reduces the cost of fuel consumed and reduces emissions.

There is experience of co-combustion of agricultural residues and coal. In Europe conducted study of co-combustion coal and waste from the production of olive oil. Wastes from the production of olive oil called «alpeorujo». Studies have shown that when added to a mixture of about 10-25% «alpeorujo», boiler efficiency is not decreasing and increasing slagging not significant. Increasing percentage add «alpeorujo» caused problems with burning. Studies have shown that use «alpeorujo» beneficial only in boilers located close to places of production of olive oil, because transportation «alpeorujo» is not profitable.

Studies of co-firing straw with coal has shown that the best performance achieved by adding 20% of straw in the mixture. This percentage does not decrease the efficiency of the boiler and not increasing drossing and corrosion. If you add a larger percentage of straw increases degree of drossing and corrosion. This is caused by a high content of chlorine and potassium in the straw. (EUBIONET,2003)

3.4.1 Types of technological configurations for biomass co-firing

Three basic types of technological configurations for biomass co-firing in power plants can be identified: direct co-firing, parallel co-firing, and indirect co-firing.

Direct co-firing

In this option biomass enters the boiler together with coal. In case of direct co-firing of biomass with coal in large-scale PC boilers, the following options are possible:

Blending biomass with coal in the fuel yard and transportation of the mix through the coal system with the application of coal processing and combustion equipment. This is the cheapest and most straightforward option; however problems resulting from differences in the characteristics of the two mixed fuels can occur. Also, some types of biomass cannot be processed this way, for example herbaceous biomass is known to cause many problems during feeding and sizing. It can be applied to biomass like olive/palm kernels or cocoa shells as well as saw dust. There are a number of projects in Europe based on this option, but its application is considered to be limited.

Separate milling of biomass, mechanical or pneumatic feeding to the boiler followed by firing of the biomass material through existing coal injection system and burners. In this case the fuel mixing takes place in the combustion chamber, thus without impacting the fossil fuel delivery system. This option involves higher investment.

Installation of new, dedicated biomass milling and sometimes also burning equipment. This option increases the number of biomass materials, which can be fed to the boiler. There are projects in Europe based on this option, although it is relatively complex and expensive to install.

In the direct co-firing configuration, a minimum investment is necessary, but may face various shortcomings resulting from differences between the properties of mixed feedstocks. One of them is that the biomass ashes become mixed with coal ashes. Although coal ashes and, to a lesser extent, biomass ashes might be reused separately, the reuse of mixed ashes may be restricted substantially.(Livingston,2005)

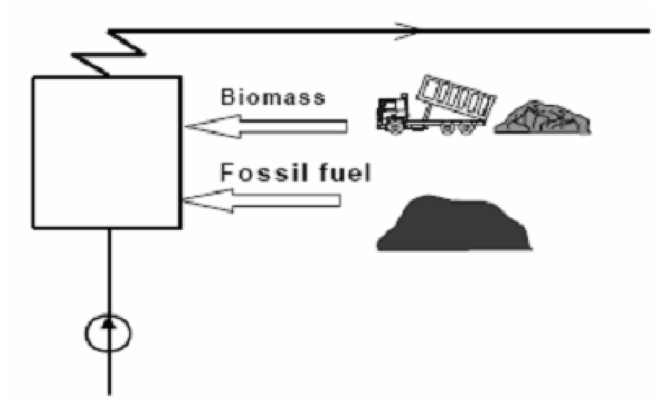


Figure 19. Simplified process layout of the unit performing direct co-firing. (Zuwala,2005)

Parallel co-firing

In this option biomass is combusted in a separate boiler, supplying steam to a common header. There is no technical possibility of supplying the biomass combusting boilers with fossil fuels, thus the fuel preparation and feeding are physically independent.

In this option, the potentially limiting factor in retrofitted power plants can be the capacity of existing downstream infrastructure such as steam turbine. The amount of biomass that could be co-fired could be limited by the steam generator capacity, so it should be made sure that there is sufficient overcapacity of steam turbine to accommodate the extra power from biomass combustion.

In parallel co-combustion configuration the biomass and coal ashes are kept separately. Since coal and biomass are converted in different units, an optimal system for each fuel can be chosen. The investment in parallel co-firing installations is significantly higher than in direct option; however the possibility to optimize the combustion process, use relatively difficult fuels with high alkali and chlorine contents, and the separation of the ashes are possible advantages.(Livingston,2005)

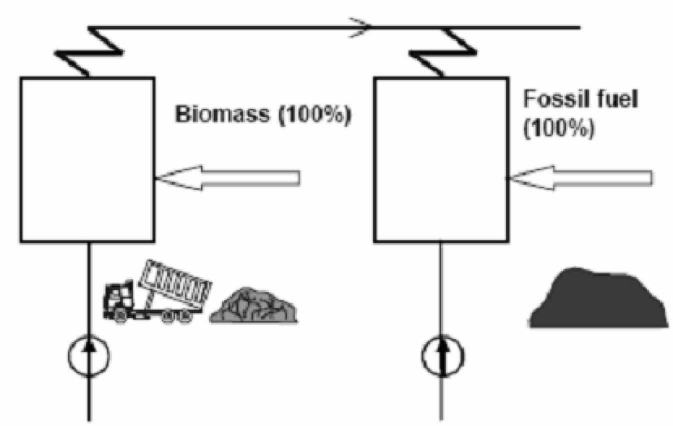


Figure 20. Simplified process layout of the unit performing parallel co-firing. (Zuwala,2005)

Indirect co-firing

In this option biomass is gasified (or combusted) separately and the produced gas is injected and burned in the coal boiler. This technique keeps the biomass ashes separated from the coal ashes, while allowing very high co-firing ratios. The drawback of indirect co-firing option is relatively high unit investment costs.

Indirect co-firing by pre-gasification is currently operated in a number of demonstration plants in Austria (Zeltweg), Finland (Lahti) and the Netherlands (Geertruidenberg).

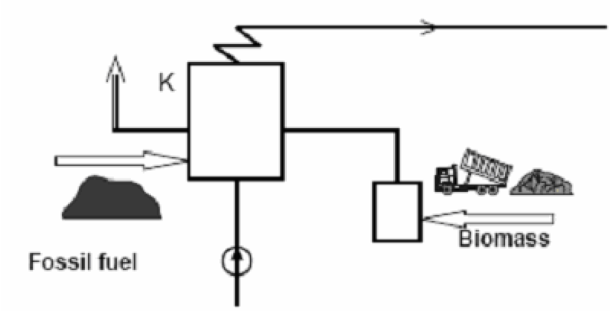


Figure 21. Simplified process layout of the unit performing indirect co-firing. (Zuwala,2005)

3.4.2 Emission reduction

The main feature in the co-firing of fossil fuels and biofuels is to reduce emissions CO2, SOx and NOx. Carbon dioxide released from burning of biomass does not increase the total content of carbon dioxide in the atmosphere, because it participates in the general carbon cycle in nature.

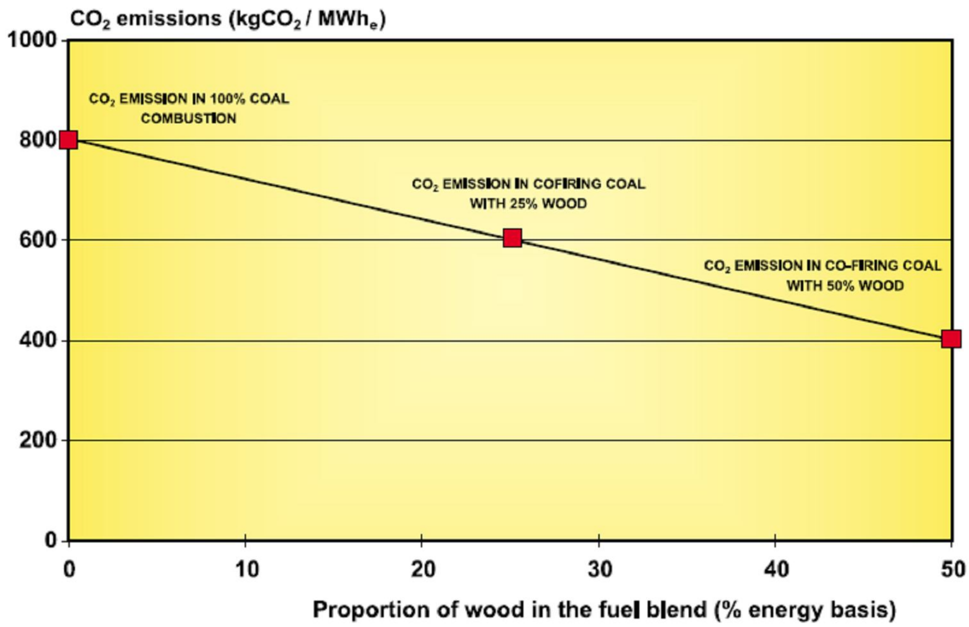


Figure 22. Theoretical decrease in CO2 emissions by co-firing of wood with coal.(EUBIONET,2003)

NOx is a symbol of all nitrogen oxides that may be formed in the boiler. When burned mix of fossil fuels and biofuels reduced emissions of NOx, due to the fact that the combustion of biofuels does not have to maintain high temperatures. Biofuels tend to have a large amount of yield of volatile and low content of fixed carbon. Also, contained calcium, potassium and sodium in the biomass have a catalytic effect on reducing NOx. SOx emissions reduced by mixing biomass with fossil fuels. Firstly because sulfur content reduction in the total mass of the mixture, since biomass usually contains a small amount of sulfur. Secondly, the biomass ash often contains calcium, and calcium can act as a sorbent for absorption SOx and formation of calcium sulfate.
Various parameters affected on emissions: method of fuel combustion, temperature in furnace, chemical composition of fuel, method of filing and number of supplied air, etc. Accurate predictions of what would be the emissions from the combustion of a fuel mixture are difficult, in some cases it is better to set up experiments.(EUBIONET,2003)

3.4.3 Experience in use of mixed fuels

Most of the problems arising from fuel combustion occurs because the fuel properties. There are the following differences between the properties of biofuels and coal:

- For biofuels pyrolysis occurs earlier
- Volatile in biofuels more than coal

- Biomass heat value is lower than coal heat value
- Biofuel contains more oxygen than coal, biofuels are more porous and more reactive
- Ash of biomass more alkaline, which could aggravate the problem of contamination of the boiler heating surfaces
- The chlorine content in the biofuel can be more, but usually the content of sulfur and ash in the biofuel less than coal.

Of this differences in co-firing of coal with biofuels can expect the following consequences:

- Increasing the rate of deposits formation
- May need more frequent cleaning of heating surfaces of boiler
- Increased risk corrosion of boiler heating surfaces
- Increasing temperature of flue gases
- Reducing emissions of CO2, SOx and NOx

The magnitude of these effects depends on what kind of fuel will be mixed with coal and in what quantities.

In Finland, conducted a project on use of wood for biofuel boiler. The aim of the project was to determine the critical properties of wood fuels, the operation unit to determine the optimal conditions for reducing the gaps, and explore how the storage and processing of various types of wood affect the operation of the boiler. Twelve boilers with fluidized bed with capacities from 100 to 300 MW participated in the experiment. As a result of the project, it was noticed that more than half of the boiler:

- there were problems with supply, loading and unloading of fuel
- some problems were noted with the fluidized bed using various types of wood
- was noted the influence of changing fuel temperature in the furnace
- encountered problems due to the change of temperature in the furnace
- was noted an increase in deposits by using wood fuel
- was noted variations in the quality of supplied wood fuel
- was noted changes in the quality of ash by using of wood fuel

Also, more than 80% of the boiler, it was noted:

- opportunity to file fuel into the furnace smoothly and quietly
- wood fuel can be distributed evenly to all sides in the oven

- that the use of wood fuel does not increase the need for soot blowing
- using of wood fuel would significantly reduce emissions from the boiler.(EUBIONET,2003)

Examples of power plants using mixed fuels combustion are presented in Appendix 3.

4 HEAT BALANCE MODELING SOFTWARE IPSEpro

IPSEpro is the program of the Austrian firm SimTech Simulation Technology.

IPSEpro is a highly flexible environment for modeling, simulation, analysis and design of components and processes for energy and chemical engineering (IPSEpro,2003). SimTech is currently offering four standard libraries: power plant, gas turbine, refrigeration and desalination. All these libraries include physical properties and the user can also add new physical properties. The power plant library contains components for conventional power plants, cogeneration power plants and combined cycles for instance. The gas turbine library contains predefined models of the most common commercial gas turbines on the market. It can be used together with the other libraries for system simulation and analysis. The refrigeration library contains the thermodynamic properties of more than 50 refrigerants and ammonia/water and lithium-bromide/water mixtures for absorption heat pumps. The desalination library contains components for the modeling and optimization of multi-stage flash desalination processes. (SimTech,2010)

Different scheme can be created many processes can be simulated with IPSEpro. Standard library components or components made by the user can be used to create charts and models.

IPSEpro allows flexibility at two levels

- The Component Level. IPSEpro has not limited flexibility and great potential for creating various diagrams and models. Existing models can be changed and new models can be created in the library. The process of creating new models is complex and interactive. You can create a new graphical and a mathematical model using subprogram MDK.
- The Process level. IPSEpro allows complete freedom in arranging the available components in order to represent a process scheme. Graphical interface allows access to any object, look or change its settings. All calculations are also immediately visible in a graphical diagram. During creating of a schema, chose a

component from an accessible library, move it into the working window and connect it with other components of the scheme.

Only one component, or part of the general scheme or process, or whether the whole scheme can be simulated in IPSEpro.

Note the following features of the software IPSEpro. Modeling is based on solving systems of nonlinear equations based on the components and fluxes used in the model. Calculations are made on the basis of mass and heat balances, as well as the equations for the pressure losses and dimensionless conductance. IPSEpro program allows changing the input values until a unique solution. The results of the successful simulation can be used in the following simulation.

Among the negative features of the program would like to point out just one, but, in the authors opinion, very weighty negative property. If for some reason the scheme can not be calculated, the program gives out the window, stating an error, but exactly where the error, and how it would be cost to fix the program does not show.

MDK is Model Development Kit of IPSEpro for construction new component models or modifying existing ones in a library.

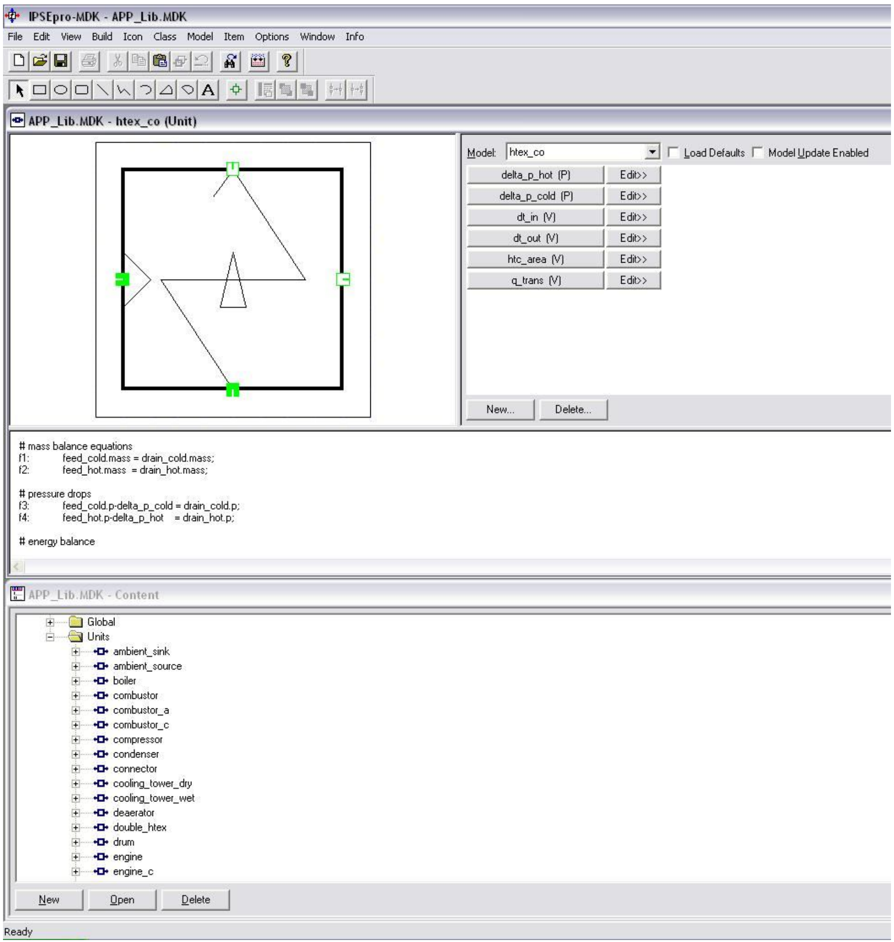


Figure 23. Operating window of Model Development Kit.

Mathematical model of the element of the overall system can be build with MDK. Can be gave it a graphical form and asked what parameters should be input for this element and which outputs and how they depend on each other. Change component from library, giving it new properties and functions easier than build a new component from scratch.

PSE is Process Simulation Environment of IPSEpro. Circuits using components from available libraries can be created with IPSEpro. The component library selected and transferred to a working window where it connected with other components. Upon completion of the construction scheme, it should be, ask all the necessary parameters of components. Then it is possible to carry out the process of calculation. The results of calculations also appear on the diagram. If it needs to calculate ratio of any parameters or perform any other mathematical calculations with parameters of the system, it can be done in the workspace IPSEpro, creating tables with calculations.

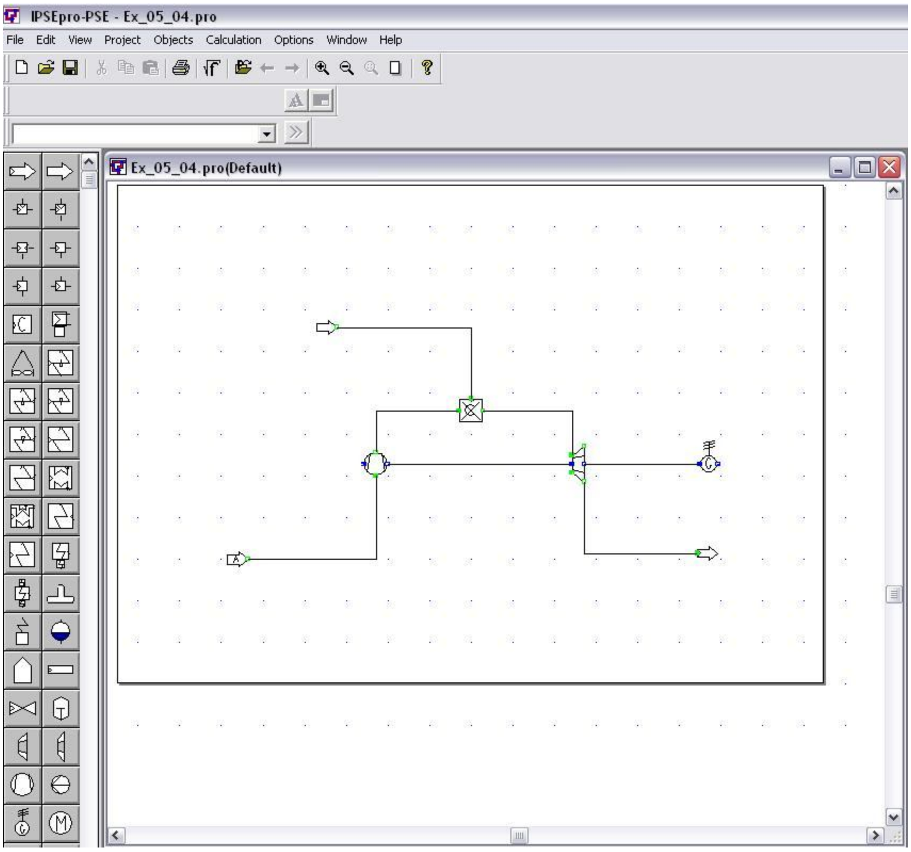


Figure 24. Operating window of Process Simulation Environment.

The Advanced Power Plant Library for IPSEpro has been designed for modelling a wide range of thermal systems. The design of this library is based on many years of experience, gained with the power process modelling package.

The Advanced Power Plant Library allows designing and analyzing any power plant, including:

- Combined-cycle plants.
- Cogeneration plants.
- Conventional plants.

The library contains models for both design and off-design analysis.

The component models are formulated in a way that virtually all of them can be used in connection with a wide range of working media.

PSE-MS Excel Integration is a module of the program allows exchanging data between the PSE and MS-Excel.

This element of the program allows transferring data obtained from the model constructed in the PSE to the workspace MS-Excel and allows working further with the data in MS-Excel, or creating a report with data on the work done in PSE.

Another helps promote the ability to the PSE-MS-Excel Integration Module is possibility to transfer to Excel series of different calculations with model. These calculations can be obtained by varying some parameters of system components. (IPSEpro,2003)

5 BOILER MODEL AND SIMULATION RESULTS

The boiler model was built in the program IPSEpro for a number of experiments on the use of mixed biofuels. The basis of the boiler model was adopted by the boiler-type CFB kaukaan boiler.

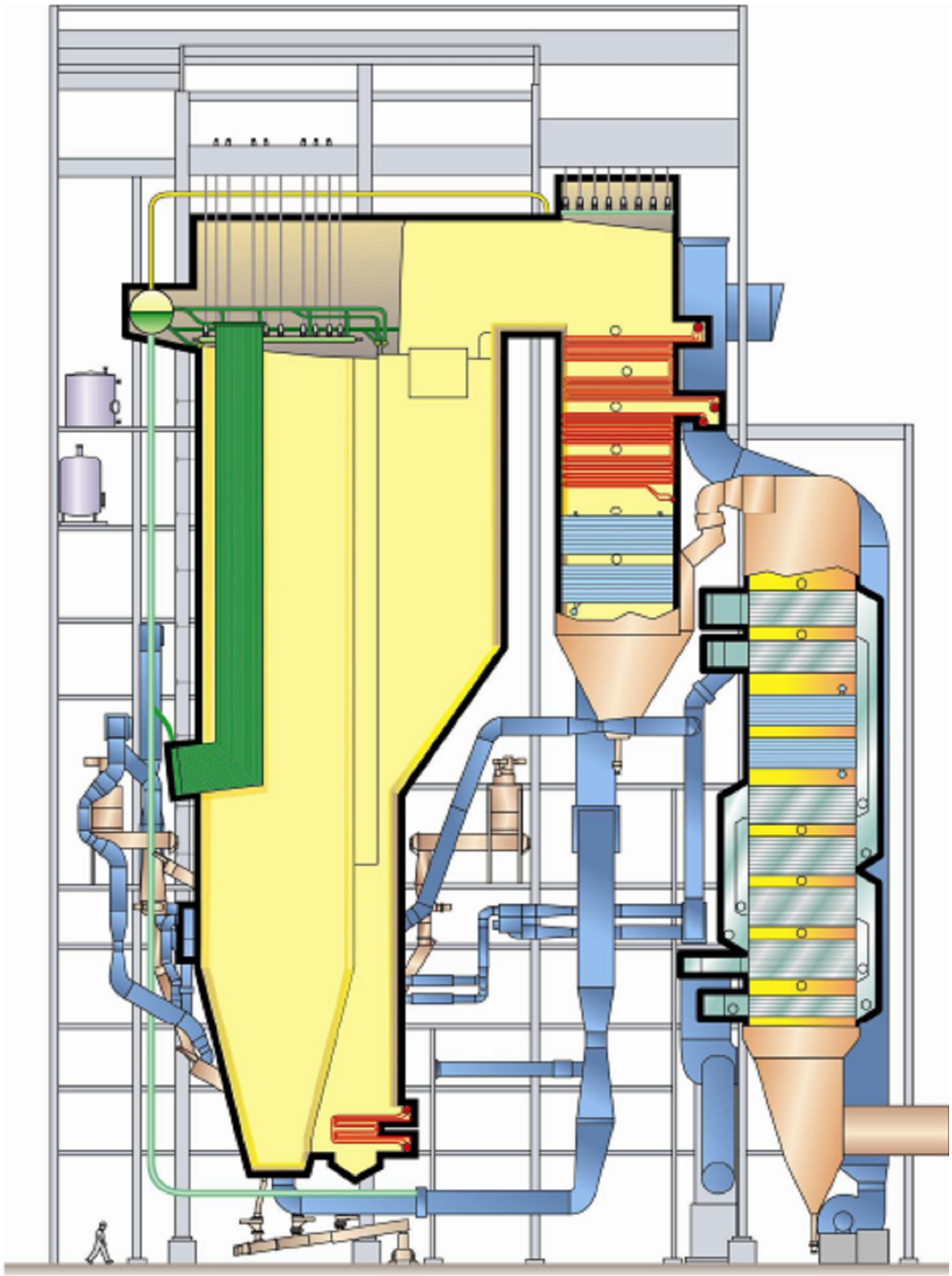


Figure 25. CFB boiler of Kaukaan Voima Oy. (FosterWheeler,2010)

The Kaukaan Voima boiler has different types of heat transfer surface. Water walls, intrex walls, superheaters and air heater are displayed in figure 25.

The main performance characteristics of the Kaukaan Voima boiler are presented in the table 2.

Table 2. Specification for the CFB boiler Kaukaan Voima Oy. (FosterWheeler,2010)

Total Thermal Output	358 MW/Th
Steam Flow	149 kg/s
Steam Pressure	115 bar
Steam Temperature	550 ^{0}C
Feedwater Temperature	213 ^{0}C
Boiler Efficiency	91%
Flue Gas Exit Temperature	Biomass
	149 ^{0}C
Lover heating value	9.2 MJ/kg

During the experiments it will be interesting to explore heating surfaces. Water-steam path and air-combustion gas path are showed schematic on the boiler model.(see fig. 27) The model of the boiler has been developed in LUT and serves as a starting point for the calculations. The model serves as a representation of a CFB boiler that uses biofuel. In the model of fuel combustion is modeled as a separate process and assuming the complete combustion of fuel.

Notation conventions for figure 26 and 27 are as follows:

SH – Super Heater;

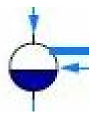
DSH – Desuperheater;

- Flue Gases;

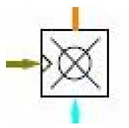
- Air;

- Steam;

- Water;

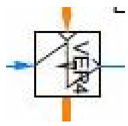


- Drum;



- Combustor;

- Pump;



- Heat exchanger.

Work process of the boiler model can be described using the water-steam and air-combustion gas paths.

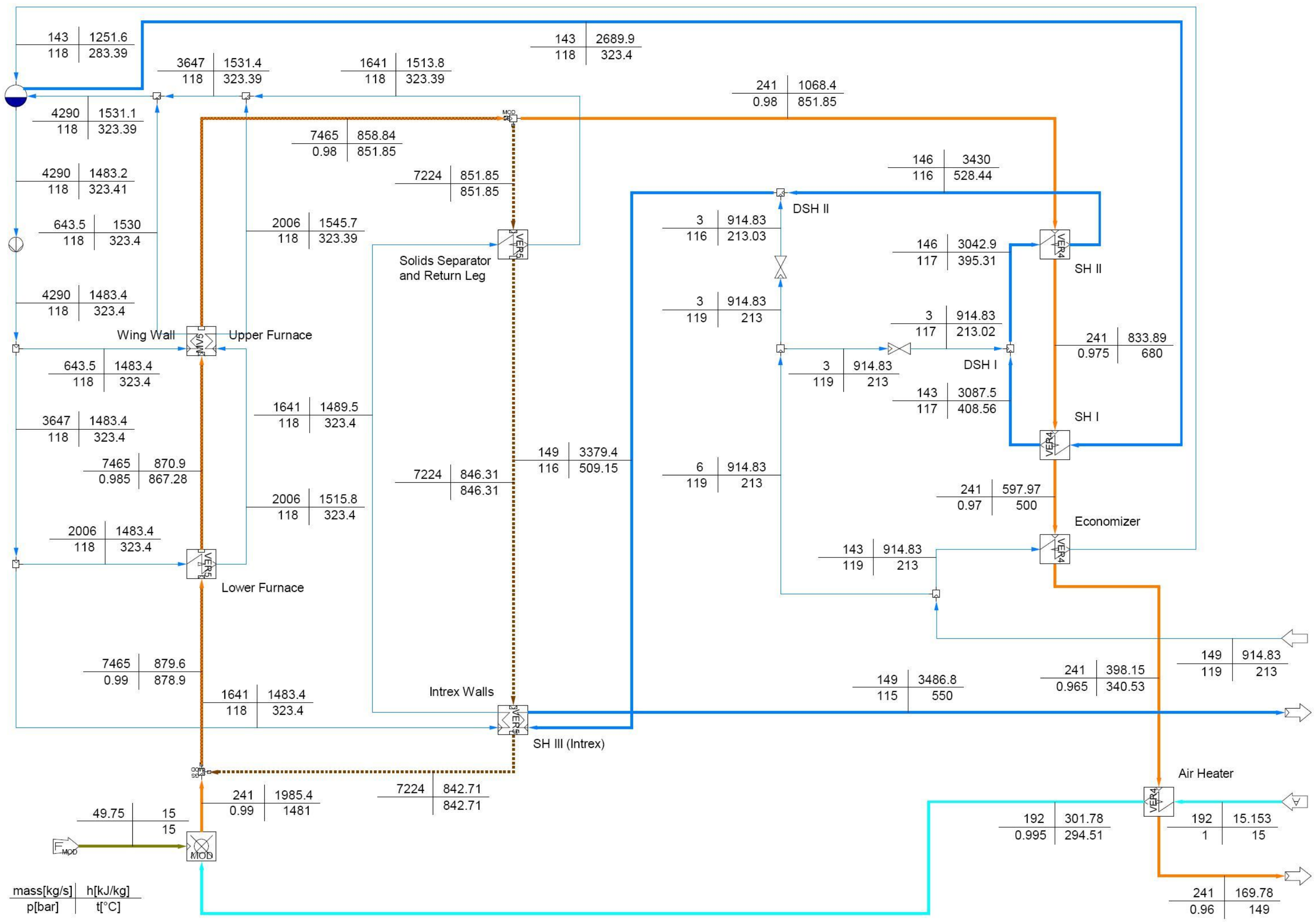


Figure 26. Boiler model with design-point operating values.

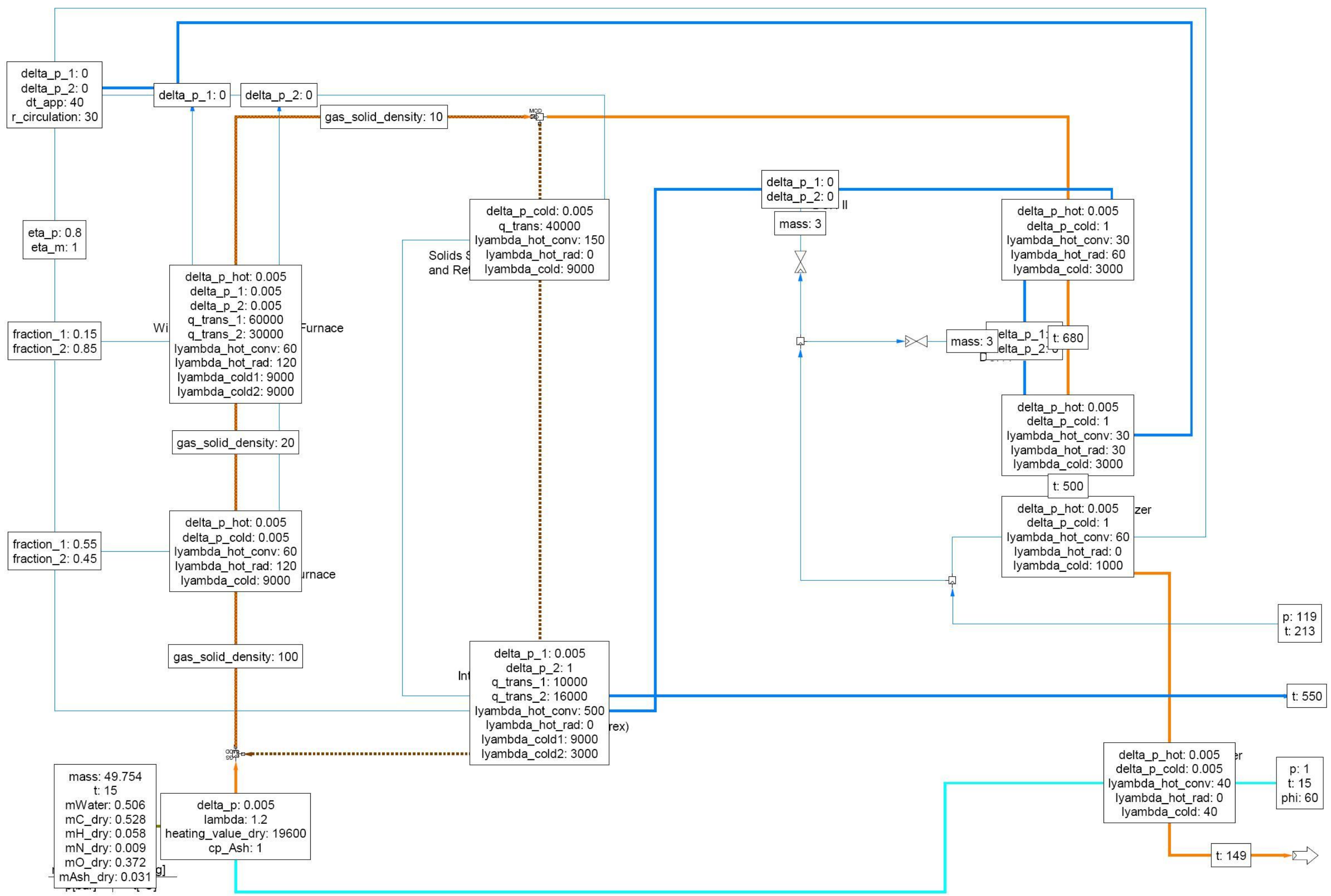


Figure 27. Boiler model with input values for design-point calculation.

Air-combustion gas path of boiler model.

The air is taken directly from the atmosphere with pressure of 1 bar and a temperature of 15^0C and sent to the air heater. In the air heater air is heated to a temperature of 294^0C and sent to combustor. Biofuels with LHV=8.45 MJ/kg are also fed into combustor. In combustor fuel reacts with air and burns with an excess air ratio of 1,2 , while combustion gases are formed. Flue gases are sent to the circulating ring, where they mix with circulating agglomerate. Next, a mixture of flue gases and sand with a temperature of 879^0C passes the lower furnace heat exchanger which is of a parallel flow type. Then the mixture of gases and sand with a temperature of 867^0C passes the upper furnace heat exchanger and external heat transfer surface, both of parallel flow type. After that the mixture of gases and sand are separated in the cyclone. The sand falls down at a temperature of 851^0C and passes through the solid separator and return leg of counter flow type heat exchanger. Then sand with a temperature of 846^0C is sent to the Intrex heat exchanger. Intrex heat exchanger is of countercurrent and two-sided type. In one side water is heated and in the other side steam has the final stage of superheating. After the Intrex heat exchanger sand is sent again into the cycle and is mixed with the flue gases. After the separation flue gases with a temperature of 851^0C pass through two superheaters that are of the countercurrent type. Then, after superheaters gases with a temperature of 500^0C are sent to the economizer of the countercurrent type. After the economizer flue gas with a temperature of 340^0C pass through the counter type air heater. After the air heater flue gases with a temperature of 149^0C are sent to flue gas treatment and are exhausted into the atmosphere.

Water-steam path of boiler model.

Feed water with a temperature of 213^0C is served in the economizer. Also, a small part of the feed water is fed for the spray desuperheater to reduce the temperature of steam. After economizer heated water with temperature of 283^0C comes to the drum, where heated water is mixed with water located there. From the drum saturated water is sent to the heat exchanger to be partially evaporated. At the beginning after the drum the water passes through the pump. After the pump the water flow is divided. 15% of water is sent directly to the external heat transfer surface. 38% of water is taken and sent first to the Intrex heat exchanger and then into solids separator and return leg heat exchanger. 47% is sent to the lower furnace heat exchanger, after which it goes to the upper furnace heat exchanger. Then, all the flows of steam-water mixture are mixed and sent to the drum. Saturated steam from the drum with a temperature of 323^0C is sent to the superheaters and is heated successively. After superheater I the steam temperature is 409^0C, after superheater II 528^0C and after Intrex the steam temperature is 550^0C and pressure 115 bar.

At the bottom of the furnace is particularly strong effervescence particle flux and where the density of solid particles greater than at the height of the furnace, before which reaches only a small fraction of the particles. In the model different gas-solid densities have been used for different furnace heights. At the furnace bottom the bed density is 100kg/m^3. Between the lower and upper furnace is 20kg/m^3 and at the furnace top is 10kg/m^3. The heat transfer coefficients of various heating surfaces have been selected to reflect the typical values for the boiler type and are given in table 3. The heat transfer coefficients have no effect in design calculation, but they are used as a basis for simulation outside design conditions.

Table 3. Heat transfer coefficients for heat exchangers in design point calculation.

Heat exchanger	$\alpha_{hot.conv}$	$\alpha_{hot.rad}$	α_{cold}
air heater	40	0	40
economizer	60	0	1000
Superheater I	30	30	3000
Superheater II	30	60	3000
The solid separator and return leg	150	0	9000
Intrex Walls(water)	500	0	9000
Intrex Walls(steam)	500	0	3000
Upper Furnace(1)	60	120	9000
Upper Furnace(2)	60	120	9000
Lower Furnace	60	120	9000

In the table, $\alpha_{hot.conv}$ and $\alpha_{hot.rad}$ refer to the convection and radiation heat transfer coefficient on the hot side of the heat exchanger, α_{cold} refer to the convection heat transfer coefficient on the cold side. The cold side flow is an internal tubular flow in all heat exchangers and therefore, radiation has no significance here.

For simulation outside design conditions, additional correlations are introduced to determine the variation of heat transfer coefficients. The correlations are based the theory presented in chapter 2, but have been simplified, for instance by neglecting the fluid properties.

Values with the subscript "0" refer to the design model. On the hot side of the heat exchangers the heat transfer coefficient may be divided into convective and radiant part. Convective heat transfer coefficient is assumed to deped on changes in mass flow of matter.

$$\alpha_{hot.conv} = \alpha_{hot.conv0} \cdot (q_m / q_{m0})^{0,7} \quad (5.1)$$

In turn, the radiation heat transfer coefficient is assumed to depend the temperature of the flow.

$$\alpha_{hot.rad} = \alpha_{hot.rad0} \, (T/T_0)^4 \quad (5.2)$$

On the cold side (tubular flow) only convection is taken into account

$$\alpha_{cold} = \alpha_{cold0} \cdot (q_m / q_{m0})^{0,7} \quad (5.3)$$

Using the plane will assumption and neglecting the heat resistance of the tube material and possible fouling layers, the overall heat transfer coefficient in a heat exchanger can be determined from

$$\frac{1}{k} = \frac{1}{\alpha_{hot.conv} + \alpha_{hot.rad}} + \frac{1}{\alpha_{cold}} \quad (5.4)$$

During the simulation, some boilers parameters were kept constant. These parameters are presented in table 4.

Table 4. Constant parameters.

Excess air ratio	1,2
Fees water temperature	213[^{0}C]
Air	p=1[bar]
	T=15[^{0}C]
Steam	p=115[bar]
	T=550[^{0}C]
Mass flow of evaporative cycle	4290[kg/s]
Spray mass flow in DSH I	3[kg/s]
Fuel composition on a dry mass:	
C[%]	52,8
H[%]	5,8
N[%]	0,9
O[%]	37,2
S[%]	0.2
Ash[%]	3,1
LHV dry [MJ/kg]	19,6
Gas-solid density	
At the furnace bottom	100kg/m^3
Between the lower and upper furnace	20kg/m^3
at the furnace top	10kg/m^3

5.1 Effect of the fuel moisture

The purpose of this simulation is to investigate the effect of fuel moisture on the heat transfer and operating values.

In the simulation, the fuel moisture is decreased and increased by 10%-points in increments of 5%-points with moisture of 50,6 mass-% at design point. The values of the studied variables are summarized in table 5.

Table 5. Results from simulating the effect of fuel moisture.

Fuel moisture[-]	0,4	0,45	0,5	0,55	0,6
fuel mass flow[kg/s]	39,5	44	49,75	57,2	67,3
Temperature after solids separation [C]	873,7	864	851,8	836,5	816,3
Temperature after air-heater [C]	134,1	141	149	159	172
Boiler Efficiency[-]	0,92	0,91	0,9	0,89	0,87
water mass flow[kg/s]	151,4	150,1	149	146,2	143
LHV as fired [MJ/kg]	10,65	9,55	8,446	7,34	6,24
Steam mass flow[kg/s]	151,4	150,1	149	146,2	143
Convection heat transfer coefficient for hot side [W/m^{2}K]					
air heater	38	38,9	40	41,4	43,2
economizer	57	58,4	60	62	64,7
Superheater I	28,5	29,2	30	31	32,4
Superheater II	28,5	29,2	30	31	32,4
Intrex Walls	478,9	488,4	500	514,7	534
The solid separator and return leg	143,7	146,5	150	154,4	160,1
Upper Furnace	57,4	58,6	60	61,76	64
Lower Furnace	57,4	58,6	60	61,76	64
Radiation heat transfer coefficient for hot side [W/m^{2}K]					
air heater	0	0	0	0	0
economizer	0	0	0	0	0
Superheater I	28,5	29,2	30	30,9	31,7
Superheater II	61,6	60,9	60	58,7	56,6
Intrex Walls	0	0	0	0	0
The solid separator and return leg	0	0	0	0	0
Upper Furnace	129,9	125,4	120	113,4	105,2
Lower Furnace	130,4	125,7	120	113,2	104,7
Heat transfer coefficient for cold side [W/m^{2}K]					
Superheater I	3081	3036	3000	2922	2844
Superheater II	3079	3036	3000	2923	2847
Intrex Walls	3048	3022	3000	2944	2880
economizer	1027	1012	1000	974	948

Upper Furnace(1)	9000	9000	9000	9000	9000
Upper Furnace(2)	9000	9000	9000	9000	9000
Lower Furnace	9000	9000	9000	9000	9000
Intrex Walls	9000	9000	9000	9000	9000
The solid separator and return leg	9000	9000	9000	9000	9000
air heater	38,1	39	40	41,3	43,1
Dimensionless conductance (kA)					
air heater	637	651	668,6	691,2	721,3
economizer	273,7	279,4	286,4	295,1	306,6
Superheater I	245,4	251,1	257,7	265,7	274,6
Superheater II	186,4	186,3	185,9	185,2	183,6
Intrex Walls(steam)	49	49,8	50,8	51,9	53,4
Intrex Walls(water)	18,4	18,8	19,2	19,7	20,4
The solid separator and return leg	72,9	74,3	76,1	78,3	81,1
Upper Furnace(1)	116,4	114,3	111,9	109	105,4
Upper Furnace(2)	58,2	57,2	55,9	54,5	52,7
Lower Furnace	123,3	120,9	118,2	115	111
Heat transfer rate [MW]					
air heater	49,6	52	55	59	64,3
economizer	43,1	45,4	48,2	51,6	56
Superheater I	52,54	54,6	56,9	59,4	61,9
Superheater II	59,7	58,4	56,5	53,8	50,4
Intrex Walls(steam)	16,5	16,3	16	15,6	14,9
Intrex Walls(water)	10	10	10	10	9,9
The solid separator and return leg	40	40	40	40	39,8
Upper Furnace(1)	65	62,7	60	56,7	52,6
Upper Furnace(2)	32,5	31,4	30	28,3	26,3
Lower Furnace	70,7	68,1	65	61,3	56,7

With an increase in moisture the mass of consumed fuel increases, due to constant fuel power that during.

If fuel moisture increases, then amount of produced steam decreases. This is due to decreasing boiler efficiency with constant fuel power decreases the steam mass flow rate, too.

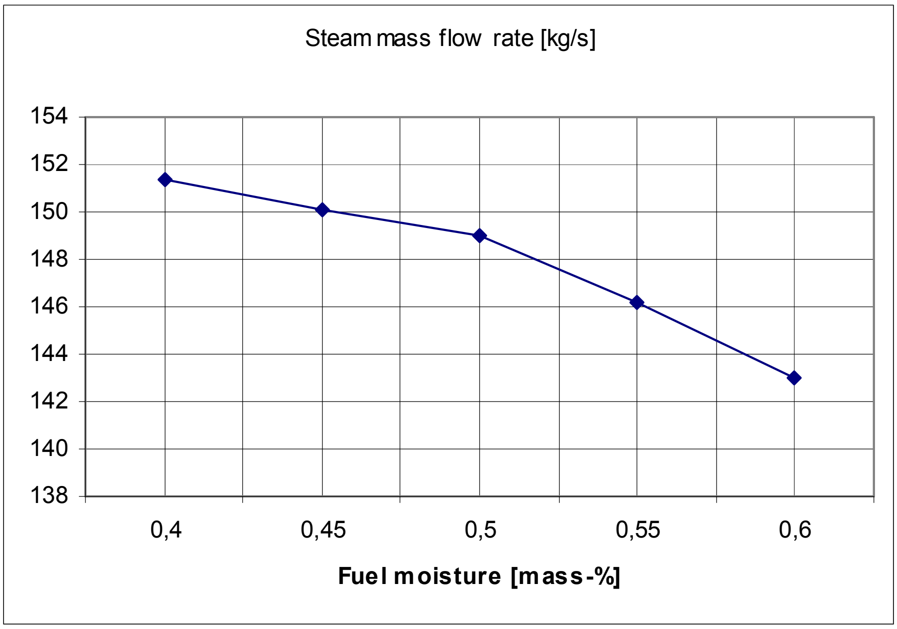


Figure 28. Dependence between steam mass flow rate and fuel moisture.

Also, with increasing moisture content of fuel reduces the temperature of flue gas before the first superheater. This is because as the fuel moisture increases, the adiabatic combustion temperature decreases. The fuel mass flow and consequently, combustion gas mass flow rate increases to maintain the fuel power constant. As a result of these factors, the heat transfer rate to water in the furnace decreases. The combustion gas temperature decreases after the solids separator while its heat capacity flow rate increases.

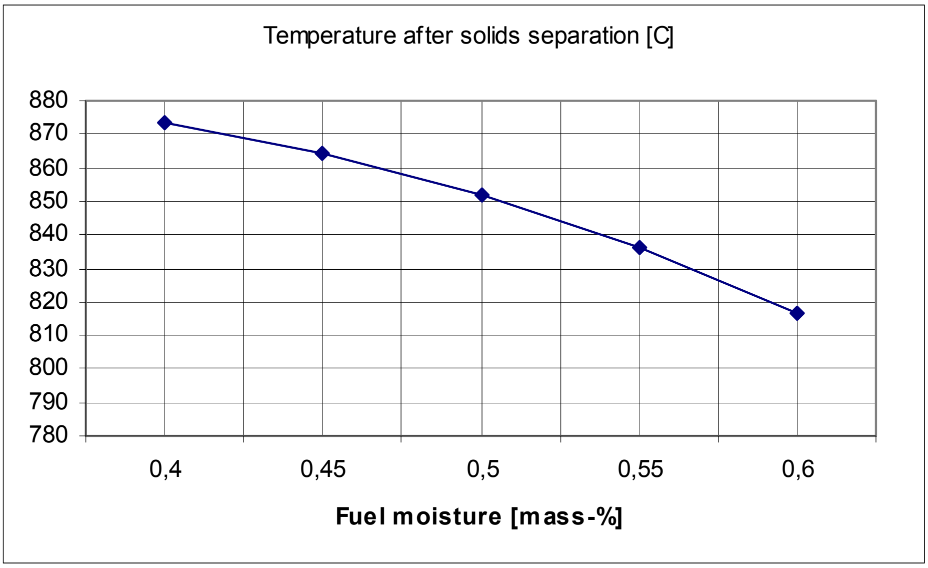


Figure 29. Dependence between temperature after solids separation and fuel moisture.

The efficiency of fuel conversion into heat energy or in other words, the efficiency of the boiler model, also decreases with increasing moisture content of fuel.

Due to increasing heat capacity flow the temperature drop of the combustion gases decreases in the exhaust gas duct, despite the increasing heat transfer rates in the air heater and economizer. This results in increasing the flue gas exit temperature. Increasing flue gas temperature and mass flow rate contribute to increasing flue gas losses and consequently, decreasing boiler efficiency.

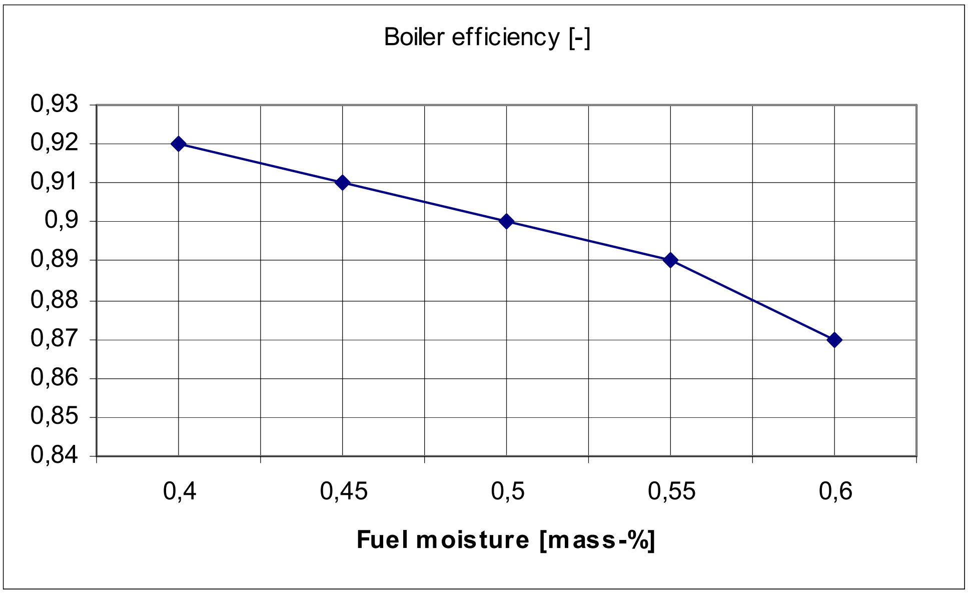


Figure 30. Dependence between boiler efficiency and fuel moisture.

The influence of fuel moisture on the heat transfer coefficients and the overall heat transfer coefficient is shown in the graphs in Appendix 1 with the value given as relative to their design-point values.

For the lower and upper furnace the heat exchangers heat transfer coefficient increases with decreasing moisture content of the fuel while in the other heat exchangers the heat transfer coefficient increases or remains unchanged.

In the furnace heat exchangers radiation component plays an important role in heat transfer. The radiation heat transfer coefficient decreases in the furnace heat exchangers with increasing moisture content, because of the decreasing flue temperature, which directly affects the radiative heat transfer. The heat transfer coefficient increased, even if the heat transfer coefficient for the cold side decreased. This is due to the fact that the heat transfer coefficient is mainly affected by the hot side. Where the heat transfer coefficient are essential lower than on the cold side, as can be seen in table 3 too.

As can be see from equation (5.4) the impact of smaller heat transfer coefficient on the overall heat transfer coefficient is higher than with the larger heat transfer coefficient.

The heat transfer coefficient for the cold side does not change in furnace heat exchanger, in the solid separator and return leg heat exchanger and in the intrex heat exchanger. This is due to the fact that the mass flow of water through these heat exchangers is constant.

5.2 Effect of boiler load

The purpose of this simulation is investigate the load level on boiler operation. In the simulation, the thermal power of the boiler varies from 100% to 80%, or from 383,2 MW to 306,6 MW in absolute terms. The values of the studied variables are summarized in table 6.

Table 6.Results from simulating the effect of boiler load

Boiler load [%]	100	95	90	85	80
Thermal Power [MW]	383,2	364	344,9	325,7	306,6
Fuel power [MW]	421	400,6	378,9	357,3	335,7
fuel mass flow [kg/s]	49,75	47,35	44,78	42,23	39,67
Temperature after solids separation [C]	851,9	844,9	837,1	828,9	820,3
Temperature after air-heater [C]	149	146,6	143,9	141,1	138,4
Boiler Efficiency [-]	0,9	0,9	0,9	0,9	0,9
water mass flow[kg/s]	149	141,5	134,1	126,6	119,2
Steam mass flow[kg/s]	149	141,5	134,1	126,6	119,2
Convection heat transfer coefficient for hot side [W/m^{2}K]					
air heater	40	38,8	37,5	36,2	34,9
economizer	60	58,2	56,3	54,4	52,4
Superheater I	30	29,1	28,1	27,2	26,2
Superheater II	30	29,1	28,1	27,2	26,2
Intrex Walls	500	483	465,3	447	428,5
The solid separator and return leg	150	145	139,6	134	128,5
Upper Furnace	60	58	55,8	53,6	51,4
Lower Furnace	60	58	55,8	53,6	51,4
Radiative heat transfer coefficient for hot side [W/m^{2}K]					
air heater	0	0	0	0	0
economizer	0	0	0	0	0
Superheater I	30	29	28	26,9	25,8
Superheater II	60	58,3	56,5	54,5	52,6
Intrex Walls	0	0	0	0	0
The solid separator and return leg	0	0	0	0	0
Upper Furnace	120	117,12	114	110,7	107,3

Lower Furnace	120	117,2	114,2	111	107,8
Heat transfer coefficient for cold side [W/m^{2}K]					
Superheater I	3000	2852,7	2711	2569	2427
Superheater II	3000	2855,7	2717	2578	2439
Intrex Walls	3000	2849	2700	2549	2400
economizer	1000	951	904	856	809
Upper Furnace(1)	9000	9000	9000	9000	9000
Upper Furnace(2)	9000	9000	9000	9000	9000
Lower Furnace	9000	9000	9000	9000	9000
Intrex Walls	9000	9000	9000	9000	9000
The solid separator and return leg	9000	9000	9000	9000	9000
air heater	40	38	36	33,9	31,9
Dimensionless conductance (kA)					
air heater	668,6	642,6	614,4	585,8	557,1
economizer	286,4	277,7	268,3	258,6	248,9
Superheater I	257,7	249,7	241	232,1	223,1
Superheater II	185,9	180,6	174,6	168,6	162,4
Intrex Walls(steam)	50,8	49	47	45	43,1
Intrex Walls(water)	19,2	18,5	18	17,2	16,5
The solid separator and return leg	76,1	73,6	71	68,1	65,4
Upper Furnace(1)	111,9	109	105,7	102,3	98,9
Upper Furnace(2)	56	54,5	52,8	51,2	49,5
Lower Furnace	118	115,1	111,8	108,3	104,8
Heat transfer rate [MW]					
air heater	55	51,8	48,3	44,8	41,5
economizer	48	45,3	42,3	39,2	36,34
Superheater I	56,8	53,6	50	46,5	43
Superheater II	56,5	53,9	51,2	48,5	45,8
Intrex Walls(steam)	16	15	14	13,1	12,16
Intrex Walls(water)	10	9,5	9	8,6	8,1
The solid separator and return leg	40	38,2	36,2	34,3	32,3
Upper Furnace(1)	60	57,7	55,1	52,6	50
Upper Furnace(2)	30	28,8	27,6	26,3	25
Lower Furnace	65	62,5	60	57,2	54,5

Decreasing boiler thermal power decreases the steam mass flow rate.

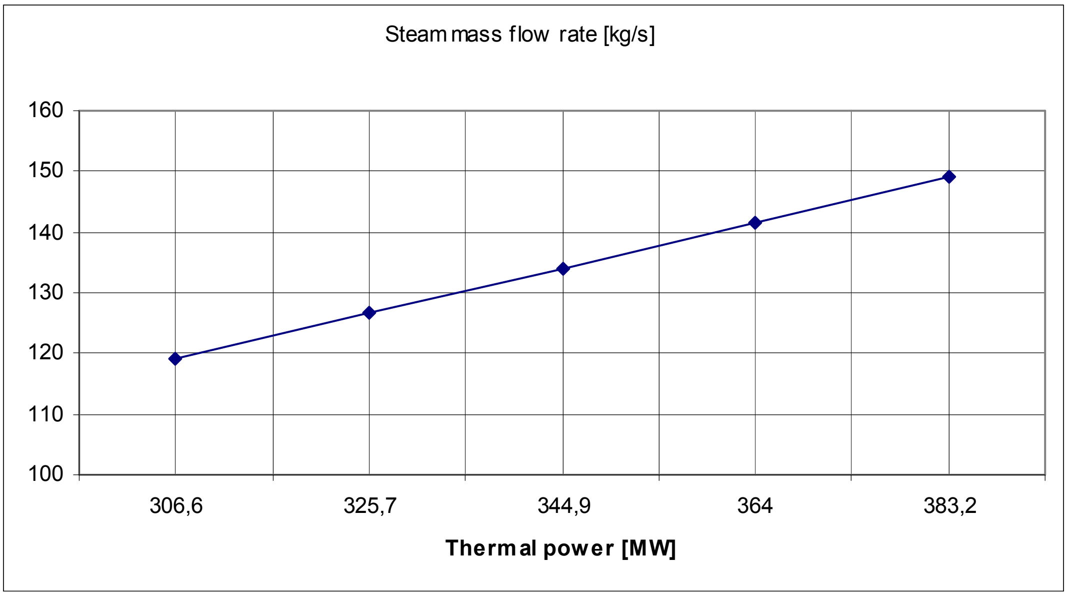


Figure 31. Dependence between steam mass flow rate and thermal power.

The fuel mass flow and combustion gas mass flow rates decrease, too The adiabatic combustion temperature decreases slightly due to decreasing heat transfer rate in the air heater Both these factors contribute to decreasing the heat transfer rate to water in the furnace In this case, both the combustion gas temperature and heat capacity flow rate decrease after the solids separator

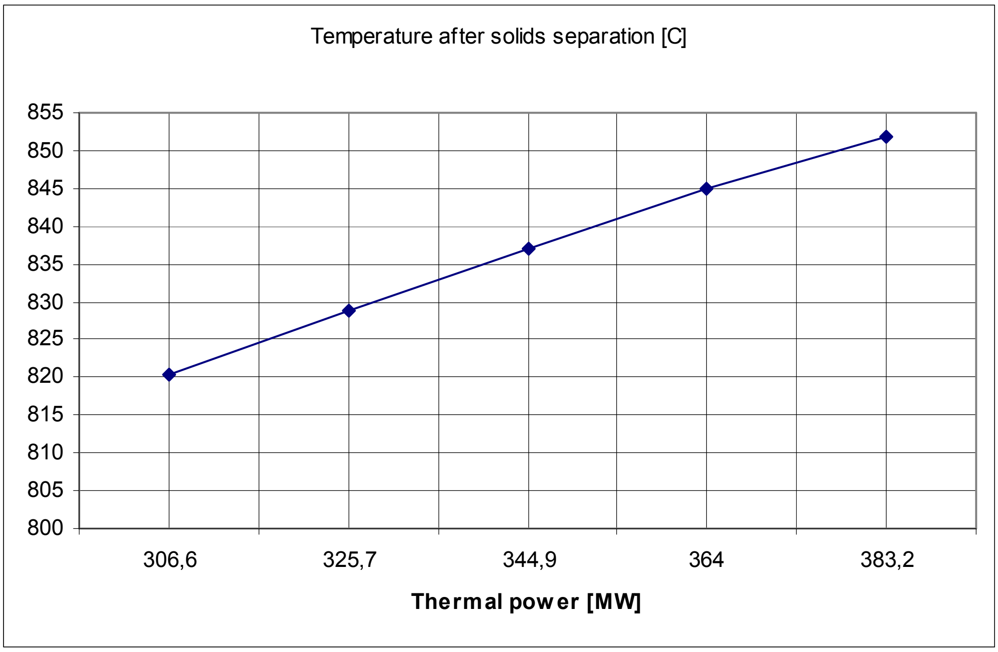


Figure 32. Dependence between temperature after solids separation and thermal power.

•The heat transfer rates in the exhaust gas duct heat exchangers decrease which decreases the temperature drop of the combustion gases, despite decreasing heat capacity flow. As a result the flue gas exit temperature decreases

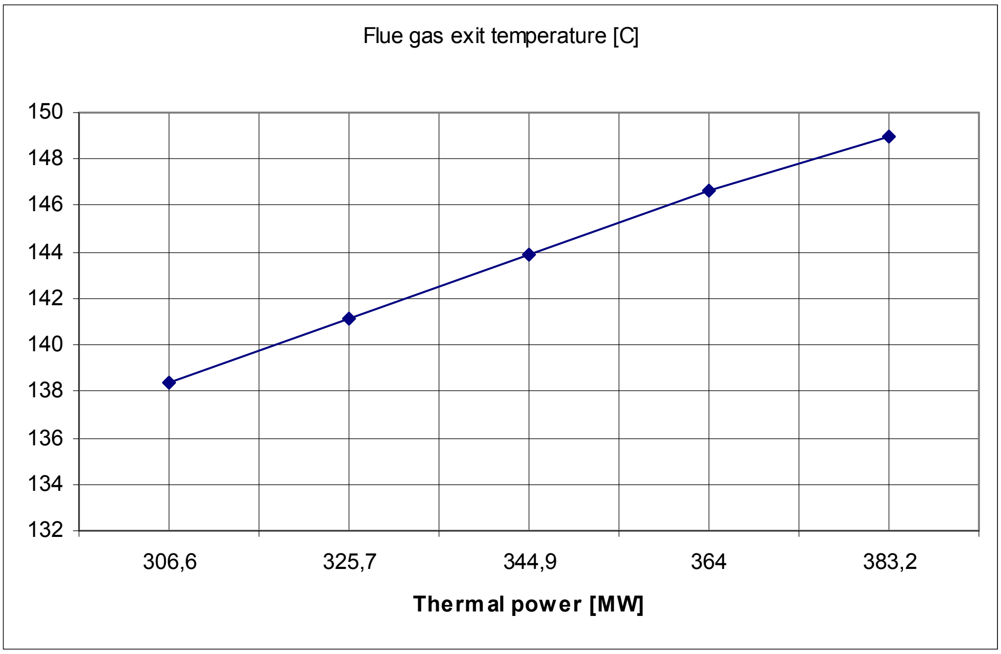


Figure 33. Dependence between flue gas temperature and thermal power.

Decreasing flue gas temperature and mass flow rate decrease flue gas losses and consequently, boiler efficiency increases slightly.

The influence of boiler thermal power on the heat transfer coefficients and overall heat transfer coefficient is shown in the graphs in Appendix 2.

In all heat exchangers the heat transfer coefficients decrease with decreasing power of the boiler. The only exceptions are furnace heat exchangers, heat exchanger The solid separator and return leg heat exchanger and intrex heat exchanger. Heat transfer coefficient of the cold side was not changed due to constant water mass flow.

Based on the results of the first simulation can say that it is preferable to use as dry fuel as possible. During different mixing of fuels care should be taken as bringing in an additional element affects the overall moisture content of the mixture. With decreasing moisture content of the fuel boiler efficiency and produced steam mass flow rate increase. Among the negative points it may be noted that with decreasing moisture content the temperature of the flue gases increase in the furnace and this may lead to increased corrosion and drossing. The flue gas temperature after the air heaters decreases to prevent cold-end corrosion.

The second simulation shows with small reduction in the thermal power, boiler efficiency experiences a slight increase. The flue gas temperature after the air heater decreases here, too.

In the simulations, convection heat transfer on the hot side is assumed to be a function of the mass flow rate in all heat exchangers. Moreover, the gas-solid suspension densities are assumed constant at different heights of the furnace. In reality, this is not the case with for instance heat exchangers in the CFB furnace, where convection is mainly affected by the gas-solid density. At part load, the bed density decreases at the upper section of the furnace, which decreases heat transfer strongly. These assumptions affect the validity of the simulation results and therefore, the results may be considered only as suggestive from the heat transfer point of view. On the other hand, the simulations, even in their current form, have proven the applicability of the software to model CFB type processes

6 CONCLUSIONS

The problem of environmental pollution can not be denied and ignored. Humanity must take some measures to reduce emissions in all spheres of activity. Energy sphere is no exception. People should try to use renewable energy as well as fuel production and utilization, which does not pollute the planet. Example may serve as many power plants running on biofuels. But on the whole, the world's use of biofuels is very small, and people should seek to increase the use of biofuels.

When translating the boiler from fossil fuels to biofuel one must take into account the difference in the fuel properties, in fuel composition, the difference of properties of ashes, volatile and moisture. Some types of boilers require major improvements during translation of the boiler to another type of fuel and some boilers are mobile and able to work on different fuels. These are boilers with fluidized bed. They are most suitable for use in their biofuels. This is due to the fact that due to fluidized bed fuels with high moisture content can be burnt in the boilers. Also in the fluidized bed can be added limestone to reduce emissions of sulfur oxides. In such boilers the maximum temperature of flue gases does not exceed 1000^0C and nitrogen oxides are not formed. In many European countries fluidized bed boilers are well established itself for the use of biofuels.

In this paper the operation of fluidized bed boilers is carefully disassembled. The main heating surfaces of boiler are described such as furnace water walls, superheaters, economizers and air heaters. Issues that may arise during operation of the boiler also are analyzed.

When using biofuels, the composition of fuels should be carefully considered. The elementary composition, lower heating value, moisture content of the fuel must be know and the composition and properties of ash be studied. The properties of ash can not be predicted, based only on the composition of fuel, they must be studied separately. For mixing different biofuels one should definitely know the properties of individual fuels, as well as the properties of the mixture, and the properties of the ash obtained by burning fuel mixture. The mixed biofuels should complement each other. Resulting mixture should help to improve the process of using biofuels. More on this is described in the work and examples of using biofuels mixture are described.

Model of CFB boiler build in LUT can be used for investigations influence of different parameters for boiler operation. In this paper showed than software can be used for simulation process in CFB boiler. Factors affect the heat transfer are investigated with the help of the boiler model.

In this paper the boiler operation at different moisture content of fuel, as well as at various loads of the boiler was investigated. The investigations were conducted with a computer model developed for the CFB boiler. The boiler model was built using the program IPSEpro. According to investigations, it can be stated that basic energy indicators for CFB boiler mobile to use fuels with varying moisture content as well as the production of different amounts of energy. Nevertheless, the behavior of the boiler, the distribution of temperature should be studied before changing its settings. The best indications are obtained in the standard configuration model of the boiler, to which it was designed.

Before translating the boiler from one fuel to another one should examine not only fuel properties, but also the behavior of the boiler when using this fuel. Such a study could also be using a computer model of the boiler, explore the range of temperature distribution, changes in energy transfer in each heat exchanger and the costs. Such a study should be carried out to avoid unnecessary losses and breakages.

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Appendix 1. Influence of fuel moisture on heat transfer coefficients and overall heat transfer coefficient.

Notation conventions for Appendix 1.

- $\alpha_{hot.conv}/\alpha_{hot.conv0}$

- $\alpha_{hot.rad}/\alpha_{hot.rad0}$

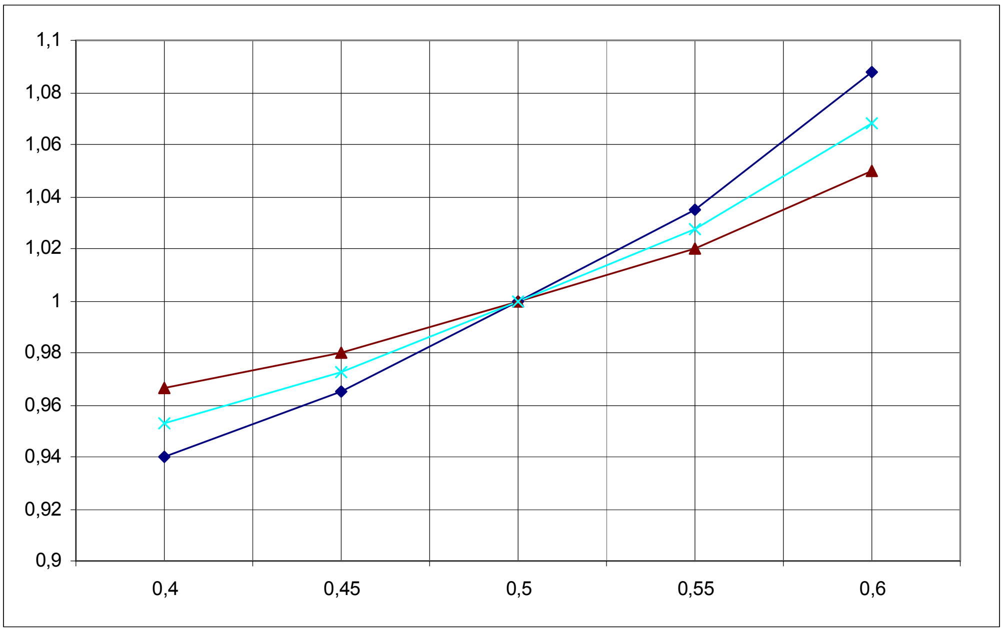
- $\alpha_{cold}/\alpha_{cold0}$

- k/k_0

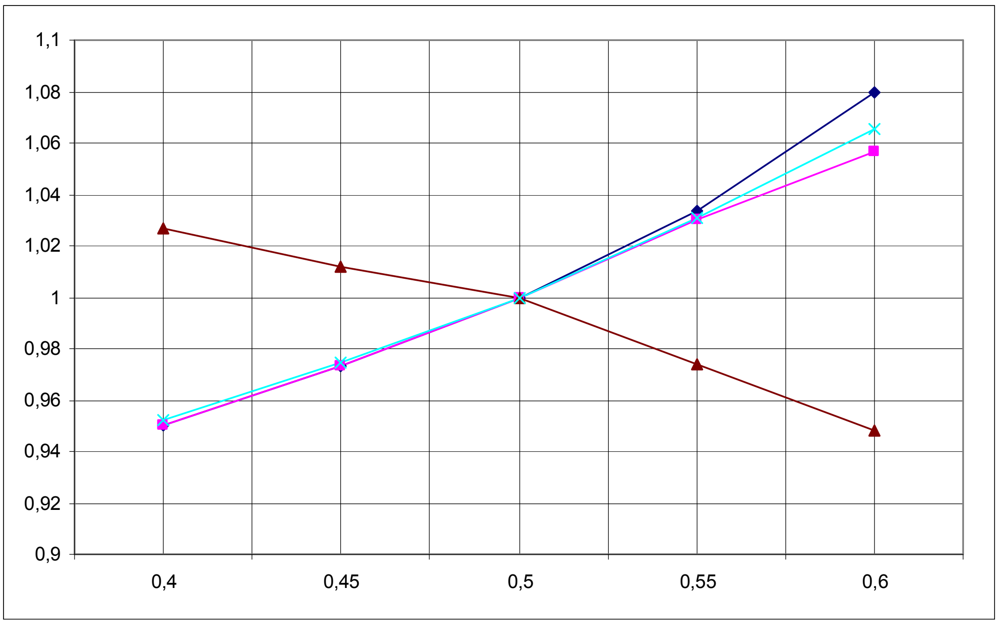
X-axis: fuel moisture[-]

Y-axis: heat transfer coefficient relative to design value [-]

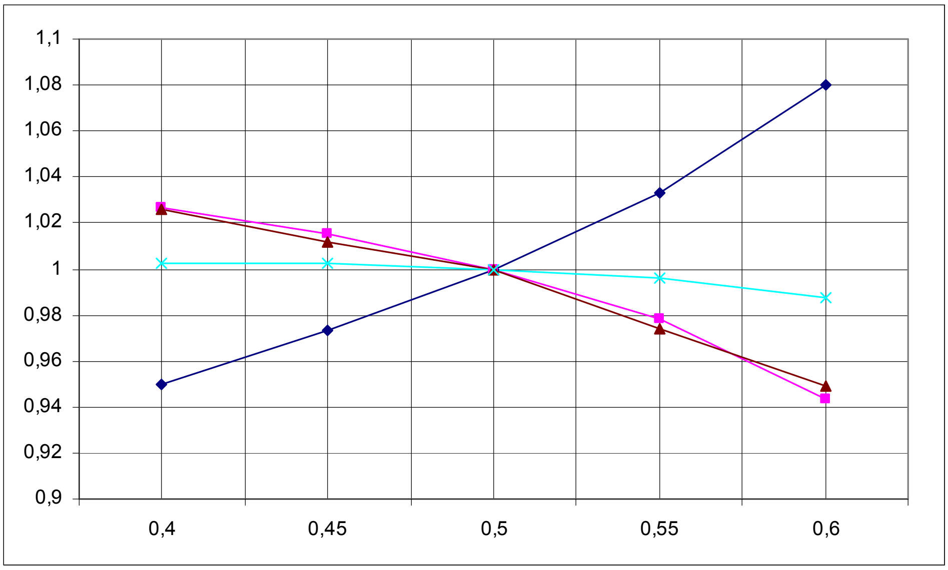
Appendix 1.1 Air Heater



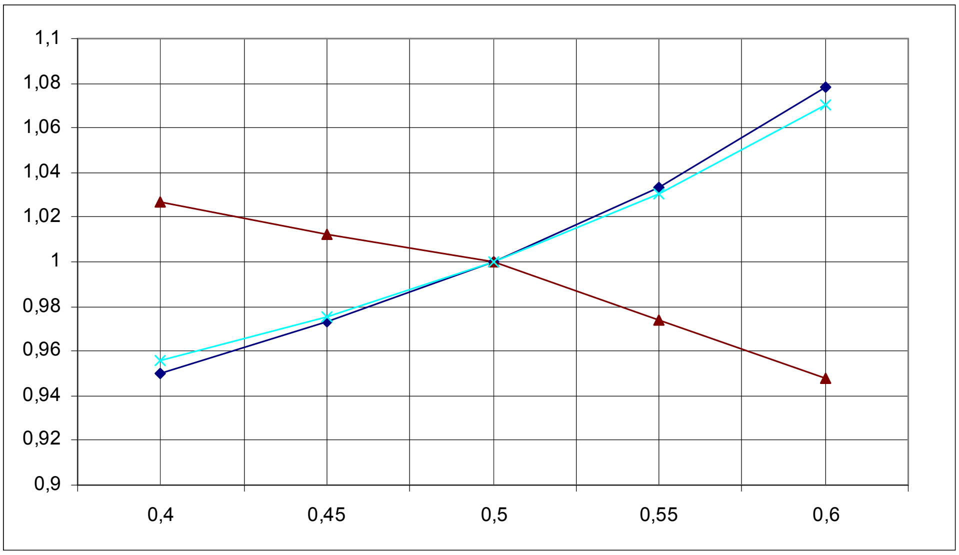
Appendix 1.2 Super Heater I



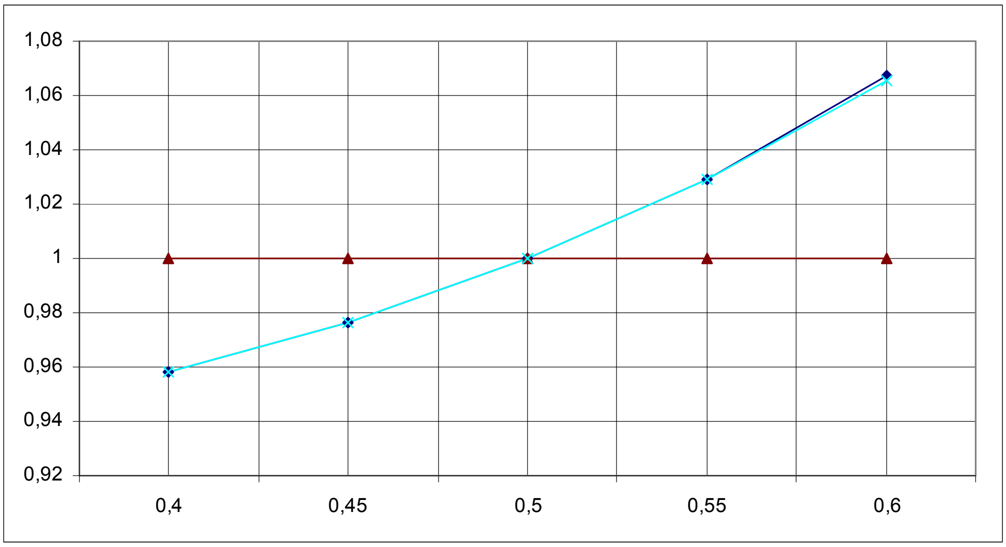
Appendix 1.3 Super Heater II



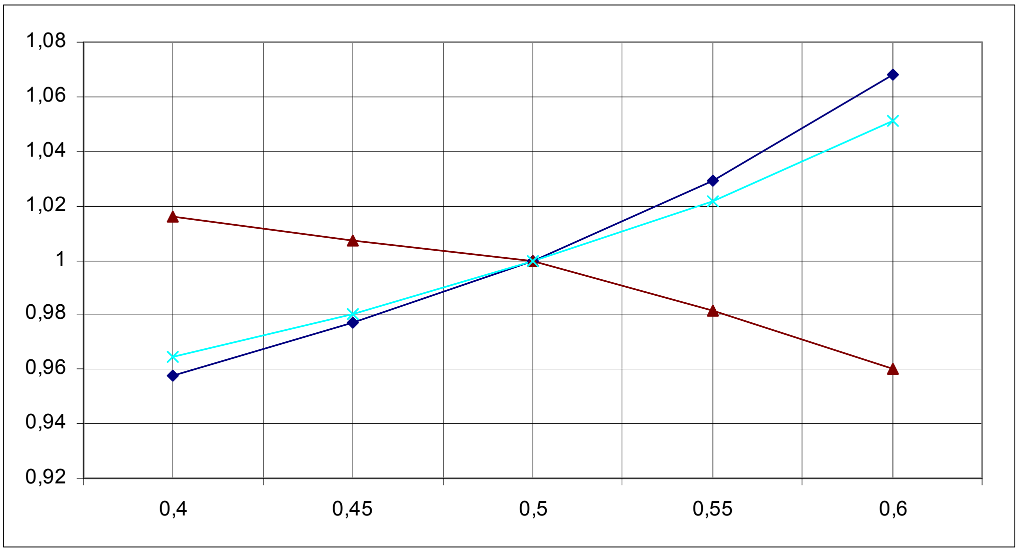
Appendix 1.4 Economizer



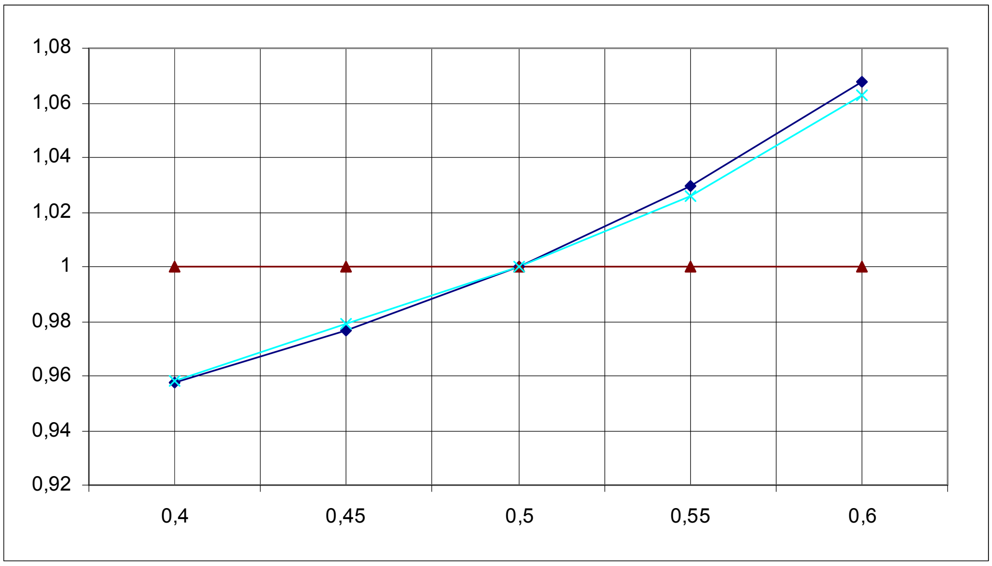
Appendix 1.5 The solid separator and return leg Heat Exchanger



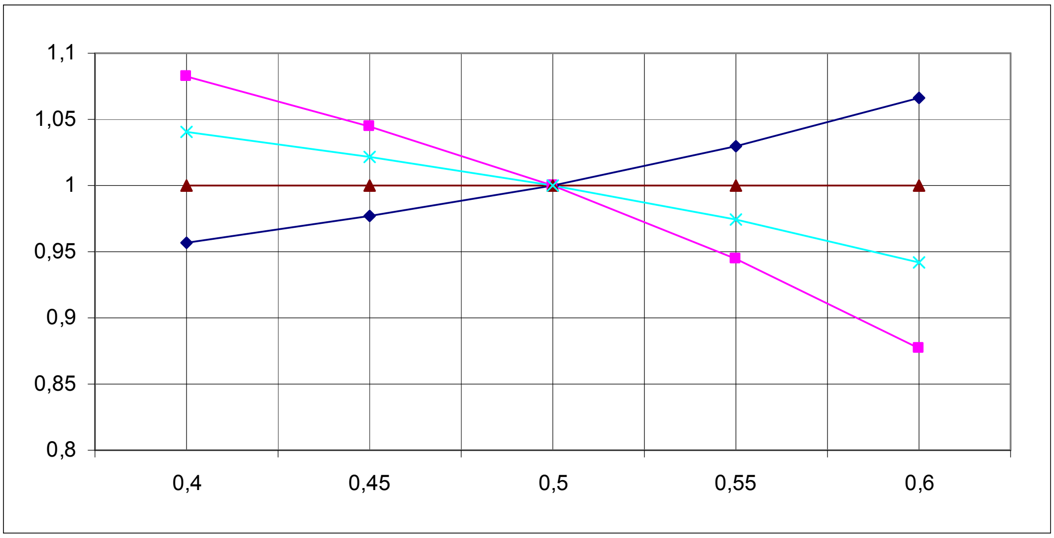
Appendix 1.6 Intrex Walls(steam) Heat Exchanger



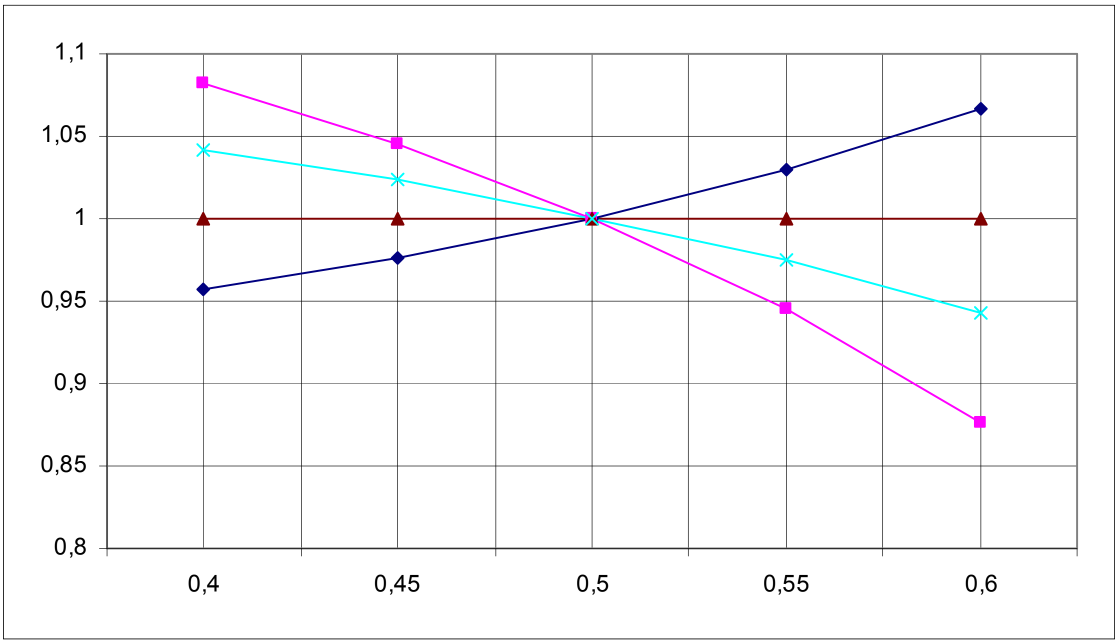
Appendix 1.7 Intrex Walls(water) Heat Exchanger



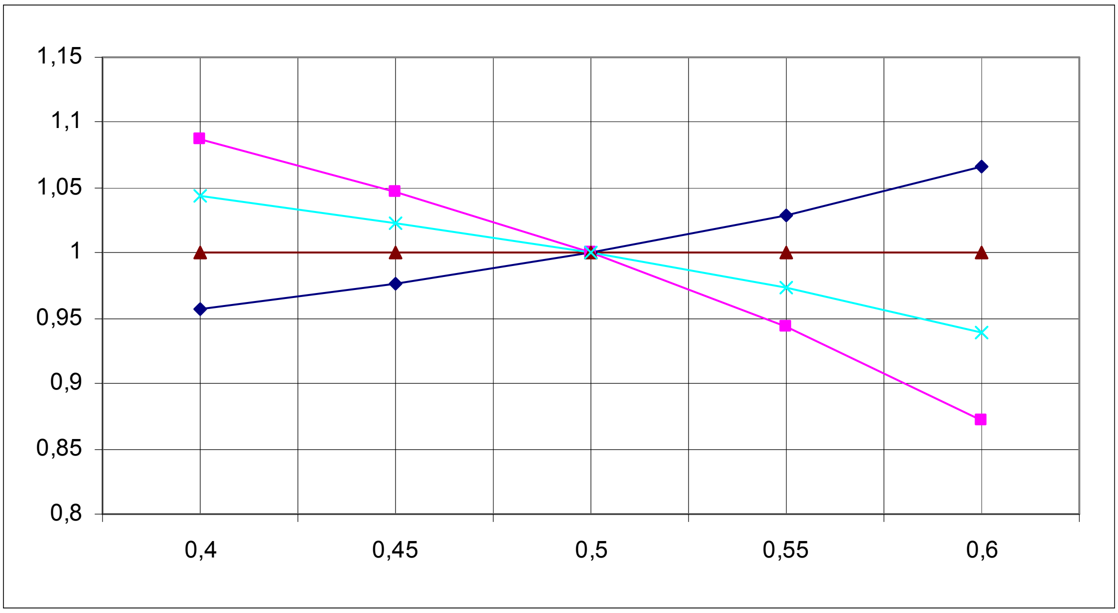
Appendix 1.8 Upper Furnace(1) Heat Exchanger



Appendix 1.9 Upper Furnace(2) Heat Exchanger



Appendix 1.10 Lower Furnace Heat Exchanger



Appendix 2. Influence of boiler thermal power on heat transfer coefficients and overall heat transfer coefficient.

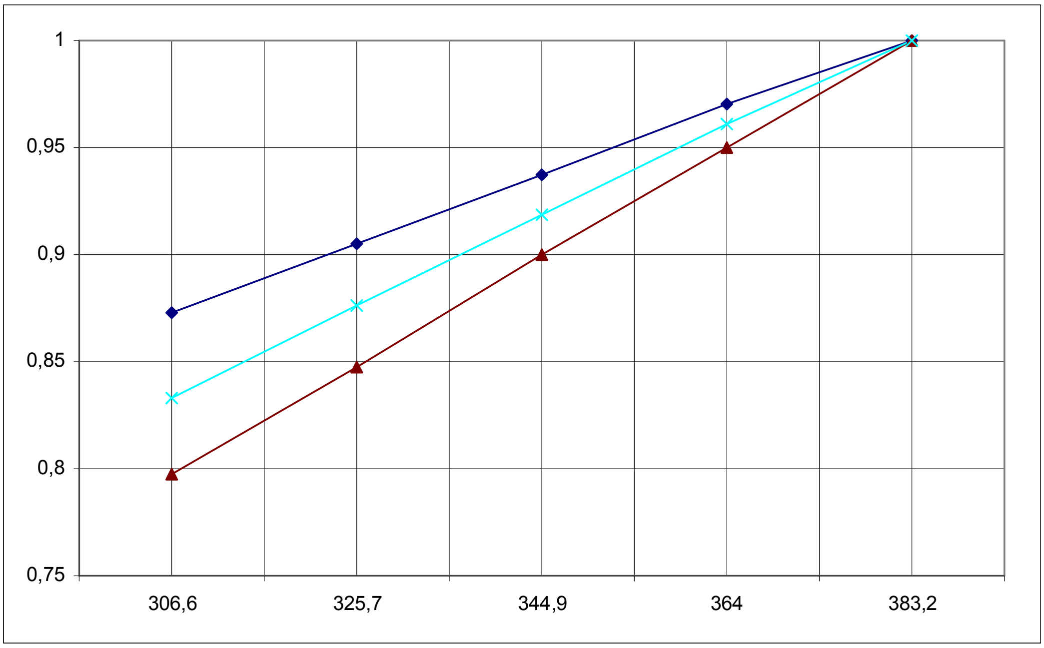
Notation conventions for Appendix 2.

- $\alpha_{hot.conv}/\alpha_{hot.conv0}$
- $\alpha_{hot.rad}/\alpha_{hot.rad0}$
- $\alpha_{cold}/\alpha_{cold0}$
- k/k_0

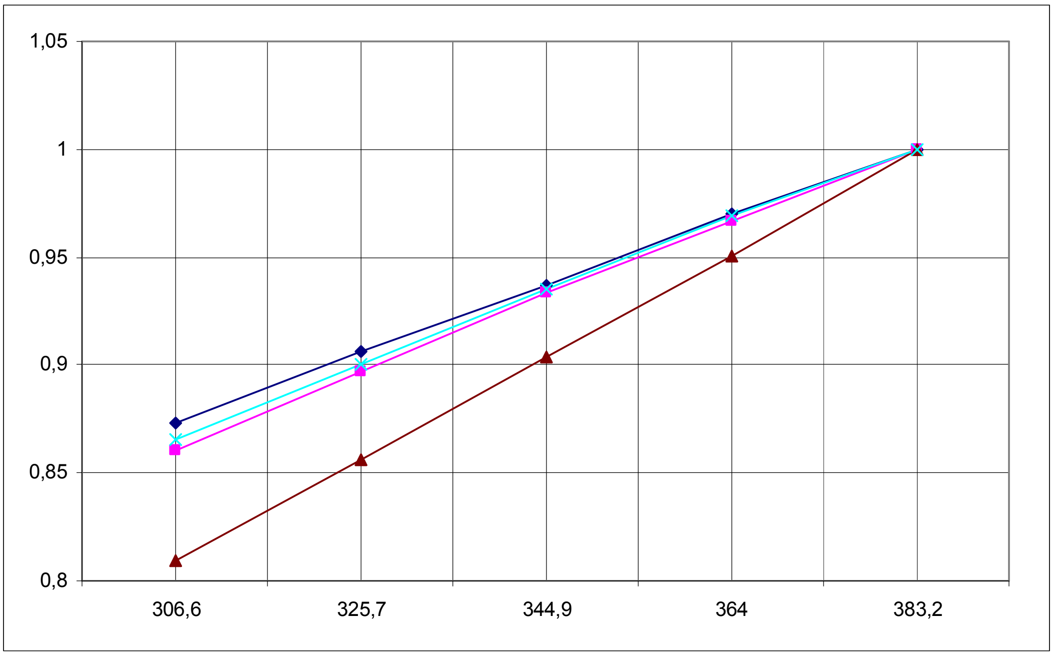
X-axis: thermal power [-]

Y-axis: heat transfer coefficient relative to design value [-]

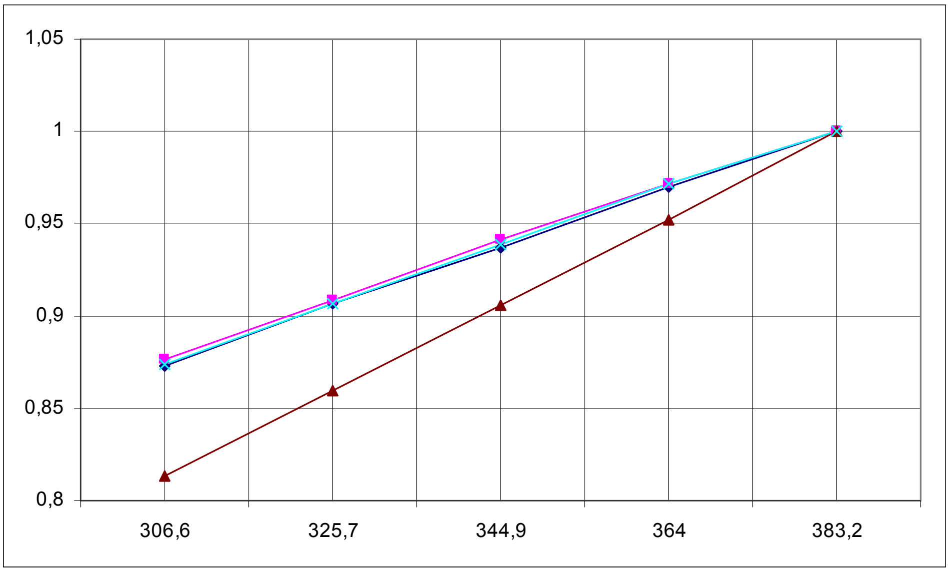
Appendix 2.1 Air Heater



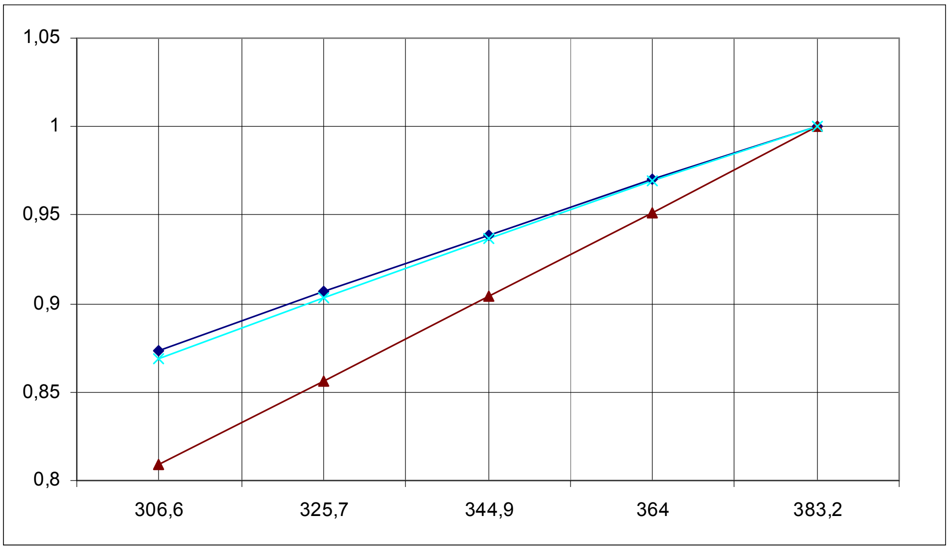
Appendix 2.2 Super Heater I



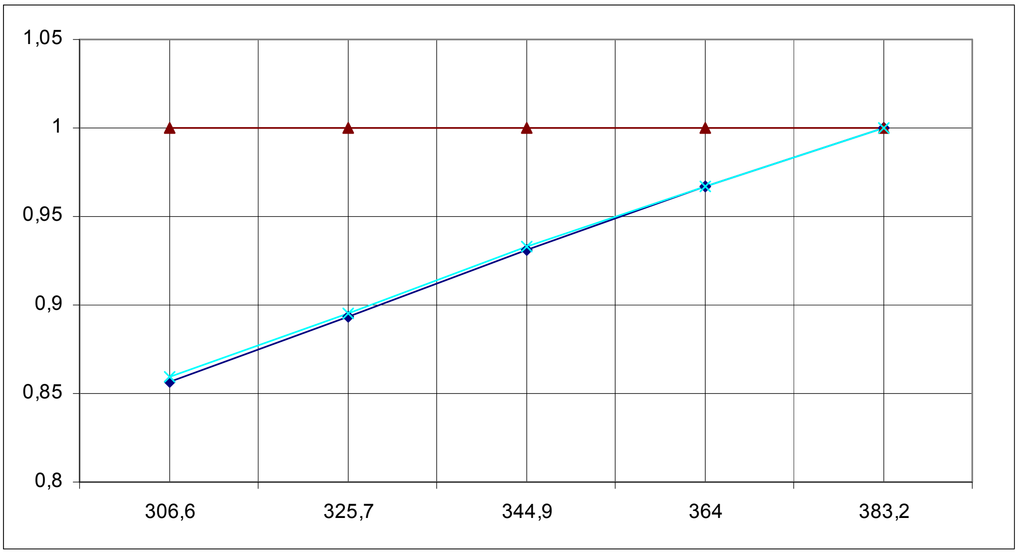
Appendix 2.3 Super Heater II



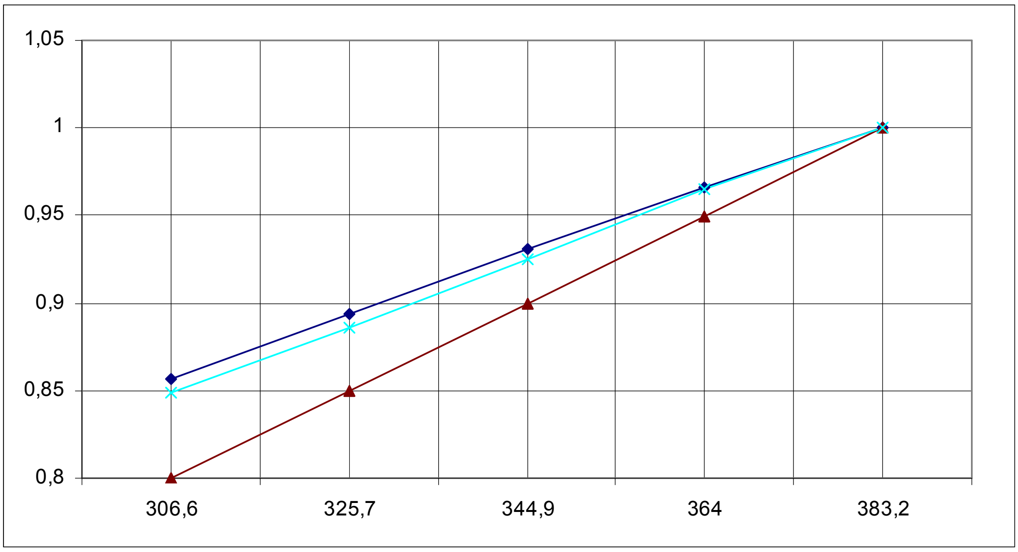
Appendix 2.4 Economizer



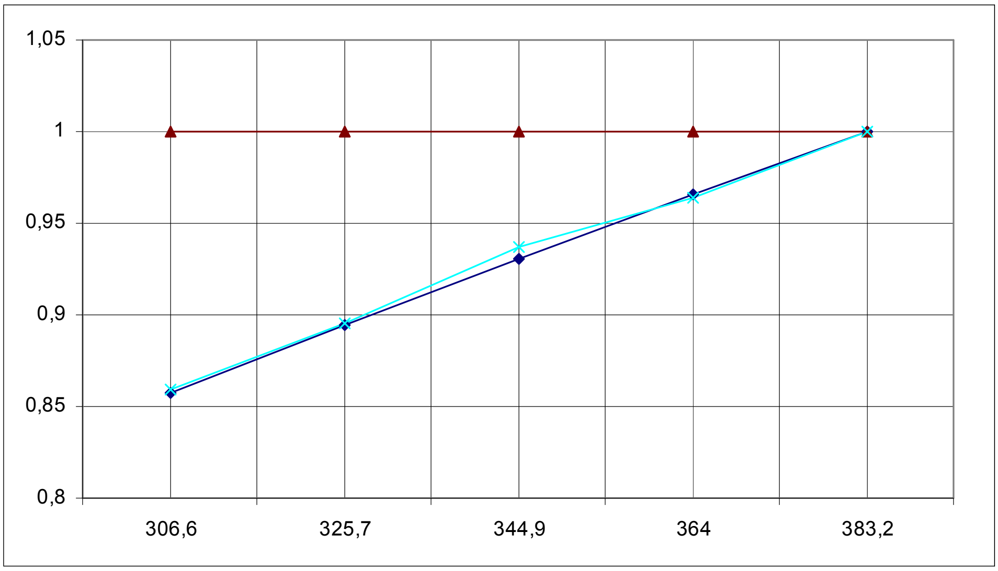
Appendix 2.5 The solid separator and return leg Heat Exchanger



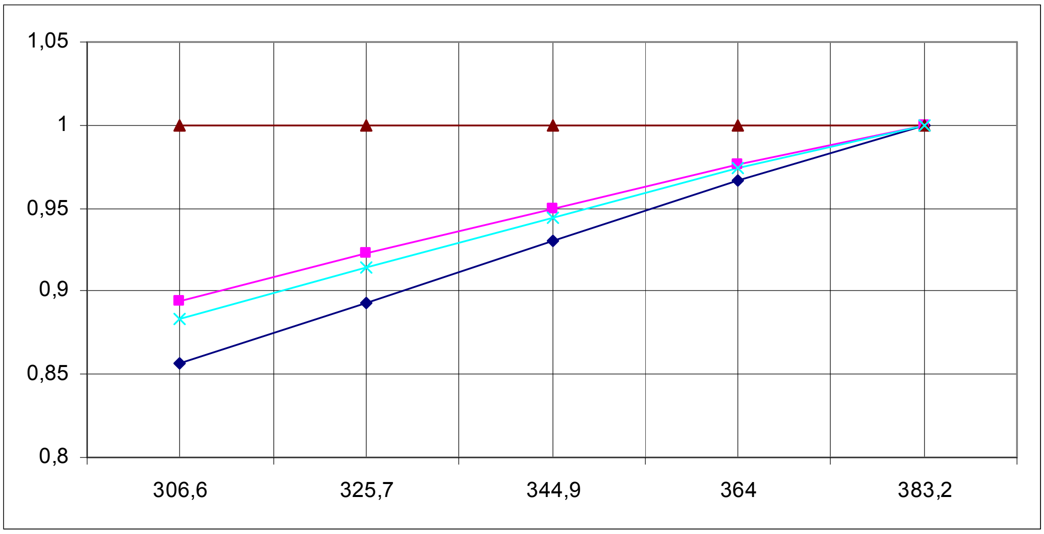
Appendix 2.6 Intrex Walls(steam) Heat Exchanger



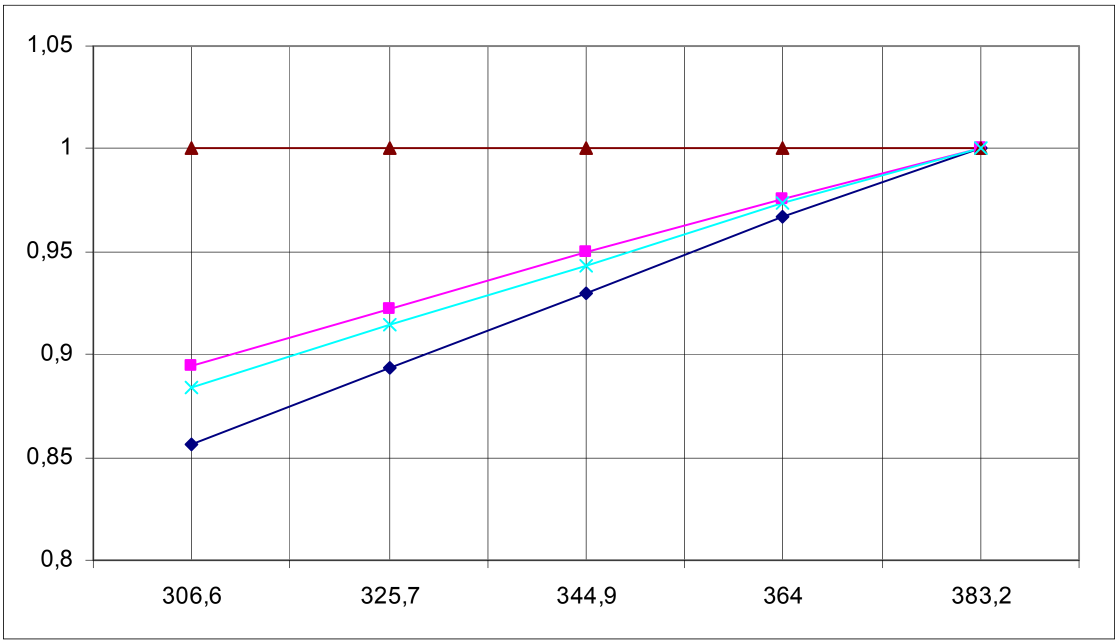
Appendix 2.7 Intrex Walls(water) Heat Exchanger



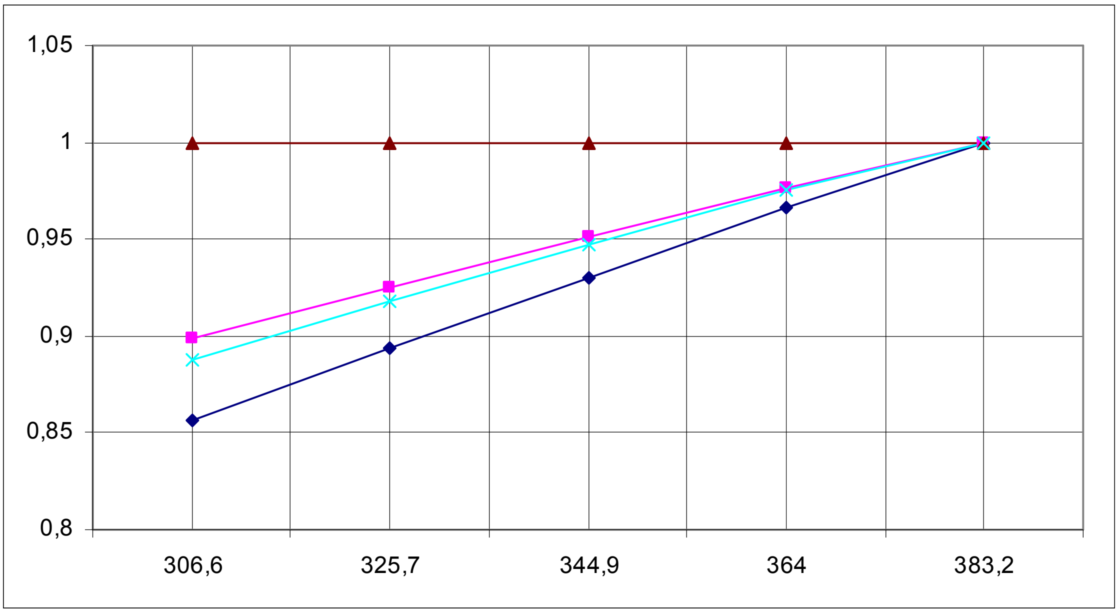
Appendix 2.8 Upper Furnace(1) Heat Exchanger



Appendix 2.9 Upper Furnace(2) Heat Exchanger



Appendix 2.10 Lower Furnace Heat Exchanger



Appendix 3. Examples of power plants using mixed fuels combustion.

The Alholmens Kraft CHP

Appendix 3.1. The Alholmens Kraft CHP plant. (EUBIONET,2003)

Technical data

Owner	Alholmens Kraft Ltd
Commissioned	2001
Investment cost	EUR 170 million
Electricity output	240 MWe
Process steam output	100 MWth
District heat output	60 MWth
Annual electricity production	1,300 GWh
Annual heat production	2,520 TJ

Fuel data

Annual fuel consumption	12,600 TJ
- Industrial wood and bark residues	35%
- Forest residues	10%
- Peat	45%
- Heavy fuel oil or coal	10%

Boiler data

Boiler supplier	Kvaerner Power Oy
Boiler type	Circulating fluidised bed combustion
Boiler output	550 MWth
Steam	194 kg/s, 165 bar, 545^{o}C

Data from (EUBIONET,2003)

In Finland in Pietarsaari is a major station, the Alholmens Kraft CHP. The station uses a system of mixed biofuels, mainly wood waste from the production, bark and peat. Plant produces electricity and steam for paper mills, and also provides the city with electricity and heat. The Alholmens Kraft CHP is one of the largest stations on the use of biofuels. The Alholmens Kraft CHP is good example for the production of energy from biofuels in large quantities.

Avedøre power station

Appendix 3.2. Avedøre plant in Copenhagen.(EUBIONET,2003)

Technical data

Owner	i/s Avedøreværket 2
Commissioned	2001
Capacity at full load, net	435 MWe, without gas turbines
	585 MWe, with gas turbines
	365 MWe and 475 MWth heat without gas turbines
	505 MW electricity
	565 MWth heat with gas turbines

Fuel data

- Ultra supercritical boiler	Natural gas, fuel oil, pulverized wood pellets
- Biomass plant	Straw
- Gas turbines	Natural gas

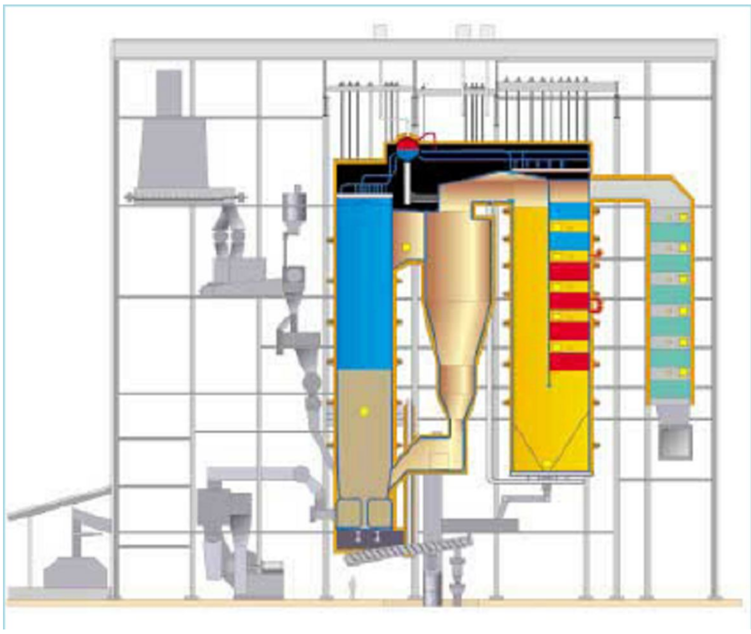
Boiler data

USB boiler supplier	BWE/FLS miljø A/S
Boiler type	Benson type single pass boiler
Biomass boiler supplier	Ansaldo Vølund/ Babcock Borsig Power
Boiler type	Vibrating grate boiler
Steam turbine	The two boilers and two gas turbines share one common steam turbine plant.
Steam	336 kg/s, 585^{o}C 300 bar USC boiler, 310 bar biomass boiler

Data from (EUBIONET,2003)

In Denmark in Copenhagen is Avedøre power station. This plant produces heat and electricity for Copenhagen and the surrounding areas. This is one of the most energy-efficient plants for production heat and electricity. Avedøre power station is working on mixing, parallel use of natural gas and biofuels. Special feature of Avedøre power station is that the ash obtained by burning straw in the boiler is returned to the fields as fertilizer.

The Händelö CHP



Appendix 3.1. The Händelö CFB boiler(EUBIONET,2003)

Technical data

Owner	Sydkraft Östvärme AB
Commissioned	2002
Electricity output	11 MWe
Thermal heat output as district heat and process steam	64 MWth

Annual electricity production	88 GWh
Annual heat production	1,840 TJ

Fuel data

Annual fuel consumption	consumption 200,000 tonnes of waste (2,400TJ)
Net calorific value of fuel	10–16 MJ/kg
Moisture content of fuel	15–40%
- Combined household waste	30–50%
- Classified industrial waste	50–70%
- Sewage sludge max.	20%

Boiler data

Boiler supplier	Kvaerner Power Oy
Boiler type	Circulating fluidised bed combustion SNCR system using ammonia for NOx reduction
Boiler output	75 MWth
Steam	27.2 kg/s, 6.5MPa, 470^{o}C
Flue gas treatment	Ahlstrom Power AB, NID system

Data from (EUBIONET,2003)

In Sweden in Norrköping is a major station The Händelö CHP. This station is a new concept of energy production from waste. Plant operates on the mixed fuel, mostly different types of waste. Currently the plant has four boilers: two CFB boilers for biomass and waste, a vibrating grate for wood and woods residues and one traveling grating were originally designed for coal. Newest CFB boiler was installed in 2002 and is designed specifically for burning solid waste, industrial waste, sewage sludge, rubber and demolition wood. There was developed a flexible combustion technology, special conditions of carriage of fuel and a special system of cleaning flue gases. Power station is chosen so that consumes the waste products from the region of Norrköping.