

## Section A. Nomenclature Topics

### Part I. Thermodynamic Processes, Real and Ideal Gases

#### Chapter 1. General Characteristic of Thermodynamic System and Heat and Work Mutual Conversions

### LECTURE 1. THERMODYNAMIC SYSTEM AND SURROUNDING MEDIUM

#### § 1.1. Mutual conversions of heat and work

General principles of physics. Law of energy transformation. Law of energy conservation. [79=Jones E. R, Childers R. L. Contemporary college physics. 3<sup>rd</sup> ed. USA: WCB/McGraw-Hill, 1999. – 1025 p.], [1-6, 10, 81-86, 88, 121], and others.

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#### § 1.2. Thermodynamic system

The whole collection (combination, complex, set) of material bodies, being an object of studying and being in the state of interaction with the environment (surrounding environment, medium) is called a **thermodynamic system** [Кудинов В.А., Карташов Э.М. Техническая термодинамика. Учеб. пособие

для втузов. М.: Высш. шк., 2000. – 261 с.: ил., р. 7], [Jones E.R, Childers R.L. Contemporary college physics. 3<sup>rd</sup> ed. USA: WCB/McGraw-Hill, 1999. – 1025 p., p. 405].

The simplest example of a thermodynamic system can be some sort of gas, enclosed (placed) in a cylinder with a piston [Jones E.R, Childers R.L. Contemporary college physics. 3<sup>rd</sup> ed. USA: WCB/McGraw-Hill, 1999. – 1025 p., p. 377]. The surrounding medium here is the cylinder and the piston, the air, which surrounds them, and so on and so forth (etc.).

A thermodynamic system is called **an isolated** one if it does not allow exchanging both heat and work with the surrounding medium. Thus it allows exchanging neither heat nor work [Кудинов В.А., Карташов Э.М. Техническая термодинамика. Учеб. пособие для втузов. М.: Высш. шк., 2000. – 261 с.: ил., р. 7].

A system is called a **semi-isolated (half-isolated)** if it allows exchanging either heat or work.

A system is called **non-isolated** if it allows exchanging both heat and work.

A system that has in all its parts the same composition and physical properties is called a physically **regular (uniform)** one. A regular thermodynamic system, inside which there is no surface of division is called **homogeneous** one (ice, water, vapor (steam)), in the opposite case (on the contrary) – **heterogeneous** one (ice and water, water and steam).

A **working body** is a body by which the mutual conversions (transitions, transformations) of heat and work are realized. For instance, in steam turbines the water steam is the working body, in gas turbines – the gas, in refrigerating installations – freons, ammonia, carbon dioxide, and others etc. [Кудинов В.А., Карташов Э.М. Техническая термодинамика. Учеб. пособие для втузов. М.: Высш. шк., 2000. – 261 с.: ил., р. 7].

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# LECTURE 2. THE MAIN THERMODYNAMIC PARAMETERS OF STATE

## § 1.3. Parameters of state

Each **equilibrium state** (when in all points of the volume of a system there are the same all parameters of state and physical properties, see § 2.3) of a thermodynamic system is characterized with a certain physical values – **equilibrium parameters of state** [113, pp. 7-12], (**state variables** [79, p. 381]). **Internal parameters** (state variables) characterize the inner state of a system. Pressure, temperature, volume and others are pertaining (applied, relevant) to them. **External parameters** characterize the position (place) of a system (coordinates) in outer fields of forces and its velocity.

Internal parameters, in their turn, are subdivided into intensive and extensive. **Intensive** – these are the parameters, the magnitude of which does not depend upon the dimensions (sizes, mass) of a body (pressure, temperature, specific volume, but not the volume, specific heat capacity). **Extensive parameters** depend upon the amount (quantity) of a substance in a system (volume, mass and others).

In thermodynamics there also exist divisions of parameters into **thermal** (pressure, temperature, volume) and **caloric** (specific energy, specific heat capacity, specific hidden heats of phase transitions).

In order to characterize the special (particular, individual, concrete) conditions, in which the given system is, or a process, that goes on in the system, it is necessary, first of all, to know such internal parameters of state (state variables) as **specific volume, absolute pressure, absolute temperature**.

**Specific volume** ( $v$ ,  $\text{m}^3/\text{kg}$ ) – this is the volume of the unit mass, or the value, which is determined by the ratio of the volume to its mass [113, p. 8, (2.1)]

$$v = \frac{V}{m}, \quad (2.1)$$

where  $V$  – the volume of arbitrary amount of a substance quantity,  $\text{m}^3$ ;  $m$  – the mass of that substance, kg.

The value, which is reverse to the specific volume, is called **density** ( $\rho$ , kg/m<sup>3</sup>); or this is the mass of a substance, contained in the unite volume [113, p. 8, (2.2)]

$$\rho = \frac{m}{V} = \frac{1}{v}. \quad (2.2)$$

**Pressure** – is the value, determined by the ratio of a force (the normal (perpendicular) component of the force to a surface), acting upon the surface, to the area of the surface ( $p$ , Pa = N/m<sup>2</sup>) [113, p. 8, (2.3)]

$$p = \frac{F_n}{S}, \quad (2.3)$$

where  $F_n$  – the normal (perpendicular to the surface) component of the force, N;  $S$  – the area of the surface, normal (perpendicular) to the acting force, m<sup>2</sup>.

Accordingly to the International System of Units (SI), specific pressure is measured in Newtons per one meter squared (N/m<sup>2</sup>). This measurement unit of pressure is called Pascal (Pa). One Mega-Pascal equals to 10<sup>6</sup> Pa (1MPa = 10<sup>6</sup> Pa).

Up until now, in engineering, there also used the old measurement unit of the specific pressure – engineering (technical) atmosphere (at), representing by itself a force in 1kgf, acting upon 1 cm<sup>2</sup> of the area.

$$1 \text{ at} = 1 \text{ kgf/cm}^2 = 10^4 \text{ kgf/m}^2 = 9.81 \cdot 10^4 \text{ N/m}^2 = 0.981 \text{ bar};$$

$$1 \text{ bar} = 1.01972 \text{ kgf/cm}^2.$$

There distinguished **atmospheric, exceeding (beyond) pressure, and rarefaction** [АНГ, p. 434] (**vacuum**). **Atmospheric pressure** [79, p. 375] is called the one of the atmosphere air at the sea level. The magnitude of the atmospheric pressure is taken as the pressure of the column of mercury with the height of 760 mm (one physical atmosphere is depicted *atm*). Thus,

$$1 \text{ atm} = 760 \text{ millimeters of mercury column (mm. m. c.).}$$

The pressure which is more than atmospheric is called **exceeding**, and which is less than that – **rarefaction**. For measuring pressure there used **pressure gauges** (manometers), for atmospheric pressure – barometers, rarefaction – vacuum-gages (vacuum-meters).

*The thermodynamic parameter of state is only the absolute pressure, which is measured from the absolute zero pressure or absolute vacuum.*

For measuring pressure in engineering there applied gauges (instruments), measuring not absolute (complete, total) pressure, but the difference between the absolute and atmospheric (barometric) pressure. The instruments used (applied) for measuring pressures which greater (more) than atmospheric are called **manometers**. They show the excess of pressure of the measured medium over atmospheric (manometer pressure). For measuring pressures less than atmospheric there used vacuum meters, which show how much the absolute pressure of the surroundings (ambient) medium is less than atmospheric. This lack of the pressure up to atmospheric is called **vacuum**.

If the pressure in the container (bottle, balloon, reservoir) is greater than atmospheric ([113, fig. 2.1 a]), then, at the points of  $c$  and  $d$  of the left and the right elbow of the pipe, the pressures would be the same, because the liquid is in the equilibrium, and the point of  $c$  and  $d$  are at the same level. The condition of the equilibrium of the forces with respect to the level of  $cd$  would be written in the view of

$$F = F_1 + F_2,$$

where:  $F = p_a S$  – is the force of the pressure of the gas upon the liquid in the pipe at the point of  $c$ ;  $F_1 = p_b S$  – is the force of the pressure of the atmospheric air upon the liquid in the pipe at the point of  $f$ ;  $F_2 = \rho g h S$  – is the force of the pressure of the column of the liquid with the height of  $h$  at the point of  $d$  (the weight of the column of the liquid with the height of  $h$ ).

Substituting the formulas for the forces of the pressures into the condition of the equilibrium, we will get

$$p_a S = p_b S + \rho g h S,$$

where  $p_a$  – is the absolute (complete, total) pressure of the gas in the container;  $p_b$  – is the atmospheric (barometric) pressure by a barometer;  $\rho$  – is the density of the liquid in the manometer;  $g = 9.81 \text{ m/s}^2$  – is the acceleration of the free fall;  $\rho g h S$  –

the weight of the column of the liquid with the height of  $h$ ;  $S$  – the area of the cross-section of the manometer pipe.

After cancelling of  $S$  we will get [113, p. 10, (2.4)]

$$p_a = p_b + \gamma h, \quad (2.4)$$

where  $\gamma = \rho g$  – is the specific weight of the liquid in the manometer (manometric liquid);  $\gamma h = p_m$  – is the manometer (manometric) pressure of the column of the liquid with the height of  $h$ , expressed in the same units as the pressures of  $p_a$  and  $p_b$  is given.

From the formula of (2.4) follows that  $p_m = p_a - p_b$ . Thus, one can determine the excess of the pressure of the measured medium over atmospheric by the manometer.

If the pressure in the container is less than atmospheric, then, the condition of the equilibrium of the forces acting upon the liquid in the manometer with respect to the level of  $cd$  will have the view of ([113, fig. 2.1 b])

$$p_b S = p_a S + \rho g h S.$$

From here  $p_a = p_b - p_v$ , where  $p_v = \rho g h$  – the pressure exerted by the column of liquid with the height of  $h$ . This pressure determines the vacuum in the reservoir. That is, the lack of the pressure  $p_a$  in the container up to atmospheric is called **vacuum**.

Exceeding pressure and vacuum are not parameters of state (state variables) because they can be of different magnitudes at the same absolute pressure dependently upon the value of atmospheric pressure.

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Fig. 2.1. a), 2.1. b) ([113, fig. 2.1 a, b])

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In engineering there used quite (rather, pretty) great (big, large) number of units for measuring pressure. Relations between them are shown in the table of [113, p. 10, {[5] = [Бол]}].

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When measuring pressures by liquid instruments, due to expansion (enlarging) of the liquid at heating its volume increases and, therefore, increases the column of the liquid, which leads to false (unfair, wrong) showings of the instruments. At such measurements it is necessary to adduce the height of the column of the liquid to 0 °C. This adduction is carried on (executed, performed) by the formula

$$h_0 = h(1 - \alpha t),$$

where  $h_0$  – the showings of a barometer (manometer), adduced to 0 °C;  $h$  – the height of the column of the liquid, observed at the  $t$  °C;  $\alpha$  – the volumetric coefficient of expansion for the liquid (for mercury  $\alpha = 0.000172$ ).

**Temperature** ( $T$ , K) – the value that characterizes the degree of a body heating. It represents

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$$T = \frac{2}{3k} \cdot \frac{mw^2}{2},$$

where  $m$  – mass of a molecule;  $w^2$  – mean quadratic velocity (speed) of the molecule translational motion;  $k = 1.38 \cdot 10^{-23}$  J/K – Boltzmann's constant.

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[113, p. 11, (2.5)]

$$T \text{ K} = 273.15 + t \text{ }^\circ\text{C}. \tag{2.5}$$

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$$dT = dt .$$

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[113, pp. 7-12].