TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

METHODICAL GUIDELINES

on course «Thermodynamics»

for students studying master degree program

«Nuclear Power Engineering»

Tomsk 2018

1. General notions.

All individual homework assignment (IHA) should be made according to STO TPU (12 fond, single line-spacing). Report on individual homework assignment should include the following parts:

- Front list (example is given in appendix 1);
- Initial data for given variant (all letters N should be changed on appropriate numbers).

<u>*Example.*</u> *Given in initial data sentence "Excess pressure in steam generator is p=(1+N)/10 bar while barometrical pressure is B1=(725+N) mmHg" for 12th variant should be "Excess pressure in steam generator p=1,3 bar while barometrical pressure is B1=737 mmHg".*

- Solution of task in given below form:
-

Given:	Solution:
p_1=5 bar=5 10^5 Pa	$$q = RT_1 \ln\left(\frac{p_1}{p_2}\right) = 8,314 \cdot 288 \cdot \ln\left(\frac{5 \cdot 10^5}{5 \cdot 10^3}\right) = 11027\ J/\text{mole}$$
T_1=15 °C=288 K	Ответ: q=11027 J/mole.
p_2=5 kPa=5 10^3 Pa	
T=const	
q [J/mole] – ?	

Section"Given" has appropriate heading and includes main parameters which were used during calculation with units from initial data as well as their equivalent in SI system. Additional data could be introduced into this part like parameters of processes etc.

Under "Given" section the "Find" section is situated. It separated from "Given" section by horizontal line and doesn't have heading. There (through comma) the symbol of parameters which should be found is put together with units into square brackets with question symbol after the last of them through dash.

The section "Solution" is situated on the right with appropriate heading. The needed equation should be presented there with numeric values of each parameter used. Only physical constants, parameters from "Given" section or from "Solution" section above should be used in this section. Using of parameters from other sources or those without explanation into "Solution" section is forbidden. This section is completed by word "Answer" with answers on question from initial data which were also presented in "Find" section.

For individual homework assignment including calculations of thermodynamic cycles its recommended (but not obligatory) to present image of cycle in pv or Ts-diagrams. The image should be situated into :Solution" section right after heading "Solution". In this case, parameters for each point of cycle should have appropriate subscript (for example, pressures p_1 and p_2 refer to points 1 and 2, respectively).

Methodical guidelines for individual homework assignment №1.

The tasks of this IHA are devoted to the conversion of parameters from various systems of units and the connection between the basic thermodynamic parameters. To complete the task, you must use the following expressions:

1) $p_a = p_{bar} + p_{ex}$ – here p_a – absolute pressure, Pa; p_{atm} – atmospheric (barometric) pressure, Pa; p_{ex} – excess (manometric) pressure, Pa.
2) $p_a = p_{bar} - p_{vac}$ – here p_{vac} – vacuumetric pressure, Pa.
3) $\rho = \frac{m}{V}$ – here ρ – density, kg/m^3; m – mass of substance, kg; V – substance volume, m^3.
4) $Q = cm\Delta T$ – here Q – amount of energy (heat), J; c – substance heat capacity, J/(kg K); ΔT – change of substance temperature, K.
5) $N = \frac{Q}{\Delta t}$ – here Δt – time interval, s.

Methodical guidelines for individual homework assignment № 2.

The tasks of this IHA are devoted to the equation of state of an perfect gas and to mixtures of a perfect gases. To complete the task, you must use the following laws and expressions:

1) Mendeleev-Clayperon equation: $pV = \frac{m}{\mu}RT$ – here p – pressure, Pa; V – gas volume, m^3; m – gas mass, kg; μ – gas molar mass, kg/mole; R – universal gas constant, J/(mole K); T – temperature, K.
2) Molar mass of perfect gas mixture: $\mu = \sum_{i=1}^{m} \mu_i g_i$ here μ_i – molar mass of ith component, kg/mole; g_i – mass concentration of ith component; m – amount of components in mixture.
3) Conversion of mass concentration into molar concentrations: $q_i = \frac{g_i / \mu_i}{\sum_{i=1}^{m} g_i / \mu_i}$.
4) Conversion of molar concentration into mass concentrations: $g_i = \frac{q_i \cdot \mu_i}{\sum_{i=1}^{m} q_i \cdot \mu_i}$.
5) Definition of partial pressure of ith component of perfect gas mixture: $p_i = q_i \cdot p$.

Methodical guidelines for individual homework assignment № 3.

The tasks of this IHA are devoted to the thermodynamic processes of an perfect gas. To complete the task, you must use the following laws and expressions:

1) Mendeleev-Clayperon equation: $pV = \frac{m}{\mu} RT$ – here p – pressure, Pa; V – gas volume, m^3; m – gas mass, kg; μ – gas molar mass, kg/mole; R – universal gas constant, J/(mole K); T – temperature, K.

2) Equation for process work, J/kg: $l = \int_{v_1}^{v_2} p dv$ – here subscripts 1 and 2 refer to parameters of system at the beginning and end of process, respectively.

3) Equation for process technical work, J/kg: $W = l_t = \int_{p_1}^{p_2} v dp$.

4) Equation for process heat, J/kg: $Q = \int_{s_1}^{s_2} T ds$ here s – system entropy, J/(kg K).

5) Equation for entropy change: $\Delta s = \int_{q_1}^{q_2} \frac{dQ}{T}$.

6) Equation for internal energy change, J/kg: $\Delta U = c_v \cdot (T_2 - T_1)$ – here $c_v = \frac{n}{2} \cdot \frac{R}{\mu}$ – isochoric heat capacity of perfect gas, J/(kg K), here n – constant, equal to 3 for monoatomic gas, 5 – for diatomic gas and 6 – for multiatomic gas.

7) Equation for entropy change, J/kg: $\Delta H = c_p \cdot (T_2 - T_1)$ – here $c_p = \frac{n+2}{2} \cdot \frac{R}{\mu}$ – isobaric heat capacity of perfect gas, J/(kg K), here n – constant, equal to 3 for monoatomic gas, 5 – for diatomic gas and 6 – for multiatomic gas

8) Turbine efficiency: $\eta = \frac{l_t^{real}}{l_t^{ideal}}$ – here indexes *ideal* and *real* refer to perfect and real processes, respectively.

9) Compressor efficiency: $\eta = \frac{l_t^{ideal}}{l_t^{real}}$.

10) Connection between power N, W, with mass flow rate G, kg/s: $N = G \cdot l_t$.

Methodical guidelines for individual homework assignment № 4.

The tasks of this IHA are devoted to the thermodynamic parameters and processes of water and steam. To complete the task, you must use the following laws and expressions:

1) The parameters of the underheated to boiling water and superheated steam are determined by two of any of the following parameters T, p, v, h, s which are temperature, pressure, specific volume, enthalpy and entropy, respectively.
2) The parameters of water vapor on the saturation line are determined by the temperature or pressure and one of the following parameters - v, h, s or x ($x = \frac{v - v'}{v'' - v'} = \frac{h - h'}{h'' - h'} = \frac{s - s'}{s'' - s'}$ the degree of dryness of the steam, indicating the amount of dry steam in the wet vapor). Parameters with one dash refer to the parameters of water vapor on the saturation line corresponding to boiling water, and with two dashes to the parameters of dry steam.
3) Process heat, J/kg: $Q = h_2 - h_1$ – here indexes 1 and 2 refer to parameters of system at the beginning and end of process, respectively.
4) Specific work of perfect turbine, J/kg: $l = h_2 - h_1$.
5) Internal relative efficiency of turbine: $\eta = \frac{h_2 - h_1^{real}}{h_2 - h_1^{ideal}}$ – here indexes *ideal* and *real* refer to parameters of system for perfect and real processes, respectively.
6) Connection between power N, W, and mass flow rate G, kg/s: $N = Q \cdot G$.
7) Equation of continuity: $G = \frac{S \cdot w}{v}$ – here S – cross-section area, m^2; w – substance flow rate in cross-section, m/s.

Methodical guidelines for individual homework assignment № 5.

The tasks of this IHA are devoted to the processes of flow through the nozzle and throttling of the perfect gas, water and steam. To complete the task, you must use the following laws and expressions:

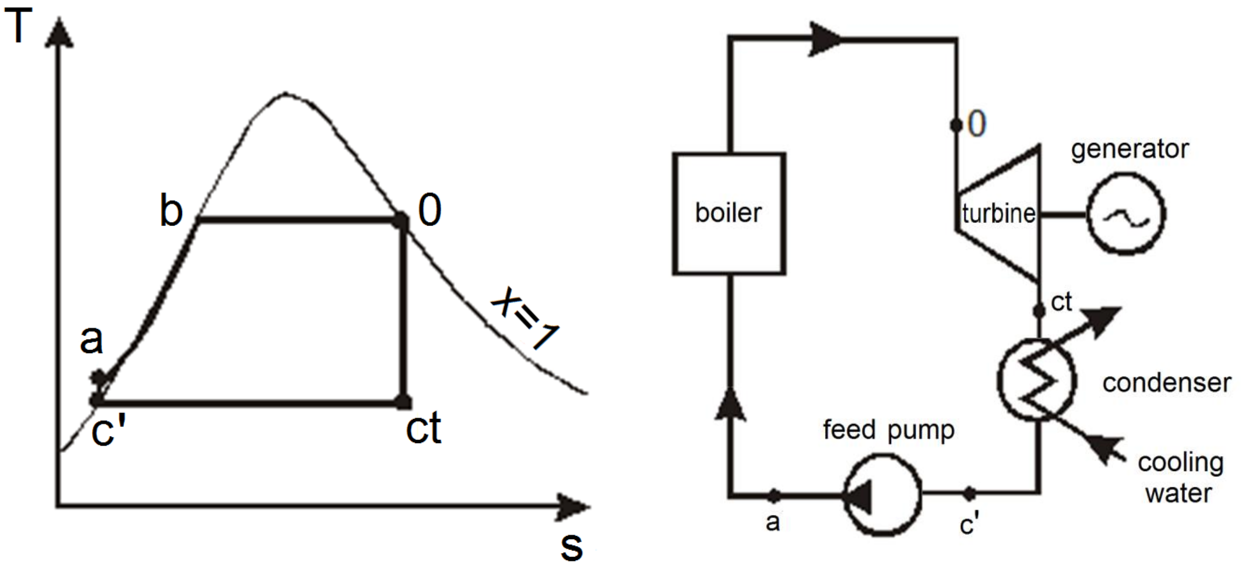
1) Temperature on the outlet of the nozzle: $T_0 = T + \frac{w^2}{2 \cdot c_p}$ – here T_0 – temperature at the inlet to the nozzle with an insignificant flow velocity, K; T – temperature in an arbitrary section of the nozzle, K; w – velocity in the cross section of the nozzle, m/s; c_p – isobaric heat capacity of gas, J/(kg K).
2) Process of efflux could be assumed to be adiabatic: $pv^k = const$ и $s = const$.

3) The ideal process of throttling a perfect gas can be considered isoenthalpic and adiabatic: $h = const$ и $q = 0$.

4) The process of throttling of steam can be considered to be isoenthalpic: $h = const$

<u>Methodical guidelines for individual homework assignment № 6.</u>

The tasks of this IHA are devoted to the calculation of the Rankine cycle on a saturated and superheated steam. The scheme and cycle for such an installation are shown in Fig. 1.



а) б)

Fig. 1 – Scheme of simple steam turbine unit on saturated steam.

The calculation is made in the following order (all enthalpies are determined using the water and steam properties tables):

1) The enthalpy and entropy of steam at the inlet to the turbine are determined using the pressure p_0 in the steam generator and the degree of dryness equal to 1 (for the Rankine cycle on a saturated vapor) or to the temperature T_0 (for the Rankine cycle on an superheated steam):

$$\begin{matrix} h_0 = h''(p_0) \\ s_0 = s''(p_0) \end{matrix} \quad \text{или} \quad \begin{matrix} h_0 = h(p_0, \mathrm{T}_0) \\ s_0 = s(p_0, \mathrm{T}_0) \end{matrix}$$

2) The enthalpy is determined from the pressure p_k in the condenser and entropy s_0 at the end of the ideal expansion process in the turbine:

$$h_{kt} = h(p_k, s_0)$$

3) The enthalpy is determined at the end of the actual expansion process in the turbine, taking into account the relative efficiency of the turbine η_{oi}:

$$h_k = h_0 - \eta_{oi}(h_0 - h_{kt})$$

4) The degree of dryness of steam at the outlet of the turbine is determined by pressure p_k and enthalpy h_k:

$$x_k = x(p_k, h_k)$$

5) The enthalpy at the outlet of the condenser is determined from the pressure in the condenser p_k and the degree of dryness is 0:

$$h_{k'} = h'(p_k)$$

6) Since the conditions indicate to neglect the operation of the pump, it means that the enthalpy of feed water at the inlet of the steam generator is:

$$h_{fw} = h_{k'}$$

7) The efficiency of the cycle is determined by the following formula:

$$\eta = \frac{h_0 - h_k}{h_0 - h_{k'}} = \frac{h_0 - h_k}{h_0 - h_{fw}}$$

<u>Methodical guidelines for individual homework assignment № 7.</u>

The tasks of this IHA are devoted to the calculation of the Rankine cycle on a saturated steam with separation and intermediate steam superheating. The calculation is made in the following order (all enthalpies are determined using the water and steam properties tables):

1) The main parameters of the cycle without overheating are defined similarly to the algorithm presented for the IHA 6.
2) The scheme and expansion process in the turbine for the 2nd task is shown in Fig. 2.

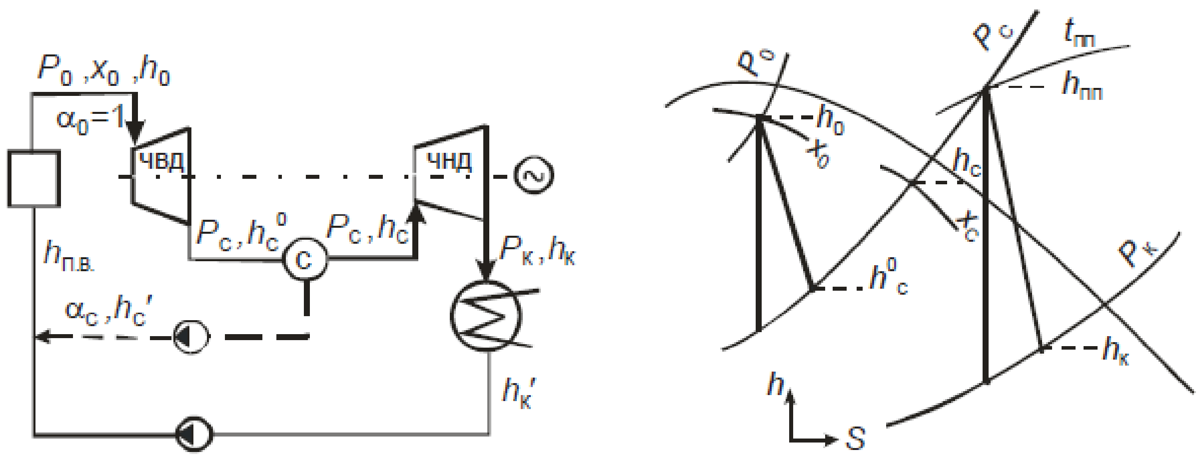


Fig.2 – Scheme and process of expansion in the turbine for the steam turbine unit with separation.

3) The separation pressure is selected according to the formula:

$$p_c = 0,4 p_0$$

4) The first stage of expansion in the turbine is calculated similarly to p.1-p.4 with pressure p_c instead of pressure p_k. In this way we define the values of h_c^0, x_c^0.
5) The values of the enthalpy at the outlet of the separator are determined from the separation pressure p_c and the degree of dryness $x_c = 1$.
6) Relative steam flow on separation is determined by the following formula:

$$\alpha_c = 1 - x_c^0$$

7) The enthalpy of the separated water is determined by the separation pressure p_c and the degree of dryness $x_c' = 0$:

$$h_c' = h\left(p_c, x_c'\right)$$

8) The enthalpy of steam at the outlet of the separator is determined by the separation pressure p_c and the degree of dryness $x_c = 1$:

$$h_c = h\left(p_c, x_c\right)$$

9) The second stage of expansion in the turbine is calculated similarly to p.1-p.4 with pressure p_c instead of pressure p_0. In this way we define the values of h_k, x_k.
8) The enthalpy at the outlet of the condenser p_k is determined from the pressure in the condenser and the degree of dryness equal to 0:

$$h_{k'} = h'\left(p_k\right)$$

10) The enthalpy of feed water is determined from the heat balance of the mixing point:

$$\alpha_c\left(h_c' - h_{fw}\right) = \left(1 - \alpha_c\right)\left(h_{fw} - h_{k'}\right)$$

11) The efficiency of such unit is determined by the formula:

$$\eta = \frac{\left(h_0 - h_c^0\right) + \left(h_c - h_k\right)}{h_0 - h_{fw}}$$

12) The scheme of the steam turbine unit with steam superheating for the 3rd task is shown in Fig. 3.

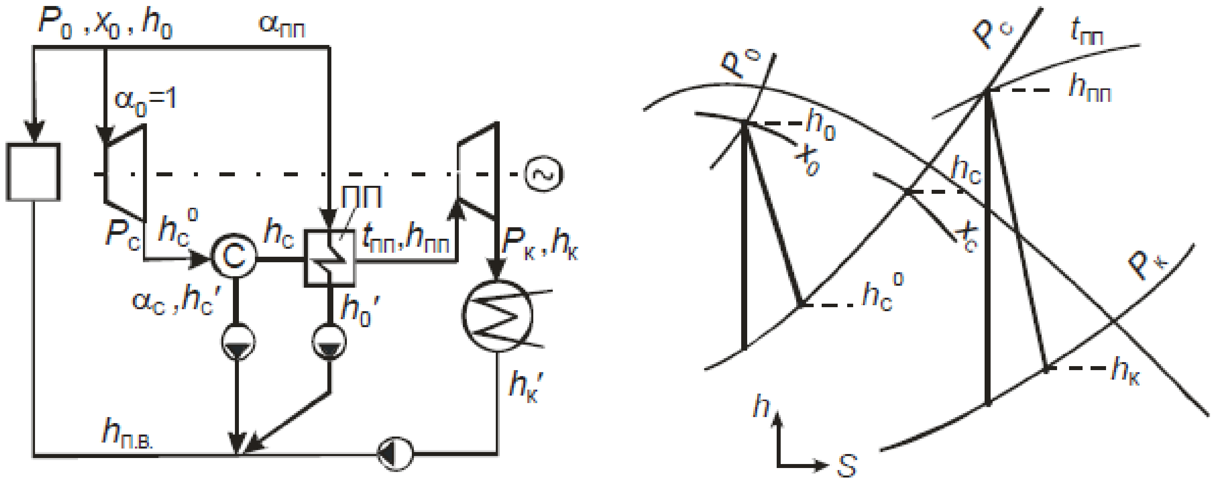


Fig.3 – Scheme and process of expansion in the turbine for the PTU with separation and superheating by steam.

13) The scheme is calculated similarly to the previous one with the following corrections:

a. The enthalpy and entropy of steam at the inlet to the second stage of the turbine will be determined by pressure p_c and temperature $t_{pp} = t_s(p_0) - 10$:

$$h_{pp} = h(p_c, t_{pp}) \text{ и } s_{pp} = s(p_c, t_{pp})$$

b. The steam flow rate on the superheater is determined from the heat balance equation of the superheater ($h_0' = h'(p_0)$ – the enthalpy of the steam condensate at the output of the superheater):

$$(1-\alpha_c)(h_{pp} - h_c) = \alpha_{pp}(h_0 - h_0')$$

c. The enthalpy of feed water is determined from the heat balance of the mixing point:

$$\alpha_c(h_c' - h_{fw}) + \alpha_{pp}(h_0' - h_{fw}) = (1-\alpha_c)(h_{fw} - h_{k'})$$

d. The efficiency of such unit is determined by the formula:

$$\eta = \frac{(h_0 - h_c^0) + (h_{pp} - h_k)}{(1+\alpha_{pp}) \cdot (h_0 - h_{fw})}$$

<u>Methodical guidelines for individual homework assignment № 8.</u>

The tasks of this IHA are devoted to the calculation of the Rankine cycle with regeneration. The calculation is made in the following order (all enthalpies are determined using the water and steam properties tables):

1) The basic parameters of the cycle are determined in a manner similar to the algorithm of the IHA 6.

2) The difference are following

   a. The pressure in the bleed is defined using temperature t_{fw} at the outlet on the heater, which is calculated from the formula given in the initial data:

$$p_b = p_s\left(t_{fw}\right)$$

   b. The enthalpy of steam at the point of bleed is determined by the following formula (here $h_{bt} = h\left(p_b, s_0\right)$):

$$h_b = h_0 - \eta_{oi}\left(h_0 - h_{bt}\right)$$

   c. The relative steam consumption α for bleed is determined from the heat balance equation of the regenerative heater:

$$\alpha\left(h_b - h_{fw}\right) = (1-\alpha)\left(h_{fw} - h_{k'}\right)$$

   e. The efficiency of such unit is determined by the formula:

$$\eta = \frac{\left(h_0 - h_b\right) + (1-\alpha)\left(h_b - h_k\right)}{h_0 - h_{fw}}$$

3) Task № 2 is solved similarly to the previous one by adding additional stages of regenerative heating.

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INDIVIDUAL HOMEWORK ASSIGNMENT № 3

on course «Thermodynamics»

Variant 5

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