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Integral Mathematical Model for Venturi Apparatus Integrated with Plate Heat Exchanger

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Abstract— The idea for integration of Venturi apparatus with heat plate exchanger gas – gas, based on possibilities of using heat of the gases undergoing cleaning, with simultaneous unfolding of the two process – heating of the gases and their cleaning. With rising of the temperature of the gasses at the outlet, scattering getting better, and appearance of "heavy gasses" will be avoided, which is one of the main disadvantages of Venturi scrubber devices. For the postulated construction of this type, it is necessary to outline an integral mathematical model which will integrate the processes in the construction, per segments following the proposed division.

Index Terms— Venturi apparatus, plate heat exchanger, mathematical model, cleaning.

1 Introduction

THE proposed construction consists of two parts: plate heat exchanger and Venturi apparatus. Figure 1 displays the aspect and cross section of the module. Thereby, the gas comes into the interior of the exchanger and then in the Venturi apparatus (white arrows), and after coming out from the Venturi apparatus through the external side of the exchanger (gray arrows) is let out in the atmosphere. The Venturi apparatus besides cleaning also cools the gas by water ejection. In the heat plate exchanger the cleaned cooled gas is heated by ingoing hot gas. The ingoing gas flows through the internal side of the exchanger while the exhaust gas flows through the exchanger from the external side.

Due to the specific shape of the proposed integrated construction (module), that is, the Venturi apparatus with plate heat exchanger, and in order to postulate the mathematical model for fluid flow and heat transfer processes in the whole module or package, the treatment of the processes by segments of the physical model – module is necessary (Fig.2), where the first, the second and the third segment are presented separately.

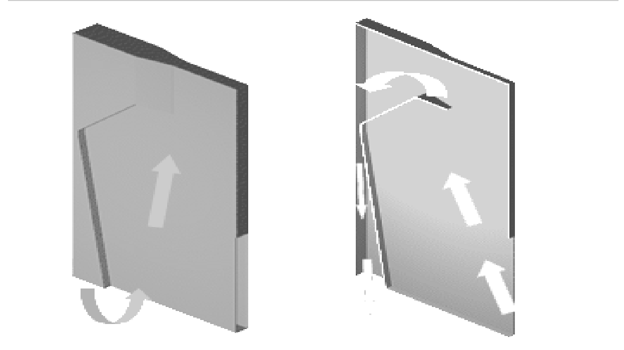

Fig. 1. Venturi apparatus integrated with plate heat exchanger

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The modeling of the process was made in the direction of the gas flow, from the inlet to the outlet of the construction. In order to get integrity during modeling, the outlet data for the first segment are inlet data for the second one, the outlet data from the second are inlet data for the third, and the outlet data from the third are in the same time outlet data for the whole construction [1].

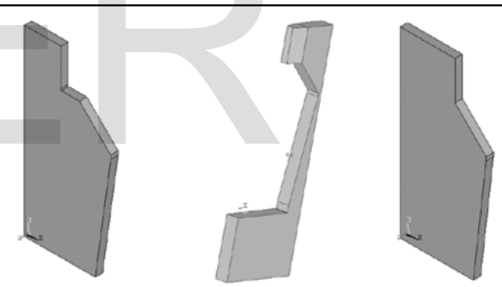

Fig.2. Relations between the segments of the module, first, second and third segment (from left to right)

2 Physical Model

Fig.3 displays a single module as an integrated whole consisting of plate heat exchanger and Venturi apparatus with rectangular cross section, where the real dimensions of the module have been given. The material is sheet 0.5 thick. Two or more such modules form a package, which functions like a whole aiming to achieve the main function of the construction, Fig.4.

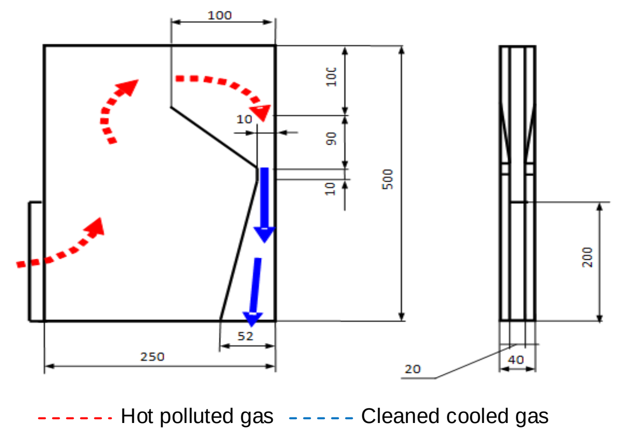

Fig.3 Real dimensions of the module

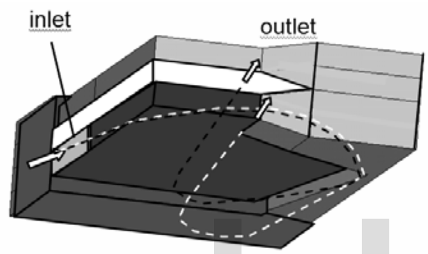

Fig.4 Package of the modules

In order to simplify the postulation of the mathematical model, a division of the module on segments is adopted. The first segment is the part from the inlet to the construction to the inlet to the confuser, which is considered as the internal side of the plate heat exchanger where polluted hot gas flows on one side, and beyond the physical barrier is the third segment, which is considered as the external side of the plate heat exchanger where cooled cleaned gas flows, Fig.4. The process of cleaning of the hot polluted gases is performed with water that is injected in the throat of the Venturi apparatus having a rectangular cross section. The process after drops elimination precedes the inlet to the external side, i.e.the third segment, and the outlet from this side is the outlet of whole construction as well. By coupling together of the external and the internal side through the barriers, a plate heat exchanger gas – gas is formed, where the one-direction heat transfer prevails [1].

3 Mathematical Model

3.1 Mathematical Model for the First and Third Segment

The heat transfer from the interior side (first segment) to the external side (third segment) depends on the temperature profile through the construction from inlet to the outlet, Fig.5a and Fig.5b.

$$t_a > t_b > t_c > t_k > t_j > t_i > t_h \quad (1)$$

In these two segments the heat transfer is intensive through the dividing surface of the construction, where the gas flows from the both sides through the channels with rectangular cross section. The fluid is considered incompressible, and the flowing in the two segments is stationary, without mass transfer, having one component and one phase (without phase change), while due to the geometry of the plate segment of the module, the flowing is considered to be two-dimensional [1-3], [10].

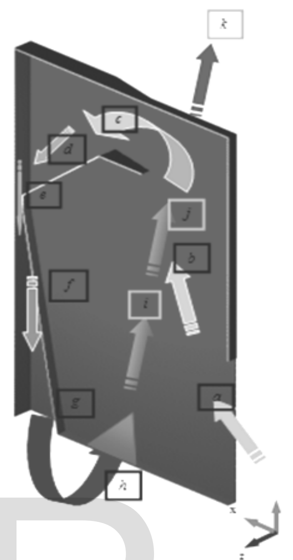

Fig. 5a Flow direction in the module with temperature profile

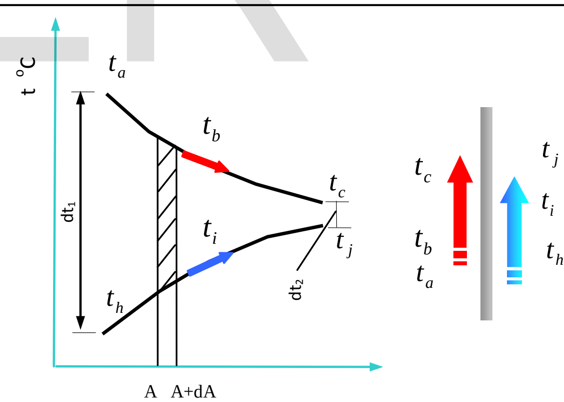

Fig. 5b Temperature of the gas in the heat exchanger, one-direction flow

3.2 Mathematical Model for the Second Segment

According to the adopted division of the module, the second segment is the part from the inlet to the confuser, through the throat and through the diffuser up to the inlet to the drop eliminator part. It is characteristic that the cross section throughout all the length of the Venturi channel has a rectangular shape with constant width. The segment has a shape as the one shown on Fig.5.

The Venturi channel is characterized by the gas cleaning

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process with water injection in the throat, whereby one of the main purpose of the integrated whole is achieved [11].

In this segment the heat and mass transfer is dominant having a temperature profile in direction of the gas flow as on Fig.6a and Fig.6b:

$$t_c > t_d > t_e > t_f > t_g \qquad (2)$$

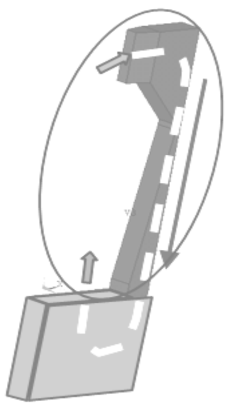

Fig. 6a. Flow direction in the Venturi channel

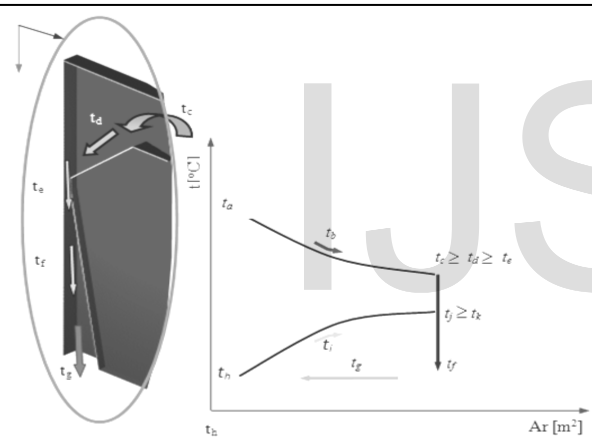

Fig. 6b. Temperature of the gas in the Venturi channel

In this segment, very complicated processes with intensive heat and mass transfer take place, which according to the construction design are going on in the confuser, throat and the diffuser, being elements of the Venturi channel. In accordance to the above, the gas flow in the throat is considered to be one-dimensional, whilst the gas flow in the confuser and the diffuser is considered to be two-dimensional. For all three segments, a complex mathematical model is postulated.

In the confuser as inlet part of the second segment, the fas flow is assumed to be two-dimensional, two-phased and stationary. The gas is polluted, has several components containing dust particles and gas components SO_2, NOx, CO_2. Owing to the short length of the confuser, it is considered that the gas temperature change is negligibly small and it can be deemed as being constant. Based on these assumptions, a complex mathematical model is postulated [4-9].

In the throat, the most complicated processes in construction take place, that is, it is the very place where interaction between the gas and the water happens, whereby the process of cleaning occurs, the place where the flowing velocities are maximal, and a fully developed turbulent flowing exists. Because of the throat dimensions, its small cross section and short length, the flowing can be assumed with satisfactory accuracy to be one-dimensional, three-phased (gas-water-dust), having a phase change (evaporation-condensation), having an adhesion of dust particles to the water and their absorption, and therein chemical reactions occur as well, forming weak chemical solutions. The process of the drop decay into disperse compositions with defined dimensions, has been a subject of investigation in many scientific papers [5]. For this part of the Venturi channel, i.e. the entire integrated structure, a mathematical model for drop movement in the gas flow is postulated, also a mathematical model for moisturizing and drying of the gas, for absorption of the gas components in the water, as well as for the process of rinsing of the gas from dust [8], [9].

In the diffuser, the process of water drops decay continues, with possibilities of secondary decay appearance depending on the local conditions and the influential magnitudes. The motion of the water drops depends on gas velocity, so it should be treated separately [9].

4 The Program Solution of the Mathematical Models

4.1 Program Solution of the Mathematical Model for First and Third Segment – Plate Heat Exchanger

As to the programmed computation of the mathematical model for the plated part of the module, program designs have been made to estimate the local values of the velocities, pressure, temperatures, heat capacities. The program designs are realized based on VBA (Visual Basic Application) using ADI method based on known initial data, including the geometry of the channel, as well as the limitations defined by the flowing type [1], [2]. The program design has been created in the following order: 1) generating of the 2D mesh having defined geometry with fixed coordinates and borders, 2) solving of the Poiss-on equation, getting stream-vortex distribution, 3) getting velocity components, 4) determining the pressure field distribution, 5) obtaining temperature field distribution, 6) determining of other values (total heat transfer coefficient, specific heat, density, Re – number).

4.2 Program Solution of the Mathematical Model for Second Segment – Venturi channel

As to the programmed computation of the mathematical model for the second segment, subroutines designs and a main program have been made made, which are interrelated by orders, branching, references, which are implemented by employing of VBA (Visual Basic Application) [1], [4], [6]. In the program design, a separate subroutine was made related to the thermo-physical characteristics of the gas and the water, depending upon the temperature. From the main program subroutines for numerical solution of the system of differential equations can be called based on the applied method of Runge – Kuta with forth order of accuracy and on TDMA method.

By solving of the model following is obtained: stream distribution, gas velocity components, field of gas pressure, the components and the resultant velocities of water drops for all fractions, local drops velocities, drop velocities in the gas flow for defined dispersion composition along the diffuser, calculation of the dust concentration change with defined disperse composition along the diffuser of the Venturi channel, calculation of the process of absorption of the few influential gas components, and calculation of the other local parameters as well.

5 Conclusion

Thus set integral mathematical model, which is composed of separated models for the plated part of the construction and Venturi channel (confuser-throat-diffuser), provides a comprehensive definition of the thermal – fluid processes in the proposed construction.

Such proposed structure (construction) cannot be encountered in the professional and scientific literature, suggesting an opportunity for deepening and continuation of studies, which indicate the possibility for real practical application of it.

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