ESF II project of the University of West Bohemia in Pilsen

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Energy Efficiency and Consumption Characteristics

Exercise 1 (KEE/TTE)

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Basic relationships

Temperature $t \ (°C)$

= state quantity expressing the thermal state of the substance (working medium)

Absolute (thermodynamic) temperature

$$T = T_0 + t \quad (K)$$

Absolute zero = 273,15 K

Energy $E \ (J)$

= ability of the substance to do work (state variable)

Heat transferred

= energy transferred between the thermodynamic system and the environment (not a state variable)

$$Q = m \cdot c \cdot \Delta t \ (J) \quad resp. \quad Q = m \cdot c \cdot \Delta T \ (J)$$

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Basic relationships

Specific heat capacity $c \ (J \cdot kg^{-1} \cdot K^{-1})$

= specific value of the heat

- **The amount of heat needed to heat 1 kg of substance by 1 degree.**
- It depends on how the substance are heated
  - – heating at constant pressure
  - - heating at constant volume

Work

= force acting in the direction of travel on a unit of length

$$W = F \cdot s \quad (J)$$

Power

= work per unit time

$$P = \frac{W}{t} = F \cdot v \ (J \cdot s^{-1} = W)$$

Basic relationships

$$P = \frac{W}{t} \; (J \cdot s^{-1} = W)$$

$Ws = J$ ⇒ $?\,kWh = ?\,kJ$ ⇒ $1\,h = 3\,600\,s$

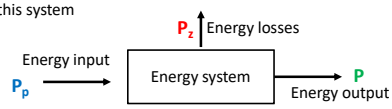
$$1\,kWh = 860\,kcal = 3\,600\,kJ$$

$$1\,cal = 4,186\,J$$

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Energy efficiency

- Energy **cannot be produced or destroyed**, but **only transformed** into another form of energy
- **The energy entering** the into energy system **must be equal to** the **energy leaving** this system



Energy input = Energy output + Energy losses

Energy = the ability of matter to work
W = F . s (N . m = J)

- **Energy efficiency** = ratio between energy input and output

$$\eta = \frac{P}{P_p} \; (-, \%)$$

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Energy efficiency

Efficiency can also be expressed in terms of losses:

Energy input — Energy losses

$$\eta = \frac{P_P - P_Z}{P_P} = 1 - \frac{P_z}{P_P}$$

Energy efficiency for a specific period of time (T):

$$\eta = \frac{\int_0^T P dT}{\int_0^T P_p dT} = \frac{W}{W_p}$$

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Example 1

The electric motor with a power input of **15 kW** lifts the elevator car weighing **450 kg** with a steady movement at a speed of **3 m / s**. What is the energy efficiency of this electric motor?

Solution

Given values

- Electric motor input..... P_p = **15 kW**
- Elevator weight..... **m = 450 kg**
- Stroke speed..... **v = 3 m/s**

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Example 2

What must be the power input of the heating system if we want to heat **3 kg** of water in half an hour to the boiling point? The energy conversion efficiency is **50 %** and the initial water temperature is **20 ° C**. The specific heat of water is **c = 4,186 kJ.kg^{-1}.K^{-1}**.

Solution

- The amount of work that must be supplied to the water $W = \eta \cdot P_p \cdot t$
- Energy needed to heat the water $W = Q = m \cdot c \cdot \Delta t$

$$P_p = \frac{m \cdot c \cdot \Delta t}{\eta \cdot t} \Rightarrow P_p = \frac{3 \cdot 4{,}186 \cdot (100 - 20)}{0{,}5 \cdot 30 \cdot 60} = \mathbf{1{,}116\ kW}$$

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Example 3

By braking the motor with power **P = 25 kW**, **all the energy** from the motor was converted **into heat**. Calculate the **required amount of cooling water** in **1 minute** if the temperature of the supply water **t_1 = 15 °C** and the temperature of the discharged water **t_2 = 45 °C**.

Solution

Given values

- Engine power ..... P = 25 kW
- Time ..... t = 1 min
- Supply water temperature..... t_1 = 15 °C
- Discharge water temperature..... t_2 = 45 °C

$$Q = m \cdot c \cdot \Delta t$$
$$W = \eta \cdot P_p \cdot t$$
$$W = Q$$

$$m = \frac{\eta \cdot P_p \cdot t}{c \cdot \Delta t} = \frac{P \cdot t}{c \cdot \Delta t} = \frac{25\,000 \cdot 60}{4\,186 \cdot 30} = 11{,}94\ kg$$

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Summary

1. All forms of energy can be transformed into heat completely, but conversely not.
2. Heat can only be removed from the systems based on the temperature difference.
3. The transformation of heat into another energy form can also be performed only on the basis of the temperature difference.
4. Any other energy transformations that are not performed by heat transformation have small losses and can theoretically be considered 100%.

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Consumption characteristics

= dependence of the output power on the input power P_p = **f (P)**, for thermal power plants **Q = f (P)**

The power plant unit operates in the technical range **from P_{min} to P_{max}**

Graphically

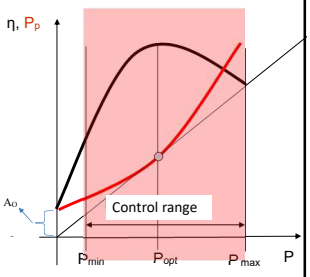
- approximation of measured (observed) heat consumption (power input) - **polynomial of the 2nd degree**

$$P_P = A_0 + B.P + C.P^2$$

No-load losses

= approximation constants

- ***linearization*** *of quadratic function*



The consumption characteristic can be determined only by measuring, when we change the power consumption and determine the power input to the system.

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Consumption characteristics

Specific heat consumption

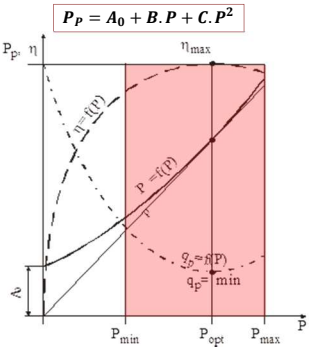
= dependence of the specific heat consumption on the output power

$$q = \frac{Q}{P}$$

Optimal performance and energy efficiency

(see graph)

$$P_P = A_0 + B.P + C.P^2$$



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Consumption characteristics

Hospodárné rozdělování zatížení

- celkové **náklady minimální**
- **účinnost nejvyšší** – extrém funkce
  (tj derivace podle výkonu = 0)

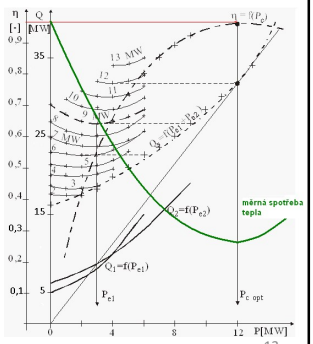
$$\eta = 3600\frac{P}{P_p} = \frac{3600}{q_p}$$

$$\frac{d\eta}{dP} = 0 \Rightarrow \frac{P_p \cdot dP - P \cdot dP_p}{P_p^2} = 0$$

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Výpočet směrnice přímky jdoucí z počátku, která se dotýká celkové součtové charakteristiky v bodě **ekonomického výkonu $P_{c\ opt}$** (viz přednáška)

$$P_{c\ opt} = \sqrt{\frac{A_0}{C}}$$



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Example 4

When measuring at the power plant unit, the following points of consumption characteristics were measured (see table). Determine the square shape of this consumption characteristic.

i		1	2	3	4	5
P_p [t_{mp}]	x_i	80	100	150	180	200
P_e [MW]	y_i	38,1	42,7	54,5	64,4	71,8

Solution

Quadratic regression curve of the measured values:

$$y = a + bx + cx^2$$

The least squares condition is:

$$\sum_{i=1}^{n}\left(y_i - a - bx_i - cx_i^2\right)^2 \overset{!}{=} \min$$

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Example 4

$$y = a + bx + cx^2 \quad \Rightarrow \quad \sum_{i=1}^{n}\left(y_i - a - bx_i - cx_i^2\right)^2 \overset{!}{=} \min$$

We derive this function according to the parameters a, b, c (derivation of this function). Then we set the results = 0 and in the next step we get three linear equations:

$$s_0 a + s_1 b + s_2 c = \sum_{i=1}^{n} y_i$$

$$s_1 a + s_2 b + s_3 c = \sum_{i=1}^{n} x_i y_i$$

$$s_2 a + s_3 b + s_4 c = \sum_{i=1}^{n} x_i^2 y_i$$

kde: $s_m = \sum_{i=1}^{n} x_i^m \qquad m = 0 \div n - 1$

From this system of equations we can calculate the coefficients a, b, c:

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Example 4

$$a = \frac{(s_2 s_4 - s_3^2)\sum_{i=1}^{n} y_i + (s_2 s_3 - s_1 s_4)\sum_{i=1}^{n} x_i y_i + (s_1 s_3 - s_2^2)\sum_{i=1}^{n} x_i^2 y_i}{\Delta}$$

$$b = \frac{(s_2 s_3 - s_1 s_4)\sum_{i=1}^{n} y_i + (s_0 s_4 - s_2^2)\sum_{i=1}^{n} x_i y_i + (s_1 s_2 - s_0 s_3)\sum_{i=1}^{n} x_i^2 y_i}{\Delta}$$

$$c = \frac{(s_1 s_3 - s_2^2)\sum_{i=1}^{n} y_i + (s_1 s_2 - s_0 s_3)\sum_{i=1}^{n} x_i y_i + (s_0 s_2 - s_1^2)\sum_{i=1}^{n} x_i^2 y_i}{\Delta}$$

kde: $\Delta = s_0(s_2 s_4 - s_3^2) + s_1(s_2 s_3 - s_1 s_4) + s_2(s_1 s_3 - s_2^2)$

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Example 4

i		1	2	3	4	5
P_p [t_{mp}]	x_i	80	100	150	180	200
P_e [MW]	y_i	38,1	42,7	54,5	64,4	71,8

In the given example, the number of measured values is n = 5, so:

$\sum_{i=1}^{n} y_i = 271,5$ $\qquad$ $\sum_{i=1}^{n} x_i y_i = 79\,875$

$\sum_{i=1}^{n} x_i^2 y_i = 6\,855\,267$ $\qquad$ $s_0 = 5$

$s_1 = \sum_{i=1}^{n} x_i^1 = 710$ $\qquad$ $s_2 = \sum_{i=1}^{n} x_i^2 = 143\,700$

$s_3 = \sum_{i=1}^{n} x_i^3 = 18\,718\,991$ $\qquad$ $s_4 = \sum_{i=1}^{n} x_i^4 = 3,297.10^9$

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Example 4

$$\Delta = s_0(s_2 s_4 - s_3^2) + s_1(s_2 s_3 - s_1 s_4) + s_2(s_1 s_3 - s_2^2)$$

$$\Delta = -1,92867 \cdot 10^{14}$$

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$$a = \frac{(s_2 s_4 - s_3^2)\sum_{i=1}^{n} y_i + (s_2 s_3 - s_1 s_4)\sum_{i=1}^{n} x_i y_i + (s_1 s_3 - s_2^2)\sum_{i=1}^{n} x_i^2 y_i}{\Delta}$$

$$b = \frac{(s_2 s_3 - s_1 s_4)\sum_{i=1}^{n} y_i + (s_0 s_4 - s_2^2)\sum_{i=1}^{n} x_i y_i + (s_1 s_2 - s_0 s_3)\sum_{i=1}^{n} x_i^2 y_i}{\Delta}$$

$$c = \frac{(s_1 s_3 - s_2^2)\sum_{i=1}^{n} y_i + (s_1 s_2 - s_0 s_3)\sum_{i=1}^{n} x_i y_i + (s_0 s_2 - s_1^2)\sum_{i=1}^{n} x_i^2 y_i}{\Delta}$$

$$a = \frac{3,34975.10^{16} + 1,41455.10^{16} - 4,987576.10^{16}}{-1,922867.10^{14}} = 11,61$$

$$b = \frac{2,47671.10^{13} - 3,326546.10^{14} + 5,78039.10^{13}}{-1,922867.10^{14}} = 1,29$$

$$c = \frac{-1,99816.10^{12} + 6,743074.10^{11} + 1,46977.10^{12}}{-1,922867.10^{14}} = -7,566.10^{-4}$$

Example 4

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$$P_P = A_0 + B.P + C.P^2$$

The resulting quadratic consumption characteristic is:

$$P_p = 11,61 + 1,29P_e - 7,566.10^{-4} P_e^2$$

Used and recommended literature

- Dvorsky, Emil; Hejtmankova, Pavla; Kocmich, Martin. Elektrarny : zaklady vyroby elektricke energie : priklady. 1. vyd. Pilsen : UWB, 1994. ISBN 80-7082-133-7.
- Dvorsky, Emil; Hejtmankova, Pavla. Elektrarny : zvysovani ucinnosti premen energie v tepelnych elektrarnach : priklady. 1. vyd. Pilsen : UWB, 1999. ISBN 80-7082-523-5.
- …… and other literature listed in the course syllabus on the website Portal of the UWB in Pilsen

Next exercise

Thermal cycles

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