

Lecture 1

Modern high temperature technologies

As a rule, one understands high temperature technology processes as the process which realizes when concentrated energy sources are used. The technology processes where iron melting temperature is achieved are related conditionally to high temperature ones. Any determination is not exact.

Laser and electron beam technologies (welding, cutting, thermal treatment), arc welding and other ways of material conjugation (diffusion soldering, termite and SHS-welding); plasmic technologies of coating deposition and surface treatment; ion technologies; oxygen cutting; combined technologies of cutting, welding, building-up; the processes of thin film obtaining and mono crystal growing; the processes of chemical and diffusion treatment of material surfaces etc. are typical examples of high temperature technology processes. Many technologies of new material obtaining in chemical industry; reprocessing and burning of solid fuel; various metallurgical processes could be conspicuous as (cover) high temperature technology processes

The transformation of various energy types to heat one and/or its direct using happens for obtaining, reprocessing and modification of materials and their surfaces at all high temperature technologies.

Each called high temperature process (HTP), in turn, includes many particular technologies depending on concrete technical solution, conditions and materials which are used here.

Features of high temperature technologies:

- Essential irreversibility of the processes connecting with inhomogeneous temperature distribution and their change with time;
- High rates of the heating and cooling of various elements of the system;
- Complex heat exchange;
- Several various phases' presence, the correlation between which changes;
- Various physical-chemical phenomena, accompanying the heating and cooling or forming the basis for the technology.

Last years HTP using high concentrated energy sources (technology electron beam, laser irradiation, plasma flows, oxygen stream etc.) are overall used in electronic industry and mechanical engineering to solve many problems.

Technology process can be present in the form of scheme shown on fig.1.

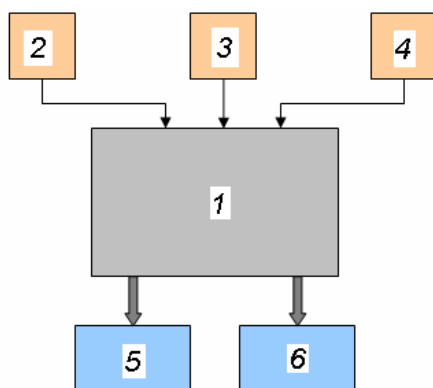


Fig. 1. Block structure of the technology process. 1 – technology chamber; 2 – basic energy sources; 3 – ancillary energy sources; 4 – material fluxes; 5 – finally product; 6. – technology waste products

Energy sources

Heat sources used in HTP can be surface or volume; continuous, impulse and impulse-periodic; concentrated or distributed; stationary and moving.

Such classification is conditional and depends on real technology parameters and material properties.

Surface sources: technology electron beam; laser irradiation of various wave length acted on the metals; plasma flows generated by plasmatrones or other ways; welding arc; optical radiation of wide spectral diapason (for example focused emission of xenon lamps).

Traditional volume heat sources are characterized by relatively large heating time to working temperature (of second portions to minutes or even hour). The transition to working regime in some high frequency plasmatrons can equal to thou' of second. The capacity of volume sources achieves to hundreds of kilowatt or even megawatt; energy concentration is small in comparison with concentrated sources.

The same source can be related to different types dependently on space-time scales.. For example, when laser acts on some dielectrics, energy release and absorption occur in a volume, but no in surface. When electron beam power grows, the energy release maximum moves into a material volume.

Space-time characteristics of heat sources (energy distribution in a volume or along a surface; time parameters) play significant role in HTP.

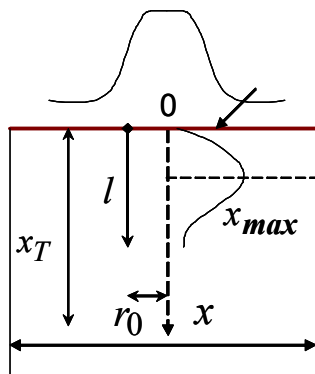


Fig.2. Qualitative energy distribution

Gaussian sources are the most accepted source types; their emission is distributed along the surface in accordance with the law of normal distribution:

$$q = q_0 \exp\left(-\left(\frac{r}{r_0}\right)^2\right) \exp\left(-\left(\frac{x - x_{\max}}{l}\right)^2\right) \quad (1)$$

where q_0 is the maximum of the heat release; r_0 - is effective (conditional) radius of the source. When

$$x_T \gg l,$$

where x_T - is specific heat scale, we could speak about surface source. The arrow on this figure shows the surface.

The mathematical modeling significance during modern technologies development

Mathematical modeling in the region of modern technologies includes

- Investigations and development of physical and mathematical models of technology processes;
- Development of analytical and numerical methods for the solution of thermal-physical problems corresponding to different model of various technologies;
- Engineering relations obtaining to describe temperature and concentration field at the conditions of material treatments;
- Investigation and development of the solution methods of inverse problems (including, heat exchange) as the way of technology processes design;
- The study of conjugate and coupling problems to obtain more full information on heat and mass transfer at the condition of material treatment; the optimization conditions for technology processes and the methods for their realization;

- The obtaining the conditions for monitoring, controlling and regulation of technology processes.

Numerical experiment (NE as constituent part of mathematical modeling) is used as during preliminary analysis of technology process (for identification of the model parameters; for adequacy checking and investigation of technology process) as during the synthesis of technology processes – for testing and comparison of project solutions.

The using necessity of NE as the investigation method connects with following circumstance. The solution of modern science – technical problems characterizing extremely complex mathematical description is difficult and sometimes practically no possible on the base of traditional analytical methods.

Quantitative characteristics of heat transfer

Heat transfer intensity is characterized by the density of the heat flux, that is by quantity of the heat propagating through unit surface square during time unit. This value is measured in **Watt/cm²** or **J/(cm²s)**. Let designate it with letter q .

Heat quantity propagating through arbitrary surface F is called in heat exchange as power of heat flux or simple heat flux - Q . **J/sec** or **Watt** serve as unit for it measurement.

The heat quantity passed during arbitrary time interval τ through arbitrary surface F is designed as Q_τ . This value is measured in **J**.

Listed values are connected by relations

$$q = Q/F = Q_\tau/(F\tau). \quad (2)$$

The regularities of the heat transfer and quantitative characteristics of this process relate to the object for study of heat exchange theory (heat transfer).

Relationship of heat transfer to thermodynamics

In thermodynamics course which is studied by students of engineering specialities there are information on heat exchange between thermodynamic systems. To ascertain the connection between heat exchange and thermodynamics recall some basic notions.

The first thermodynamic law for closed systems can be formulated in following manner:

The heat imposed to the system spends on its internal energy change and work accomplishment

$$\delta Q_\tau = dU + \delta A \quad (3)$$

where $dU > 0$, if internal energy increases; $\delta A > 0$, if the work is accomplished by the the system. All values in (3) are measured in **J**.

This equality can be rewritten for specific values (related to mass unity)

$$\delta q_\tau = du + \delta w. \quad (4)$$

All values in (4) are measured in **J/kg**.

In thermodynamics, ones understand under **internal energy** the energy of chaotic motion of molecules and atoms, including the energy of translation, rotation and oscillating motions (molecular and inter molecular), and potential energy interaction between molecules. Kinetic energy of molecules is single valued function of the temperature; the potential energy value depends on the middle distance between

molecules, and hence, on occupied volume. As a result, the internal energy is single valued function of the state.

The work in thermodynamics is determined by product of corresponding force and pass of its action. So, the work against the external pressure is the expansion work

$$\delta A = p \int_F dF dn,$$

where $p dF dn$ is elementary work expended on the displacement of each elementary area forming the square F , restricted the volume V , or

$$\delta A = p dV.$$

That is, the work is the product the pressure and volume increment. If $dV > 0$, the work is positive, the body accomplishes work. If $dV < 0$, the volume diminishes, the work is accomplished under body.

The work value depends on the conditions of process course or on the conditions of work accomplishment. *The heat and the work ate energetic characteristics of the processes of heat and mechanical interrelation between the system and environment.*

Heat capacity

The relation of the heat quantity δQ_τ , received by the body during infinite small change of its state to temperature change dT connecting with them is called as **heat capacity** for this process

$$C = \delta Q_\tau / dT.$$

Body temperature change at the same quantity of supplied heat depends on the character of going process; therefore the heat capacity is the function of the process function. It means that, depending on the process (or depending on the conditions), the body needs different heat quantity for its heating to 1 grad.

The heat capacity is that heat quantity needed for temperature change in 1 grad at given conditions.

For thermodynamical calculations two heat capacities have the most significance. *They are the heat capacity at constant pressure*

$$c_p = (\delta q_\tau / dT)_p \quad (5)$$

and the heat capacity at constant volume

$$c_v = (\delta q_\tau / dT)_v. \quad (6)$$

The heat capacity of the body at constant volume equal partial temperature derivative from its internal energy and characterize the change rate of internal energy during isochoric process

$$c_v = (\delta q_\tau / dT)_v = (\partial u / \partial T)_v \quad (7)$$

For isobaric process, we have

$$c_p = (\delta q_\tau / dT)_p = (\partial h / \partial T)_p. \quad (8)$$

That is, *the heat capacity for constant pressure equals to partial temperature derivative from enthalpy.*

The second thermodynamic law establishes the existence such thermodynamic state function as entropy s . For reversible processes, the equality

$$\delta Q_{\tau} = TdS \text{ or } \delta q_{\tau} = Tds .$$

takes a place. So, from (3) and (4) we have

$$TdS = dU + \delta A \text{ and } Tds = du + \delta w \quad (9)$$

Using this determination, we find

$$T \frac{ds}{dt} = p \frac{dv}{dt} + \frac{du}{dt} \text{ or } T \frac{ds}{dt} = \frac{dh}{dt} - v \frac{dp}{dt} . \quad (10)$$

Equations (9), (10) are particular forms of Gibbs equation.

Generally speaking, second thermodynamic law can be formulated in various manners.

This law establishes for irreversible processes only the possibility and the direction of their course.

The thermodynamical laws can not ascertain why irreversible processes pass and why all real processes are irreversible.

Entropy for irreversible processes is not determined as the function of state parameters only. To describe irreversible processes there are many ways in science, which are used depending on object of specific investigation.

The third thermodynamical law, has no that principal significance as second and first ones.

To find the heat transfer rate, we should use new physical principles absent in classical thermodynamics. It is necessary to introduce the transfer laws which are not part of thermodynamics. That are, for example heat exchange laws of Fourier, Newton, Stephen-Boltzmann etc. But it is important to remember that new (or additional) physical principles must correspond to fundamental thermodynamical laws.