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Economizer, main part of boiler, modelling, CFD

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MODELING OF FLOW AND TEMPERATURE FIELD IN AN ECONOMIZER

Abstract

This article deals with the economizer as one of the main parts of a boiler. Economizers and air heaters perform a key function in providing high overall boiler thermal efficiency by recovering the low level energy from the flue gas before it is exhausted to the atmosphere. The most common and reliable economizer design is the bare-tube, in-line, cross-flow type. To reduce capital costs, most boiler manufacturers build economizers with a variety of designs to enhance the controlling gas-side heat transfer rate. From this point of view it creates a lack for an investigation and modeling of these parts.

1. INTRODUCTION

Economizers are basically tubular heat transfer surfaces used to preheat boiler feedwater before it enters the steam drum (recirculating units) or furnace surfaces (once-through units). The term economizer comes from early use of such heat exchangers to reduce operating costs or economize on fuel by recovering extra energy from the flue gas [2]. Economizers also reduce the potential of thermal

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shock and strong water temperature fluctuations as the feedwater enters the drum or waterwalls. Fig. 1 shows the location of an economizer in a coal-fired boiler. The economizer is typically the last water-cooled heat transfer surface up-stream of the air heater.

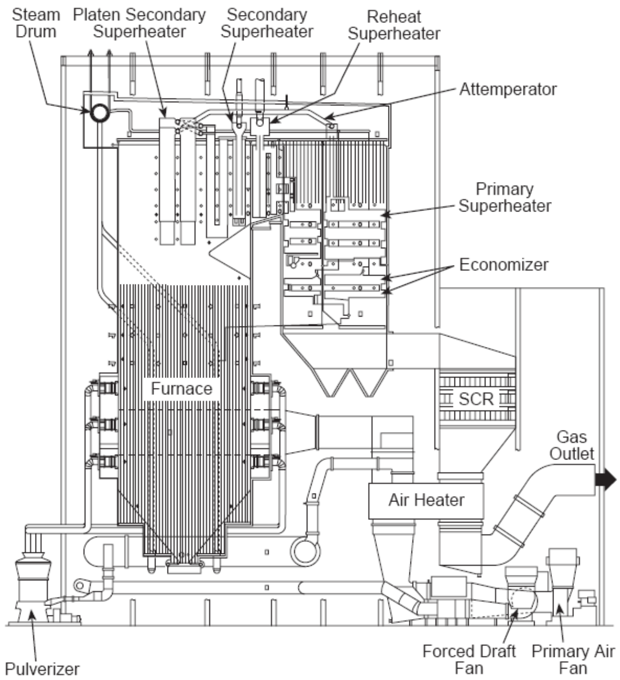

Fig. 1. Economizer and air heater locations in a typical coal fired boiler [9]

Modern heat exchangers (economizers) are characterized by high steam pressure and temperature values, and the tubes used in these devices have complex cross-sectional shapes [3, 4]. Tube geometry allows the construction of heat exchanger plates with smooth sidewalls, which can be placed in the upper part of the combustion chamber. This prevents erosion of superheater tubes and deposition of slag and ash in the spaces between adjacent tubes.

The mechanisms of heat transfer in flow conditions are complex because they may comprise the phenomena of natural forced convection and convection associated with the turbulent flow of medium in the tubes. Computational Fluid Dynamics (CFD) software and the results of laboratory tests of thermal conductivity make it possible to model the real phenomena occurring in heat exchangers. Other test methods are dedicated to specific economizer designs. The authors of [7], for example, present a mathematical model of a shell-and-tube heat exchanger with helical baffles (STHXsHB) in which the rate of heat transfer and the total cost of energy are subject to multi-objective optimization.

Modeling results can also be used to validate the adequacy of mathematical models and the accuracy of equations used in those models. Simulations conducted using FLUENT 6.3 software have been used to solve the equations of continuity, momentum, and energy in [8].

Studies [4, 6] present the results of modeling of flow and heat processes in superheaters with complex flow systems. In those works, 3D models have been replaced by 2D models. The proposed computation method can be used in subcritical and supercritical boilers.

The application of simplified models based on the finite element method (FEM) to calculate the steady-state temperature field and flow in tubes remains a basic study method that allows one to obtain results with an error not exceeding 5% [1]. The results one obtains are the basis for optimizing the geometry of economizers and selection of pumps which set the fluid in motion. In this article, FEM modeling was used to determine the stress fields and temperatures of economizer components.

2. ECONOMIZER SURFACE TYPES

Bare Tube – the most common and reliable economizer design is the bare tube, inline, cross flow type shown in Fig. 2a. When coal is fired, the fly ash creates a high fouling and erosive environment. The bare tube, in line arrangement minimizes the likelihood of erosion and trapping of ash as compared to a staggered arrangement shown in Fig. 2b. It is also the easiest geometry to be kept clean by sootblowers. However, these benefits must be evaluated against the possible larger weight, volume and cost of this arrangement.

Extended Surface – to reduce capital costs, most boiler manufacturers build economizers with a variety of fin types to enhance the controlling gas-side heat transfer rate. Fins are inexpensive parts which can reduce the overall size and cost of an economizer. However, successful application is very sensitive to the flue gas environment. Surface cleanability is a key concern. In selected boilers, such as PRB coal-fired units, extended surface economizers are not recommended because of their peculiar flyash characteristics.

Stud fins: Stud fins work reasonably well in gas-fired boilers. However, stud finned economizers can have a higher gas-side pressure drop than a comparable unit with helically-finned tubes. Studded fins perform poorly in coal-fired boilers because of high erosion, loss of heat transfer, increased pressure loss and plugging resulting from flyash deposits.

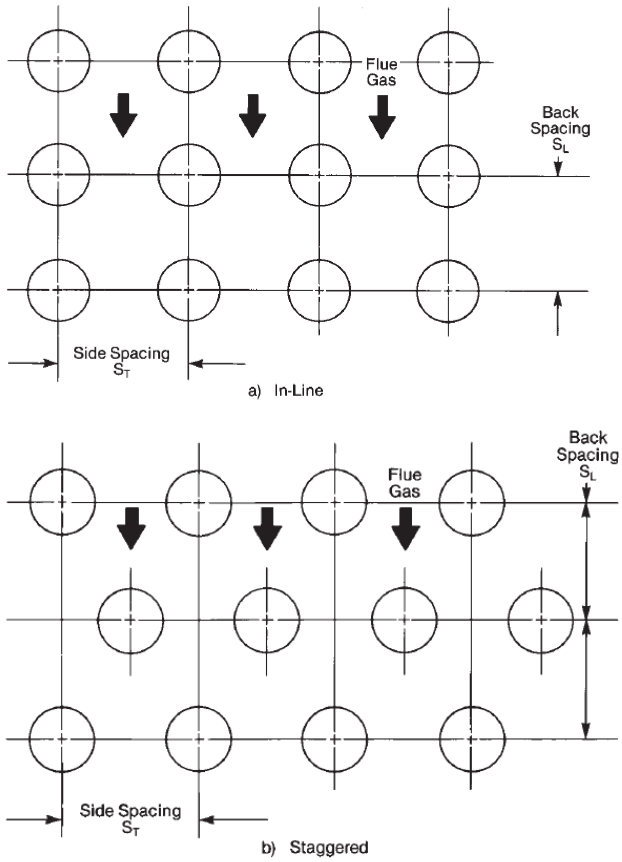

Fig. 2. Bare tube economizer arrangements [source: own study]

Longitudinal fins: Longitudinally-finned tubes in staggered crossflow arrangements (Fig. 3) also do not perform well over long operating periods. Excessive plugging and erosion in coal-fired boilers have resulted in the replacement of many of these economizers. In oil- and gas-fired boilers, cracks occur at the points where the fins terminate. These cracks propagate into the tube wall and cause tube failures in some applications. Plugging with flyash can also be a problem (tight spaces).

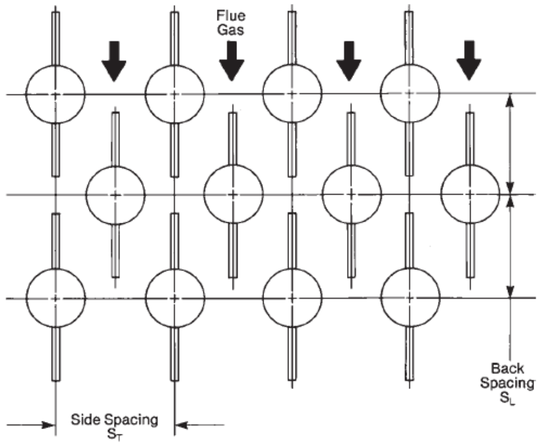

Fig. 3. Longitudinal fins, staggered tube arrangement [source: own study]

Helical fins: Helically-finned tubes (Fig. 4a) have been successfully applied in some coal-, oil- and gas-fired units. The fins can be tightly spaced in the case of gas firing due to the absence of coal flyash or oil ash. Four fins per inch (1 fin per 6.4 ram), 1.5 to 1.9 mm thick and 19.1 mm high are typical. For 51 mm outside diameter tubes, these fins provide ten times the effective area of bare tubes per unit tube length. If heavy fuel oil or coal is fired, a wider fin spacing must be used and adequate measures taken to keep the heating surface as clean as possible. Economizers in units fired with heavy fuel oil can be designed with helical fins, spaced at 13 mm intervals. Smaller fin spacings promote plugging with oil ash, while greater spacings reduce the amount of heating surface per unit length. Sootblowers are required and the maximum bank height should not exceed 1.2 to 1.5 m to assure reasonable cleanability of the heating surface. An in-line arrangement also facilitates cleaning and provides a lower gas-side resistance.

Rectangular fins: Square or rectangular fins, arranged perpendicular to the tube axis on in-line tubes as shown in Fig. 4b, have been used occasionally in retrofits. The fin spacing typically varies between 13 and 25 mm and the fins are usually 3.18 mm thick. There is a vertical slot down the middle because the two halves of the fin are welded to either side of the tube. Most designs are for gas velocities below 15.2 m/s. However, because of the narrow, deep spaces, plugging with flyash is a danger with such designs.

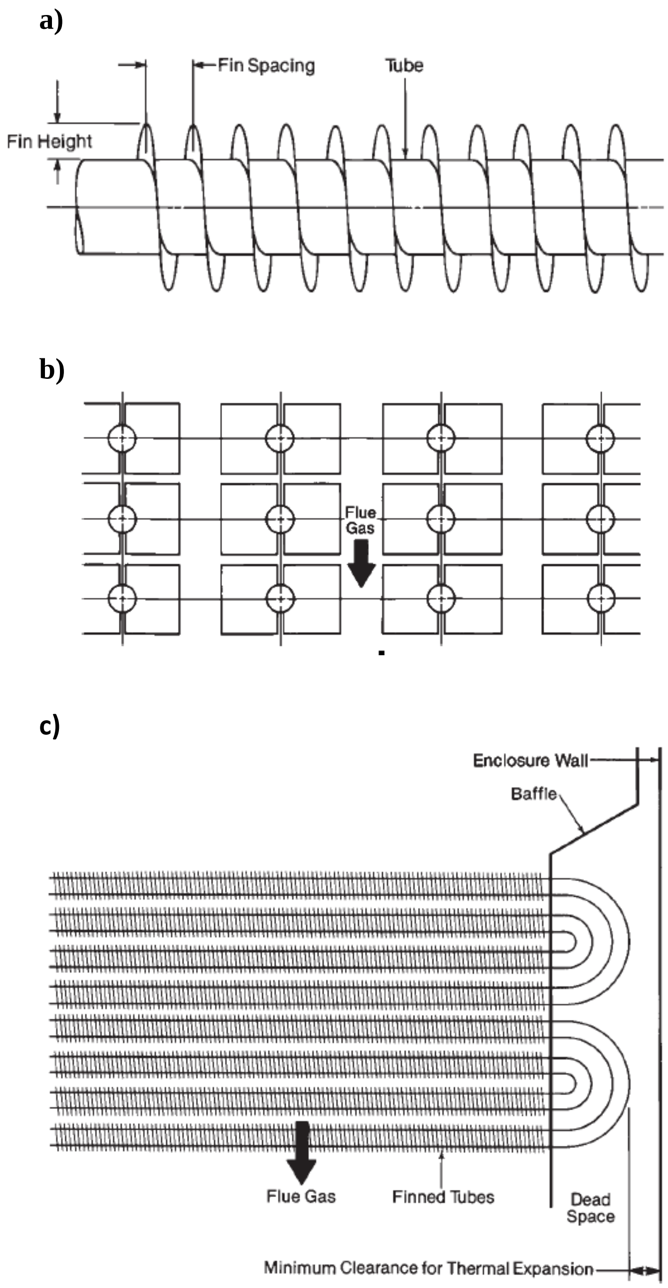

Fig. 4. Components: a – helically-finned tubes, b – rectangular fins, c – fully baffled [source: own study]

Baffles: The tube ends should be fully baffled (Fig. 4c) to minimize flue gas bypass around finned bundles. Such bypass flow can reduce heat transfer, produce excessive casing temperatures, and with coal firing can lead to tube bend erosion because of very high gas velocities. Baffling is also used with bare tube bundles but is not as important as for finned tube bundles. Tube bend erosion can be alleviated by shielding the bends.

Velocity limits the ultimate goal of economizer design is to achieve the necessary heat transfer at minimum cost. A key design criterion for economizers is the maximum allowable flue gas velocity (defined at the minimum cross-sectional free flow area in the tube bundle). Higher velocities provide better heat transfer and reduce capital cost. For clean burning fuels, such as gas and low ash oil, velocities are typically set by the maximum economical pressure loss. For high ash oil and coal, gas-side velocities are limited by the erosion potential of the flyash. This erosion potential is primarily determined by the percentage of AI_2O_3, and $Si0_2$ in the ash, the total ash in the fuel and the gas maximum velocity. Experience dictates acceptable flue gas velocities. Note: PRB coal contains ash with a low erosion potential. Velocities above 21.3 m/s can typically be allowed for such coals. Further criteria may also be needed. For example, a 1.5 m/s reduction in the base velocity limit is recommended when firing coals with less than 20% volatile matter. In other cases, such as Cyclone boilers, high flue gas velocities can be used because much less flyash is carried into the convection pass, as a large part of the ash (> 50%) is collected at the bottom of the boiler as slag. The particles that enter the boiler furnace are also less erosive.

For a given tube arrangement and boiler load, the gas velocity depends on the specific volume of flue gas which drops as the flue gas is cooled in the economizer. To maintain the gas velocity, it can be economical to decrease the free flow gas-side cross-section by selecting a larger tube size in the lower bank of a multiple bank design. This affords better heat transfer and reduces the total heating surface.

3. A MODELING APPROACH TO ECONOMIZER DESIGN

As it has been mentioned above the goal of this study was to get a closer look at flow in the economizer part of the boiler, as optimized flow can enhance the efficiency of both the boiler and the entire power plant.

In the present approach flow field was described with a 3D mathematical model developed using ANSYS FLUENT software. The model represented the simplest economizer design for which two fluids were defined: water and the flue gas. To achieve a more realistic result symmetry conditions were applied.

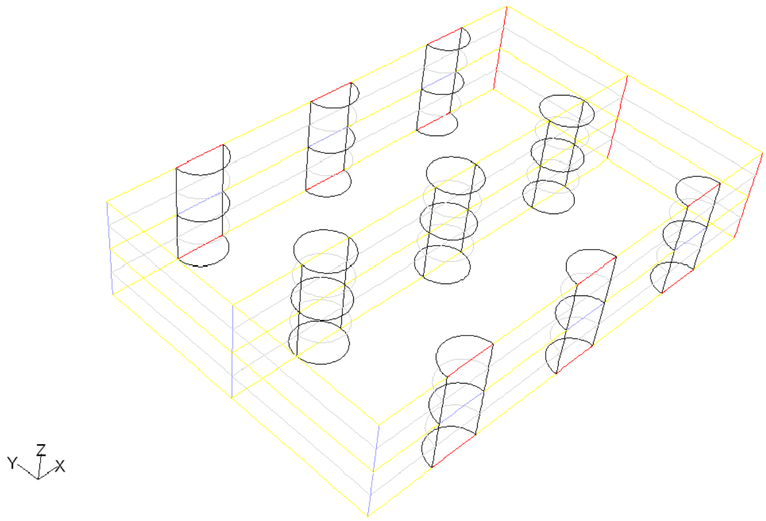

Fig. 5. A 3D model with symmetric conditions [source: own study]

In the model, water flew through pipes and the surrounding space was filled with flowing flue gas. Beside symmetry conditions, velocity inlet and pressure outlet were defined for both of these zones. Appropriate temperatures and pressure were set at velocity outlets. Convection and conduction heat transfer was considered and a suitable mesh was created for this purpose (Fig.6, 7).

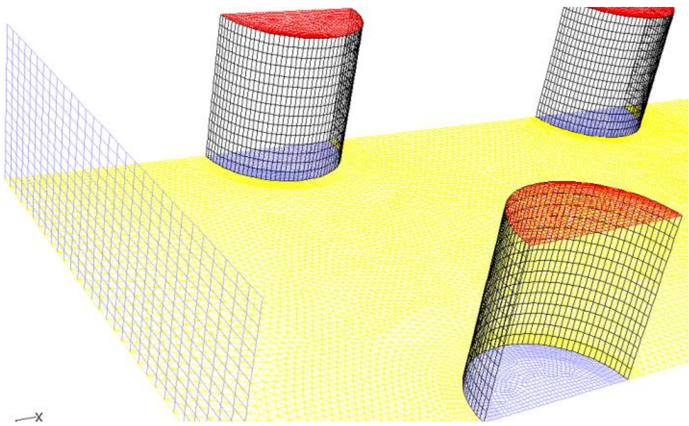

Fig. 6. Layers of elements for an appropriate heat transfer gradient around the walls [source: own study]

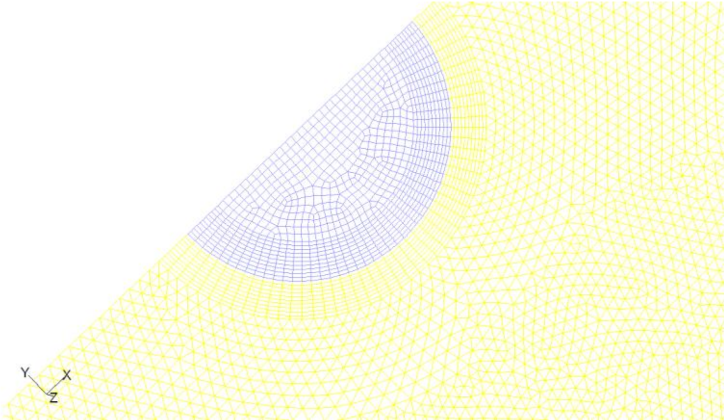

Fig. 7. Layers of elements for an appropriate heat transfer gradient [source: own study]

When the mathematical model was defined as an RNG k-epsilon model and the boundary conditions the solution could be computed. The solver was defined as steady which means that the solution was not dependent on time. Only one stationary level was examined.

By taking this approach, we were able to consider the velocity, pressure, and heat fields around the heated pipes for various types of economizer design and to use the results of the observations to choose the best design with an improved efficiency. The figures below shows the test values in a cut plane.

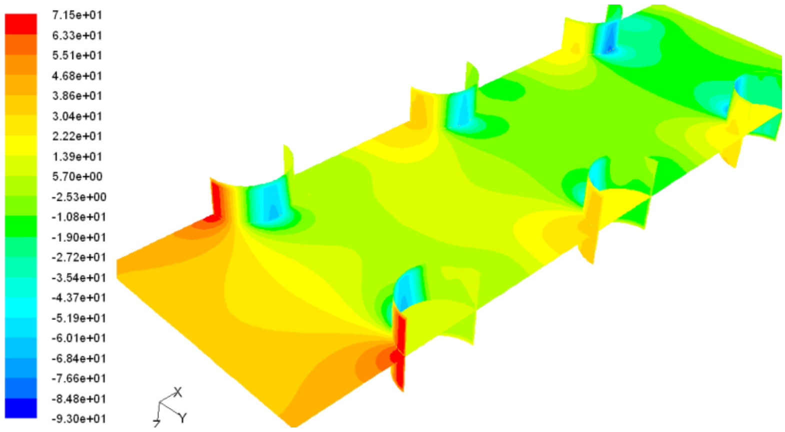

Fig. 8. Static pressure field for the simplest economizer design [source: own study]

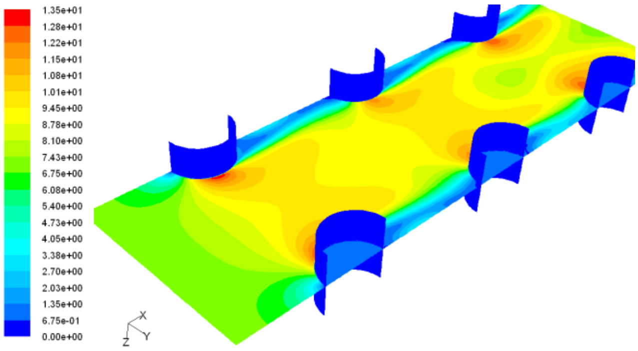

Fig. 9. Velocity flow field for the simplest economizer design [source: own study]

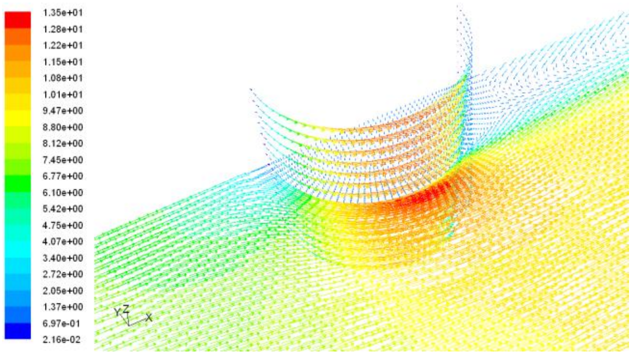

Fig. 10. Velocity vector of the flow field for the simplest economizer design [source: own study]

4. CONCLUSION

The purpose of this article was to show that CFD can be a helpful tool in optimization studies aimed at increasing the energy-transfer efficiency of a boiler or a power plant. There are numerous benefits to using a sophisticated tool such as a numerical model for engineering analysis. These modelling tools can often provide information that can only be obtained through expensive experiments or is not available from any other source. Numerical modelling can be used to obtain the required information quickly and at a reduced cost [1, 4, 5].

The primary purpose of using numerical modelling is to increase the understanding of physical processes. This is why it is often used in addition to or in conjunction with other available tools. Considering the economizer example described above, it is possible to use a network model on a large number of economizer designs to narrow down the selection to a few candidate designs. A full CFD model could then be used to analyze each of the candidate designs to gain a better understanding of their strengths and weaknesses.

Acknowledgement

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