NUMERICAL MODELING OF DRUM STEAM BOILERS WITH SOLID FUEL APPLIED TO A 300 MW UNIT FROM BRASOV POWER PLANT

Prof. dr. ing. ***Lucian MIHĂESCU****, As. dr. msc. ing.* ***Alexandru Sorin ENE****,*
Conf. dr. ing. ***Tudor PRISECARU****, Ş.l. dr. ing.* ***Mălina PRISECARU***

UNIVERSITATEA POLITEHNICA Bucureşti

Abstract. *Numerical modeling of large steam boilers by means of modularization concept is investigated in the present paper. The 300 MWt (420 t/h steam) drum type, natural circulation, coal fired steam boiler is divided into fifteen modules, each one containing basic configurations of heat exchangers. The goal of numerical research accomplished in this paper is to predict steam boiler behavior (by means of live steam parameters and overall efficiency) when the low heating value of coal fuel fluctuate in a range of 15 % from mean value.*

1. INTRODUCTION

With the rise of prices for primary energetic resources, their economic use has become more and more important. By introducing technical measures, the efficiency, specific costs of the central and its availability can be influenced in such a manner that the costs of generating electrical and thermal energy become minimal. The availability and safety of functioning of a central can be strongly affected by damages caused by the "fall" of the main components or of their subsystems (Berndt and Doleszal 1983). For these reasons it is necessary to study the dynamic behavior of the components of the central in the case of perturbed conditions of functioning.

The steam generators are one of the main components of an electrical power plant be it with or without cogeneration and any possibility to improve the performances of such a unit must be analyzed and developed to its maximum potential because it can lead to a rise in the efficiency as well as to a higher availability (Honig 1979).

The static modular simulation of "functioning point" type is an analysis method of steam generators for which the system of equations of thermal balance(Doleszal 1981, Franke 1980) written for the module ensembles of the boilers is solved by obtaining parameters of the work agent (water/steam) and the flue gases for a certain operating regime (a certain amount of steam and a certain burning configuration). A simulation program for statically simulation is characterized by a short calculation time and a high accuracy of results, being able to be implemented in an on-line system of pursuit of the boiler(Kley 1982, Doleszal 1983, Klug 1983). At the same time, on the basis of such a program the characteristics of such a boiler can be built (such as the variation of the efficiency, of the steam flow produced and of the temperature of flue gases on boiler exit with the low calorific value of the fuel).

Below, the principles that are at the base of conception of a static simulation ("functioning point" type) of a steam generator will be presented first as well as the methods through which the general algorithm was made and finally the results of an application referring to a steam boiler of 420 t/h, 140 bar, 540 C, lignite fuel firing with natural gas for flame stability purpose and respectively pit-coal (with different degrees of re-circulation of flue gases from the end of the boiler).

2. THE METHODS OF BUILDING THE CALCULATION ALGORITHM

The basic principle of the model of the numeric modular simulation of the boiler is the division of the steam generator in working modules, characterized by parameters of entry and exit (Prisecaru 1996). The general module, found at the base of decomposition of the steam generator is found in figure 1.

As can be seen from this figure such a module, generally speaking, is made up of all types of heat exchangers that can make a steam generator. Normally, the burning area contains, for example, only membrane walls; a superheater only contains the exchanger itself, the support pipes and the four afferent membrane walls. In the case of a semi-radiation superheater, the support pipes disappear as well as the convective exchanger. Exceptions can be found in the areas between the convective exchangers, where only the support pipes will be left in the module as well as the membrane walls.

Also in figure 1 we find that this type of module is characterized by 24 entry points and 24 exit points respectively, in normal conditions, mentioned above, it is obvious that their number will be significantly reduced, we can also see that by conception the module was considered in such a manner that the flue gases are the reference agents for all heat exchangers included.

It must be shown that the separate presence of the four membrane walls is justified due to the fact that with many steam generators some membrane walls are connected to the steam superheating system and not to the regular vaporizer, which sensitively changes the temperature regimes.

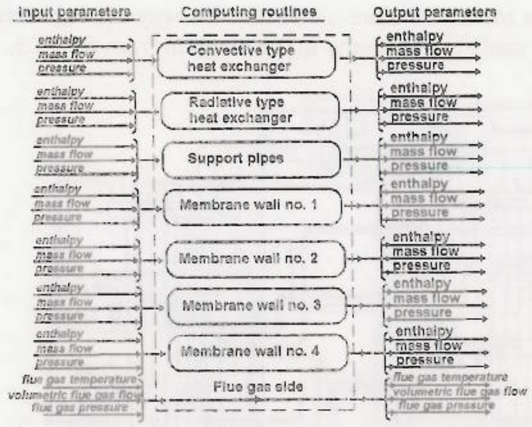

Fig. 1. The basic module for decomposition of a steam generator.

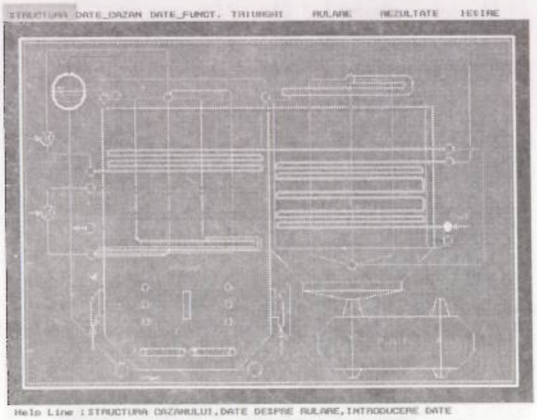

Fig. 2. The statically modeling pattern for a 420 t/h steam generator.

An important factor for numerical modeling of a steam boiler is to establish the amount of heat transferred from flame and flue gases to furnace water walls, for the current steam load (in terms of fuel and air mass flow rate), and consequently to determine the ratio of heat transferred to boiler vaporizing system and to convective heat transfer surfaces. This ratio determines the flue gas temperature at the end of the furnace (at the entrance into the boiler convective path). The value of this ratio and the absolute value of flue gas temperature is influenced by a large number of factors which include the type of coal fired (and the moisture content), burning configuration (number of burners in use and their locations, on the furnace walls) boiler load. For a certain burning configuration the flame kernel could be shifted toward the upper end of furnace, leading to a decrease in heat amount transferred to the vaporizing system and subsequently increase in heat available for convective transfer into the superheater, economizer or combustion air heating system. Such a flame kernel shift could have a negative effect on boiler overall behavior, leading to a flow instability in serpentine type heat exchangers (due to von Kármán vortex) and to damaging vibrations.

The static simulation (working point) carried out in this paper need, as a input data, the heat content of flue gases at the furnace exit, and also the amount of water vaporized in the water-walls system of the boiler. Because the full load for this type of boiler could be achieved with four or five burners in use, in different burning configuration, before starting the simulations it is necessary to proceed a CFD simulation of the furnace (fig. 3 and 4). This simulation is carried out with the commercial code FLUENT, witch combine models witch take in account the complex interaction between flow pattern (including turbulence), heat transfer (by radiation and convection) and combustion reactions (described by reaction mechanism and involving a large amount of chemical species). Both lignite and pit-coal fuels have been set for CFD simulation, and the results were implemented in the boiler simulation program database.

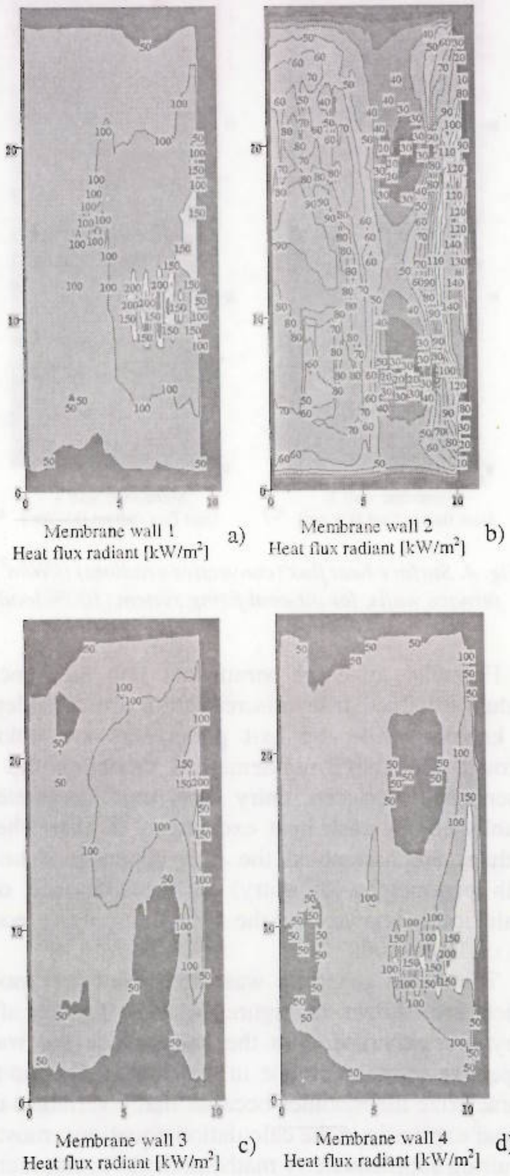

Fig. 3. Surface heat flux (convective+radiant) (kW/m²) on furnace walls, for lignite firing system (100% load).

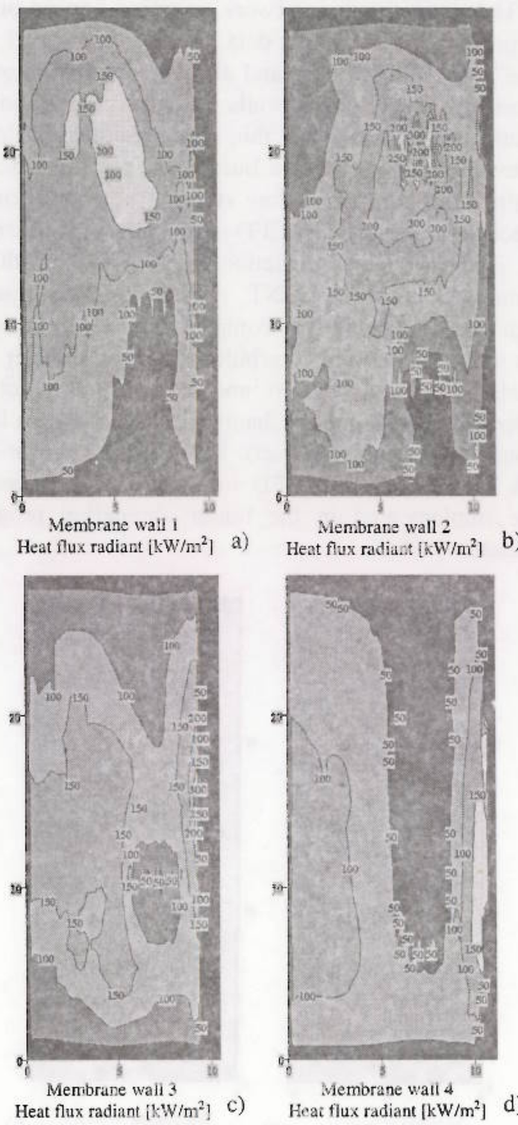

Fig. 4. Surface heat flux (convective+radiant) (kW/m^2) on furnace walls, for pit-coal firing system (100% load).

Formally all entry parameters into the functional module obtained from discretization are considered to be known, while the exit parameters are unknown. Through the above mathematical modeling the inter-dependence between entry and exit parameters is established for each heat exchanger, so that when the modules are assembled the inter-dependence between main parameters (of entry) in the reference outline (realistically known) and the main exit parameters from this outline result.

The steam generator was discretized into modules, which are shown in figure 5, next to the afferent entry/exit parameters. In the same place the way the respective terms intervene in the transfer functions that characterize the modules because many variables do not appear explicitly in the calculation equations, most often requiring supplementary mathematical developments.

The way in which the above mentioned modules are connected mainly complies with the direction of the flux traveled by the burning gases, which leave the burning area towards the pre-air heater, the way the connections are made can be found in the diagram from figure 5.

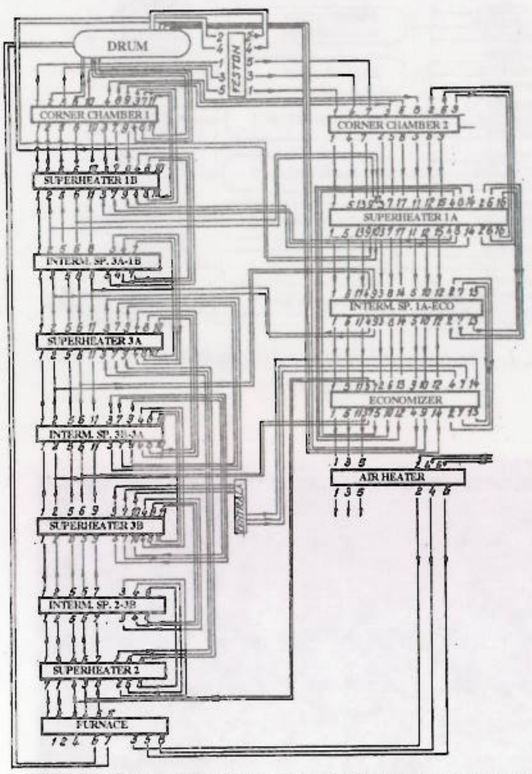

Fig. 5. The connection pattern for boiler work modules.

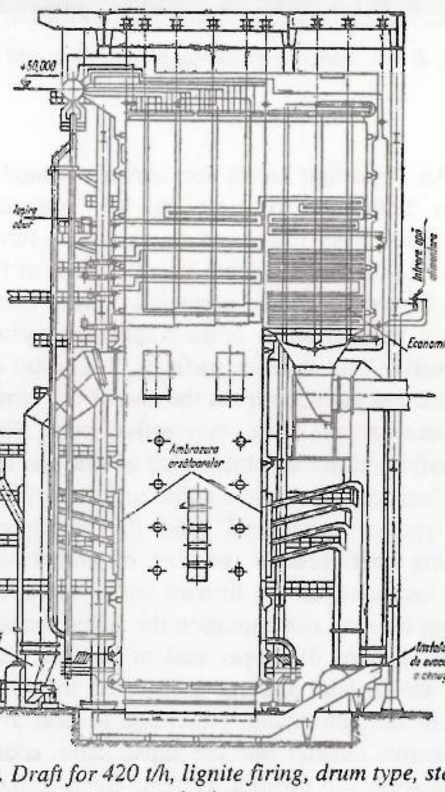

Fig. 6. Draft for 420 t/h, lignite firing, drum type, steam boiler.

Four main types of modules have been established for the heat exchangers that make up the analyzed boiler:

◊ *Serpentine type superheater*
◊ *Exchanger type membrane wall (vaporization system walls and superheaters of route II)*
◊ *Festoon*
◊ *Support pipes*

The method of solving the system of equations is using the Newton method to evaluate the solutions to the system of non-linear thermal balance equations (Rolf 1983). The stopping point in the iterations was considered to be the point in which the maximum value of the difference between two successive temperature values in the same point on the route of the flue gases is lower than 1 °C, because, after the study of the system of equations, the conclusion was reached that the slowest convergence is established on the flue gas side.

3. CONCLUDING REMARKS

From the analysis of the graphics, for functioning with lignite and an amount of natural gas for flame stability purposes, it is found that on the lowering of the low value of the coal from 7000 to 6000 kJ/kg: the mass flow of steam reduces almost linearly by 20 t/h; the efficiency is reduced by approximately 1 %; the temperature of the flue gases upon the boiler exit steeply increases by approximately 10÷12 °C towards a maximum limit; the temperature of the flue gases at the end of the burning area decreases almost linearly by about 30÷40 °C; the temperature of pre-heating air rises by about 12÷14 °C towards a maximum limit (fig. 7).

The rise in the amount of natural gas, for flame stability purposes, by between 10 % and 25 % leads to: the almost linear rise in the steam mass flow produced and of the flue gas temperatures at the end of the burning area; the rise in efficiency, yet the influence decreases with the rise of low heat value of the coal.

From the analysis of the graphics for functioning with pit-coal it is seen that the performances of the boiler sensitively increase and, at the same time, the variation of the main parameters of the above takes place in a smaller area.

Thus, upon decreasing the low heat value from 27800 to 22600 kJ/kg: the nominal mass flow of steam decreases, the decrease is steeper as the degree of re-circulation is bigger; the temperature of the flue gases at the end of the furnace and the efficiency of the boiler have a contrary tendency of variation, the decrease in efficiency and the rise in temperature being emphasized by the rise of the degree of re-circulation; the temperature of the flue gases at the end of the burning area and the temperature of pre-heating of air decrease, yet the rise in the degree of re-circulation is emphasizes the decrease of the temperature of the gases and diminishes the decrease of the temperature of the air (fig. 8).

By the numerical simulation of functioning of a steam generator at real parameters, characteristic curves of the functioning of the aggregate can be obtained curves that can later be used to ensure its economical operation.

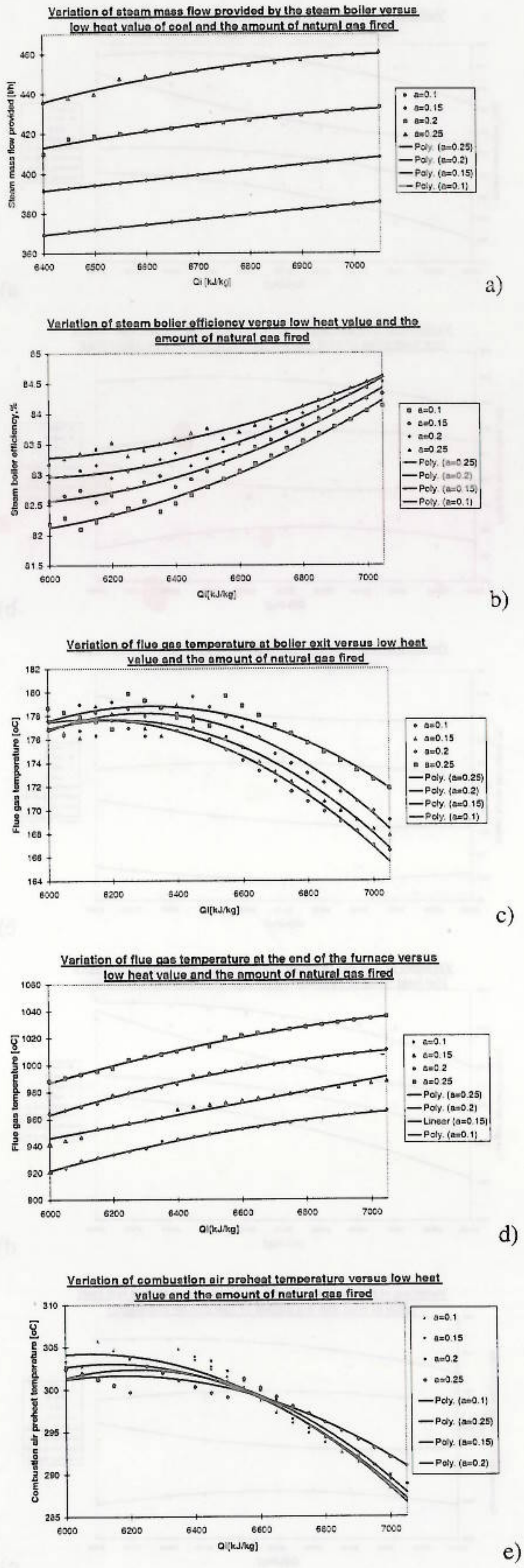

Fig. 7. Variation of main operating parameters for 420 t/h steam boiler, lignite firing, for a variation of low heat value between 6000 and 7000 kJ/kg.

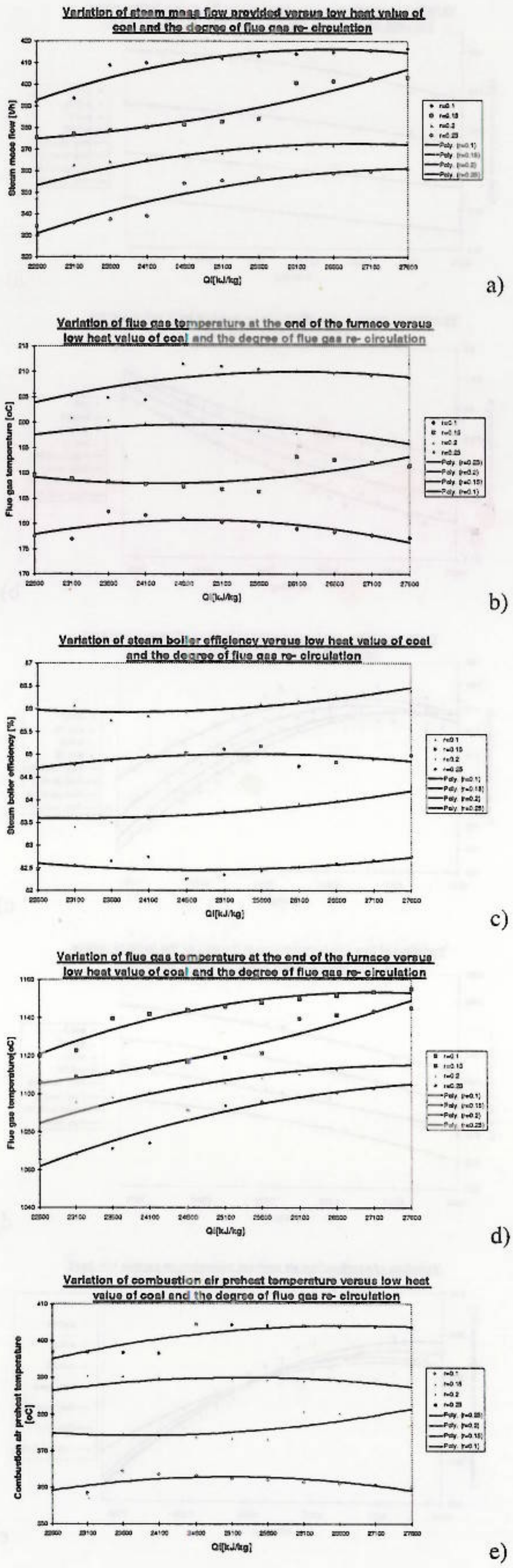

Fig.8. Variation of main operating parameters for 420 t/h steam boiler, pit-coal firing, for a variation of low heat value between 22600 and 27800 kJ/kg.

In the situation in which the real composition of the flue gases from operation is available for the numerical simulation of functioning of the steam generator, measured in different points on the gas route, then a complex running system can be made assisted by a computer, the operator being able to interrogate the computer regarding the effectiveness of a number of possible maneuvers, with the results being displayed in virtual reality, thus being able to choose the optimum option of functioning.

In conclusion, certain calculations regarding the real conditions of functioning are imposed even from the design phase of the boilers, conditions to which the equipment will be exposed throughout its working life, these calculations allowing constructive measures to be implemented from this stage in order to reduce the risk of damage and to lengthen the as much as possible the lifetime of the equipment.

REFERENCES

Berndt, G., Doleszal, R., *Vergleich der Stromab-und Stromaufwartsrechnung*, VGB-Konferenz, 1983.

Doleszal, R., et al., *Merkmale der fur Krafwerksbetrieber entwickelten Rechenprogramme zur Simulation des Blockbetriebe*, VGB Kraftwerkstechnik, 63, Nr.2., pp. 122-133, 1983.

Doleszal, R., *Nictlineare Simulation von dynamischen Vorgangen*, Regelungstechnik, 29, pp. 312-318, 1981.

Franke, J., et al., *Simulation des Betriebeverhaltens von Dampferzeugern*, Jahrbuch der Dampferzeugern, pp. 541-555, 1980.

Honig, O., *Untersuchung des dynamischeen Verhaltens eines konvektiv beheizen Naturumlauf-Dampferzeugers*, Dissertation TU Braunschweig. 1979.

Kley, J., *Anwendung und experimentelle Uberprufung der Simulation mit semianalitischer Losungmethode*, Disertation Univeritat Stuttgart, 1982.

Klug, M., *Simulation von Storfallen in Zwangdurchlauf-dampferzeugern mit einem phisicalisch-mathematischen Modell*, Disertation Univeritat Stuttgart, 1983.

Prisecaru, T., et al. *Influenţa variaţiei puterii calorifice a combustibilului solid asupra randamentului şi a regimului de temperaturi caracteristice funcţionării unui generator de abur de 420 t/h*, Producerea, transportul şi distribuţia energiei electrice şi termice, nr. 2, Bucureşti, 1996.

Rolf, A., *Simulation des nichtlearen dynamischen Verhaltens von Warmeaustauschern*, Disertation Univeritat Stuttgart, 1983.