Lecture 5 «Heating processes. Heating by sharp and deaf steam. Heating by combustion gases, intermediate heat carriers and electric current. Heat-exchange devices»

Aim: Characterize the heating processes. Describe the heating by sharp and by deaf steam. Formulate the heating by combustion gases and by electric current. Characterize the heating by intermediate heat carriers.

Lecture summary: Heating processes. Heating is used to accelerate heat and mass transfer processes and chemical transformations. In chemical engineering, the following heating methods are most common: water vapor, flue gases, intermediate coolants, and electric current.

The substances participating in process of transfer of heat, are called as *heat carriers*. The heat carriers having more high temperature, than the heated environment, and giving heat, call *heating agents*.

As direct sources of heat in chemical technology use the furnace gases representing gaseous products of combustion of fuel, and electric energy. The substances receiving heat from these sources and giving it through a wall of the heat exchanger to the heated environment, carry the name of *intermediate heat carriers*. Water vapor and hot water, and also high-temperature heat carriers belong to number of widespread intermediate heat carriers – superheated water, mineral oils, organic liquids (and their couples), the melted salts, liquid metals and their alloys.

The choice of the heat carrier depends first of all on the demanded temperature of heating. The industrial heat carrier has to provide rather high intensity of heat exchange at small mass and its volume expenses. Respectively it has to possess small viscosity, but high density, a thermal capacity and warmth of steam formation.

Heating by “sharp” steam

One of the most widely used heating agents is saturated water vapor. Water vapor is used to heat to a temperature of 150-170 ^{0}C. In this case, the saturated vapor pressure does not exceed 10 atm.

Water vapor as a heating agent has a number of valuable properties:

1) As a result of vapor condensation receive large numbers of heat at rather small consumption of steam. Warmth of vapor condensation makes $\approx 2,26\cdot 10^6$ J/kg (540 kcal/kg) at $P = 9,8\cdot 10^4$ N/m^2 (1 atm).

2) High heat emission coefficient from condensing steam to the heating wall.

3) Constancy of temperature of its condensation that gives the chance to maintain temperature of heating precisely.

The main lack of water vapor is considerable increase of pressure with temperature increase.

The hot steam is injected directly into the heated liquid in which it condenses, giving off the heat of condensation of the heated liquid, and the condensate is mixed with the liquid and their temperatures are equalized.

Heating with “sharp” steam is not suitable if mixing of condensate with heated liquid is impossible or its dilution.

The flow rate of the “sharp” steam is determined by taking into account the equality of the final temperatures of the heated liquid and condensate. Then, using the heat balance equation, we find

$$DI_s + Gct_1 = Dc_w t_2 + Gct_2 + Q_l \quad (1)$$

from where the steam consumption

$$D = \frac{Gc(t_2 - t_1) + Q_l}{I_s - c_w t_2}, \quad (2)$$

where D – the flow rate of the “sharp” steam, kg/s; G - flow rate of the heated environment, kg/s; c – the average specific heat capacity of the heated environment, J/(kg·K); t_1 and t_2 – the initial and final temperatures of the heated environment, K; Q_l – heat loss to the environment, J/s; I_s – enthalpy of heating steam, J/kg; c_w – the heat capacity of the condensate, J/(kg·K).

Heating by “deaf” steam

When heating by deaf steam heat is transmitted to liquid through a wall dividing them. Steam, adjoining to colder wall, it is condensed on it, and the film of condensate flows down on a wall surface. To facilitate removal of condensate, steam enter into the top part of the device, and condensate take away from its lower part.

The consumption of the D deaf steam at continuous heating is defined by their equations of thermal balance:

$$D = (GC(t_2 – t_1) + Q_l)/(J_v - J_c), \quad (3)$$

where G – an expense of the heated environment, C – an average specific thermal capacity of the heated environment, t_1, t_2 – initial and final temperatures of the heated environment, J_v, J_c – enthalpies of heating steam and condensate, Q_l – loss is warm in environment.

Heating by combustion (or flue) gases

When heating by combustion gases it is possible to reach temperature 1000 °C and above. However, for heating by combustion gases the following essential disadvantages are characteristic:

1. Low coefficient of a thermolysis (emission) from gases to walls of warmed devices (α = 15-30 kcal/m^2·h·degree).).
2. The small volume specific thermal capacity of gases (C_v = 3,6 kcal/m^3·degree) that causes of a transmission of considerable volumes of gas.
3. Unevenness of heating owing to cooling of gases at return of warmth by them.
4. Owing to high temperatures of furnace gases and difficulty of their regulation overheats of heated products are possible.
5. Product pollution by warmth transfer at direct contact.
6. Heating by combustion gases of easily flying and flammable materials dangerously.

Combustion gases are formed when burning solid, liquid or gaseous fuel in fire chambers or furnaces of a various design.

Heating by intermediate heat carriers

For the majority of the chemical processes proceeding at high temperature, it is required to carry out uniform heating of the equipment. In this case apply intermediate heat carriers (various liquids or couples circulating in system, perceiving warmth from smoke gases or an electric current) and transferring it to a device wall.

Circulation of intermediate heat carriers in system can be natural or compulsory.

Natural circulation happens at the expense of a difference of density. Circulation speed thus makes 0,2 m/s. For ensuring circulation the heat exchanger has to be located above the furnace on 4-5 m. Owing to the small speed of circulation heat transfer coefficient the very low. Compulsory circulation is carried out by means of the pump. As intermediate heat carriers mineral oils, superheated water, the organic heat carriers, the melted salts, mercury, etc. are applied. Superheated water under pressure, near-critical (225 atm), is applied to heating to 300-350 ^{o}C on a circulating way.

Having warmed with oil make only in that case when it is impossible to apply other, more rational ways of heating 250 ^{o}C. Individual organic substances belong to group of high-temperature organic heat carriers: glycerin, ethylene glycol, naphthalene and its substituents, and also some derivatives of aromatic hydrocarbons (diphenyl, diphenyl ether, diphenylmethane, etc.). The greatest industrial application was received by the diphenyl mix consisting of 26,5% of a diphenyl and 73,5% of diphenyl ether.

Heating it in vapors is used at a temperature of 260-380 °C. In this case, the absolute vapor pressure reaches 8-10 at.

Heating by an electric current

Heating by an electric current make in electric furnaces. Depending on a way of transformation of electric energy in the thermal distinguish electric furnaces of resistance, arc and induction.

In electric furnaces of resistance it is possible to receive temperature 1000-1100 ^{o}C at uniform heating of volume. Heating elements carry out, mainly, from a wire or a nichrom tape – an alloy of nickel, chrome and iron. Passing current through a metal wire, the electric power is transformed to the thermal. Warmth is thus released:

$$Q = 860W\tau, \text{ [kcal]} \tag{4}$$

where 860 – quantity of warmth in the kcal, equivalent to electric power in 1 kW·h; W – capacity of the heater (kW) equal to work of current of J (ampere) on voltage V (volts); τ - time, h.

Electric furnace power is found according the formula:

$$P = U \cdot I, \text{ [W]} \tag{5}$$

where U – voltage, V; I – current strength, A.

Arc furnaces give the chance to receive temperature to 2000 ^{o}C and above.

Heat exchanging devices

Devices intended to transfer heat from one body to another are called heat exchangers. Bodies that give or perceive warmth are usually called heat carriers. Depending on the purpose, heat exchangers are called heaters, condensers, evaporators, steam generators and others. By the methods of heat transfer, there are two main groups of heat exchangers: surface and mixing. In surface heat exchangers, the transfer of heat between the heat exchanging environments takes place through the heat exchange surface that separates them – a blank wall.

In turn, surface heat exchangers are divided into *recuperative* and *regenerative*.

If heat exchange between different heat carriers occurs through the separation walls, the heat exchanger is called recuperative.

In regenerative heat exchangers, heating of liquid environments occurs due to their contact with previously heated bodies – the nozzle filling the apparatus, periodically heated by another heat carrier.

In the mixing apparatus, the transfer of heat occurs when it directly contacts and mixes the heat carriers.

Surface heat exchangers

Apparatus with a jacketed heat exchange surface. In apparatuses with shirts, a closed space forms between the shell and the surrounding jacket-shirt. When heating from above, a heating heat carrier is introduced, when cooled, the heat carrier is fed from below (Fig. 1). The use of such devices is limited to a small heat exchange surface (up to 10 m^2) and overpressure in the shirt (up to 10 atm).

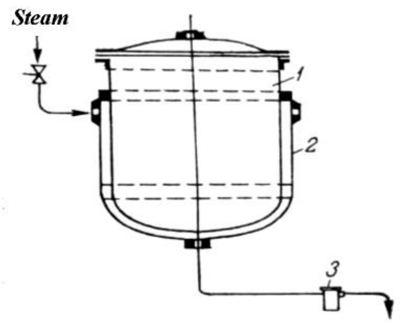

Fig. 1. The device with a jacket:
1 – the case of the device; *2* – shirt; *3* – condensation pot

Coil heat exchangers. The heat exchange element – coil, is a pipe bent in any way. Coils are installed in refrigerators, condensers, evaporators, distillation devices. The velocity of heat carriers in such devices is somewhat lower than in straight pipes (up to 1 m/s), but the coefficient of heat emission of coils is somewhat higher than that of straight pipes.

Casing tubular heat exchangers. These devices are the most common type of heat exchange equipment in chemical technology. Casing tubular heat exchangers are apparatus made of bundles of tubes assembled with pipe grids and bounded by casings and lids with fittings (Fig. 2, 3).

Pipe and intertubular space in the apparatus are disconnected, and each of these spaces can be divided by partitions into several moves. Partitions are installed in order to increase the speed, and consequently, the coefficient of heat exchange of heat carriers. Casing tubular heat exchangers are used when a large heat exchange surface is required. In most cases, the steam (heating heat carrier) is introduced into the intertube space, and the heated liquid flows through the pipes.

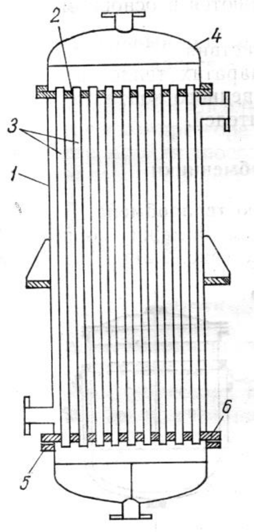

Fig. 2. Casing tubular single-pass heat exchanger: *1* – casing; *2* – tube grid; *3* – tubes; *4* – camera (output, input); *5* – flange; *6* – choke

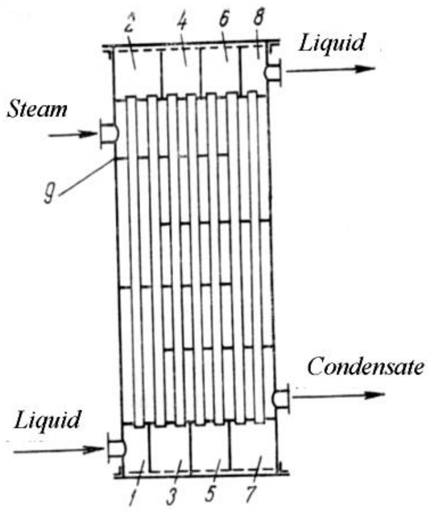

Fig. 3. Multu-hull casing tubular heat exchanger: *1*, *3*, *5*, *7* – compartments of the lower chamber; *2*, *4*, *6*, *8* – compartments of the upper chamber; *9* – transverse partitions

Heat exchangers "pipe in the pipe". Heat exchangers of this type are a battery of several heat exchange elements located one below the other. Each of the elements consists of an inner tube and an outer tube surrounding it (Fig. 4).

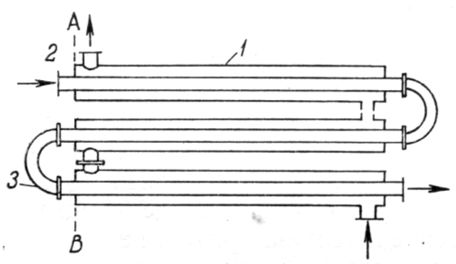

Fig. 4. Heat exchanger "pipe in pipe": *1* – outer tube; *2* – inner tube; *3* – roll

Heat exchange between heat carriers is carried out through the walls of internal pipes. In two-tube heat exchangers, a high velocity of heat carriers and a high intensity of heat exchange are ensured. However, these heat exchangers are cumbersome and metal-laden.

Irrigation heat exchangers are mainly used for cooling liquids and gases or condensing vapors. The irrigation heat exchanger consists of a series of pipes placed one above the other (Fig. 5).

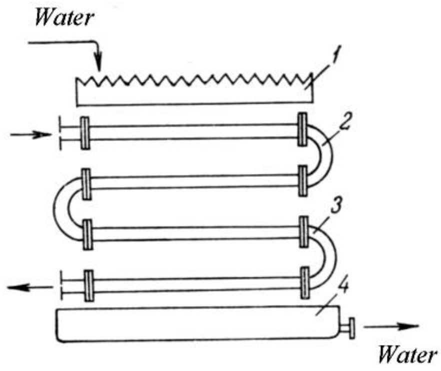

Fig. 5. Irrigation heat exchanger:
1 – chute; *2* – roll; *3* – pipe; *4* – the pallet

Outside, the pipes are watered. A coolant flows through the pipes. Irrigation water is fed to the upper pipe, which drains to the pipes below. In order to evenly irrigate the upper pipe, a chute with serrated edges is mounted on it. In the lower part there is a trough for collecting water. Heat exchangers of this type are used when the temperature of the cooled liquid is above 100 °C [1-3].

Mixing heat exchangers

In mixing heat exchangers, the transfer of heat from one heat carrier to another one occurs when they are in direct contact and are mixed. Such apparatuses are used primarily for condensing vapors and cooling gases with water, and also for cooling water with air.

Mixing heat exchangers in which condensation of any vapors with a cold liquid takes place are called mixing capacitors.

By the method of outputting flows from the apparatus, wet and dry mixing capacitors are distinguished. In wet condensers, the cooling water, the condensate formed and the non-condensable gases are pumped out of the apparatus by the wet-air pump together.

In dry condensers, cooling water and condensate are drained from the bottom of the apparatus by gravity through one pipe, and non-condensing gases are evacuated by a vacuum pump from the top of the apparatus through another pipe.

Mixing devices can be direct-flow and counter-current, depending on the mutual direction of movement of water and vapors.

In countercurrent, the temperature difference between the condensing steam and the outgoing water is 1-3 °C, and with a direct flow of 5-6 °C, and consequently the water flow in the direct-flow capacitors will be large.

The main factor determining the operation of the mixing apparatus is the contact surface of the heat carriers, which should be as large as possible. Therefore, in the mixing apparatus, the contact surface is increased by arranging the shelves, spraying the liquid, and placing the nozzles.

The consumption of cooling water is determined from the heat balance equation:

$$GI_{st} + Wc_w t_{2in} = (G + Wc_w)t_{2f}, \quad (6)$$

where G – the amount of condensable vapor, kg/s; I_{st} – enthalpy of incoming steam, J/kg; c_w – specific heat of water, J/(kg·K); t_{2in} and t_{2f} – the initial and final temperatures of the cooling water.

As follows from equation (6)

$$W = G \frac{I_s - c_w t_{2f}}{c_w (t_{2f} - t_{2in})} \quad (7)$$

The amount of aspirated air (in kg/s) is determined by the empirical formula

$$G_{\text{air}} = 0{,}001(0{,}025W + 10G), \quad (8)$$

where W – the flow rate of the cooled water, kg/s; G – the amount of condensed steam, kg/s.

The volume of suction air is calculated

$$V_{air} = \frac{288 G_{air}(273 + t_{air})}{p_{air}}, \quad (9)$$

where t_{air} – the air temperature, °C; p_{air} – partial air pressure, N/m^2; 288 – gas constant for air, J/(kg·K) [2, 3].

Questions to control:

1. Name the types of heat carriers for supplying heat to heat exchange equipment.
2. List the main advantages and disadvantages of heating saturated steam.
3. When is “sharp” steam used for heating up?
4. How to determine the consumption of “sharp” steam for heating the cold heat carrier?
5. What is the peculiarity of heating by the “deaf” water steam?
6. Give the equation for the consumption of “deaf” water steam during continuous heating.
7. List the main advantages and disadvantages of heating with flue gases.
8. Give a comparative description of high-temperature heat carriers.
9. What are the main types of electric heating?
10. List the advantages and disadvantages of cooling of hot heat carriers with water and air. To what temperatures can the hot heat carrier be cooled with these cooling agents?

Literature

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