Software for simulation of utilization schemes of secondary energy from the exhaust gases of metallurgical units

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Abstract. The work is devoted to the program complex intended for designing schemes of secondary energy utilization from metallurgical units. The structure of the software system is based on three levels of complex systems assembled from subsystems. The mathematical models of a complex process of heat transfer and gas dynamics occurring in the energy utilization units and gas cleaning devices. We describe the user interaction with the software package, and show the calculation results in the form of plots.

1. Introduction
In the metallurgical process the cycle efficiency rate is only about 20%. Part of the energy is consumed for the process flow in the main production unit. About 20-30% of the energy goes to heat losses through the unit walls, skull cooling and 40-50% is lost in the flue gases [1-3].

Given that every day fuel extraction and processing is becoming more expensive, and the world reserves are being depleted, energy saving issues are placed on one of the first places. Energy-saving technologies should find a much wider application. Therefore, the most rational option is to create energy-metallurgical complex based on two approaches to energy use. This is the physical and chemical thermal energy regeneration.

The first approach is based on the utilization of thermal energy in the power plants: waste-heat boilers, skull cooling systems, fuel heating installations. Depending on the power of metallurgical unit, thermal energy obtained in the first two units, an average of 2 MW to 15 MW, can be used for heating the production halls. Connection of the recovery boiler with the steam turbine will provide from 50 to 420 kW of electricity. This approach will reduce the load on the boiler or CHP plant, and the energy of exhaust gases utilization will be about 70-85%.

The second approach is based on the use of exhaust gas from the engine fuel, followed by obtaining chemical potential. This process consists of the following steps: first, the exhaust gas enters the reformer, then passes desulfurization, catalytic synthesis is performed, where the synthesis gas is produced. The resulting gas with a volumetric ratio of CO / H₂ close to 1.1 can be used as power fuel and as a raw material for production of synthetic fuel. This utilization option allows all of physical and chemical energy of the exhaust gas to be used with the efficiency up to 98% of energy use. This technology will create a completely smoke-free process.
It is not an easy task to perform the design of any variant of exhaust gas energy utilization. The purposes of the use of utilized secondary energy resources (SER) should be clearly understood, and intensive calculations need to be performed. A promising method of this problem solution is the modeling of heat transfer, gas dynamics on a computer that can significantly reduce labor intensity and avoid many mistakes in the design and evaluation.

2. Methods

During the development of models used in the software package we considered the approach to the modeling of complex systems. It is based on the elementwise-physical formulation of the problem, analysis and synthesis of the system in its individual components. This approach is called a direct analogy method [4].

Adequacy of complex models build that way is based on the additional concept about the similarity of complex systems, formulated by V.A. Venikov in the development of the first similarity theory [4].

In the present work we deal with at least three levels of complex systems assembled from subsystems.

First level: processes in the individual structural elements of heat-assemblies (bundles of pipes and ducts, etc.). Here the complex processes of heat exchange between heat-perceiving elements and environments, the gas friction processes on the walls, etc., are considered as basic systems, which are described by the fundamental laws of physics, the validity of these laws is considered to be proved, and the final result depends on the used combinations and connections.

Second level: heat-perceiving units as a whole. They consist of the structural elements described above. And therefore, a complex system of this kind (second) level depends on the combination and method of connecting the individual structural elements (first level systems). Examples of complex systems of the second level are: waste heat boilers, gas turbines, fluidized bed units, etc. This level includes the complex heat transfer model in the recovery boilers [5-8]:

For line bundles

$$\alpha_K = 0.2 C_s C_z \frac{\lambda}{d} \left( \frac{wd}{v} \right)^{0.65} Pr^{0.33} + 5.67 \cdot 10^{-8} \frac{\alpha_c + 1}{2} aT^3 \frac{1 - \left( \frac{T_c}{T} \right)^{3.6}}{1 - \frac{T_c}{T}},$$

where $C_s$ – correction for the geometric arrangement of the beam, determined by the relative pitch pipes; $C_z$ – corrected for the number of rows of tubes in the course of gas, it is determined depending on the average number of packets in individual rows calculated beam; $\lambda$ – coefficient of thermal conductivity of the material of the tube bundle; $d$ – diameter of the tube bundle; $w$ – gas flow rate; $v$ – the kinematic viscosity of the flowing medium; $Pr$ – Prandtl number; $\alpha_c$ – emissivity factor of the contaminated walls of receptive surfaces; $\alpha$ – emissivity of gas flow depending on the temperature; $T$, $T_c$ – gas temperature and the outer surface of the wall, taking into account contamination.

For staggered

$$\alpha_s = 0.36 C_s C_z \frac{\lambda}{d} \left( \frac{wd}{v} \right)^{0.6} Pr^{0.33} + 5.67 \cdot 10^{-8} \frac{\alpha_c + 1}{2} aT^3 \frac{1 - \left( \frac{T_c}{T} \right)^{3.6}}{1 - \frac{T_c}{T}}.$$

Model for determination of the frictional pressure loss in view of the gas transporting pressurized
The third level consists of a combination of the units described above, their set is determined by the criterion of efficiency of heat use, which is defined after calculations of thermal installations included in the gas path and identification of their particular coefficients of thermal energy use as follows [7]:

\[ \sum \eta = \eta_{mu} \cdot \eta_{sc} \cdot \eta_{u1} \cdot \eta_{u2} \cdot \eta_{uN} + \eta_{e1} \cdot \eta_{e2} \cdot \eta_{eN} + \ldots + \eta_{eN} \cdot \eta_{eN}, \]

where \( \eta_{mu}, \eta_{sc}, \eta_{u1}, \eta_{u2}, \eta_{uN} \) – respectively, the useful heat factor of a metallurgical unit, skull cooling and successively connected energy utilization units and gas cleaning systems; \( \eta_{e1}, \eta_{e2}, \eta_{eN} \) – efficiencies of skull cooling system, heat-exchangers and gas cleaning systems.

Thus, using successively the indicated additional provision about the adequacy of the derived complex systems from the subsystems of the lower level can be considered (primarily qualitative) proven. Specific parameters setting, especially for units of the second level, naturally appear, but only after the implementation of design solutions.

2. Software package
On the basis of the created models the software SKV_SAPR is being actively developed at the present time using the object-oriented approach [5, 9], as well as multi-threaded applications technology.

The task of the software includes: layout of the exhaust gas energy utilization schemes; structural calculation of thermal power units used in the scheme; calculation of the amount of heat energy received by the utilization units; evaluation of pressure losses along the gas path, including energy utilization units; calculation of physical parameters of the exhaust gases in each section of the gas path; search for the optimal variant of thermal power plants and the whole scheme with the participation of experts; issuance of technical documentation and guidance on the design.

Figure 1 shows the structure of the software system. At the initial stage of the simulation, the specifications and output parameters of the exhaust gas of metallurgical unit are set: composition, flow rate, pressure, temperature. In accordance with the name of the project the working files and paths are generated.

Next, the arrangement of the energy utilization scheme is performed with possible access to the database in order to select the proposed options, calculated previously, or to construct a new one. Then the thermodynamic parameters of exhaust gas on the basis of known thermodynamic laws are calculated and the entering of the necessary data for thermal power plants is described. It is possible to access to the extensible databases that are developed in Microsoft Access environment [10], and contain, regulatory, engineering, thermo physical and energy documentation of standard models offered by the manufacturer, or designed independently. Upon completion of data entry the calculations are made and the results on the current unit in the course of gases movement are displayed.

On completion of work on the last energy utilization unit in the scheme, the calculation is performed, the results of which determine the final design parameters settings, the possible absorption of heat by them, the pressure loss in each section of the scheme, determination of the gas
thermodynamic parameters and its calorific value. If the project is expected to choose an effective
option from the set of energy utilization schemes, then the analysis on the cross-cutting factor of
thermal energy use is performed. The results are evaluated by experts, if necessary, the necessary
changes to the system configuration and recalculates are introduced.

![Complex structure SKV_SAPR](image)

**Figure 1.** Complex structure SKV_SAPR.

3. Results
Below the fragment of calculation by software is given. Figure 2 and 3 considered provide three
possible energy utilization schemes, graphic dependencies of pressure losses and utilized thermal
energy are presented (at various design parameters of the heat recovery systems, gas purification,
resistance nodes and channels).
**Figure 2.** Pressure drop in energy utilization plants, gas cleaning systems, channels and nodes of resistance (MU – metallurgical unit; CH – channel; BU – waste heat boiler; GC – a group of cyclones; t90 – turn to 90°; GT – gas turbine; FB – fluidized bed dryer).

**Figure 3.** Heat energy usefully used by utilization units.

4. **Conclusions**

Thus, the use of this software package allows energy utilization schemes to be built, as well as perform calculations, and choose the best option for the cross-cutting factor of heat usage and explore the influence of the main regime parameters.

The proposed model and software system were tested at JSC “Siberian SantekhProekt”, Novokuznetsk. The findings were compared with the third-party software products and have a positive feedback from designers working in the thermotechnical field.

5. **References**

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