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IMPROVEMENT OF THE LIQUID FUEL COMBUSTION BY CONTROLLING THE RELEASE OF INITIAL VOLATILES

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Abstract

For different fuels the release of volatiles and the ignition temperature differs significantly. For this reason history of the flame development can be predicted according to known fuel characteristics. In furnaces a good burnout depends on flame ignition and development in the vicinity of the burner. We have a experience in reducing the soot residue, nitrogen oxide and carbon monoxide emissions. The release of volatiles depends on the droplets diameter, arrangement of air and fuel streams and especially on recirculation zone properties. In this article some lessons regarding numerical simulation of combustion is discussed. Theoretical knowledge on oxidation chemistry results enables to understand how the combustion process in the furnace is developed. The zones of methane, hydrogen, carbon monoxide formation vary according to boundary conditions.

Keywords: Combustion, volatiles, burners, combustion tuning.

INTRODUCTION

Main information about the combustion process, volatile hydrocarbon formation and its changes are briefly presented in Warnatz et. all [1] and more detail analysis is given in Bartok and Serofim [2].

The knowledge concerning all details of combustion process is sought from experiment. Complicated nature of turbulent mixing, fossil fuel composition, oxidation chemistry, mass traufer and soot formation restrict the performance of theoretical approach of calculation. These two books is a source for deeper understanding some needed physics.

In nowadays numerical simulation can help to solve many questions. By these methods we can imagine how boundary conditions influence the results or to see the relationship between the inside parameters. Fluent code [3] is the most relevant for evaluating the combustion process, in which accomplishments of researchers are summarized for direct solution of tasks. Lithuanian Energy Institute purchased this code for academic use and it is useful since here calculation base and premises are presented very clearly. We can present an example to illustrate the concerning issue on the combustion process of fuel droplet. Six laws are emphasized for droplet combustion: warming up, surface evaporation, volatile boiling, tar decomposition from porous ball, surface carbon combustion and cooling of incombustible residue. This code is written cleary with all theoretical background, therefore the combustion process looks like a simple system. Despite all calculation scope, the hidden data analysis is arranged very well.

In this article some lessons concerning numerical simulation of combustion are discussed. Theoretical knowledge on oxidation chemistry results enables to understand the combustion process in the furnace. The zones of methane, hydrogen, carbon monoxide formation are shown.

Laboratory of combustion processes initiated the burning improvement in district heating boilers. Pollution limits were established to be 450 mg/Nm^3 by NO_2 and 200 mg/Nm^3 by soot. This task and effectiveness of fuel usage was achieved creating better burning in the first stage of the flame: there must be faster release of light volatiles and its burning should be better dosed.
The experience accumulated in our laboratory can be very useful for Russia and Kazakhstan, where the events of transformation are similar and the type of boilers is the same. Our measures are simple, cheap and precise.

The longer is the way for carbon oxidation in the furnace, the higher is the quality of combustion. In this respect, the KVGM boilers may be praised, tough all the furnace walls are covered with shields of water tubes, even the floor is not covered with bricks. The capacity of these boilers is 10, 20, 50 and 100 MW, and in most of them fuel combustion of desired quality may be achieved: with air excess coefficient 1.10 and with the minimum carbon residue in flue gas 100 mg/Nm^3.

When using heavy fuel oil, the steam is needed. For this purpose, DKVR boilers with the capacity of 10 and 20 t/h are used. The bottom of these boilers is covered with bricks and the side tubes in 0.8 m height are covered with bricks as well. Heated ceramics favourably heat fuel and air mixture fed by the burner. The combustion is of high quality and there is no danger of carbonization on the furnace walls.

PTVM water heating boilers have especially tall narrow furnaces with the burners arranged near the bottom facing each other. Such arrangement of burner turbulizes the primary combustion stage and fuel gasification may be used for the reduction of NO_x. In some cases, the secondary air injection system over fire air had to be installed.

Boilers of DE type are the worst for the heavy fuel oil combustion since their furnaces are small and short, thermal loading of the furnaces is more than 400 kW/m^3.

During the last decade, it is common for a boiler to operate at lower capacity. When the capacity is smaller than 0.3, the furnace is not filled with the flame completely. In such case the burners with high velocity in the quarl and with the increased peripheral air twist are installed. The flame is created near the whole front wall and along the burner axis. In this case, some part of furnace is passive.

ANALYSIS FOR BETTER BURNING

Renovation task

When fuel oil is burnt in smaller furnaces of district heating boilers and when there is a shorter oxidation passage, it is necessary to organize better initial flame ignition, to intensify mixing with air and to maintain local temperature at high levels to ensure the complete combustion. These boilers must be exploited at different loads and adapting operation regimes to the out door temperatures during the cold season. Therefore, combustion processes must be thoroughly understood and perfectly controlled.

The formation of coke on the cold screen walls can begin while changing the use of mazouth, some of it with greater asphaltene amount. This usually happens with sudden switch to low load regime. LEI Laboratory of Combustion Processes has to redesign some burners for lower loads and formation of coke phenomena is encountered while regulating burners for future operation. Usually, for burner adjustment a governing factor is exact matching of air streams with fuel oil atomizer streams and with the furnace geometry. The fuel oil spraying is performed by steam atomizers. They splash fuel oil into droplets, having sizes of 50-200 mkm, and the operation parameters of such atomizers remains the same for many years.

The smaller the droplets, the faster they release volatile and ignite, the smaller tar and coke cenospheres. For good operating boilers, where standard burners and quarl ceramics were relevant, such atomization of fuel enabled not to exceed the limits of NO_2 regulations.

After a good atomization is arranged, there must be a burner with two air streams, Fig. 1. The central air at low velocity and peripheral air at high swirled stream.

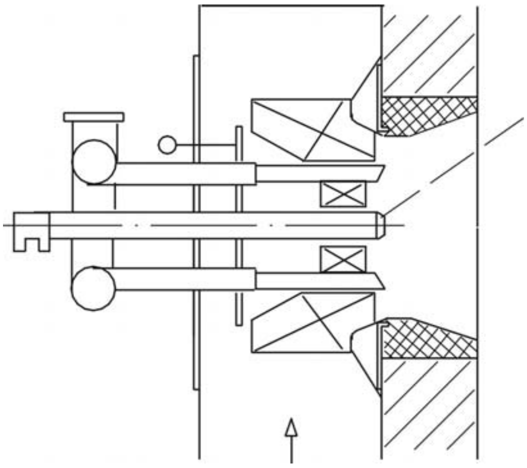

Fig. 1. The schematic of the burner with central and peripheral air streams

The tips of the burner blades must be made free and flexible for the central as well as peripheral air in order to adapt the air streams to each furnace.

The third crucial factor is the structure of air currents in the furnace. There must be an intensive air twist in the burner, giving rise to a spiral motion and after that the observable strike upon the walls in order to initiate mass exchange in the corners Fig. 2.

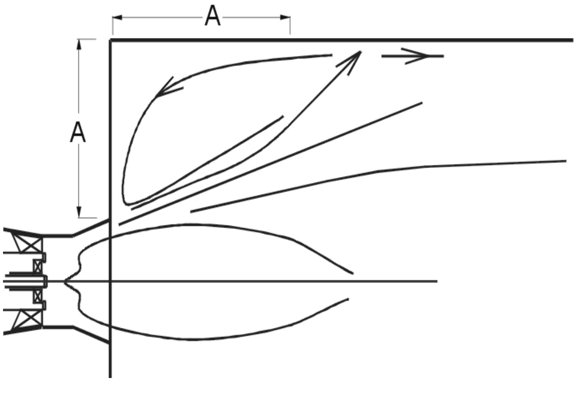

Fig. 2. The gas streams in the furnace

The bluff body in the burner, such as a narrow circular tape, helps to ensure the required recirculation zone.

The fourth factor is the quarl and different forms and length suit according to fuel, atomizer, and furnace air twist.

In all cases, we began to adjust the air streams in the furnace by measuring the size and the form of the recirculation zone, the pathway of the maximum velocity and location of stream partition on the walls. In order to do this, we would enter the furnace, turn on the air supply and exhaust fans and perform the required adjustments. In such a manner, we adjusted the air stream configuration favoring good combustion and no carbonization on the screen tubes. Different fuels have different ignition temperatures. We have experienced how the flame start point, looks like. For heavy fuel oil the flame stars early, this fuel is like a mixture of many compounds and light gas vapor mixes with air and ignites. In this case a large amount of central air enables a good flame development. Natural gas ignites more slowly, it is difficult to do this quickly, because the mixture of fuel/air needs special concentration, the ignition of rich mixtures goes slower.

When the fuel ignites more slowly we need to construct a burner suitable for this situation. The strong recirculation zone must enable large flame volume near the burner, Fig.3. We have done this for emulsion fuel and glycerol burning case.

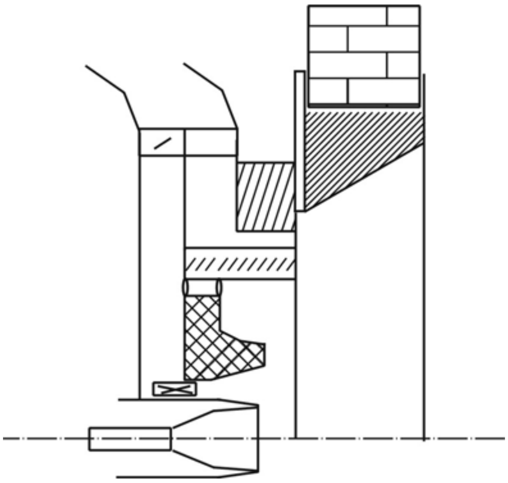

Fig. 3. The burner for high temperatures in the first step of the flame

Modeling

The next step in understanding the burning events was the study of numerical calculation results. Our aim was to compare approximate calculations with experience that we got in time of rearranging the combustion of heavy fuel oil for NO reduction in many water heating and steam boilers.

FLUENT is a program clear and simple for study hydrodynamics applications and gain experience. Combustion is a complex process where turbulent flow and mass transfer and chemical reactions dominate.

The basic for our calculations was:

- turbulence modeled by k-e model and sometimes by LES,
- species transport based on PDF model,
- oxidation reactions – mixed is burned.

As fuel n-pentane C_5H_{12} was chosen. The fuel droplets are introduced as discrete phase injections. For the n-pentane liquid equilibrium the reaction system consists of 11 species. Calculation using this liquid as an example was presented by the authors of the code Fluent and it was used for our calculations thus excluding possible mistakes when defining liquid properties and preparing tables of physical properties in the corresponding files.

The geometry of the furnace was like a prolonged cubic 1,8 × 2,1 × 3,0 m with exit in the corner at the side. One case of the burner with central and peripheral air was studied, another case with large stream of peripheral air and some small holes in the bluff body of the burner center. The quality of burnout was achieved with oxygen 2 % concentration in the flue gas. In this calculation the variation of species was our main task of this burning study. Distribution of temperature is the basis of existence for all other species. In Fig. 4 the results are shown when air taken to the burner was at ambient air temperature. In Fig. 4 at right the air was 300 °C to see what happens with higher degree of fuel devolatilization.

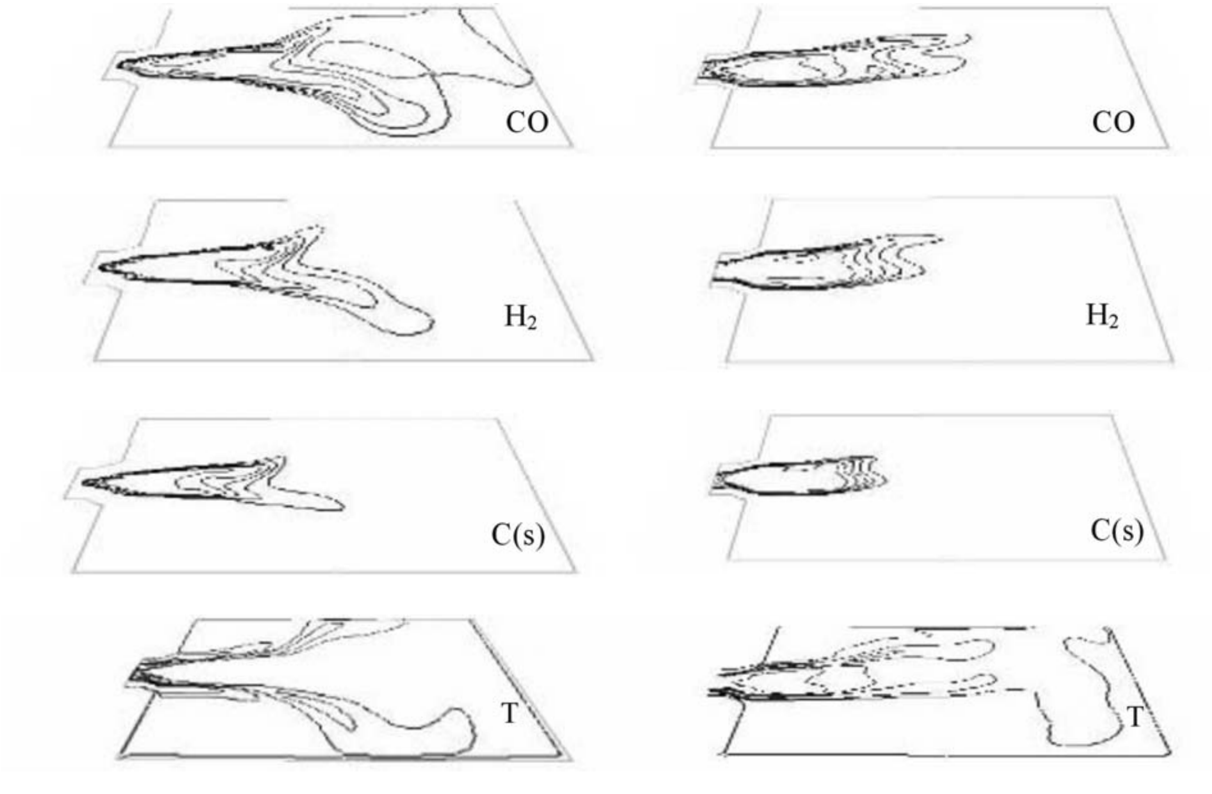

Fig. 4. Temperature and species distribution contours for the burner with bluff body at the center. At the right the case with air taken at 300 °C

From these results a conclusion can be made that the generation of carbon particles C (s) and methane CH_4 takes place where the light gas volatiles are burning and they create a continuous zone with high temperature. When the aerodynamical picture is the same at higher inlet air temperature the creation of zones with C (s) and CH_4 is smaller. The generation of hydrogen H_2 takes place at high temperature level. H_2 and CO is a product of hydrocarbon molecules and keeps high level at high temperatures. The ones of OH are in high concentrations, where intensive burning sheets exist. OH is the intermediate material in the chain of oxidation reactions and its scope lay near the oxygen sheets and the OH map repeats the temperatures sharp maxima.

It is very interesting that the concentration quantity of the carbon C (s) is high and equals to 0.06 in its zone. Very high concentration is of CO – 0.15. The peak of OH is about 0.002.

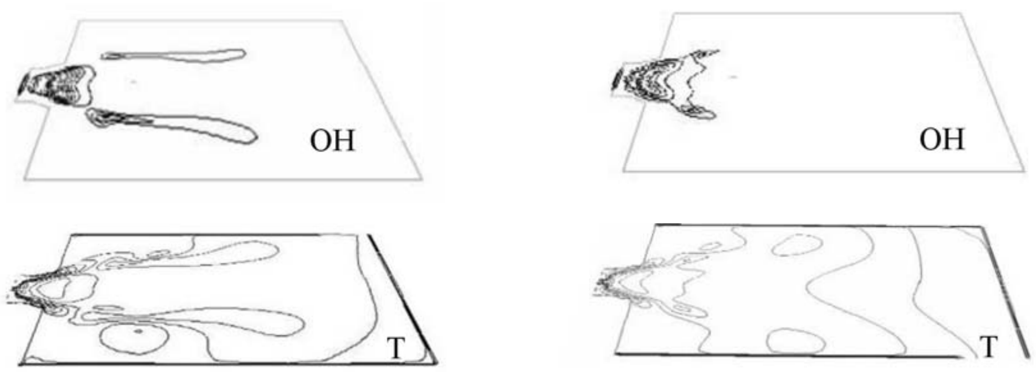

Fig. 5. Temperature and OH distribution for the burner with staged air distribution.
At the right the case with air 300 °C

Fig. 6. OH distribution contours from the data according to Fig. 4 for comparison with case of staged air burner, in Fig. 5

In Fig. 4 numerical calculation results are shown for furnace, in which the burner has bluff body in the center. The peripheral air creates the flame. In this situation all above mentioned chemical groups are widely pronounced. In Fig. 5 results are shown concerning another burner with central and peripheral air streams. The air taken in the center enables better oxidation. The zone of OH at right in Fig. 5 is very small. The amount of CH_4 and the C (s) is smaller and is not shown in figure.

Fig. 7. Flue gas species CO_2 and H_2O distribution contours in furnace

For the comparison between two different burners the cases of OH according to Fig. 4 burning situation are taken in Fig. 6.

The CO_2 and H_2O is the result of oxidation reactions and its high concentration lay in the end of the furnace Fig. 7.

Numerical modeling helps to imagine concentration zones of chemical compounds inside the flame. At different boundary conditions these zones are changing and it is the additional information to understand the better burning. In this work 6 cases with different boundary conditions were analyzed and different answers were found according to species zone structure, but in the furnace exit the differences in flow rate of oxygen , CO_2, H_2O, CO were small. Detailed numerical analysis can help to receive more information, but it can never solve the burning parameters in furnace. The numerical advice is interesting and helpful.

Our job in the burning process improvement showed the importance of experience, theoretical knowledge and experience in tuning. The last is very important: you must tune the air stream for furnace volume, tune fuel droplet size and stream directions, quarl length and geometry. If some parameters of fuel change, the burning quality changes as well. Recirculation zone and rate of air in the center affects NO_x. Heavy fuel oil ignites earlier, and a greater amount of central air is needed. If this air is too strong the NO_x increases. Methane ignites later and suit situation must be arranged earlier by mixing and heating.

CONCLUSIONS

1. The experience in burning technology is the basis for progress to get less pollution and for efficient use of fuel. In the case of heavy fuel oil burning the good fuel atomization, perfectly adjusted primary and secondary air streams for the fuel devolatilization, suitable quarl are the first needed measures. The good fit of the flame to furnace is responsible for soot and CO level in flue gas. Fuel oil burning prefers lager stream of axially air, in methane case earlier ignition must be organized.
2. Numerical modeling is competing with experience. In the zone of high temperatures near the burner the species distribution are presented. The large zone with free carbon C(s) and its equivalent CH_4 shows worse situation for burning history, for larger soot and NO_x. The high temperature volume and its equivalent OH show how large zone is for NO_x creation. According to these parameters we can understand the devolatilization process.

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