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Heat and mass transfer in fluidized layer

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Abstract
The article presents the results of analysis of heat and mass transfer characteristics of the fluidized layer in the processes of oxidative pyrolysis of biomass. The main regularities of heat and mass transfer, the relevant mathematical models and the results of the solution of the corresponding equations are presented.

Key words: FLUIDIZED LAYER, MATHEMATICAL MODELS, HEAT AND MASS TRANSFER, THERMAL CONDUCTIVITY.

Introduction. When heated, and the interaction of the material with the gas flow is intense heat and mass transfer processes in the layer, among which there are three main types of transfer of thermal energy and mass. In the first case it is necessary to consider the transfer of substance and heat inside the layer. The fluidized bed has a high volumetric heat capacity therefore transport processes are fully determined by solid-phase stirring.

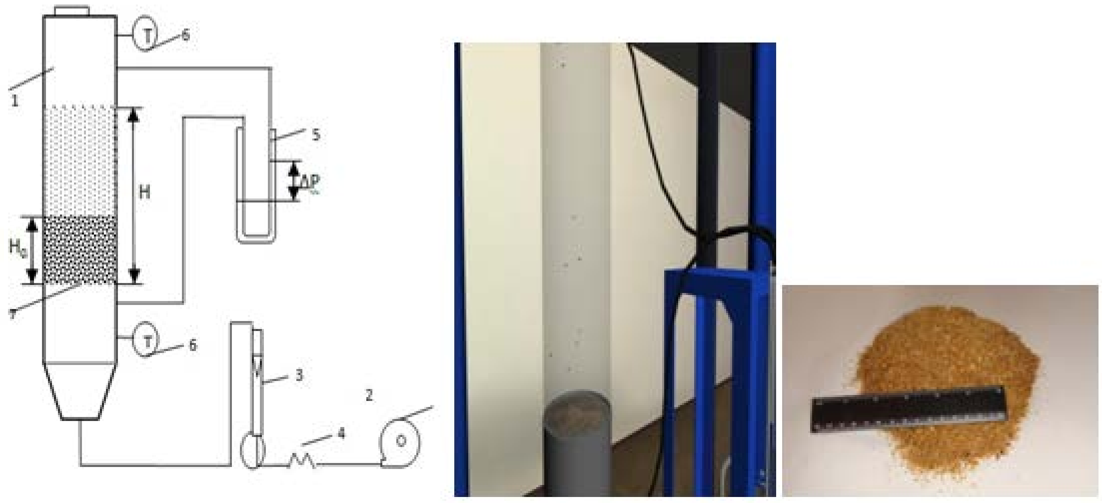
The second type of energy transfer - the transfer from gas to the particles. The presence of specific flows of heat and mass transfer in the layer is conditioned by different heating rates of particles. That is, in this case, you should consider the problem of thermal conductivity the particles and temperature changes inside the particle in time. The third type of energy transfer due to the interaction of the particle bed with the walls of pyrolysis chamber. In our case, walls are insulated, so the heat exchange with the walls will not be considered.

Purpose of work is to determine experimentally the effective parameters of the layer and develop methodology for the analytical evaluation of the intensity of heat and mass transfer in a fluidized layer.

Fluidization of raw particle starts at disequilibrium balance of forces acting on a layer: gravitational; forces dynamic pressure air flow; hydrodynamic flow resistance and resistance to friction. In many literature sources it is indicated that under certain conditions, the fluidized bed may be relatively stable in general. These conclusions are supported by our experimental studies, which set the frequency range pulsation (1-2 Hz) layer of the raw material in the pyrolysis. Satisfaction of this condition ensures the implementation of sustainable modes of fluidization.

In contrast to the fluidized layer, which is generally stable, the position of each individual particle is not stable. Even if at some point in the particle layer are distributed uniformly at equal distances from each other, even a slight displacement of one of them will lead to a rearrangement of circumfluent flow rate at which the narrow section between the converged particles increases, and the pressure (by the law of Bernoulli) decreases. Thus, particles acquire new speed U. Continuous value of this parameter leads to fluctuations of all dynamic parameters. And they will be the greater, the greater height of the layer of feed material, its density, dispersibility and moisture [1].

The materials and research results. For the experimental and calculated dependences of the hydraulic resistance of the fluidized bed of raw material ΔP, the layer with the height H and fractional void volume of the gas velocity created laboratory equipment, shown in the Figure 1.



a) b) c)

Figure 1. Laboratory stand: a) A general scheme of equipment of the fluidized layer; b) photo laboratory equipment; c) photograph of the raw material (the notation given in the text).

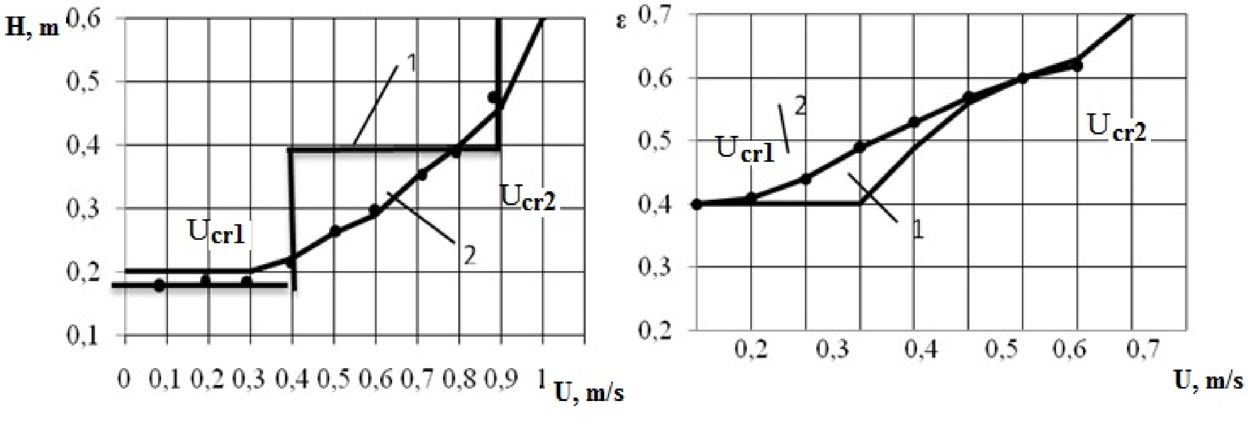
The installation consists of a glass column 1 of 200 mm diameter, in which the air blower 2 is supplied air. Air flow is determined by a rotameter 3. The air heated by an electric radiator 4. To control the temperature and pressure mounted devices 5 and 6.

Raw particle loading on distribution lattice 7. Initial layer height - H_0. The height of the fluidized layer - H. If through the fluidized bed material, which is lattice 7 miss gas stream, the state of the layer is determined by its speed.

At flow velocities below the first critical speed U_{cr1} layer goes into the fluidization. The particles start moving. This ensures good mixing of the material, an average temperature in the bed and evenly distributed interaction with the coolant.

There occur pressure pulsations (frequency υ <1 Hz). Upon reaching the second critical speed U_{cr2} the layer is destroyed [2].

Criterion for our conditions $Ar=5,9\cdot10^6$ and $L_y=0,46$, which corresponds



a) b)

Figure 2. Experimental dependence of layers: a) height; b) fractional void volume of the air velocity.

The figures show calculated dependence (curve 1) and experimental one (curve 2). In the graphs there is no clear boundary fluidization because polydispersed material for each fraction fluidization begins at different critical speeds close to 0.4 m/s.

The boundaries of the existence of the fluidized bed depends on the frequency characteristics (geometrical parameters and velocity of the gas), temperature and pressure environment. The figures show the limits of existence of a stable layer of pulsing (frequency of 1-2 Hz) particles with a moisture content of 10-40% in the temperature range 100-400°C. These dependencies are valid for the pyrolysis of raw particles of different nature and humidity subject to the equality $H_0 \approx D$ [3].

For theoretical analysis of the interaction of a particle with upflow gas there proposed simplified calculation model of the system (Figure 3).

The main obstacle is the propagation of heat air gaps, so the effective thermal conductivity (λ_{ef}) decreases with increasing of fractional void volume characteristic of the upper part of the layer material. But because of the heat transfer, moving of particles λ_{ef} is almost constant. Therefore, thermal diffusivity (a) of the layer is equal to a diffusion coefficient mixing of the solid particles [3].

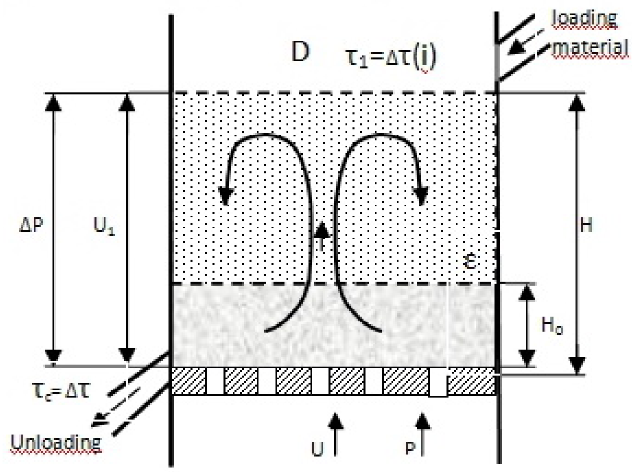


Figure 3. Scheme of the process preliminary low-temperature pyrolysis

Volumetric heat capacity of the particles: $(1-\varepsilon)C_{sp}\rho \approx 1300$ kJ/m^{3}K (1)

The effective thermal conductivity of the layer, is sufficiently high, even when compared metals. $\lambda = a(1-\varepsilon)C_{sp}\rho \approx 860$ W/mK [4] (2)
To evaluate the temperature difference over the cross section apparatus the following equation may be used:

$$G_{layer}\frac{C\rho_{layer}}{S}\frac{dT}{dR}=\lambda_{ef}\frac{d^2T}{dR^2}-\alpha(T_R-T_0) \quad (3)$$

where G_{layer}- flow characteristics of gas through the layer (m^3/s); S – sectional area of apparatus; ρ_{layer} – the density of the fluidized layer; R – the radius of apparatus; T_0 – the temperature layer in the center (axis apparatus); T_R – temperature of the layer at the apparatus wall; α – effective heat transfer coefficient.

The boundary conditions

$$\lambda_{ef}\frac{dT}{dR}|_R = G_{layer}C\rho_{layer}(T_0 - T_R) \quad (4)$$

$$\lambda_{ef}\frac{dT}{dR}|_0 = 0 \quad (5)$$

Solving the equations, we obtain the dependence, which allows us to estimate the temperature difference when loading the material during its interaction with air and layer:

$$\Delta T = T_0 - T_R = \frac{(T_S - T_R)\cdot(G_{layer}C\rho_{layer} + \alpha RS)}{G_{layer}C\rho_{layer}} \quad (6)$$

Δ T in the first 0.5 seconds is equal to about 10 ° C.

The temperature of the air before gas distribution lattice essentially differs from the temperature of the layer. Consider the rate of warming layer and thus determine the height at which layer the temperature of the particles is equal to the air temperature. If we assume that the process of heat and mass transfer can quantitative characterization of specific volumetric heat transfer coefficient α_V (W/m^{3}K) the temperature difference between the air and raw material particles should decrease exponentially in the direction of the air and at the outlet of layer will tend to zero. When high thermal conductivity of the particles can be considered their heating process is quite fast flowing [5].

Measurements of the temperature field inside the particle is difficult manageable task. Therefore, we consider the problem of thermal conductivity of the particle. But first perform an assessment of heat transfer processes for each of the phases. To do this, we write the equation of heat transfer for air:

$$d\varepsilon C_a\rho_a\frac{dT_a}{d\tau} = G(1-\varepsilon)\alpha(T_m - T_a) \quad (7)$$

for the layer

$$(1-\varepsilon)\alpha C_m\rho_m\frac{dT_m}{d\tau} = G(1-\varepsilon)\alpha(T_a - T_m) \quad (8)$$

We introduce the characteristic parameters of time warming gas τ_a^* at

T_m = const and τ_m^* at T_a=const:

$$\begin{cases} \tau_a^* = \dfrac{\varepsilon}{1-\varepsilon}\dfrac{C_g\rho_g\alpha}{G\alpha} \\ \tau_a^* = \dfrac{C_m\rho_m\alpha}{G\alpha} \end{cases} \quad (9)$$

Solving these equations we obtain:

$$\tau_a^* T_{a0} + \tau_m^* T_{m0} = (\tau_a^* + \tau_m^*)T_f \quad (10)$$

where T_f – the final temperature phase (equilibrium) T_{a0} and T_{m0} – initial temperature phases. Finally, the solution of equations of the form:

$$\begin{cases} T_m - T_f = \dfrac{T_{a0} - T_f}{e^{\frac{\tau}{\tau_0}}} \\ T_a - T_f = \dfrac{T_a - T_f}{e^{\frac{\tau}{\tau_0}}} \end{cases} \quad (11)$$

where τ_0 - the characteristic time of heat transfer

$$\tau_0 = \frac{\tau_a^*\tau_m^*}{\tau_a^* + \tau_m^*} \approx \tau_a^* \quad (12)$$

The characteristic time heat transfer determines the height layer h_0, where the condition $T_m = T_a$

$$h_0 = \frac{\varepsilon^2}{G(1-\varepsilon)}P100D \approx 10D \quad (13)$$

Height $h_0 \approx 10d$ is located in the area of sustainable existence layer (Figure 2).

The above mentioned features of interphase heat transfer also valid for interphase mass transfer process [5]. Because pyrolysis occurs in the active layer region $h_0 \approx 10D$, then the upper layers of the pyrolysis gas concentration practically does not differ from the equilibrium with the dispersed phase. In the layer height $h_0 \approx 10D$ of the concentration of volatile components raw mixture differs substantially from the equilibrium. To evaluate the intensity dependence of the mass transfer is proposed $Sh = \beta\frac{\alpha}{D_{ef}}$, where β – heat transfer coefficient; D_{ef} – diffusion coefficient. In general constant mass transfer rate in the layer must be calculated for specific conditions. Practically there usually used an effective mass transfer coefficient β^* if estimate the size h_0, that is actually determined by the effective mass transfer coefficient of correlation

$$Sh = 0{,}025\,\mathrm{Re}\,Sc^{0{,}33} \quad (14)$$

Conclusions.

1. In the pyrolysis chamber there distinguished two types of non-stationary temperature and concentration fields that

are associated with replenishment layer the cold raw particles.

2. Due to the fact that the inside layer there is an intensive mixing of the material circulation, all of thermophysical characteristics the cross section of the layer are aligned. At the same time due to mechanical transfer of thermal energy, concentrated in the particles thermal conductivity of the layer may exceed the thermal conductivity of metals.
3. It has been established that the alignment differences of temperatures and concentrations by the above effects can occur within 0,5 – 1 s, i.e. in the time interval comparable to a period of pulsation layer.
4. It is investigated that the alignment of values of concentration and temperature of the material layer and the air is at a height of particles 10d.

References

1. Pavlenko A.M., Koshlak H.V., Usenko B.O. (2014). The processes of heat and mass exchange in the vortex devices, *Metallurgical and Mining Industry*, No 3, p.p. 55-59.
2. Pavlenko A.M., Koshlak H.V., Usenko B.O. (2014). Thermal conductivity of the gas in small space, *Metallurgical and Mining Industry*, No 2, p.p. 20-24.
3. Pavlenko, A.M., Basok, B.I., Avramenko, A. A. (2005). Heat Conduction of a multi-layer disperse particle of emulsion. *Heat Transfer Research. 36,(1,2), 55-61.*
4. Pavlenko, A.M., Basok, B.I. (2005). Kinetics of water evaporation from emulsions. *Heat Transfer Research. 36, (5), 425-430.*
5. Pavlenko, A.M., Basok, B.I. (2005). Regularities of boiling-up of emulsified liquids. *Heat Transfer Research.* 36, (5), 419-424.