Researcher Links UK-Russia Workshop

Scientific and Technical Grounds of Future Low-Carbon Propulsion

19th - 22nd November 2018, Northumbria University at Newcastle, UK

Reducing heat waste from high temperature devise to the environment

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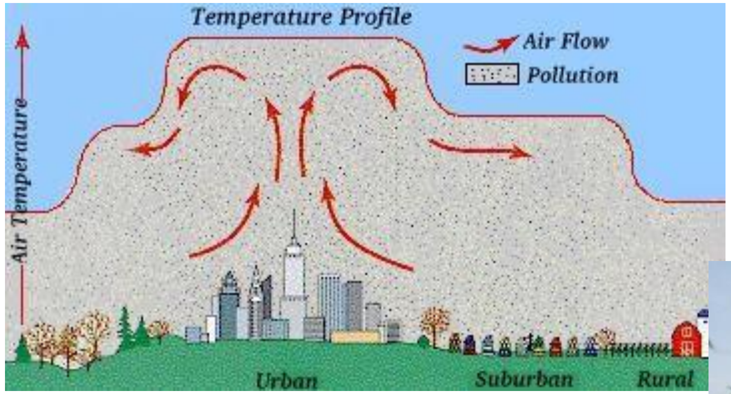
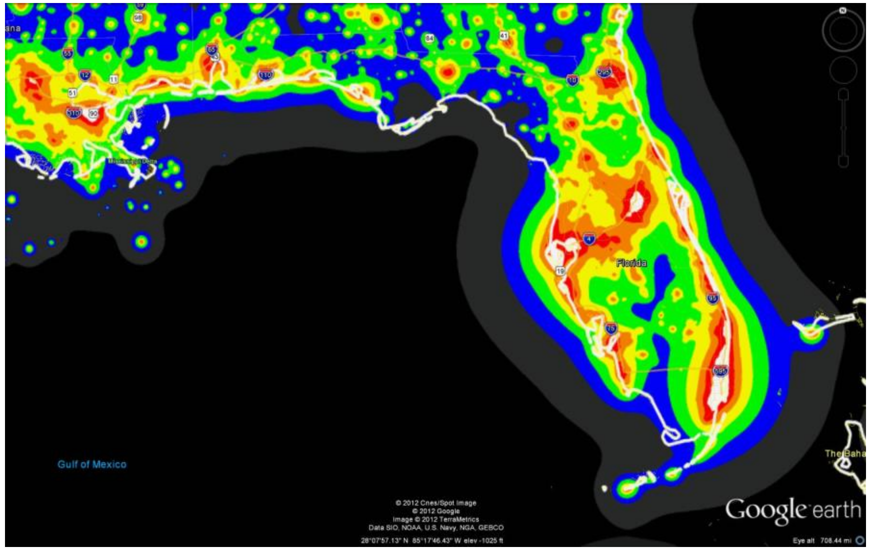
THERMAL POLLUTION





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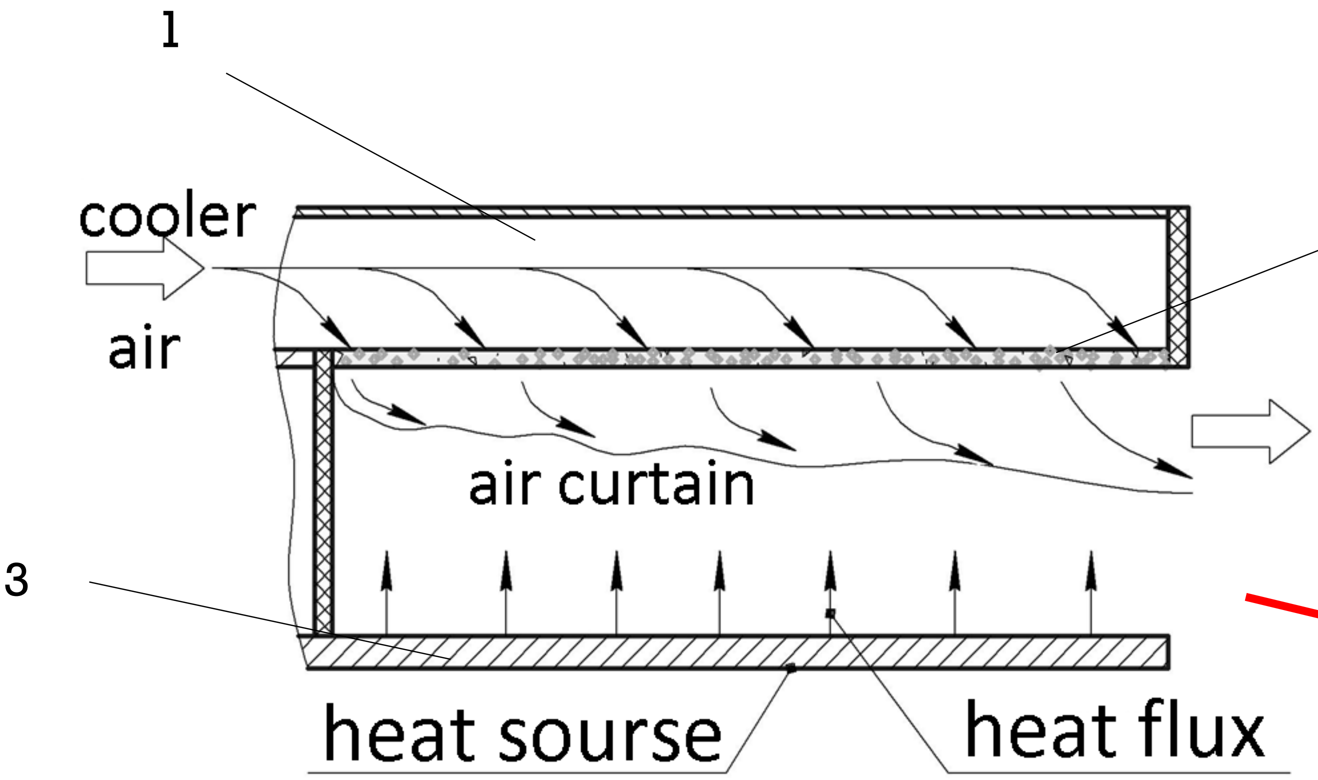
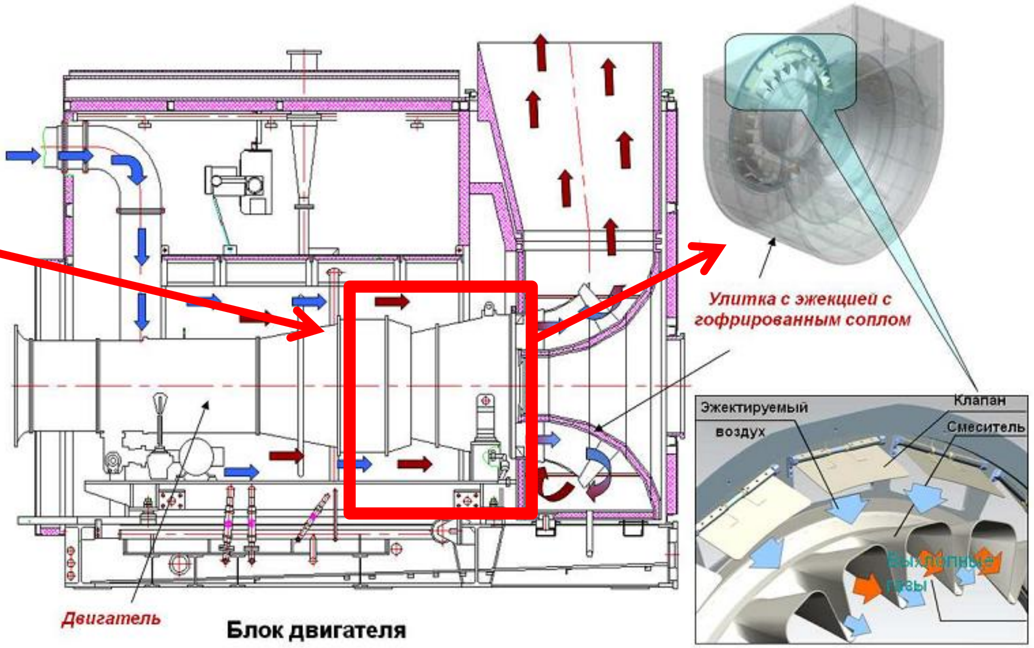
PROPOSED METHOD OF THERMAL PROTECTION

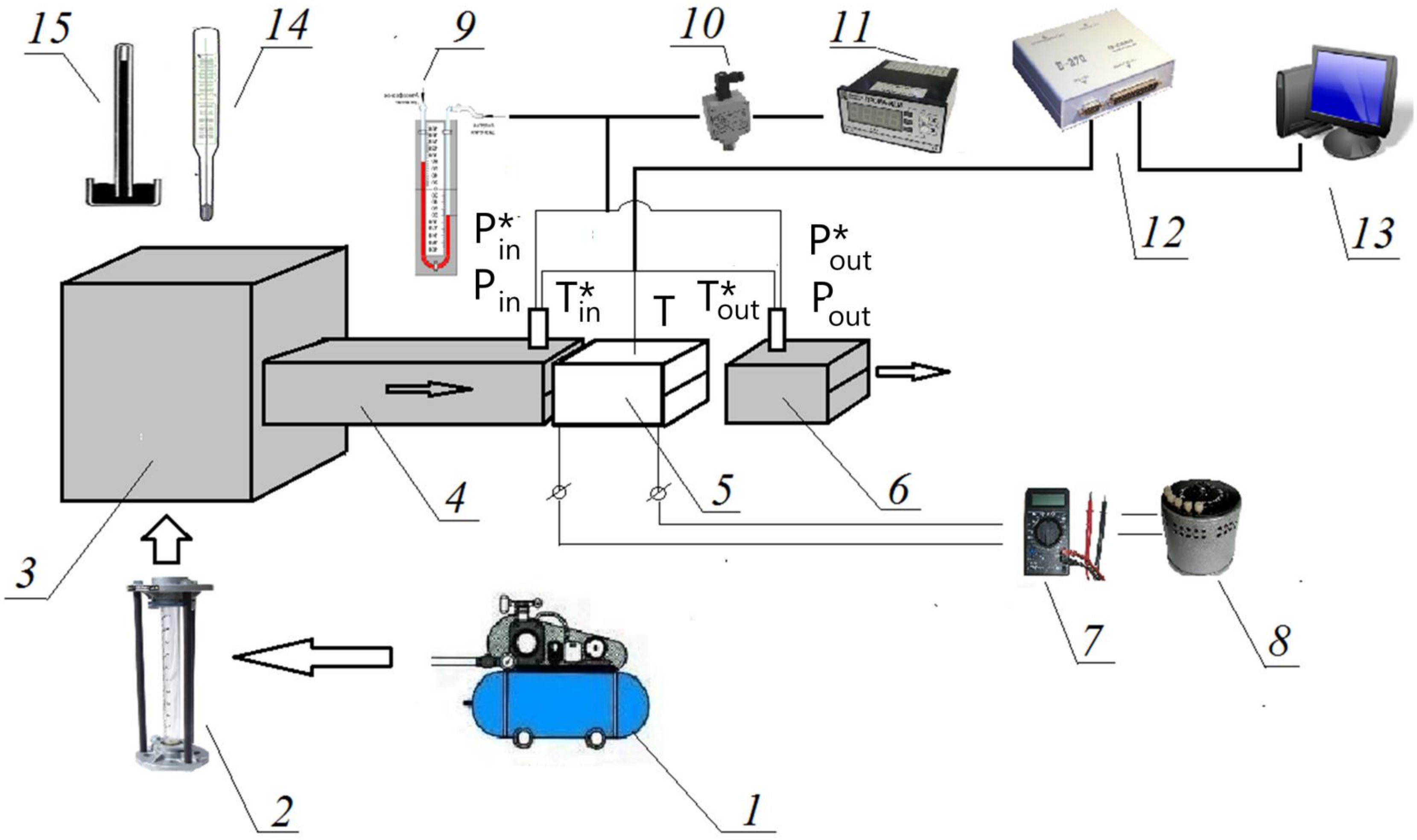


1 – "cold" zone; 2 – screen; 3 – "hot" zone;



Injection of gas turbine box (KMPO)

DESCRIPTION OF EXPERIMENTAL SETUP

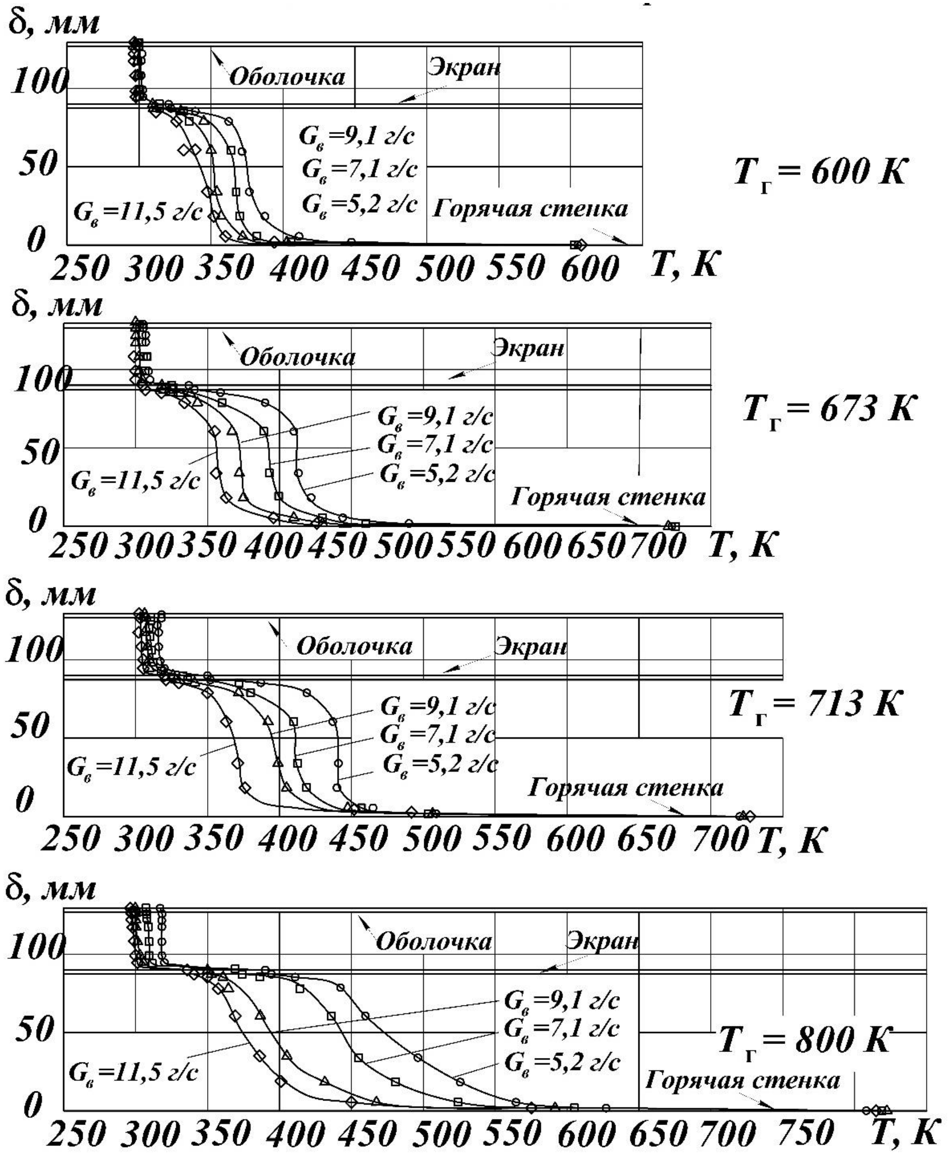


Consist of experimental setup

1 – compressor;
2 – flowmeter;
3 – air receiver tank;
4 – inlet channel;
5 – experimental setup;
6 – outlet channel;
7 – multimeter;
8 – autotransformer;
9 – manometer;
10 – pressure sensor;
11 – digital indicator of pressure;
12 – analog-digital converter;
13 – computer;
14 – thermometer;
15 – barometer.

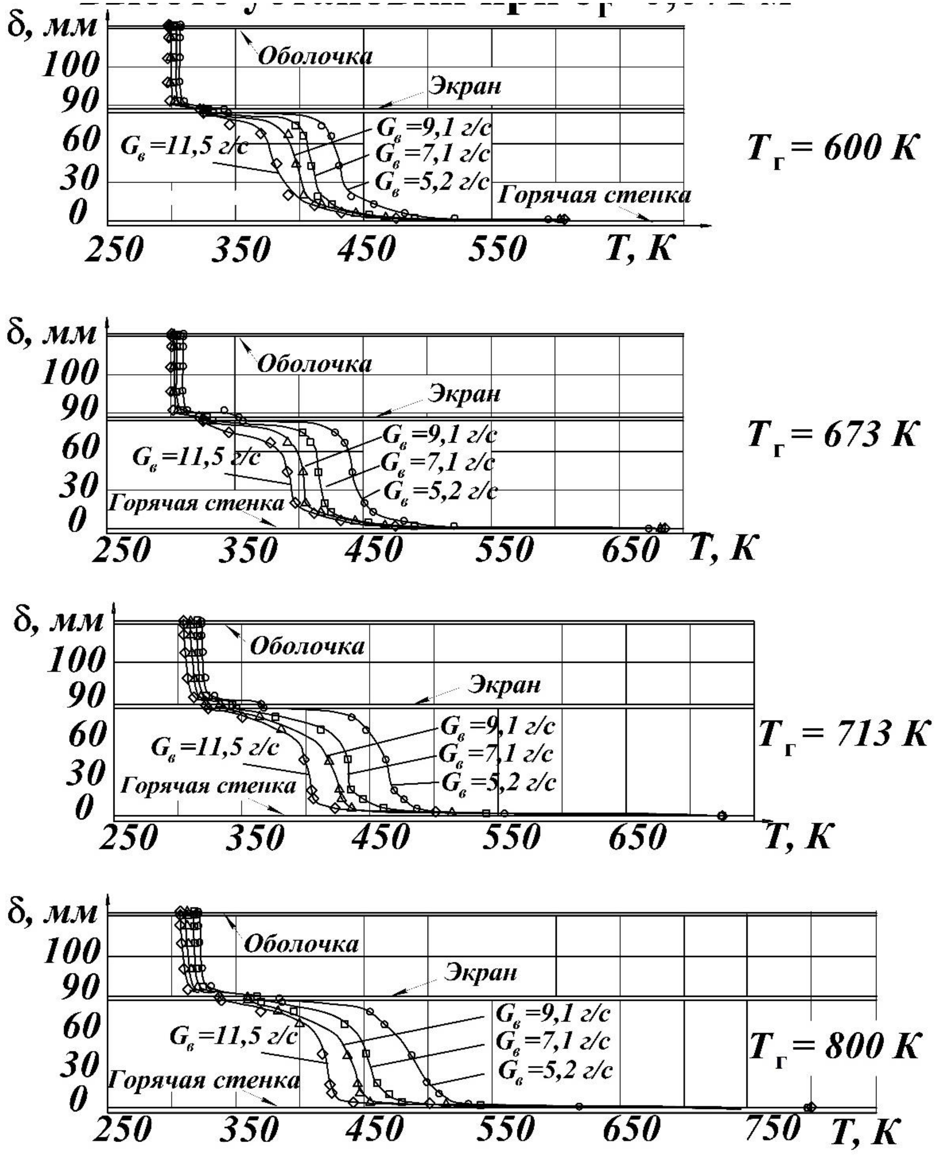
TEMPERATURE MEASUREMENT RESULTS

“Hot” gap size = 0,95 mm



◇ – $G_в$=11,5 г/с △ – $G_в$=9,1 г/с □ – $G_в$=7,1 г/с ○ – $G_в$=5,2 г/с

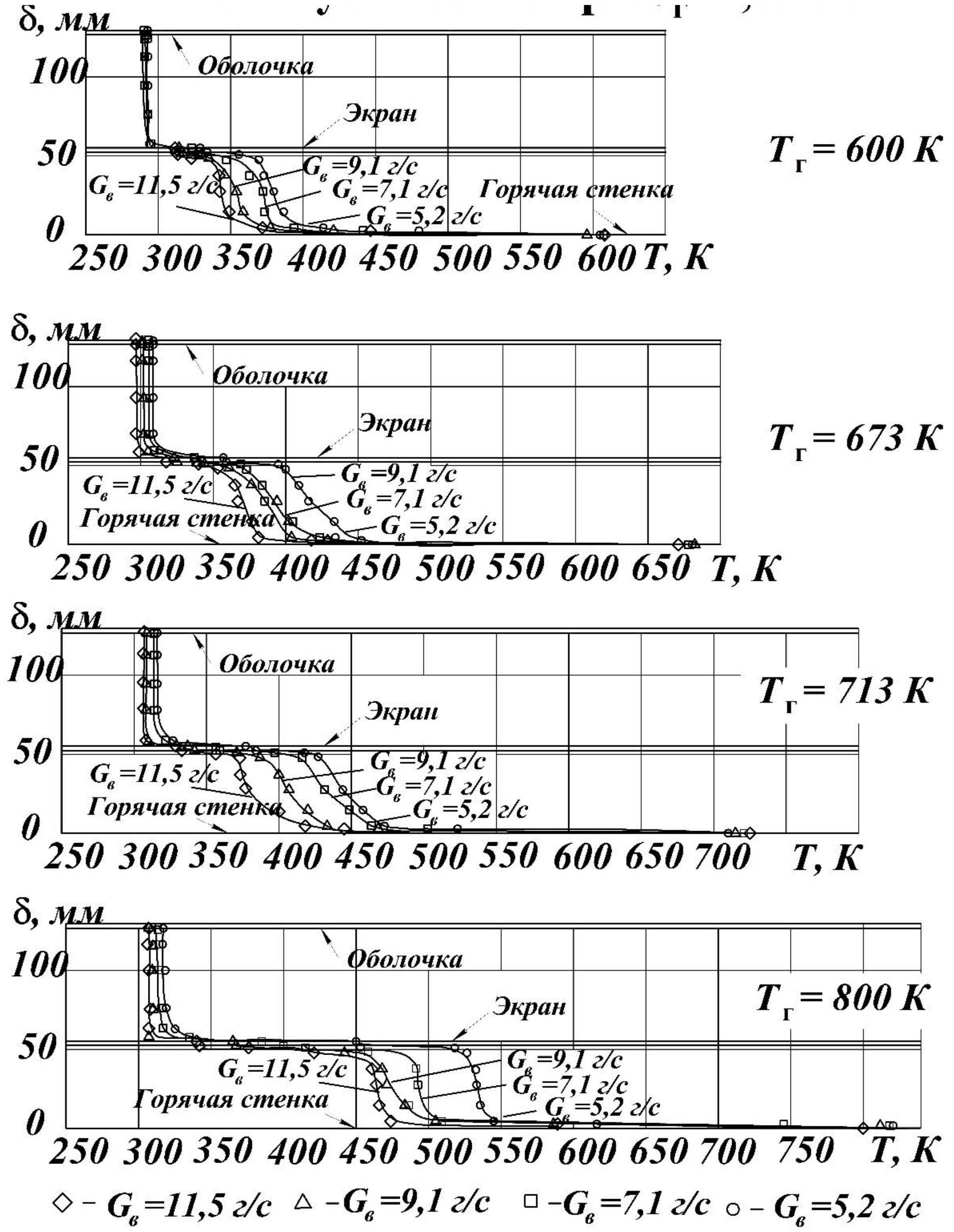
“Hot” gap size = 0,71 mm



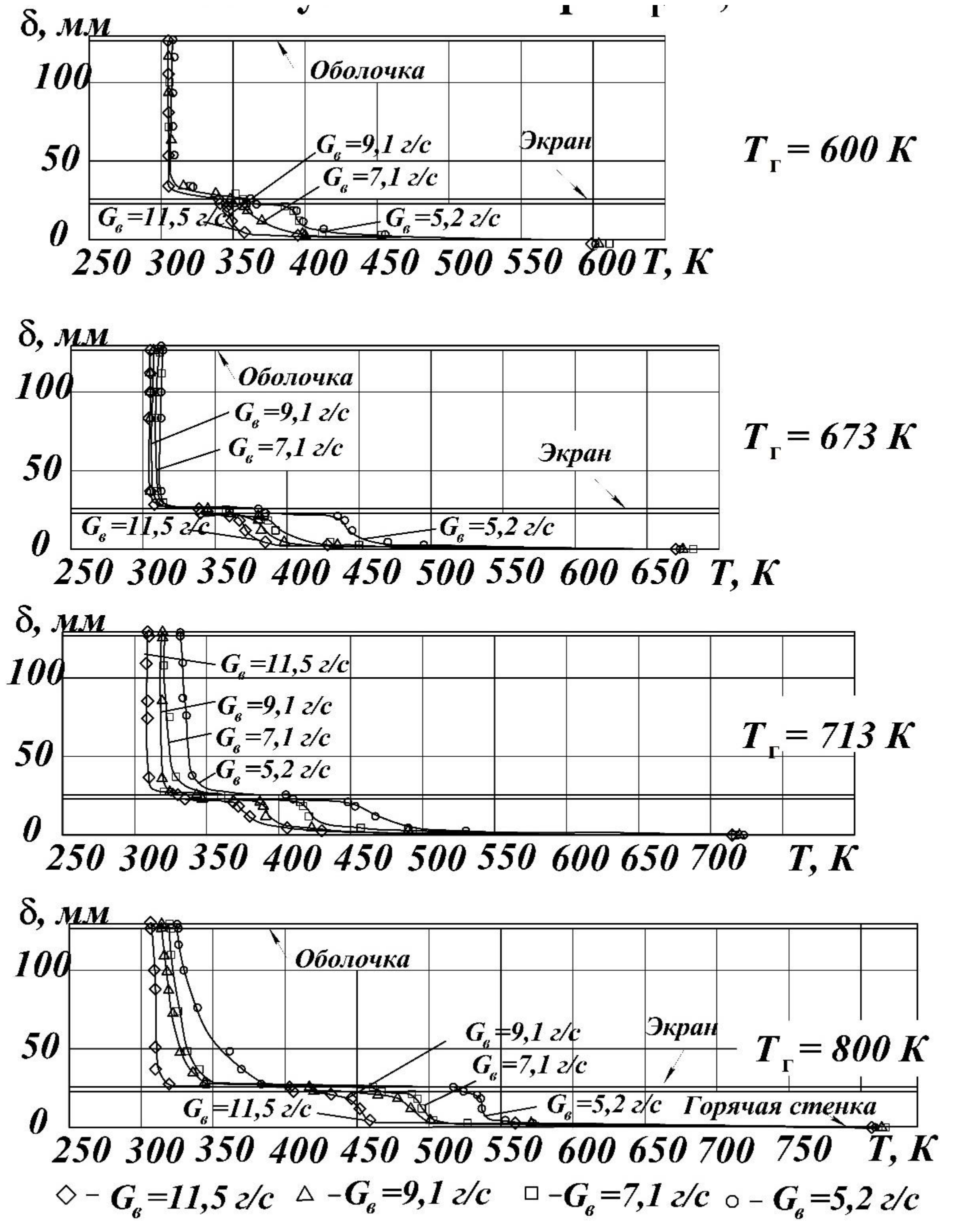
◇ – $G_в$=11,5 г/с △ – $G_в$=9,1 г/с □ – $G_в$=7,1 г/с ○ – $G_в$=5,2 г/с

TEMPERATURE MEASUREMENT RESULTS

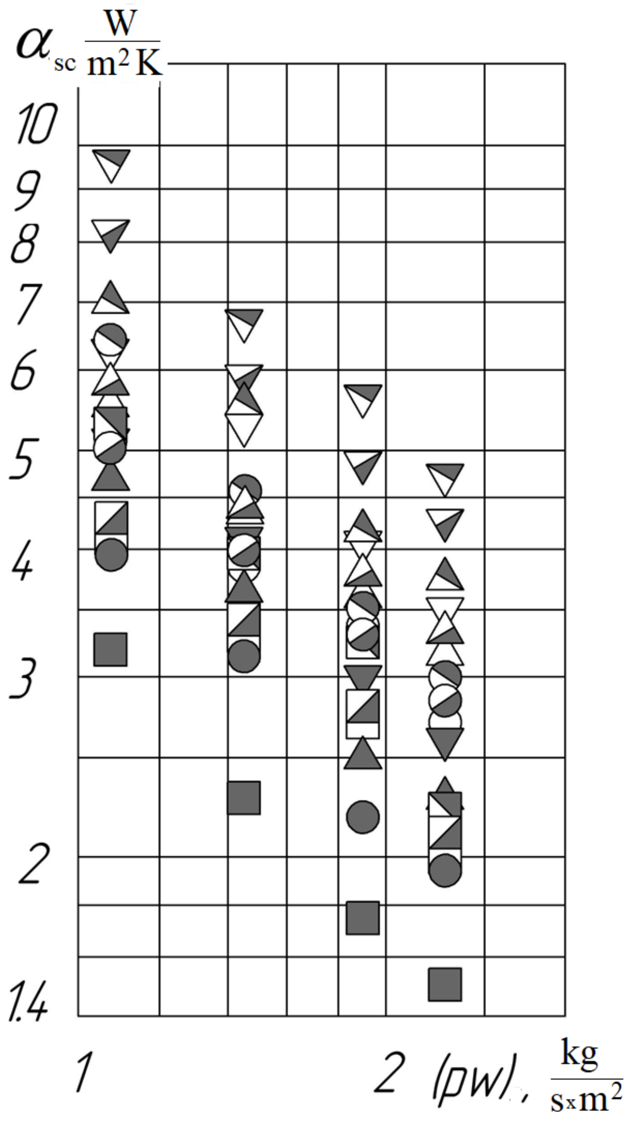
"Hot" gap size = 0,51 mm



"Hot" gap size = 0,25 mm



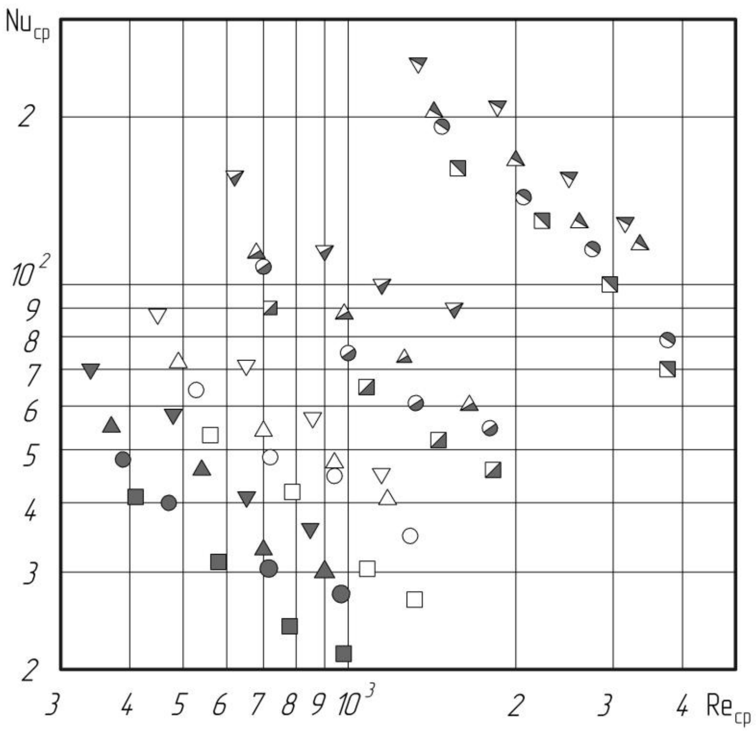
THE DEPENDENCE OF THE COEFFICIENTS OF HEAT TRANSFER TO THE SCREEN FROM THE MASS AIR FLOW



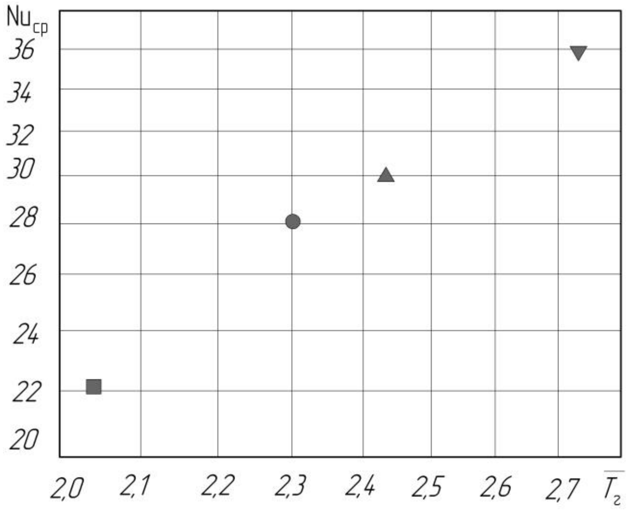
□ - T_g – 600 K ○ - T_g – 673 K; Δ - T_g – 713 K; ∇ - T_g – 800 K;

● - δ_g = 0,095 m; ○ - δ_g = 0,072 m; ◕ = 0,052 m; ◔ = 0,025 m

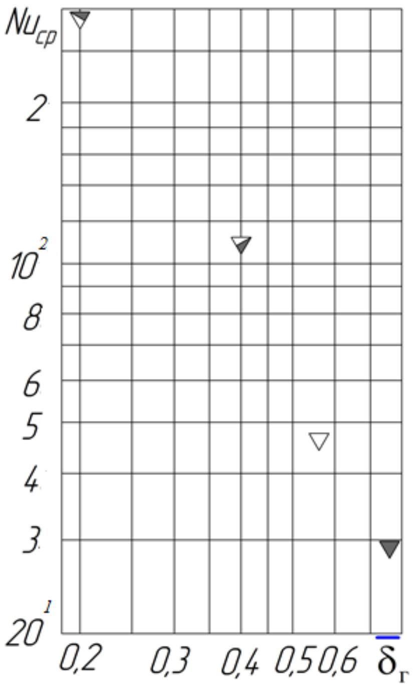
THE EFFECT OF TEMPERATURE AND CLEARANCE ON THE NUSSELT NUMBER



Dependence of Nusselt averages on Reynolds averages



The nature of the influence of the relative temperature at a constant gap



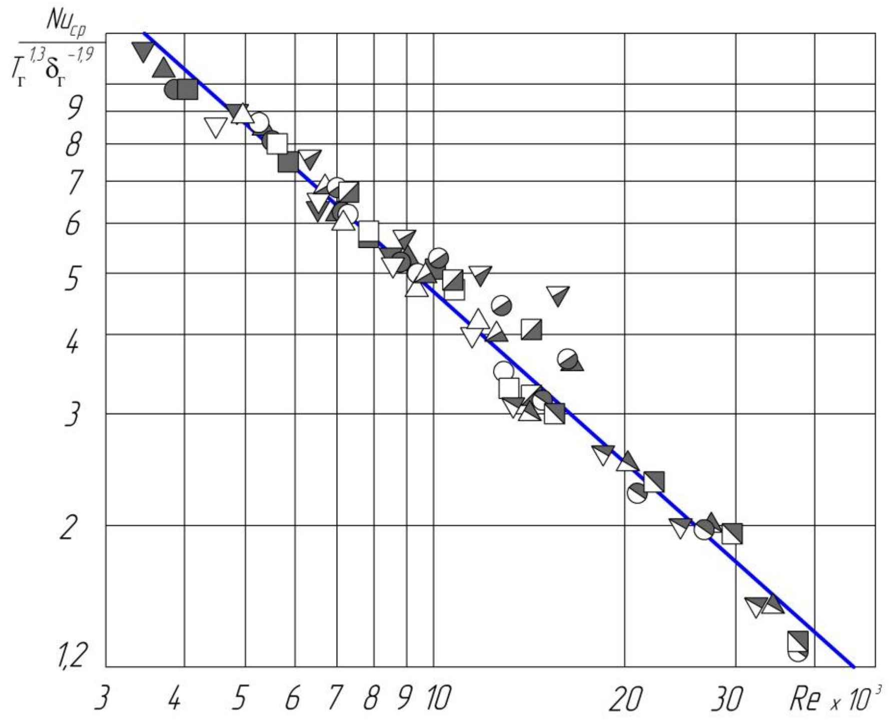
The nature of the influence of the relative temperature at a constant gap

$$Re_{av} = \frac{(\rho w) \cdot d_{eq}}{\mu}$$

$$Nu_{av} = \frac{\alpha \cdot d_{eq}}{\lambda}$$

□ - $\overline{T}_g$ – 2,0 ○ - $\overline{T}_g$ – 2,3; Δ - $\overline{T}_g$ – 2,4; ∇ - $\overline{T}_g$ – 2,73; $\overline{T} = T_г / T_{окр}$

● - $\overline{\delta}_g$ = 0,75; ○ - $\overline{\delta}_g$ = 0,56 ; ◕ = 0,4; ◔ = 0,2 $\overline{\delta} = \delta_г / \delta$

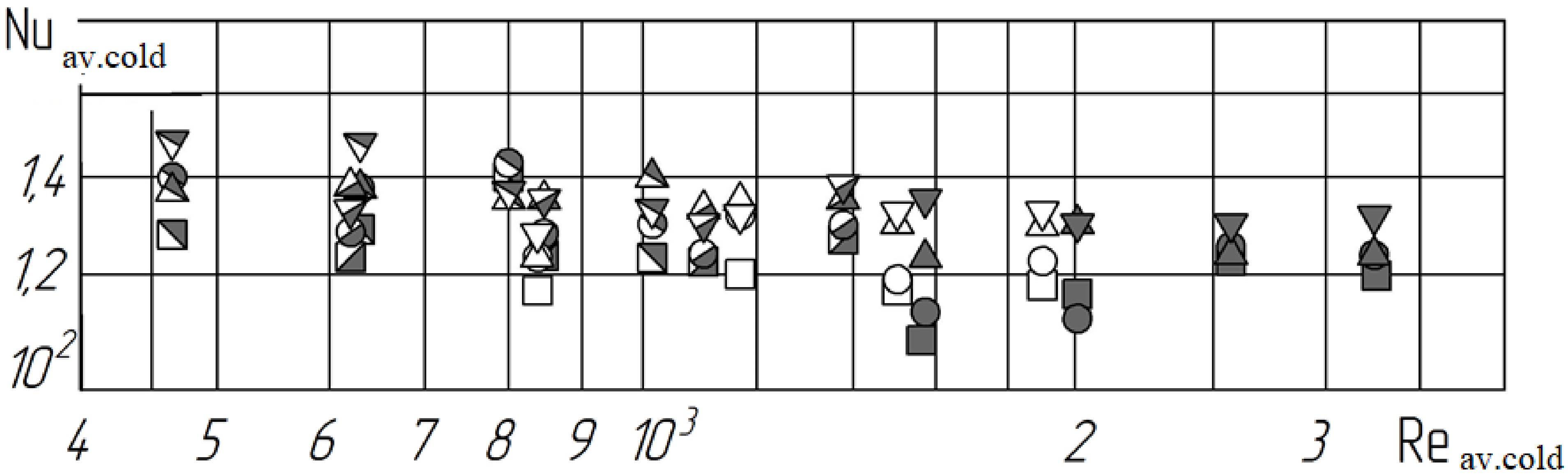


Experimental result of thermal transfer

As a result of the generalization, an empirical relationship was obtained for determining the heat transfer to the screen, taking into account the influence of the flow rate of the cooler, the relative gap and the temperature factor in the range of Reynolds numbers = 300 - 4000 :

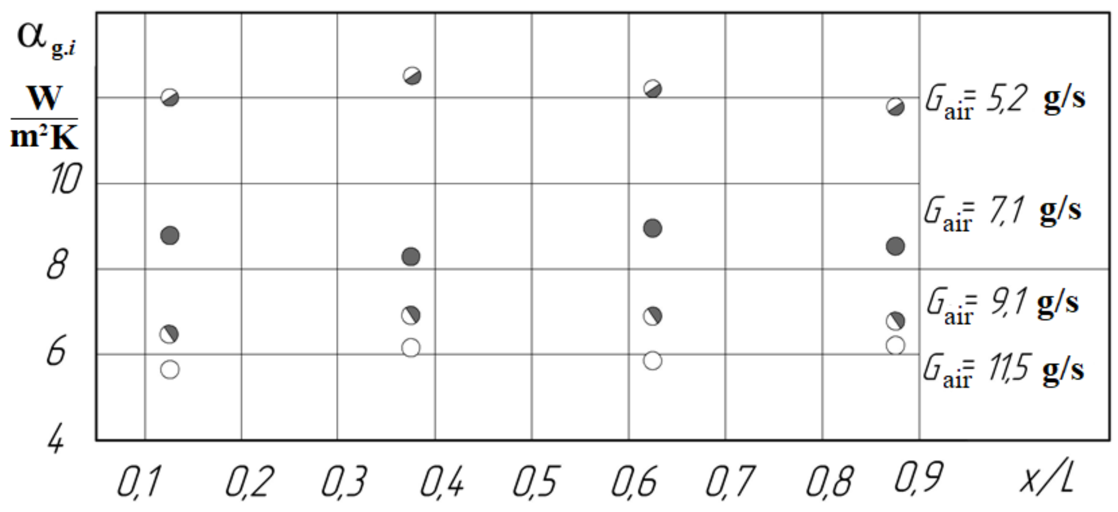
$$Nu_{av} = 2,3 \cdot 10^3 \, Re_{av}^{-0,9} \, \bar{T}_g^{1,3} \bar{\delta}_g^{-1,9}$$

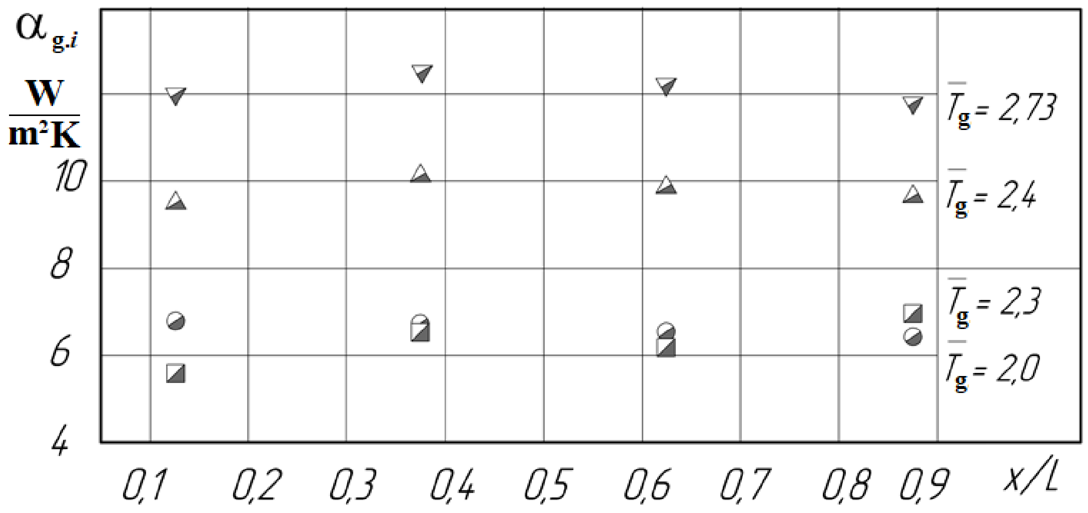
THE RESULTS OF EXPERIMENTS ON HEAT TRANSFER TO THE AIR IN THE "COLD" GAP



The dependence of the average Nusselt numbers on the average Reynolds numbers in the "cold" gap

The results of experiments on local values of heat transfer coefficients along the length of the working section for the minimum gap $\overline{\delta}_g = 0{,}2$





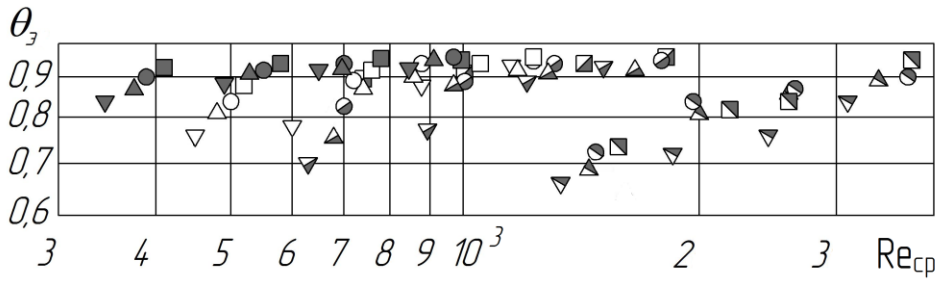
The results of the experiments of local values of heat transfer coefficients along the length of the plot

a) $T_g = 800$ K □ - $\overline{T}_g$ – 2,0 ○ - $\overline{T}_g$ – 2,3; Δ - $\overline{T}_g$ – 2,4; ∇ - $\overline{T}_g$ – 2,73;

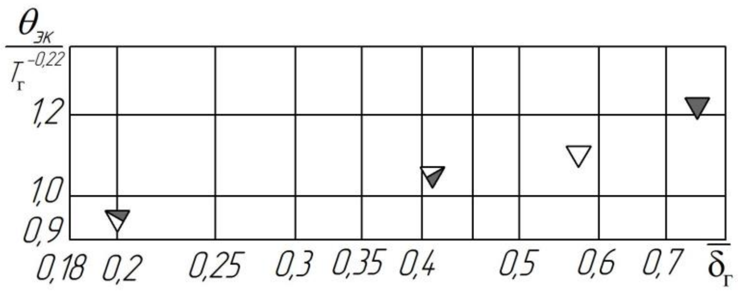
◕ - G_{air} = 5,2 g/s; ● - G_{air} = 7,1 g/s; ◑ - G_{air} = 9,1 g/s; ○ - G_{air} = 11,5 g/s ;

THE EFFECTIVENESS OF THERMAL PROTECTION OF THE SCREEN AND THE SHELL WHEN USING AN AIR CURTAIN

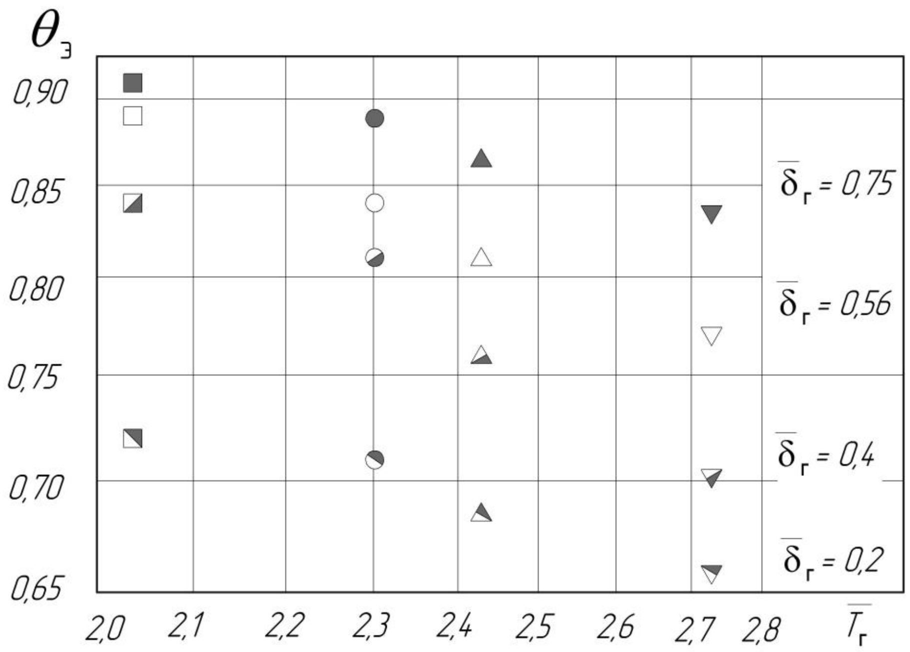
$$\theta_{э} = \frac{T_{г} - T_{э.вн}}{T_{г} - T_{в.вх}}$$



The results of experiments on the effectiveness of thermal protection of a porous screen



The nature of the impact of the gap on efficiency



The nature of the influence of temperature on the effectiveness of thermal protection

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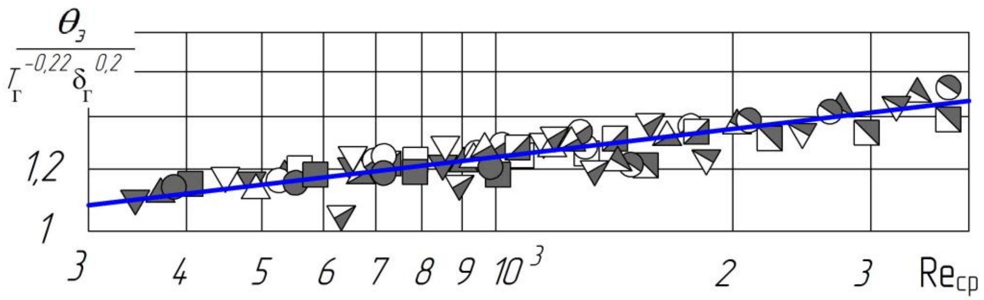
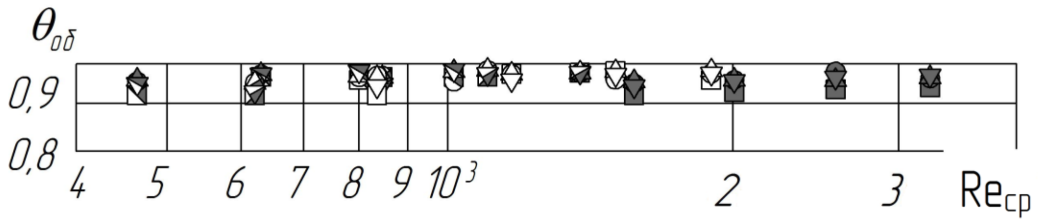
THE RESULTS OF EXPERIMENTS ON THE STUDY OF THE EFFECTIVENESS OF THERMAL PROTECTION SCREEN AND SHELL



Generalized results of experiments on the effectiveness of thermal protection of a porous screen

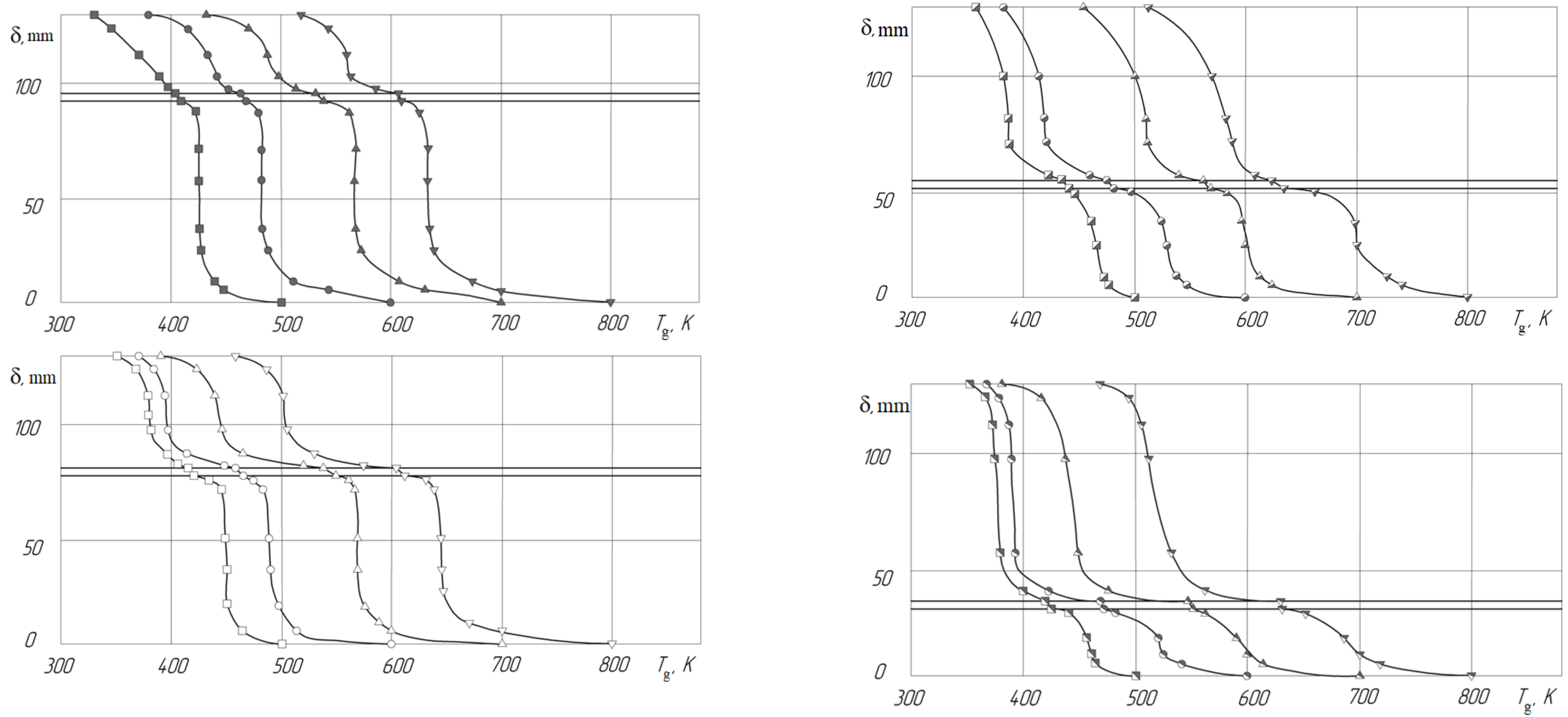


The results of experiments on the effectiveness of thermal protection of the outer shell

$$\theta_э = 0,6 \cdot \mathrm{Re}^{0,1}\left(\frac{T_г}{T_{в.вх}}\right)^{-0,2}\left(\frac{\delta_г}{\delta}\right)^{0,2}$$

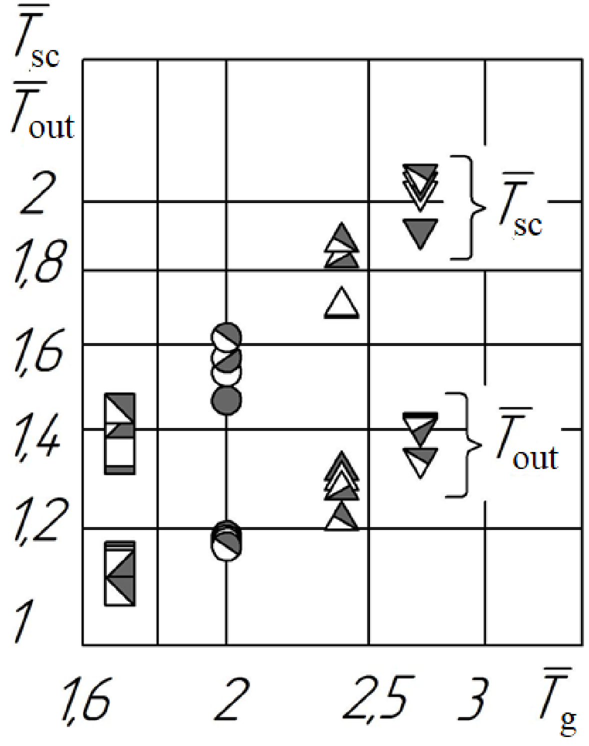
$$T_э = T_г - 0,6 \cdot \mathrm{Re}^{0,1}\left(\frac{T_г}{T_{в.вх}}\right)^{-0,2}\left(\frac{\delta_г}{\delta}\right)^{0,2}\left(T_г - T_{в.вх}\right)$$

RESEARCH OF NATURAL CONVECTION

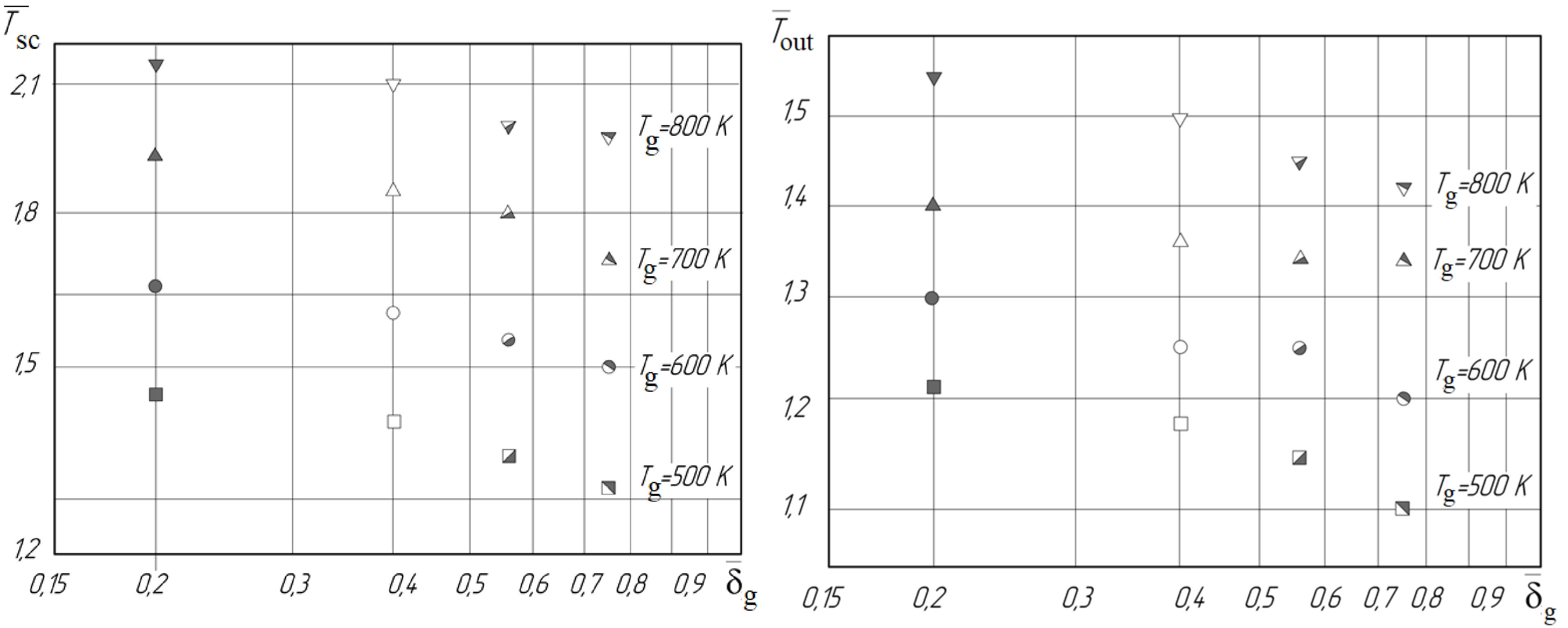


Temperature distribution over the setup height

□ - $\bar{T}_g$ – 2,0 ○ - $\bar{T}_g$ – 2,3; Δ - $\bar{T}_g$ – 2,4; ∇ - $\bar{T}_g$ – 2,73; ● - $\bar{\delta}_g$ = 0,75; ○ - $\bar{\delta}_g$ = 0,56 ; ◒ = 0,4; ◔ = 0,2

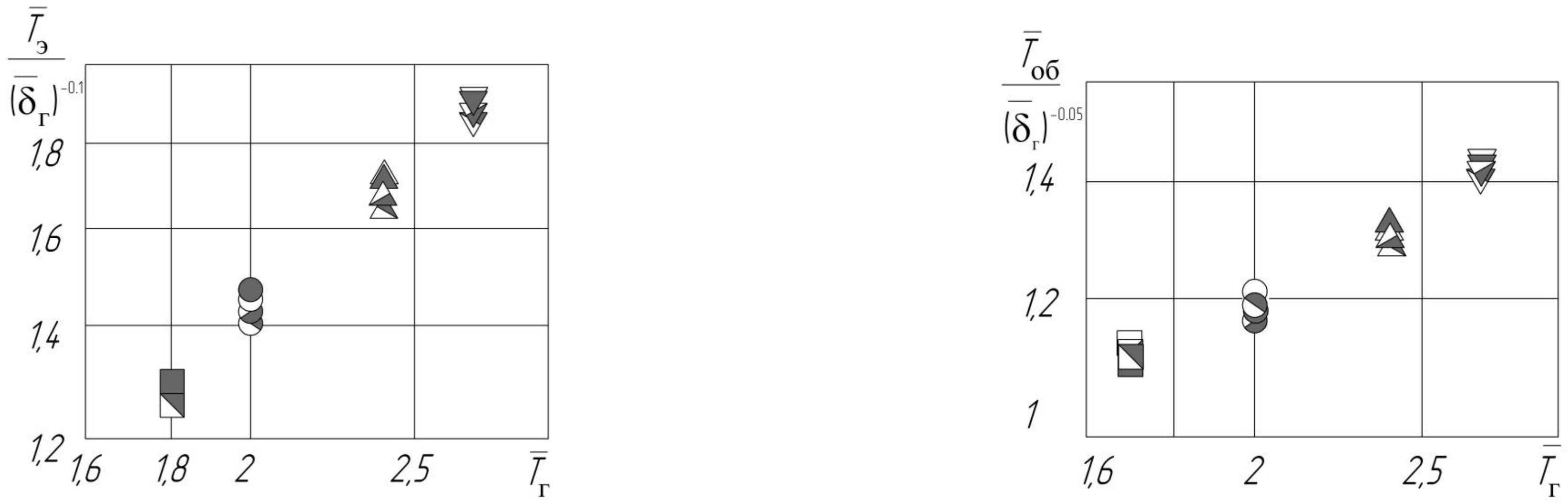


Results of temperature measurement of surfaces: hot source body, solid screen and outside shell



Dependencies of screen temperatures $\bar{T}_{sc}$ and outside shell $\bar{T}_{out}$ gap $\bar{\delta}_g$

□ - $\bar{T}_g$ – 2,0 ○ - $\bar{T}_g$ – 2,3; Δ - $\bar{T}_g$ – 2,4; ∇ - $\bar{T}_g$ – 2,73; ● - $\bar{\delta}_g$ = 0,75; ○ - $\bar{\delta}_g$ = 0,56 ; ◕ = 0,4; ◔ = 0,2



Обобщенный график распределения температур от горячей стенки к экрану (а) и к наружной оболочке (б):
□ - $\delta_г$ = 25 мм; × - $\delta_г$ = 45 мм; Δ - $\delta_г$ = 75 мм; о - $\delta_г$ = 95 мм, δ = 127 мм.

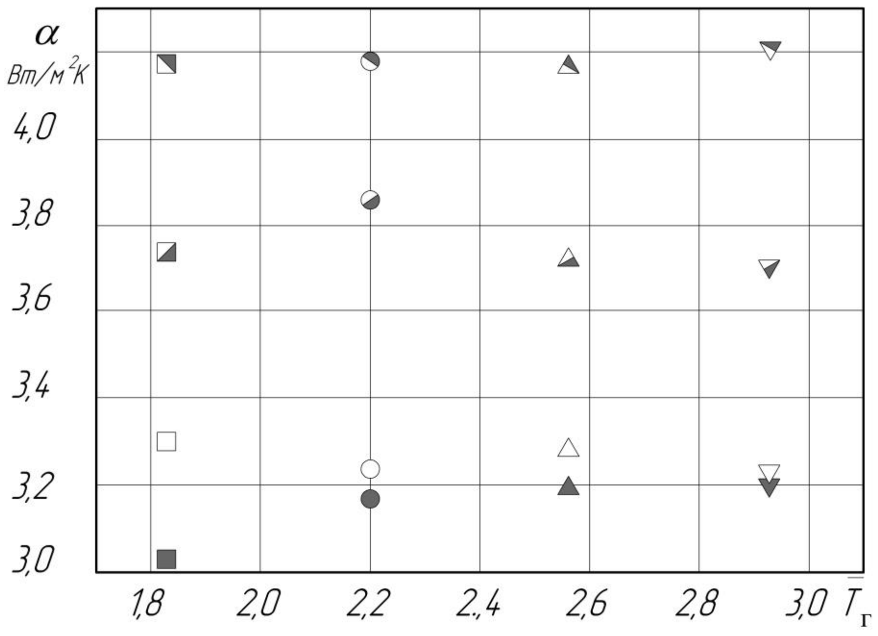
The obtained dependences for calculating the temperature of the screen and the shell in the range of variation of the gap $\bar{\delta} = \delta_г / \delta = 0{,}25 \div 0{,}75$

These equations allow to predict the temperature state of the screening system with free convection in the air gaps $T_g = 500 \div 800$ K

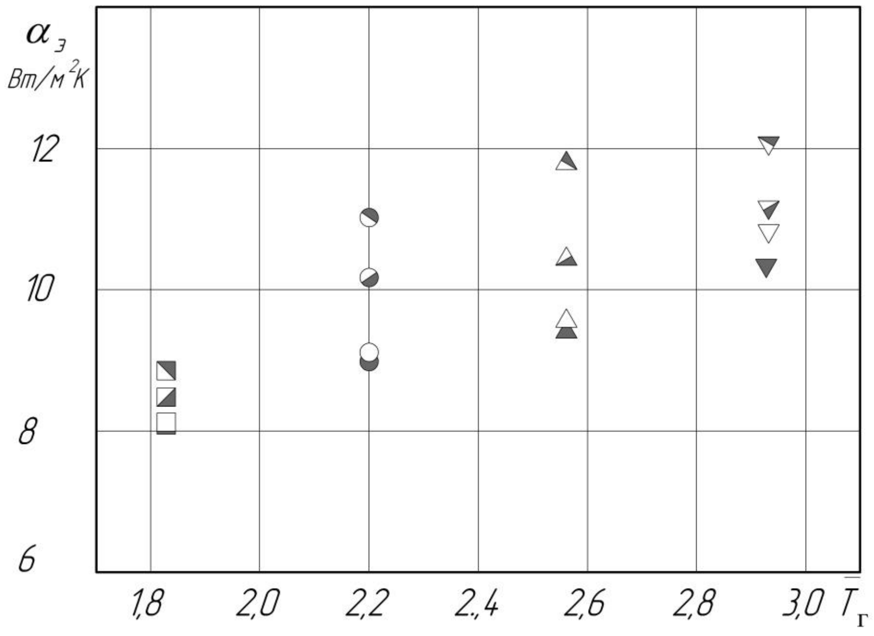
$$\bar{T}_э = 0{,}84 \cdot \left(\bar{T}_г\right)^{0{,}8} \cdot \left(\bar{\delta}_г\right)^{-0{,}1}$$

$$\bar{T}_{об} = 0{,}85 \cdot \left(\bar{T}_г\right)^{0{,}53} \cdot \left(\bar{\delta}_г\right)^{-0{,}05}$$

HEAT TRANSFER WITH NATURAL CONVECTION IN THE “HOT” GAP



Heat transfer from the hot wall to the air



Heat transfer from the air to the screen

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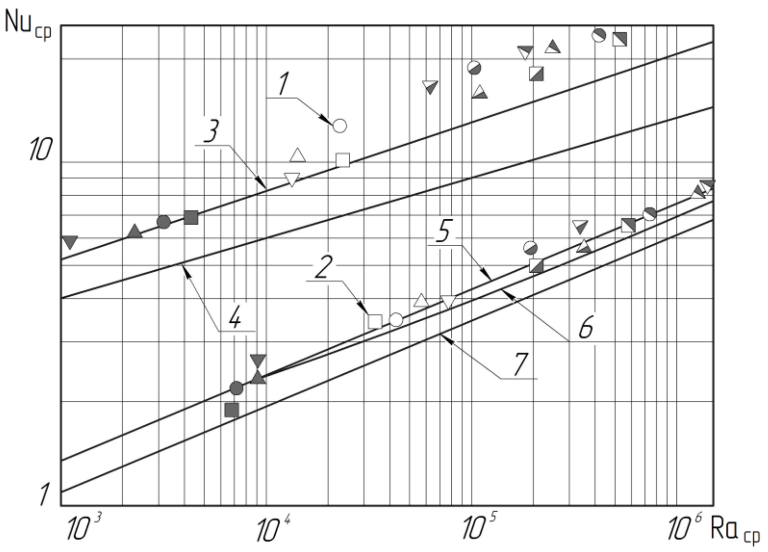
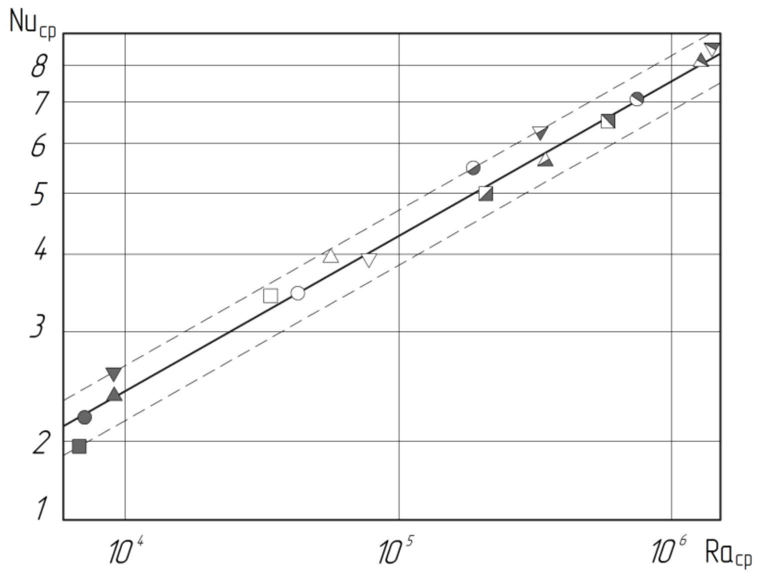


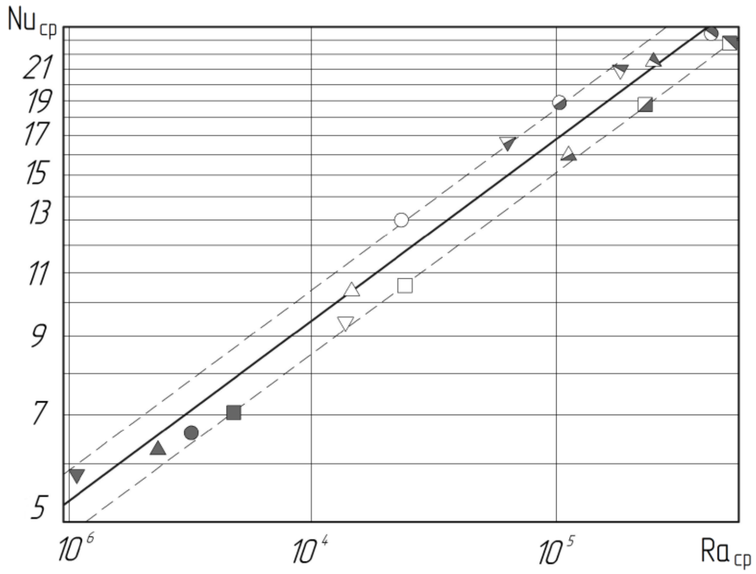
Experimental results Nu = *f* (Ra);
1 – thermal transfer to the screen (experimental points);
2 – – thermal transfer to the air (experimental points);
3 – Kitamura's equation;
4 – Morrow's equation;
5 – Pertazinskiy and Polezaev equation
6 – Hollands K.G.T., Raithby G.D., Konicer L.;
7 – Gebhart B.



Experimental result of thermal protection to the air $Nu_{cp} = f(Ra_{cp})$

Error ± 12 %

$$Nu_{cp} = 0,24 Ra_{cp}^{0,25}$$

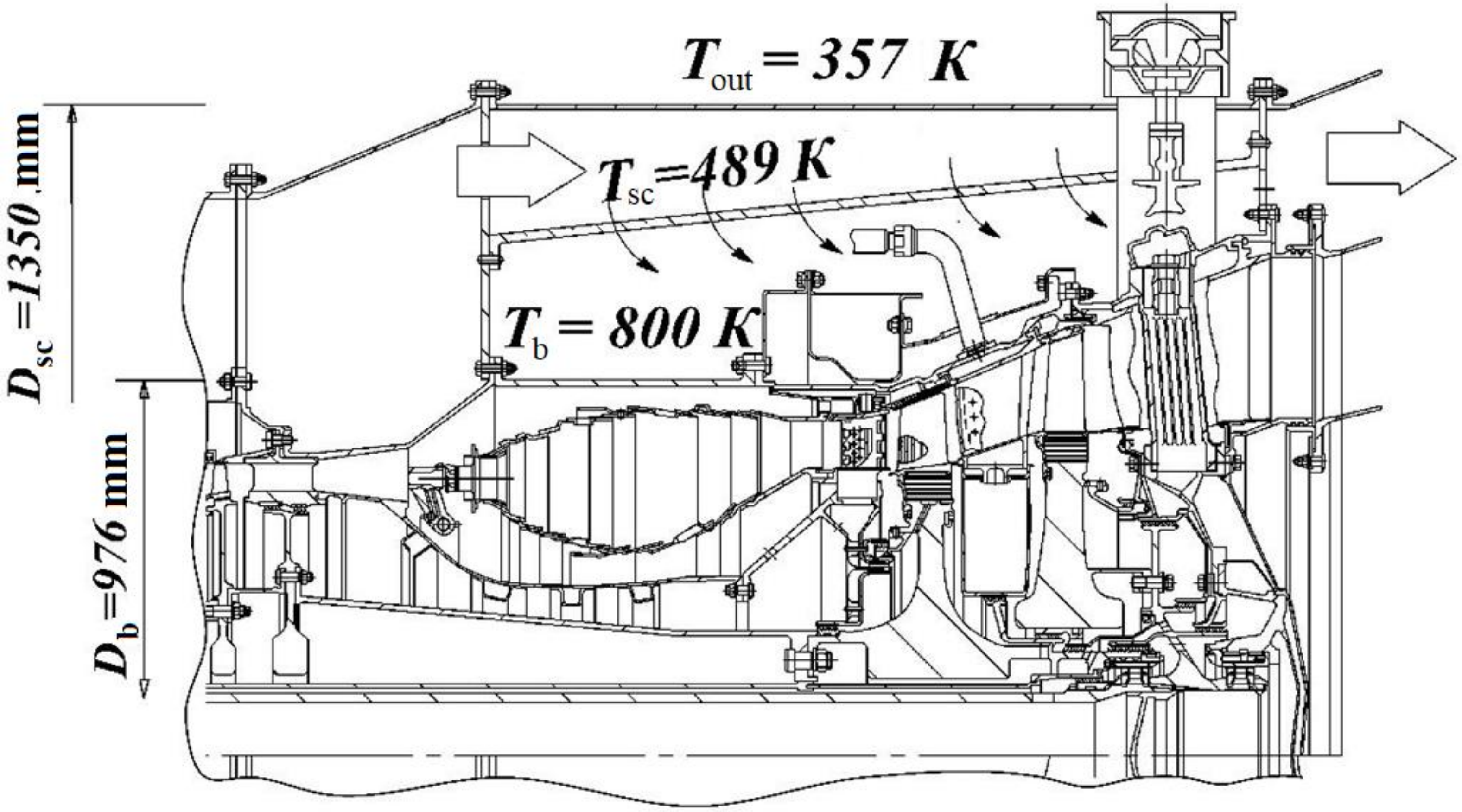


Experimental results of thermal transfer to the screen $Nu_{cp} = f(Ra_{cp})$;

Error ± 15 %

$$Nu_{cp} = 0,9 Ra_{cp}^{0,25}$$

Preliminary calculation of screen and outside shell temperature (NK-38ST engine)



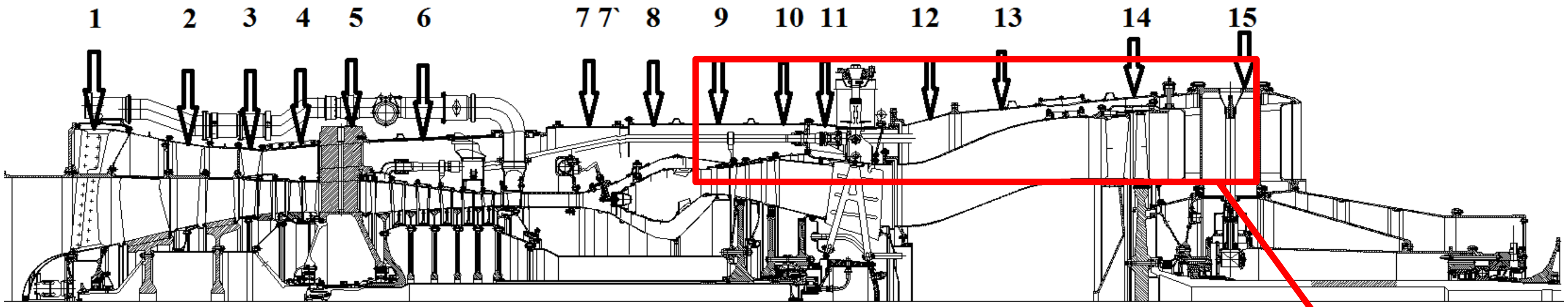
Temperature of body
T_b = 800 K

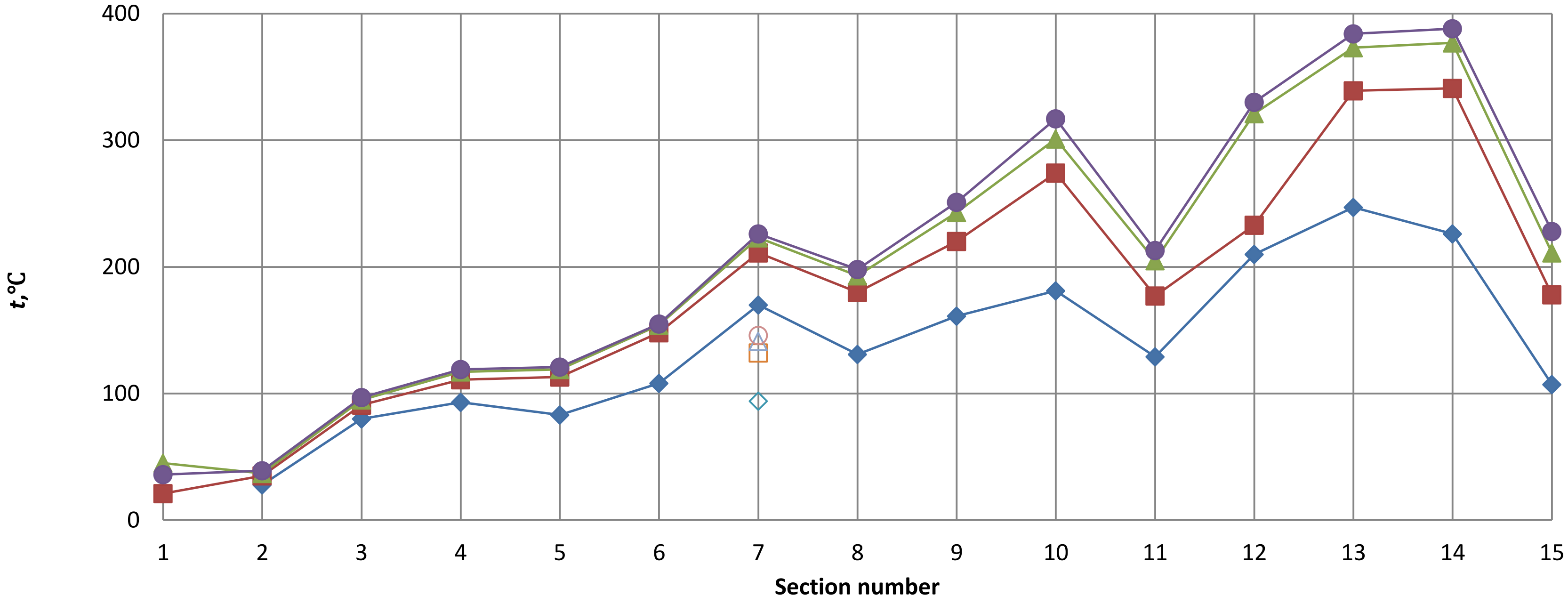
Temperature of porous screen
T_{sc} = 489 K

Temperature of outside shell
T_{out} = 357 K

The porous screen reduce to the temperature of outside shell more than 2 times

HEAT PROTECTION CALCULATION RESULTS IN ENGINE NK-16ST (KMPO)





Thermal losses:

Without protection – 20 369,3 W

With protection– 14 804 W

Reduced by 27,3 %

Change in shell temperature depending on low-pressure rotor speed [min^{-1}]

$n_{НД}$: ♦ – 4660, ■ – 5200, ▲ – 5350, • – 5400, ◊ – 4660(7'), □ – 5200(7'), △ – 5350(7'), ○ – 5400(7')

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HOT UNITS

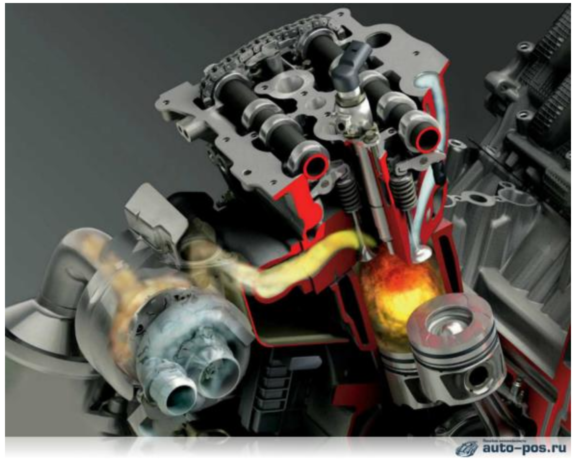
Industrial boiler

Industrial furnace

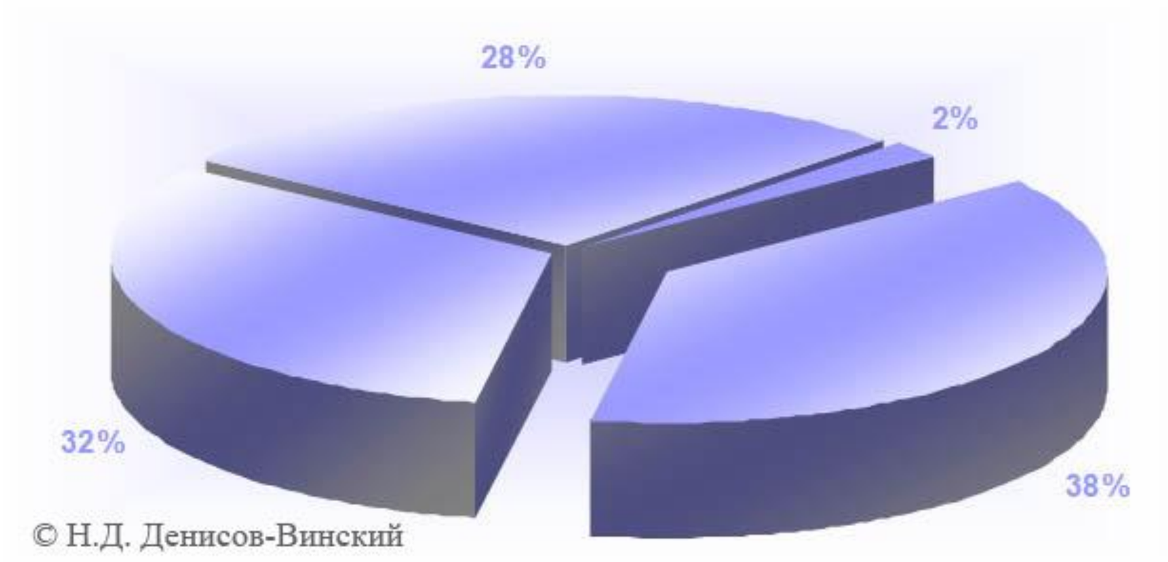
ENGINES

Gas turbine engines

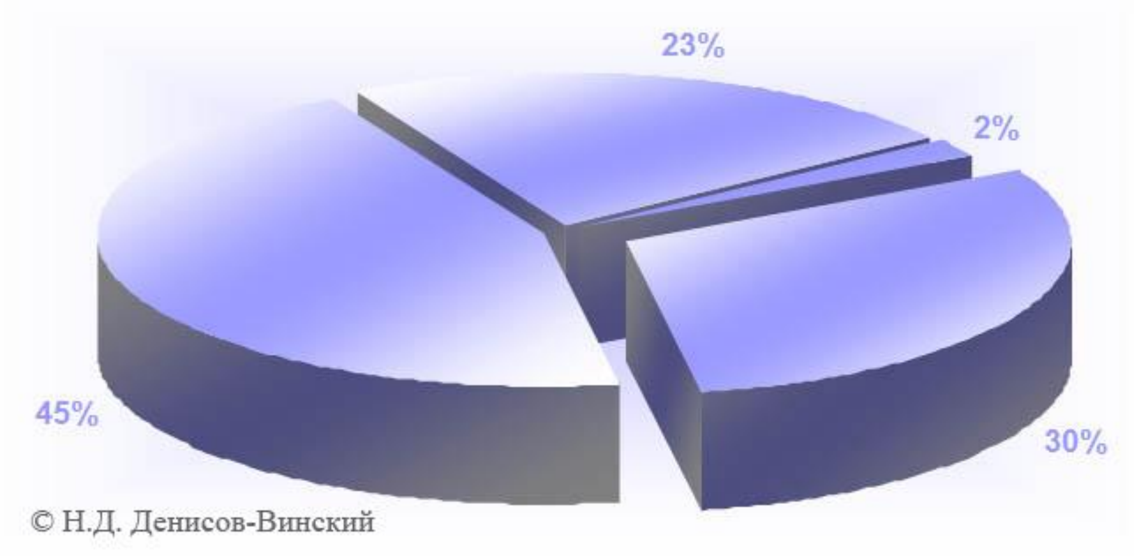
IC engine



Thermal balance of IC engine



Gasoline engine



Disel engine

32% - heat converted into work output;
28% - heat allocated to the cooling system;
2% - heat generated during piston friction;
38% - the heat removed with the exhaust gases.

45% - heat converted into work output;
23% - heat allocated to the cooling system;
2% - heat generated during piston friction;
30% - the heat removed with the exhaust gases.

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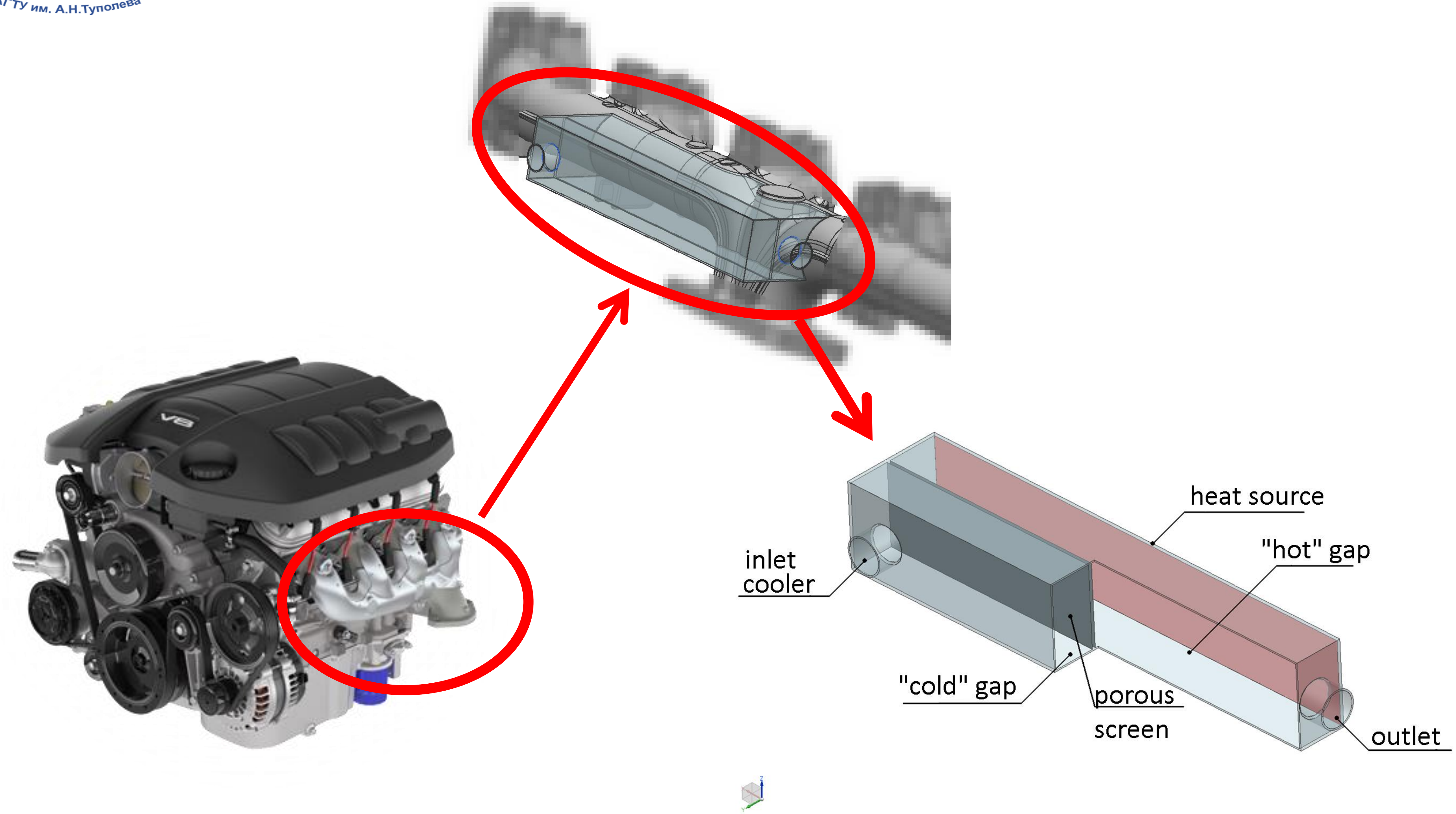
Next step study: Use of engine exhaust manifold heat



Researcher Links UK-Russia Workshop

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19th - 22nd November 2018, Northumbria University at Newcastle, UK

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THANK YOU FOR YOUR ATTENTION

READY TO ANSWER YOUR QUESTIONS

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