3-DIMENSIONAL SIMULATION AND FEASIBILITY STUDY OF BIOMASS/COAL CO-COMBUSTION BURNER

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Abstract: *Combustion of solid biomass mixed with coal in existing boilers not only reduces harmful emissions, but also allows diversifying the available fuel base. Such technology allows to implement the efficient use of food industry solid wastes, which otherwise would be dumped in piles, and thus produce harmful environmental impact. The geometrical models of research reactor and a burner thermal preprocessing of pulverized coal were developed and calculation meshes were generated. The geometrical model of the VGP-100B presents only fluid domain whereas the effect of cooled walls was substituted by the equivalent boundary conditions derived on the basis of direct experimentation. The model of theVGP-100V allowed accounting for the specifics of radiation heat transfer by comparison of experimental thermo-couple measurements to the simulated by the model one. A model has been developed allowing the determination of actual temperatures of combustion gases flow based upon the reading of unsheathed thermo-couples by taking into account the reradiation of the thermo-couple beads to the channel walls. Based on the ANSYS3-D process model in the burner of the Trypilska Thermal Power Plant (TPP) for the combustion of low-reactive coal with the thermochemical preparation of the design of an actual burner has been developed. On the basis of the experimental studies of the actual burner and the above-mentioned CFD (Computerized Fluid Dynamics) calculations, the burner draft of the 65 MW for TPP-210A boiler aimed at the implementation of biomass-coal co-combustion was designed.*

Key words*: co-combustion, biomass, coal, anthracite, thermal power plant (TPP)*

1. Introduction

The technology of the biomass using as a supplementary fuel at coal combustion began to develop in the nineties of the last century. In particular, nowadays more than 200 boilers in Europe only implement technology which uses various types of solid biomass as a supplementary fuel in coal firing boilers. For example, straw (TPP Studstrup, Denmark), wood processing and paper mill wastes (TPP Kimiyarvi, Finland), sorted municipal solid wastes (so-called RDF – TPP Lakhti, Finland), crushed olive stones and other crops (TPP Puertolano, Spain), agricultural wastes pellets (TPP Drax, Great Britain, TPP Kozenice, Poland), [1, 2]. The main advantages of biomass and coal co-combustion technology (BCCC) are the following:

• The minimal investments for capital construction, since biomass combustion takes place in existing boilers and needs only storage, transportation and biomass preparation systems;

• Reduction of harmful emissions in the environment, insofar the biomass is considered as CO_2-neutral fuel, it has lower, compared with domestic coal, sulphur

content, lower content of nitrogen compounds;

• Favorable technological effects due to the high content of volatiles (more than 80 % depending on the biomass type);

• Potential of utilization wastes of different production types and thereby reduce the environmental impact;

• Feasibility of the biomass utilization in coal boiler units under availability of appropriate legislation (the "green tariff", fee for biomass dumping in landfills, etc.).

The Biomass-Coal co-combustion (BCCC) technology may be realized within the following arrangements [1]:

• in pulverized coal (PC) boiler units;

• in circulating fluidized bed (CFB) boilers;

• biomass gasification in separate gasifiers with subsequent burning in coal boilers.

As for the environmental performances of the co-combustion process, the above-mentioned sulphur oxide reduction can be noticed due to the lower contents of such substances in the biomass. Its CO_2-neutrality in combustion processes and nitrogen oxide reduction has been proven by many foreign editions [3, 4, 5].

The NO_x reduction can be explained by technological factors, namely, by the high devolatilization rate of the biomass which leads to the creation of enriched fuel zone at the beginning of the flame at the exit of the burner. High moisture content of biomass reduces the flame temperature and also helps nitrogen oxide reduction in boiler furnace.

Nowadays Ukraine has accumulated not only industrial experience of such technology implementation, but also a sufficient volume of experimental research as per BCCC technology for domestic types of biomass and coal of Ukrainian deposits. A few works only describe the dynamics of the biomass dehydration and volatile yield and proposed different schemes of the BCCC process organization [6, 7].

The BCCC technology in application to the combustion of such heterogeneous fuels such as anthracite and herbal solid biomass is of a particular interest.

Unfortunately, insignificant part of the total world coal-biomass co firing applications utilizes these critically dissimilar types of fuels. Mostly, the studies relate to the regions where anthracite is mined (in general - 5% of the world's deposits explored). Korea, Vietnam, South Africa, Spain and Pennsylvania State (USA) are the countries where anthracite is being extracted.

Last year, in Ukraine the irregular supply of the anthracite coal from the occupied territories of the Donetsk basin became typical. For instance, in 2015, as compared to 2013, the supply of the anthracite (rank A and T) to the TPP's reduced from 18 to 8 million tons together with the supplies from Russia and the Republic of South Africa [8]. At the same time, the market of biomass as fuel is rapidly growing. A number of pellet plants were built with foreign financing and investments. The substitution of only a part of anthracite by biomass would be a solution for the critical situation that led to boilers' shutdown at some TPP this winter.

The Coal Energy Technology Institute (CETI) for 10 years has been working on the biomass and anthracite co-combustion technology projects. The beginning of the research was established by a joint project with Pittsburgh Energy Technology Center (PETC) of the Ministry of Energy of the USA under the NATO Program "Science for Peace", since 2007. Within the project the optimum regime characteristics, the synergetic effects of the mutual influence of the two different solid fuels, the kinetic characteristics of the pine sawdust for combustion process calculation, have been defined [9, 10].

The purposes of the study were set forth as follows:

• to identify the optimum biomass/anthracite ratio for the most

complete burnout of both fuels at residence time characteristic for pulverized coal furnace;

• to determine the optimal combustion performance;

• to determine the domestic biomass (pine sawdust, pulp, pellet of wheat straw, rape, etc.) characteristics for the BCCC calculation;

• to study the effect of the biomass impurities on coal burnout;

• to investigate the effect of the biomass impurities on the environmental performances of the technology used;

• based on experimental and theoretical studies, to develop the burners' and primary furnaces' constructions for combustion as separately biomass as its mixtures with coal.

Since a detailed calculation of biomass-coal co-firing processes in the pulverized boiler furnace of the existing TPP is impossible, the CFD simulation using ANSYS CSX software package was made. At the first stage, the method and computational grid for BCCC process simulation were developed in view of applying the VGP-100V experimental pilot plant. At the second stage, the experience of the VGP-100V simulation was extended to simulate the existing burner of the TPP-210A pulverized boiler of Trypilska TPP 70 MW. The completed simulation studies allowed developing the output data for feasibility study (FS) development to implement the BCCC technology at the TPP-210A boiler of Trypilska TPP.

2. Materials and methods

The BCCC experiments were conducted in the pilot plant VGP-100 V which simulates the processes occurring in the lower radiation part of the boiler furnace. The aim of experimentation was to confirm the possibility of substituting the gas supply for "lighting" that provides flame stability when combusting high-ash low-reactive anthracite with biomass. It was suggested that biomass with a high volatile content may offset some part of gas supply. It was also necessary to establish the optimum regime parameters and flow rates of the BCCC process when firing pine woodchips and sawdust as substitute fuels.

The kinetic studies of dehydration, devolatilization and coke burning of different biomass types.
To determine the prospect of some crops straw available in Ukraine for the co-combustion technology, the thermogravimetric studies of wheat straw, canola, corn, soybeans pellet samples, and samples of wood (sawdust) were conducted in cooperation with the Ural Federal University (Yekaterinburg city, Russia) and the Institute of Macromolecular Compounds of the National Academy of Science (NAS) of Ukraine (Kyiv city),

The kinetic studies of wood coke burning at the RSK-1D unit.
To determine the characteristics of the wood coke burn up, the kinetic studies at the RSK-1D stand of the Coal Energy Technology Institute (CETI) were conducted. The experimental stand is a vertical pulse gradient less fluidized bed reactor.

Detailed description of the studies at VGP-100V pilot plant, Q-1000 derivatograph and RSK-1D stand are presented in [10].

3. Results and discussion

CFD model development of the VGP-100V experimental unit.
The mathematical model of the VGP-100V unit is based on the need to determine the correct boundary conditions for adequate model creation for co-combustion regimes of some fuels, such as gas and coal, gas, coal and biomass and coal/biomass and heat balance accounting of the unit.

During the model development, we take into account the following:

• The developed VGP-100V reactor model allows data comparison of the real

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calorimetric measurements (the measurement of heat losses of reactor sections) with those calculated by the model. Thus by such comparison it turns out possible to determine the equivalent heat transfer coefficients which would ensure the compliance of the calculated heat losses to real.

• Carrying out experiments at VGP-100V unit is connected with significant material and time expenditures that significantly limits the possible number of experiments.

• The experimental data should be supplemented by receiving of continuous functions of temperature distribution along the length, reactor cross-section, determine the flow rate distribution, chemical composition of combustion products in each point of diagnostic area. The additional data may be obtained when using the available data to receive intermediate regimes.

Having the adequate mathematical model, we can conduct additional studies by varying the share of gas, biomass and coal, by clarifying and supplementing the previous data.

The first step in the creation of the mathematical model is creation of the geometrical model that reflects the VGP-100V working area construction. The geometrical model construction was conducted using the Gambit software package. On the basis of the models created before, the decision to simulate the VGP-100 V inner part only was taken aimed at the creation of the heat transfer in lining, thermal isolation and channels of cooling water in walls, since such conditions complicate significantly the

calculation, fundamentally increases machine time required to calculate the task with a given repeatability. Also, it was decided to create a model with slag collector area and part of gas outlet duct in order to obtain a correct radiation fields in the diagnostic area, and accept some simplification of the burners' geometry to avoid model complications.

The schematics of the VGP-100V pilot plant with the thermal capacity up to 100 kW in the regime of coal combustion in oxygen enriched air is shown in the figure 1.

The unit includes a vertical reactor of downstream flow, the total length of 4.8 m. The reactor active length down to the turn to the cyclone is 3.2 m; the diagnostic section length from the inlet section of the burner is – 2.4m.

The diagnostic area consists of 4 sections, each one of 0.6 m length; the inner diameter of 3 sections is 0.28 m (the diameter of the 4-th section and lower channel to the turn is 0.2 m). The detailed description is given in [11].

The geometric model of the VGP-100V experimental area is built in four stages as seen in the figure 1:

• The three-dimensional geometric model of simple elements was designed by using typical modelling operations. The back-and-forth transfer operations, integration, addition and subtraction of elementary solids were used to create the volume of interest with the optimum degree of detalisation.

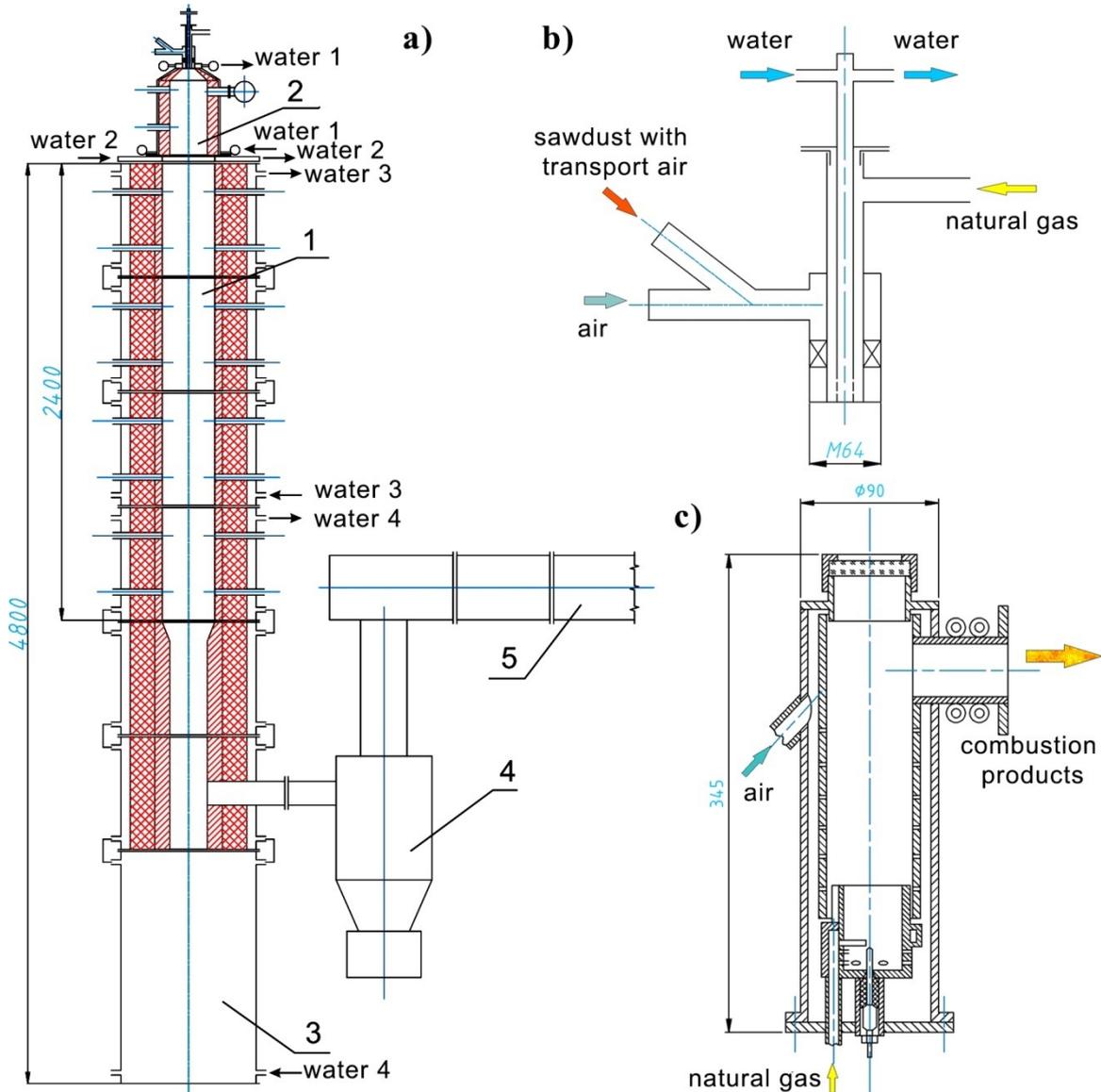• The surfaces joining and non-fixed volumes' union operations in one were performed.

Fig. 1. VGP-100B unit geometry: a) VGP-100B experimental unit (1 – reactor diagnostic area; 2 – burner device; 3 – slag collector; 4 – cyclone; 5 – cooling chamber);b) primary burner; c) auxiliary burner

• The boundary conditions on surfaces were assigned to the conditional-adiabatic walls; to the walls where the heat transfer occurred the boundary conditions of assigned heat transfer coefficients were designated. The inlets of fuels, primary and secondary, the exit zones of combustion products have been assigned.

• The surface splitting on mesh with further volume splitting on computation grid has been carried out.

The software gives an opportunity to specify various types of volume splitting, different modes of mesh generation, parameters of inflation etc.

When creating the first geometrical model the problem of the balance between the mesh cell size and the model minimal geometrical dimensions has been addressed. The generated cell sizes sometimes were larger than the geometrical dimensions of elements.

By analyzing the set of meshes with different cell sizes, the conclusion of mesh cells number and its effect upon the convergence and accuracy of calculations was obtained. The mesh with the variable cell step was selected. In the mesh mentioned, the step increase process from minimal at the smallest geometrical surface to step given for main volume division is used. Such decisions allowed significant increase of the calculation accuracy at small geometrical surfaces, without undesirable model complication, unnecessary increase of calculation nodes' number.

Taking into account the flow features at transition from primary burner zone to the diagnostic section with the bigger diameter, the mesh inflation was used at the longitudinal part of the reactor. Within the boundary region at the inlet of test section the size of cells was near 1 mm with further transition to 30mm in the core. An appropriate mesh of the variable step was also used in the middle of the volume with the purpose of more accurate calculation of flow parameters in the near-wall area, in places of the flow characteristics' change. The outer part of the mesh developed is shown in the figure 2.

For more detailed simulation of the heat transfer process and validation of the results received in direct experimentation the VGP-100V plant mesh with thermo-couple models located approximately on the flow axis in four diagnostic sections was designed. To simulate the heat transfer in thermocouples' area, the mesh cell size of 1 mm was generated.
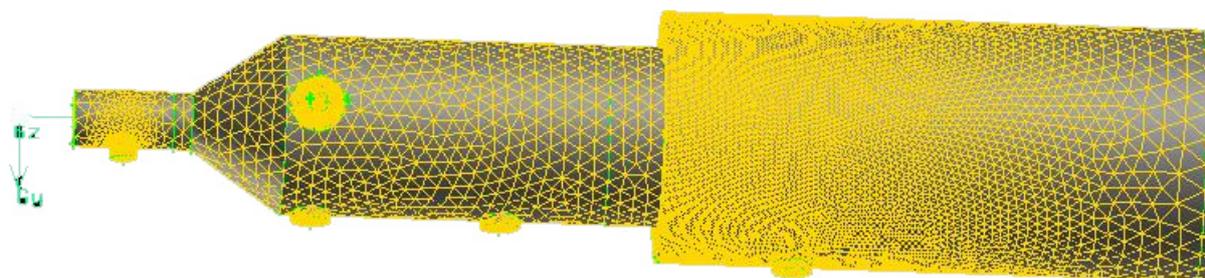

Fig. 2.The image of the VGP unit outer surface partition on computation mesh
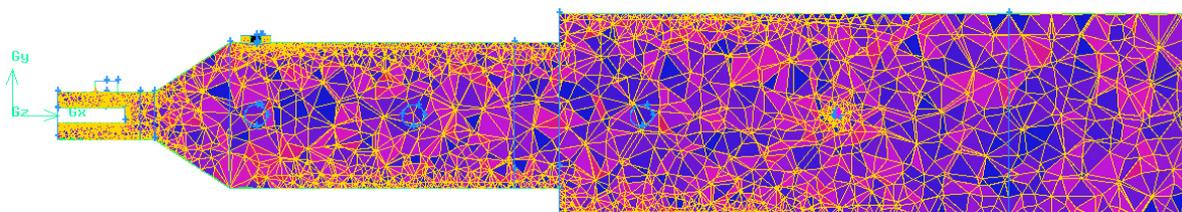

Fig. 3. The mesh of the thermocouple model in the first diagnostic section

To separate the main volume of the geometrical model created on mesh, the three-dimensional tetrahedron or hybrid cells step size of 30 mm were used. The main volume was spit into the triangular cells. The meshes of the small geometrical surfaces were broken into the triangular cells with the step size of 3 mm. The volume of the small geometrical elements which were spit in tetrahedrons was appropriate to triangles, displaying gradual increase to tetrahedron size of the main volume. Such meshes generated in the Gambit software were transferred to Fluent ANSYS software.

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The correction factors for the direct thermocouples readings placed into the flow of high temperature flue gases.

The temperature readings inside the reactor taken by three means – the lining temperature by chromel-alumel thermocouples which were mounted in lining of 5-10 mm from firing layer and constantly registered by DPR-1 pyrometer. The gas flow temperature along the reactor axis were taken by the platinum-platinum rhodium thermocouples of 0.2 mm wire diameter, which were embedded in alumina protective covers with channel diameter of 0.5 mm and introduced in diagnostic holes. The hot beads were covered with the corundum film; the cold ends were not cooled, the readings' deviation at 20°C, the air temperature in the box, were taken into account during the calculations. When comparing the data obtained experimentally and data obtained by the mathematical model calculation created in the Gambit and Fluent software, it was found that the gas temperature measured along the diagnostic reactor axis in the experiment and the temperature in the reactor axis obtained as the calculation result strongly differed. The calculated temperatures exceeded the experimentally obtained temperatures by 150-180°C, but they have a common general tendency. The difference in the data obtained experimentally can be explained by the thermocouple hot end re-radiation at cooled reactor wall surface. It was decided to create an approximate heat balance for thermocouple junction, for determination of the temperature measurement error value of the gas flow along the reactor axis

by thermocouple. It should be noted that the calculation model is complex the due to the fact that the radiant heat transfers between the thermo-couple and gas flow. The gases have the ability of absorbing and radiating energy. The absorption and radiation of monatomic and diatomic gases, including nitrogen, oxygen, hydrogen, and helium are so slight that in engineering calculations they are neglected. The water vapor and carbon dioxide are of a great interest for thermal calculations. These gases are part of different fuels' combustion products.

The radiation spectrum and the gases' absorption, respectively, unlike the most solids are selective in nature, i.e. the radiation and absorption processes occurred in the middle of the spectrum discrete bands' series. Within other wavelengths gas behaves as transparent medium [11].

There was an assumption that our gas has a constant temperature T_g, the wall has a constant temperature T_w and they both are gray bodies. The mesh radiation is characterized by a continuous spectrum. The gas medium has selective/gray radiation in the form of separate bands e_1, g_1; e_2, g_2. In general, the number of such bands may be different. The gas medium exchanges radiant fluxes with the mesh within these bands, only. The individual elements are exchanging radiant fluxes behind the spectrum bands among themselves, only. For insulated mesh, the net flux for such heat transfer will be zero. Then, the radiant flux from gas to wall can be expressed by the dependence:

$$Q_{g,w} = \left(E_{ef,g} - E_{ef,w} \right) \cdot F_w, \tag{1}$$

where F_w– the mesh surface area; $E_{ef,g}$ – the heat flux density of the gas medium effective irradiation; $E_{ef,w}$ – the heat flux density of the mesh effective radiation.

From the heat flux densities of the gas/mesh effective radiation, we find the following the following method. It can be presented by dependencies that are valid for specific radiation bands:

$$E_{ef,g} = \left(E_{0,g}\right)_{\Delta\lambda} + q_{g,w}\left(1 - \frac{1}{\varepsilon_{g\Delta\lambda}}\right), E_{ef,w} = \left(E_{0,w}\right)_{\Delta\lambda} + q_{w,g}\left(1 - \frac{1}{\varepsilon_{w\Delta\lambda}}\right). \qquad (2)$$

The gas and the mesh black radiation that is corresponded to limit values of their blackness degree can be expressed by the following expressions:

$$\left(E_{0,g}\right)_{\Delta\lambda} = C_0\left(\frac{T_g}{100}\right)^4 \cdot \varepsilon_g^{\infty}, \left(E_{0,w}\right)_{\Delta\lambda} = C_0\left(\frac{T_w}{100}\right)^4 \cdot \varepsilon_w^{\infty}, \qquad (3)$$

where ε_g^{∞} and ε_w^{∞} – the limiting degrees of the gas blackness which are determined from monographic charts at gas and wall temperatures. The gas blackness degree

$\varepsilon_{g\Delta\lambda}$ is determined by the following dependence:

$$\varepsilon_{g\Delta\lambda} = \frac{k_1 l_1 e_1 g_1 + k_2 l_2 e_2 g_2}{a_1 b_1 e_1 g_1 + a_2 b_2 e_2 g_2} = \frac{E_{g\Delta\lambda}}{\left(E_{0,g}\right)_{\Delta\lambda}} = \frac{\varepsilon_g E_{0,g}}{\varepsilon_g^{\infty} E_{0,g}} = \frac{\varepsilon_g}{\varepsilon_g^{\infty}}. \qquad (4)$$

The blackness degrees within the separate bands $_{\Delta\lambda}$ are equal to blackness integral degree $\varepsilon_{w\Delta\lambda} = \varepsilon_w$. For stationary thermal regime $q_{g,w} = -q_{w,g}$.

Then, taking into account the above-mentioned dependencies, we obtain the following expression for the radiant flux $Q_{g,w}$, $[W]$, that is transferred from the gas medium to mesh:

$$Q_{g,w} = \frac{C_0 F_w \left[\varepsilon_g^{\infty}\left(\frac{T_g}{100}\right)^4 - \varepsilon_{g,w}^{\infty}\left(\frac{T_w}{100}\right)^4\right]}{\frac{\varepsilon_g^{\infty}}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1}. \qquad (5)$$

The integral values of the absorption coefficient for gas mixture, as was shown above, in general, are not equal to their values sum for the individual mixture components. So, for mixture of CO_2 and H_2O the blackness degree and the absorption coefficient is less than the sum of their values for CO_2 and H_2O, that is explained by the partial matching of their radiation spectrum bands:

$$\varepsilon_g = \varepsilon_{H_2O} + \varepsilon_{CO_2} - \Delta\varepsilon_g. \qquad (6)$$

The steam and carbon dioxide absorption degrees are taken from the gas temperature charts at appropriate partial pressure/ray path length values, pl. The average value of ray path length is determined by the following expression:

$$l = m\frac{4V}{F_w}, \qquad (7)$$

where V – the gas volume; m=0,9 – the correction coefficient.

The calculation method for accounting for errors associated with re-radiation of thermocouple beads is derived for gas mediums only that do not include suspended solid particles of the combustion products.

The aim of the correction methodology to be developed is to determine an actual temperature of the thermocouple bead positioned in the flow of hot gases and participating in radiant heat transfer with the cooled wall. The initial and boundary

conditions of the developed correction models are to be taken from the actual experimental data when burning natural gas in pilot stand VGP-100V.

The calculation performed under the condition of the heat amount equality supplied to the couple junction and heat amount given to wall by thermocouple under reradiation. The heat balance of the thermocouple is maintained by the heat supply to the bead and heat radiated to the cooled walls. The heat supply due to convection heat transfer from the flow, radiation of the heated flue gases and due to the radiation of heated burner head lining. It was decided to use a simplified model of the radiant heat transfer between the bead surface and heated lining surface, where the bead surface and the lining surface radiating are plane-parallel, the bead surface area that absorbs radiation, is equal to half of the bead total area. The mean absorption coefficient of solid surfaces are taken at $\varepsilon_{red} = 0.9$. The heated lining temperature is set equal to the gas core temperature T_g:

$$Q = \alpha \cdot \left(T_g - T_t \right) \cdot F_{jun} + \frac{F_{jun} \cdot \varepsilon_{red} \cdot \left(\left(\frac{T_g}{100} \right)^4 - \left(\frac{T_t}{100} \right)^4 \right)}{2} +$$

$$+ \frac{C_0 F_{jun} \left[\varepsilon_g^{\infty} \left(\frac{T_g}{100} \right)^4 - \varepsilon_{g,t_w}^{\infty} \left(\frac{T_t}{100} \right)^4 \right]}{\frac{\varepsilon_g^{\infty}}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1}, \tag{8}$$

$$Q = \varepsilon \cdot C_0 \cdot F_{jun} \cdot \left(\left(\frac{T_t}{100} \right)^4 - \left(\frac{T_w}{100} \right)^4 \right), \tag{9}$$

where T_t– the bead temperature, in absolute units, $[K]$; T_w– the wall temperature, in absolute units, $[K]$; T_g – actual gas temperature, in absolute units, $[K]$; α–the heat transfer coefficient between the thermocouple junction and gas medium, $\left[\frac{W}{m^2 \cdot K} \right]$; ε_g^{∞}– the limiting degree of the gas absorptivity under wall temperature; ε_w^{∞}– the limiting degree of the gas absorptivity under gas temperature; ε_g – the gas absorptivity degree; ε – the corundum cover of junction absorptivity; F_{jun} – the junction surface area, $\left[m^2 \right]$. The heat-transfer coefficient α was calculated for the case of external flow by heated gases around the bead of thermocouple. The formula for calculation α was taken from [12], the thermal parameters calculated by EnecCalc3 programme, checked with data [12]:

$$\overline{Nu} = 2 + 0.03 \, \mathrm{Re}^{0.54} \, \mathrm{Pr}^{0.33} + 0.35 \, \mathrm{Re}^{0.58} \, \mathrm{Pr}^{0.36}. \tag{10}$$

The velocity for Reynolds number was obtained as a result of calculation of the 3-D model and was conditionally accepted as constant equal to $W = 4.5 \, [m \, / \, s]$. The thermo-couple diameter accepted equal to $d = 0.005 \, [m]$.

The heat-transfer coefficient values calculated for three different temperatures of incident flow.

The calculations carried out in the following sequence for the gas core temperature T_g 2200, 2000 and 1800 K:

- For gas core temperature T_g the thermal properties of the flue gases are determined (ν, λ, Pr) and the numbers Re and Nu and heat-transfer coefficients α were determined.
- The blackness degree and the limiting blackness degrees were determined based on the above-mentioned reasoning; the radiation properties of the water steam and carbon dioxide were taken into account. The blackness coefficients of the infinitely thick layer obtained from monograms [11].
- The ratio of the water steam partial pressure to the amount of the water vapor and carbon dioxide partial pressures were determined.
- The correction value Δ_ε as per parameters obtained was determined.

- Taking into account the correction factor for mutual absorption, from formula (6) the limiting gas blackness degree under gas temperature ε_g^{∞} determined.
- The combustion products' blackness degrees were determined previously ε_{CO_2} , ε_{H_2O} as a function of P – partial pressure of each of the gases.
- From formula (6), taking into account the correction factor for mutual absorption the gas blackness degree ε_g was determined.

As the results show, we obtain the 4-th degree transcendential equation with the non-linear coefficients. The solution was sought as the intersection point of the two functions in the MathCad program package. The equation results for different cases of the gas flow and wall temperatures are shown in the chart figure 4.
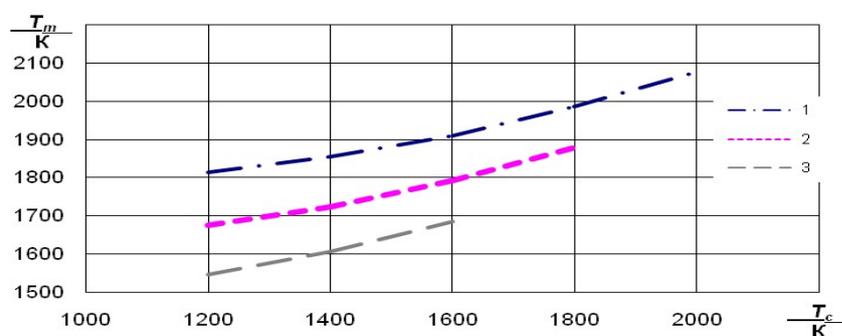

Fig. 4. Calculated values of the unsheathed thermocouple readings in flue gases with irradiating to cooled walls at *Tc* at different temperatures of flow :
$$1 - T_g = 2200\,[K]; 2 - T_g = 2000\,[K]; 3 - T_g = 1800\,[K].$$

The obtained data shown in the figure 4 that, being in the flow with actual temperature at 2200 K and exposed to the wall at 2000 K, the thermocouple will show the temperature approximately 123 K less than the actual one. The difference between the actual temperature and thermocouple readings will increase to 386 K with the wall at temperature of 1200 K. Obviously, under less core temperature of 1800 K and wall temperature of 1600 K, the error of thermocouple readings will be 114 K that is less than the correction under measurement of higher core temperature.

Analyzing the data obtained, we can conclude that re-radiation plays a significant role in the temperature measurement in the studied conditions.

The burner process modelling of theTPP-210A boiler of TrypilskaTPP in three-dimensionalapproach.

The methodology of the 3-D model mesh generation presented earlier was fruitfully employed for the development of the burner mesh of the real TTP-210 A boiler of the Trypilska TPP.

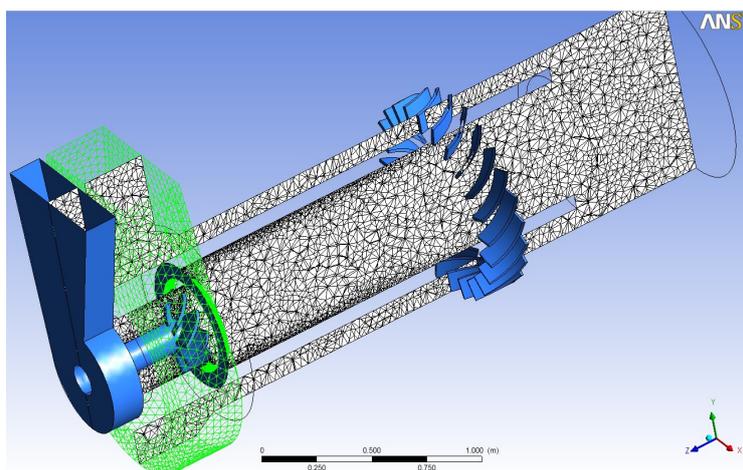The most universal tetrahedral mesh was used as shown in the figure 5.

Fig. 5. The burner mesh of the TPP-210A boiler

The working process of the modelled burner consists in splitting a whole flow of the pulverized anthracit coal into two parts. A major part of the coal dust (approx. 2.2 kg/s) together with the transport air mowes through the outer cylindric channel which is equipped with the directing blades. Having passed them, coal-air flow acuired a swirling mode of movement. A minor part of coal dust (approx. 0.8 kg/s) with the transpor air passes a central swirler positioned in a central muffle and further passes a set of natural gas burners. The central flow being exposed to the hot natural gas combation gases undergoes a thermochemical preparation (TCP). Then after the muffle the two swirling streams mix together. As a result of this the main stream of coal having passed the peripheral channel.

In order to simplify the calculation only a fraction of 25 microns was taren into account. The calculation used the following values of operating conditions: mass flow of coal to TCP – 0.8 kg/s, mainstream – 2.2 kg/s, air to TCP – 10 m/s, air to mainstream – 16 m/s, flow temperature of 300 K.

The burner aerodynamics under the TCP process during supply of flow rates typical for real processes is shown in Figure 6, namely the cross sections with velocity vectors located on it are shown. As we can see, area of low velocities is localized along the channel axis.
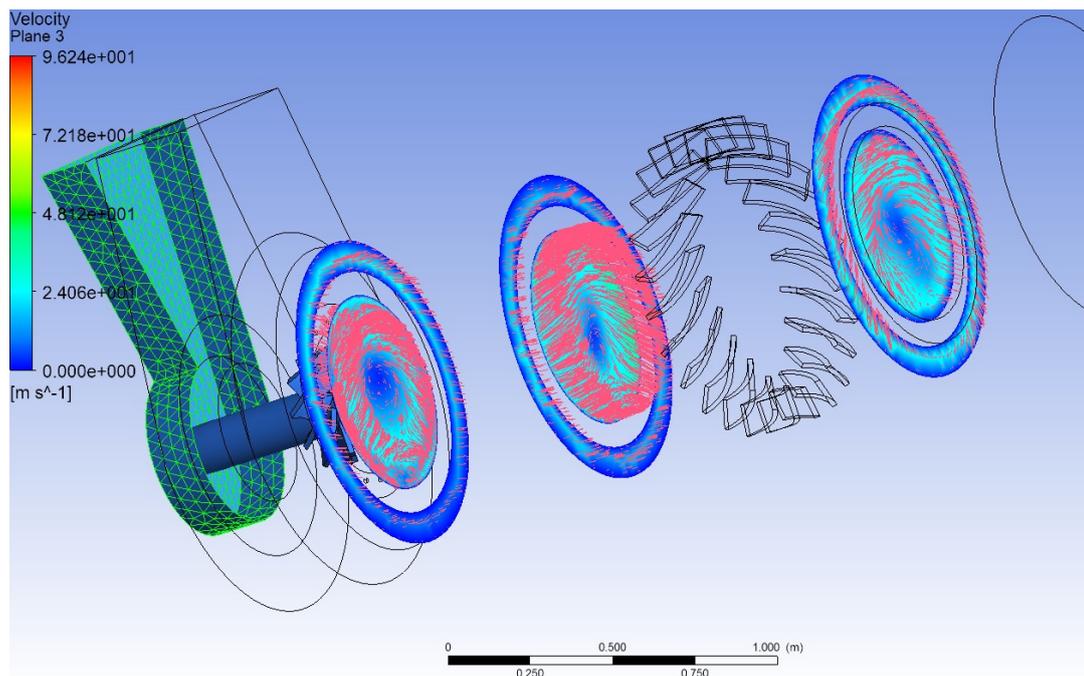
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Fig.6.The velocity vector distribution in cross sections

The particle tracks with temperatures marked by colour on appropriate tracks are shown on figures 7 and 8.
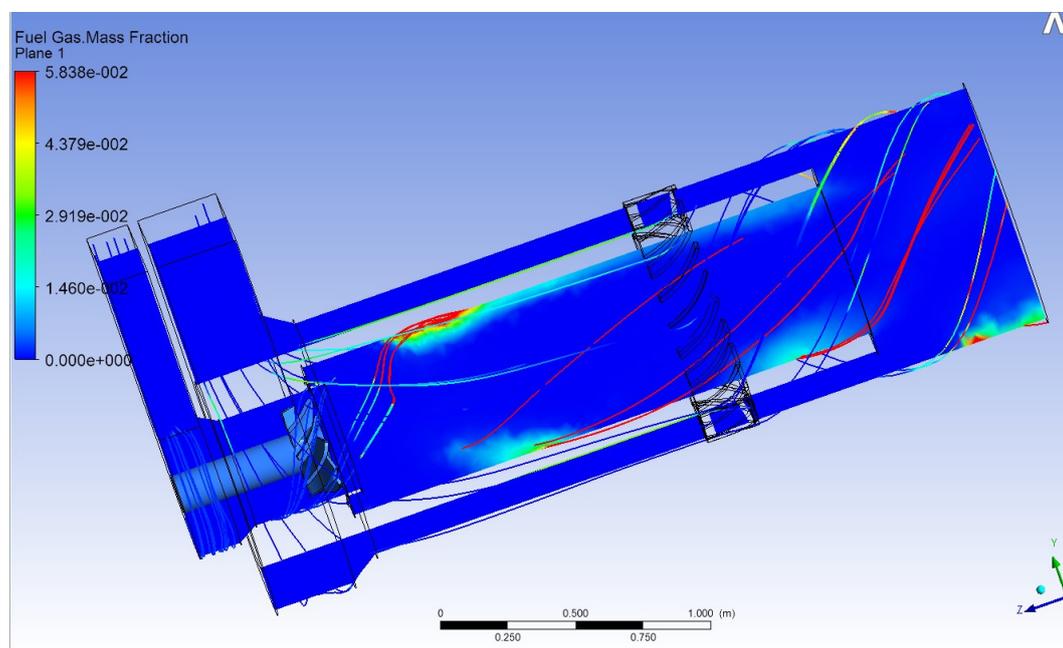

Fig.7. The volatiles concentration field in burner cross section combined with coal particles' tracks (coloured by temperature).
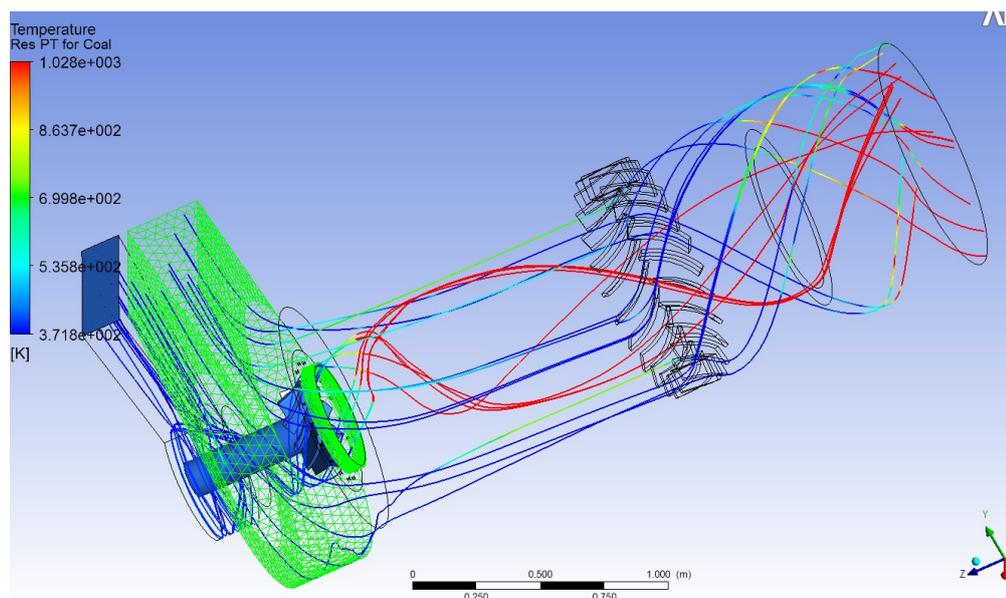
Fig.8.3-D coal particles tracks (coloured by temperature).

Based on the volatile distribution in burner, we can conclude that due to TCP conditions and natural gas supply to initiate the TCP process, the coal inside the muffle is rapidly heated (see inner tracks that pass through inner blade system). Upon that, the volatile yield is observed (see Figure 6 in muffle area), the volatile yield zone coincided with the zone of high temperature. Based on the ANSYS CFX program the 3-D process model a burner boiler with the low-reactive coal TCP of Trypilska TPP was developed, which confirmed the construction efficiency.

The input data development for BCCC implementation

On the basis of the experimental results and the above-mentioned CFD calculations, the burner design of 65 MW for TPP-210A boiler to realize the BCCC technology was developed. As regards the biomass, the woodworking industry wastes – pine sawdust was chosen.

For this case, the optimal (from the view of coal carbon burn-out) ratio under the heat 1:10 proportion was determined by the previous experiments. The necessity to transport the biomass to burner by cold air (to prevent the untimely ignition) was taken into account in the project, and from there the biomass supply directly into the burner by separate flow since the primary air-mixture of the anthracite dust and air has temperature of near 240°C.

The sawdust supplied to the burner central pipe reconstructed where the fuel nozzles for boiler lighting up was located before. The wood biomass flow was swirled to provide fine mixture of sawdust volatile and burn-out hot combustion products with coal dust. The necessary swirling parameter is n=2. In coaxial channel that will be made during burner modernization for BCCC, air is advisable to supply of a rate not less than 3000 m^3/year.

The burner schedule offered for BCCC technology implementation is shown in figure 9, and its parameters – in Table 1.
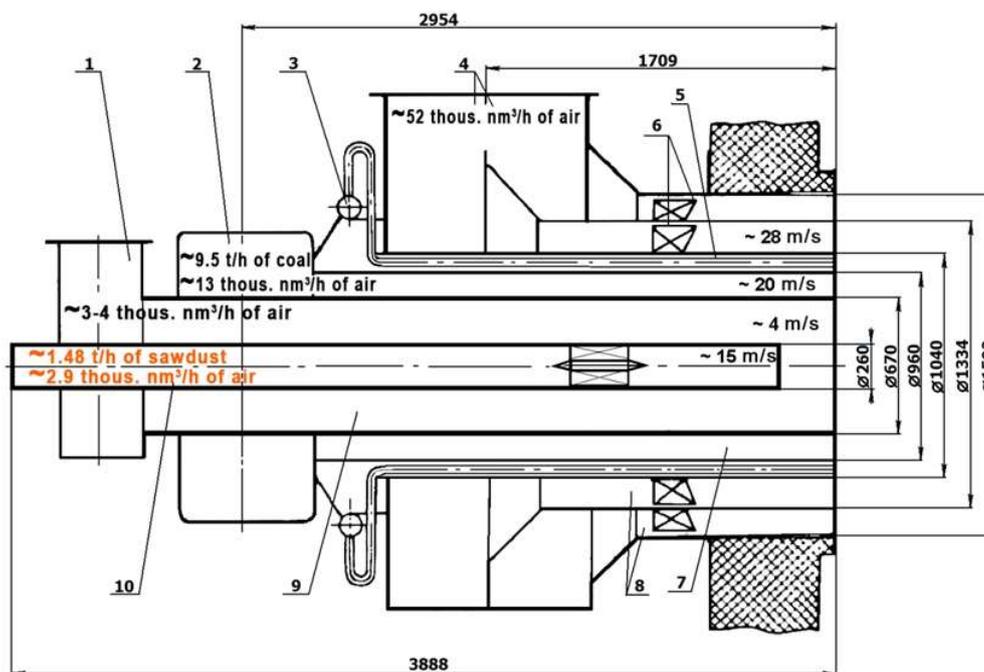
Fig. 9. Boiler unit TPP-210A burner retrofit for co-combustion:
1 – central air swirl; 2 – cold-air mixture swirl; 3, 5 – existing gas lines;
4, 6 – secondary air supply and swirl; 7 – coal-air mixture primary channel;
8 –secondary air channels; 9 – muffle; 10 – biomass supply channel

Table 1

Burner technical parameters of the boiler unit TPP-210A

Burner parameters	Value
Total length, m	3.8
Biomass coal-air mixture supply channel diameter, m	0.26
Central air channel diameter, m	0.67
Primary air coal-air mixture channel diameter, m	0.96
Secondary air first channel diameter, m	1.3
Secondary air second channel diameter, m	1.5
Project air rates, Nm^3/year: –biomass pneumatic transport –central –primary –secondary –total	2964 2500 11 500 43 200 60 164
Burner inlet temperature, °C: –air –air that transports biomass –primary coal-air mixture	340–360 ambient air temp-re 250
Estimated coal consumption under nominal load, t/year	8.17
Technical analysis: –anthracite coal –coal dust –biomass	A^d=22.4%, W_t^r=10% Q_i^r= 22.7 MJ/kg W_t^r=1%, Q_i^r=25.2 MJ/kg V^{daf}=85%, A^d=1.75% W_t^r=10% Q_i^r ~15 MJ/kg
Capacity, MW	65

4. Conclusion

The geometric models of the VGP-100V pilot plant were created, meshed and fruitfully used for simulation of combustion processes.

The correction calculation for unsheathed thermo-couple readings was conducted based upon the VGP-100V process simulation and proven by the comparison of measurements in the flow of combustion gases at natural gas experimental combustion. It is shown that re-radiation from thermo-couples' surface plays a significant role in the temperature measurements. The data may be used for correcting direct thermo-couple reading in similar conditions.

On the basis of the ANSYS CFX soft ware, the 3-D model of the coal burner was developed to install the TPP-210A boiler for low-reactive coal at the Trypilska TPP. Direct examination of the burner in working conditions has confirmed its efficiency.

• Based on the use of the experimental studies' results and on the above-mentioned CFD simulations, the draft project of 65 MW burner for the TPP-210A boiler was developed with further implementation BCCC technology at domestic TPPs.

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