INFLUENCE OF BURNER LOAD DISTRIBUTION ON FURNACE BEHAVIOR

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ABSTRACT

Once-through boilers are very sensitive to the combustion process in the steam generator combustion chamber. Fuel to feed water flow ratio should be maintained in a very narrow range in order to ensure proper functioning. This is especially true when the combustion system is complex consisting of a great number of burners. In this paper influence of a 16 burner oil-fired combustion system of a real steam generator on the temperature, velocity and heat flux distributions inside the combustion chamber was investigated. Simulations of the combustion chamber performance for normal operation and for the anomalous operation without a burner were carried out and related to the actual situations. It was shown that poor functioning of a single burner can cause distortion of the main parameter distributions which may result in the damage of the steam generator vital parts.

KEYWORDS

Numerical simulation; mathematical modeling; combustion chamber operation

INTRODUCTION

The once-through boilers belong to the category of the greatest capacity boilers of today with highest steam parameters. They can satisfy very rigorous demands for load changes. Since there is no natural circulation of water and steam in such boilers, the positive circulation is realized by an external feedwater pump. The maintenance of fuel to feed water flow ratio in very narrow range for all operating regimes is obligatory in order to ensure proper functioning. It is achieved by sophisticated control system. During operation conditions for fuel and air injection in a burner change due to the fact that nozzles get soiled; and which nozzle would get choked first cannot be estimated. The change of total burner load due to poor operation or shutdown of a single burner can change combustion conditions in the combustion chamber dramatically.

In this paper the three dimensional mathematical model of the steam generator combustion chamber was used for investigating the influence of burner load distribution on furnace behavior. Primarily attention was paid to the extent to which a single burner dropout can influence the operation of the combustion chamber as well as the steam generator itself. The furnace is a part of the tower type once-through 1000 t/h steam generator. The combustion chamber dimensions are 11.6x11.6x23 m. The superheated steam exit temperature is 540 °C at 175 bar. The oil-fired combustion system consists of sixteen burners placed in four levels on the front furnace wall. Each burner level may be controlled separately by choosing appropriate values of weight factors which ensure that overall load stays constant. During the operation the unbalance of the furnace thermal load is often encountered which results in different superheated steam temperatures on the outlet of evaporator tubes. For low load conditions the evaporator is furnished with Sulzer bottle which should be dry during higher loads. Appearance of the water level in the bottle during high load operation is undesirable and is caused by thermal unbalance of the furnace. By acting upon burner load distribution through the control system such situations may be avoided.

The frontal burner position causes the domain of highest flue gas temperatures and velocities to drift toward the furnace rear wall. The evaporator tubes are placed spirally around the furnace in four distinct groups (shown in Fig. 1.) which should equalize heat flux distribution along tube groups.
Evaporation of water is not finished at the furnace exit. The second stage of evaporator tubes is placed vertically along walls through the convective part of the steam generator. The transition called the “dry out” between wetted and not wetted part of tubes takes place just in this region where heat fluxes are lower than in the furnace. Thus the tube wall temperature jump is milder and tube lifespan prolonged. In the convective part of the steam generator there are other heat exchange surfaces as follows: a supporting tube package, two superheaters, two reheaters and an economizer. They are divided into left and right side groups of tubes. Maximal temperatures of steam along each side are controlled separately by means of water injection before the first and second superheater and the second reheater.

MATHEMATICAL MODEL OF THE COMBUSTION CHAMBER

The mathematical model of thermo-hydraulic processes in the furnace (Đurić, 1993) is based on the time-averaged three-dimensional transport equations which can be written for steady-state case using Cartesian tensor notation as:

$$
\frac{\partial}{\partial x_j} (\rho \phi u_j) = \frac{\partial}{\partial x_j} \left( \Gamma_{\phi} \frac{\partial \phi}{\partial x_j} \right) + S_j
$$

The general variable \( \phi \) stands here for three velocity components and for turbulent kinetic energy and its dissipation rate. When \( \phi = 1 \) the continuity equation is obtained. The two additional equations are used for describing transport of chemical species: the one for fuel and the other for oxygen. The one step reaction model is assumed to be of the first order with reaction rate proportional to the fuel and oxygen concentrations. The factor of proportionality is based on empirical data (Kylagin, 1967).

The same form of (1) is valid for enthalpy equation. Released heat of combustion and heat exchanged by radiation are hidden in the source term. The radiation heat transfer is modeled by applying the Monte Carlo method (Görner, 1990; Bogdan, 1994). The main improvements of the present radiation model in relation to the old model about which we reported at the former INFUB conference (Bogdan, 1995) include application of distribution functions for determining bundle emission positions and weakening of the energy bundle on its way through the furnace instead of calculating the average path length. These introductions speed up the solving procedure, make the treatment of complex geometry easier and enable application of non equidistant grids.

The described set of transport equations is solved by the control-volume approach (Patankar, 1980). For solving the strongly coupled pressure and velocity equations a modification of the PISO (Issa, 1995) method is applied.
Each variable field is solved by using the TDM method with the additive correction multigrid method (Hutchinson, 1986) for increasing the convergence rate.

RESULTS

Two different situations of furnace operation were simulated for which measurements of certain overall parameters are available. The first situation is related to the normal full load operation while the second situation refers to the operation without one burner. Dropout of the most right burner of the fourth level causes the other three burners at this level to make up for it.

The main overall parameter which describes balance of input and output heat fluxes is the furnace flue gas exit temperature. The influence of the grid size on this parameter is depicted in Fig. 1. It is shown that number of control volumes greater than 20000 is sufficient to predict the furnace exit temperature. Velocity field in the vertical plane at distance $z=0.4$ m from the burner plane is shown in Fig. 3. It is symmetric due to burner equal load distribution.

![Fig. 2. Furnace flue gas exit temperature as a function of number of control volumes (normal operation)](image1)

![Fig. 3. Velocity field in vertical plane at distance 0.4 m from the front wall (normal operation)](image2)

Frontal burner position is the reason for obtaining nonsymmetrical velocity and temperature fields in the combustion chamber in the direction of fuel injection, which can be seen in Fig. 4. Maximal axial velocities and temperatures are located near the furnace rear wall. Distribution of heat fluxes over furnace walls is given in Fig. 5, which shows that rear furnace wall receives most of the total heat flux. This heat unbalance is considerably milder by the layout of spirally wound evaporators tubes shown in Fig. 6. Numbers of tube groups are explained in Fig. 1. Each tube group takes over nearly equal heat flux. But the not homogenous velocity and temperature field is not only limited to the furnace but it is extended to the convective part of the steam generator. Since the second evaporator stage above the furnace consists of vertical (instead of spirally laid) tubes passing along the walls, unequal steam production is to be expected. And in some regimes it may cause appearance of water level in the Sulzer bottle although it does not correspond to the overall power level.
Burner operation is controlled by the automatic control system which acts upon each burner level. This means that a single burner is not in reach of the control system and that distribution of fuel among four burners of one level depends on the state of burner nozzles. The drastic but often encountered case of the burner misoperation is the dropout of a single burner. The comparison of temperature fields in the exit plane of the furnace for normal operation and for operation without the first right burner of the fourth level is given in Fig. 7. In the case of normal operation velocity and temperature fields are symmetric in regard to the central vertical plane normal to the furnace front and rear walls. In the case of a burner dropout temperature field changes with the shift toward...
the right side wall of the furnace. Distribution of velocity and temperature fields in the vertical plane in which the malfunctioning burner is visible is given in Fig. 8.

Fig. 7. Comparison of temperature fields in the exit furnace plane:
   a) normal operation, b) fourth level right burner dropout

Fig. 8. Velocity and temperature fields in the vertical plane at x=9.28 m, first column from right (one burner dropout)
Such combustion conditions influence also the convective heat exchange surfaces of the steam generator. In normal operation the left and right side values of injected water flows for controlling steam exit temperature are approximately equal. But for the case of a burner dropout measured quantities of injected water showed distinct difference between the sides.

Table 1. Measured quantities of injected water, t/h

<table>
<thead>
<tr>
<th>(one burner dropout)</th>
<th>Heat exchange surface</th>
<th>Left side</th>
<th>Right side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superheater I</td>
<td></td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>Superheater II</td>
<td></td>
<td>8</td>
<td>23</td>
</tr>
<tr>
<td>Reheater II</td>
<td></td>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Mathematical modelling and simulation of processes which govern behavior of the combustion chamber may give a good information about what is going on, especially when there is misoperation of an important part of equipment. This paper shows that dropout of only one out of sixteen burners in the combustion chamber can change temperature and velocity fields to such an extent that the whole steam generator is affected. The measure of the heat balance distortion is given through unequal quantities of water injected for temperature control. Although the total water quantity is appropriate to the operating load the redistribution among left and right steam generator sides can bring one of them to its limit and thus endanger that particular heat exchange surface. By introducing the control system which could control each burner separately, performance of the combustion system would improve significantly.

REFERENCES

[2] Duić N., The three dimensional mathematical model of the processes in the steam generator combustion chamber (in Croatian), M.Sc thesis, Faculty of mechanical engineering and naval architecture, University of Zagreb, Zagreb, 1993,