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Some Aspects Concerning Convective Transfer of Furnace Operations

Majority of the process are convective, with turbulence. With establish turbulence, the rate of heat transfer in various regions is so high that may be regarded as infinite. The turbulent state of the main mass of flow to which turbulent affects the thickness of the boundary layer is specifying in this case, especially in tunnel furnace.

1. General conditions

In furnace, majority of the process are convective, with turbulence. With establish turbulence, the rate of heat transfer in various regions is so high that may be regarded as infinite. The turbulent state of the main mass of flow to which turbulent affects the thickness of the boundary layer is specifying in this case. In practice, however, this thickness of boundary layer depended on a number of characteristics from equation:

$$Q = \alpha \Delta T_{av} F \cdot t = \alpha \frac{\Delta T_{in} - \Delta T_f}{\ln \frac{\Delta T_{in}}{\Delta T_f}} F \cdot t = \alpha \cdot \Delta T_{in} \chi \cdot F \cdot t \quad (1)$$

Where: $\Delta T'_{av}$ is the average temperature difference between the heating and heat – absorbing medium;

ΔT_f and ΔT_{in} are the temperature difference respectively at the final and initial condition of heat exchange.

Where $\alpha = \alpha_c$.

Unlike other coefficient employed in the theory of heat transfer, the coefficient α_c depends on many factors and can be determined only experimentally. Since heat transfer by convection is organically associated with hydrodynamic conditions in the flow of a fluid and the properties of that fluid, the most general expression from which the coefficient in forced motion can be determined is on

interrelating the Nusselt ($Nu = \alpha_c x_0/\lambda$), Reynolds ($Re = w x_0/\nu$) and Prandtl ($Pr = \eta_{fr}/\lambda.g$) criteria:

$$Nu = k_1 \cdot Re^{n_1} Pr^{m_1} \quad (2)$$

The criteria given above include the following quantities:

W – Velocity of the flow at a distance from the heated surface, m/s;

X_0 – characteristic geometrical dimension, m;

ρ – Density of the medium, kg/m³;

λ – Heat conductivity of the medium, W/(m.K);

c – Mass specific heat, J/(kg.K);

ν – Cinematic viscosity, m²/s.

Upon substitution of corresponding quantities into equation, the coefficient of heat transfer in forced convection α_c , can be found as function of the physical parameter ρ , geometrical parameter x_0 and a certain complex A_1 which includes characteristic physical proprieties of the medium:

$$\alpha_c = k_1 (g\rho w)^{n_1} x_0^{n_1-1} g^{-m_1} A_1 \quad (3)$$

Where:

$$A = \lambda^{1-m_1} c^{m_1} \eta_{fr}^{m_1-n_1}$$

The experimental constant k_1 describes the specific conditions of an experiment, which can affect the thickness of the boundary layer formed. These specific conditions include, in the first place, the shape of the heated surface and the type of flow near that surface (longitudinal or cross-curenr0Experimental constants n_1 and m_1 express the specific effect of one another of the physical proprieties of the medium an heat transfer by convection. As a first approximation $n_1 = 0,8$ and $m_1 = 0,4$.

The correlation of characteristic in free convection can be described satisfactory by the equation:

$$Nu = k_2 (Gr \cdot Pr)^{n_2} \quad (4)$$

Where:

$$Gr = \frac{g \cdot x_0^2}{\nu^2} \beta \cdot \Delta T \text{ is the Grashof criteria.}$$

2. Comparison between Free and Forced Convection

Forced and free convection differ from each other, firstly, in the method of formalization of the driving force of heat transfer by convection, and secondly, in the effect of parameters A_1 and A_2 which characterize the physical proprieties of the process. Thus, the driving force in forced convection is the power of the flow, whereas in free convection this power is expressed in terms of the force acting on the flow.

Further, as follows from equation (3), the density and velocity of the medium produce the same effect in forced convection, and therefore, are principally interchangeable. An essential difference between forced and free convection is due to effect of the characteristics geometrical dimension. In forced convection, the coefficient of heat transfer by convection increases only insignificantly with decreasing x_0 .

In free convection, the vertical dimension is take as the geometrical parameter. Variation of the heat transfer coefficient along the height of a vertical heated wall is in figure 1.

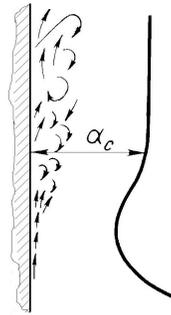


Figure 1. Variation of the heat transfer coefficient along the height of a vertical heated wall in free convection

The figure shows how the coefficient of heat transfer by convection α'_c varies along a heated vertical wall placed in an infinite space. With development of turbulence, α'_c begins to increase and further remains constant. In a finite space, way since the motion of the fluid near surface having different temperatures is interdependent.

Furnaces are said to operate in a convective mode when convection is the decisive (primary) process, while radiant heat transfer is either fully absent or has a subordinate role and can be accounted for by introducing a correction factor.

3. Through Type Convective Mode

If we write the equation of heat balance:

$$V_f \cdot c_f \cdot T_f + V_r \cdot c_r \cdot T_r = (V_f + V_r) c_{in} \cdot T_{in} \quad (5)$$

Where: V is the quantity of combustion products per second (at 0°C and 760 mm Hg); c is the specific heat, and T is temperature; the subscript f relates to gases leaving the combustion chamber, r to returned (recycled) combustion products or to air, and in , to gases entering the furnace space.

As follow from equation (5) the same value of T_{in} can be obtained by adding a certain amount of air or recycling a greater amount of combustion products. Dilution of combustion products leaving the combustion chamber with air, figure 2.

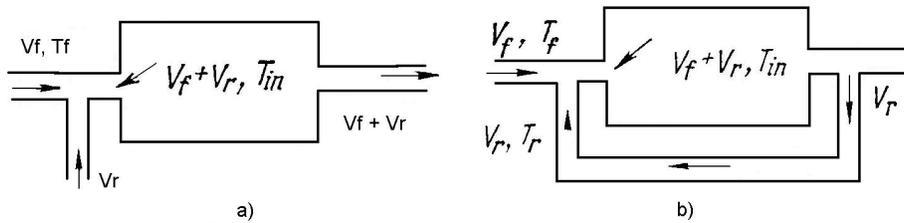


Figure 2. Schemes of plants in which hot combustion products are diluted air (a) and which recycled combustion products (b).

The problem in the design of convective furnace to operate in a through – type mode is to increase the velocity of a heat carrier. As the velocity of the heat carrier increase, it increases the resistance of the heat carrier to motion, and therefore, the consumption of energy to ensure this forced motion. When heating bodies of an elongated shape, the heat carrier is directed by means of partitions along zig – zag path so as to form a cross – current flow as the heated surface, though this is associated with a bigger hydraulic resistance, example the tunnel furnace for drying of object placed on carriage, fig.3.

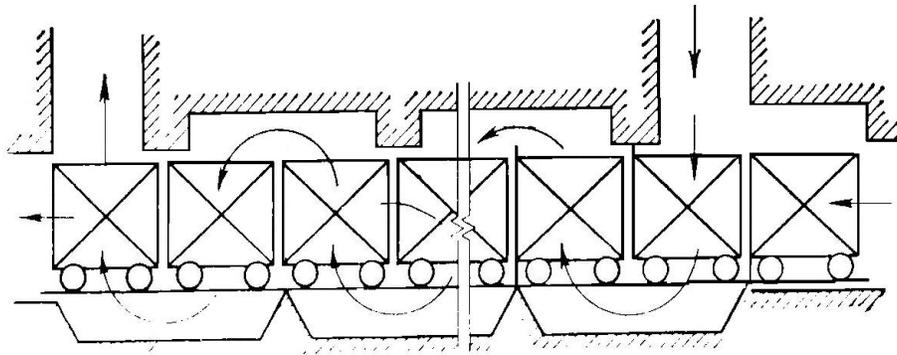


Figure 3. Scheme of tunnel furnace for drying

The principal problem in the design of convective-type furnace is to ensure conditions under which the heat carrier will flow most uniformly along the whole heated surface and to minimize “slipping” of the carrier along the walls and other elements of the furnaces.

From the standpoint of intensification of convective heat transfers, it is especially advantageous to direct currents of heat carrier directly into the heated

surface, since this gives the minimum thickness of a boundary layer. For example of this conditions representative is a convective furnace for heating metal sheet, in which heating is effected on a gas cushion formed by blowing the heating gas at a velocity of 70 100 m/s, fig.no.4.

Used to advantage are high – temperature furnaces in which the products of full combustion of fuel, at a temperature close to the theoretical value, are directed at a high velocity onto the surface of contentiously moving metal (attacking jets); this is achieved by arranging burners at a distance of 4 – 5 nozzle diameters from the metal surface. With this mode of furnace operation (direct oriented radiant heat transfer combined with intensive convection) it is possible to raise the coefficient of heat transfer up to 350 – 400 $W/(m^2 \cdot K)$, against the common values 200 – 250 $W/(m^2 \cdot K)$.

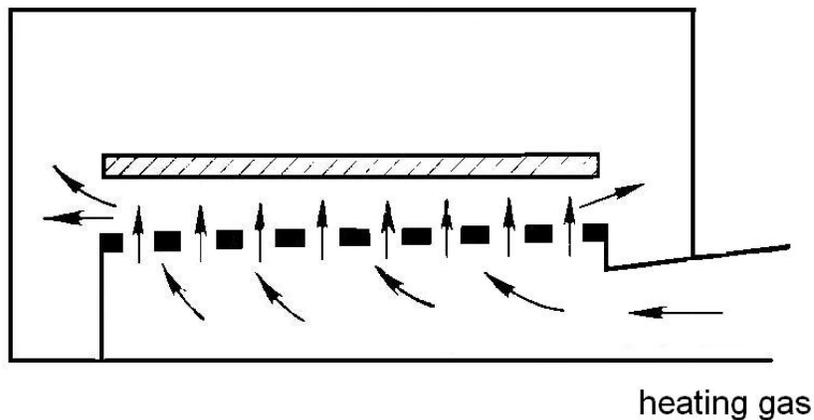


Figure 4. Scheme of a gas-cushion furnace for heating of metal sheet

Variation of the gas mechanics is the most important means for controlling heat transfer processes in furnaces, in particular in convective furnaces. The simplest example is a drying chamber fig.5.

The furnace shown in fig.5.a is fired by means of atmospheric burners, which suck in a certain amount of return gases from the bottom portion of the furnace space and thus create gas circulation.

The furnace shown, in fig.5.b has fuel-firing space separated from the furnace space by brick walls. In the bottom portion of this spaces it is possible to maintain a temperature sufficient for combustion (cca.100 °C) .

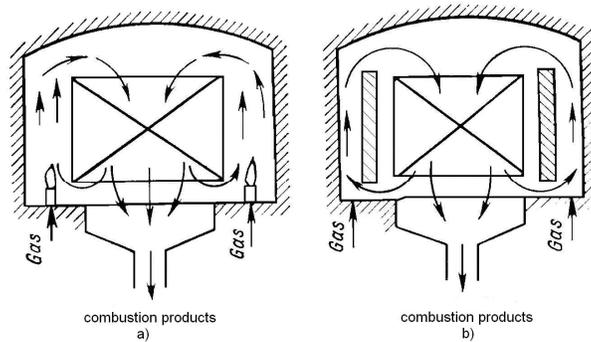


Figure 5. Scheme of a chamber drier with gas motion induced by burners (a) Heating by means of atmospheric burners; (b) Burners and flame are screened off from the furnace space

The partition walls have holes in the bottom portion, through which return gases sucked into the combustion chamber and dilute the combustion products so as to lower their temperature to the value required from the process kinds of gaseous or liquid fuel.

In figure 6 there are: A – lime-cooling zone; B – zone of fuel combustion and decomposition of the charge material; C – zone of drying and preheating of charge and fuel

The convective through-type filtration mode is a dense layer is mainly employed in furnaces for the roasting of rock minerals and for magnetizing reducing roasting of iron ores to transform Fe_2O_3 into Fe_3O_4 .

For example, melting shaft furnace for manufacture of pig iron and copper–nickel matte and also in iron-melting and slag melting cupolas, the upper portion of the shaft also operates in a convective filtration mode.

In that case the operation of dense layer is connected with the operation of the bottom portion of the shaft, which functions in a mixed mode, and cannot be considered separately.

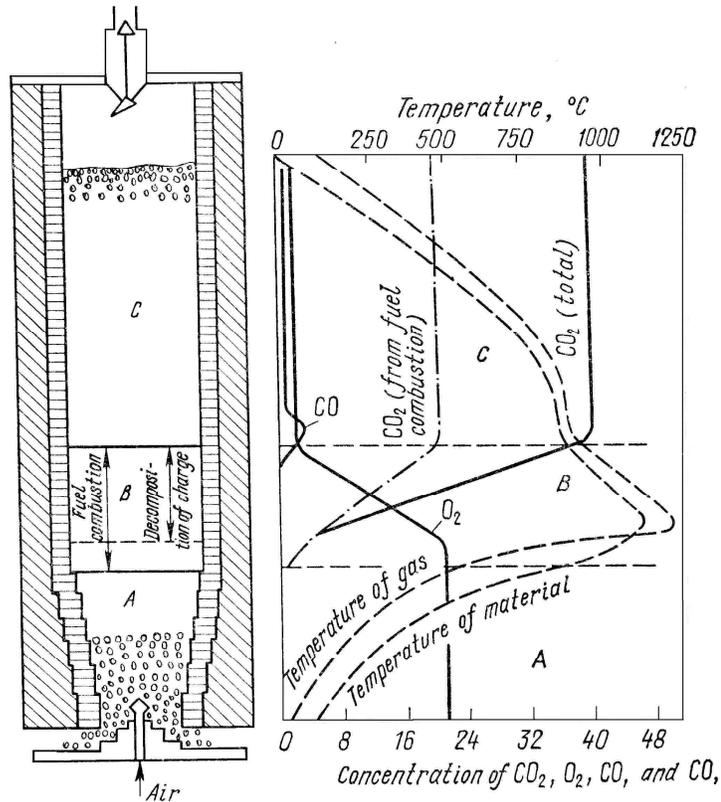


Figure 6. Variations of temperature and composition of gases along the height of a dense-layer roasting shaft furnace

The principal drawback of fuel-fired furnaces is simple, fig.6. A dense-layer roasting furnace has a cylindrical or slightly expanding shaft a conical bottom portion (cooling zone A), which is provided which a discharging device for as uniform as possible removal of the material.

4. Conclusion

From the analysis of operation of heat – generator furnaces in a mass exchange mode, we can derive a number of principles which should be considered

in the development of new and reconstruction of the existing furnaces. At the working temperature of the technological processes of decisive importance is mass transfer of the oxidant and energy-carrying elements and of the products of their interactions.

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