

# The 2D method for determining the temperatures field of the gas flow at the outlet of a multi-channel heat exchanger

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**Abstract.** The method for experimental determination of energy efficiency in the multi-channel heat exchanger was tested. The visualization of a temperatures field has been performed to determine the thermal structure of gas flows with the use of fast-response fine-meshed wire. Thermograms of the temperature fields of the multi-channels assembly at the outlet were registered by thermal imaging camera. Results show that the 2D method provides a sufficient time resolution for the temperature field for the steady-state gas flow regime, heat generation, and nonsteady regime. The 2D method allows us to determine the gas stream parameters at the channel outlet in real time, which are necessary for determining the efficiency of the heat exchanger. Qualitative and quantitative characters of temperature changes in the thermograms are consistent with modern physical understanding of the gas flow in channels.

## 1. Introduction

Mini and microchannel heat-exchanging apparatuses and gas reactors are the integral parts of innovative directions in the heat power engineering. Experimental data on the composition and temperature of gaseous reaction products, gained immediately at the outlet of such apparatuses, allow us to optimize their operation efficiency.

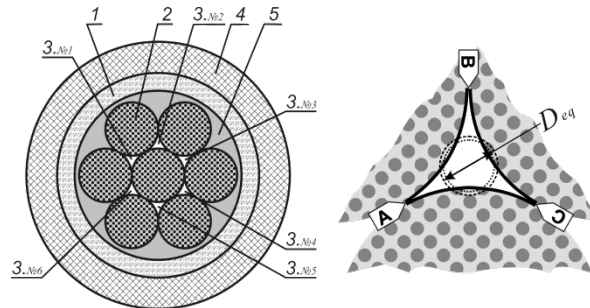
To visualize the temperature field in the medium, transparent for infrared rays, it is possible to use the heated slim tethers and meshes as indicators of temperature. The wire mesh is used in the thermographic method for experimental studying the thermal structures of the gas flow [1]. Using the thermographic method makes it possible to receive the thermogram of temperature changes inside the gas flow. In the present paper, the results of the 2D thermographic method [2] are presented for the multi-channel heat exchangers.

## 2. Measurement procedure

Experiments on measuring the nonstationary temperature fields at the outlet from six quasitriangular multi-channels were carried out on the model assembly, consisting of seven cylindrical heaters of equal diameter. The cross-section and internal passage section of the channel are presented in figure 1. Seven electric heaters (2) with the diameter of 5.9 mm and length of 0.5 m, which form six quasitriangular minichannels (3) (No. 1 ÷ No. 6) (triangle ABC consists of arcs AB, BC, CA), were positioned in a horizontal quartz tube (1) with the outer diameter of 23 mm and length of 0.5 m.



The heat losses from the packaging heaters to the atmosphere were decreased by using kaolinite wool (4) ( 7-mm layer) and non-flowing air spaces (5).



**Figure 1.** The cross-section (a) and shape (b) of the passage section of quasitriangular channel of multichannel assembly: 1 - quartz tube; 2 - heater; 3 - the passage channel (No. 1 ÷ No. 6) for gas; 4 - thermal insulation; 5 - air space; A, B and C - vertexes of the quasitriangular channel.

**Table 1.** Parameters of the passage channels in model assembly

No.	$D_{eq}$ mm	$S$ $mm^2$	$\Pi$ mm	No.	$D_{eq}$ mm	$S$ $mm^2$	$\Pi$ mm
1	1.18	2.74	9.29	4	1.15	2.66	9.25
2	1.28	2.98	9.31	5	1.20	2.78	9.27
3	1.31	3.04	9.28	6	1.16	2.68	9.24

The total heat exchange area of the passage section of quasitriangular channels is  $0.0275 \text{ m}^2$ . Table 1 shows the parameters of a passage section in channels obtained by planimetry measurements in the pictures of the outlet of cross-sections ( $D_{eq}$  is hydraulic diameter,  $S$  is sectional area of the passage section of the channel,  $\Pi$  is length of wetted perimeter of the passage section of the channel). Figure 1b shows the visual relationship between the sizes of the passage section of the channel and its hydraulic diameter  $D_{eq}$ . The minimum (1.2 mm) and maximum (1.3 mm) values of  $D_{eq}$  in assembly are shown by the dashed lines. The difference in diameters is caused by inaccuracy of electric heaters in a bundle and ovality of cylindrical heaters. The thickness of the mesh-thermal detector wire is about 80 microns; cell size of the mesh is  $0.3 \times 0.3 \text{ mm}$ . The wire is pressed close to the outlet surface of the assembly. Thermograms have been obtained by infrared imager NEC TH7100 with wavelength  $\lambda = 8 \div 12 \text{ microns}$ . Time resolution is 300ms, spatial resolution is  $100 \mu\text{m}$ .

The dependence between a change in temperature  $T$  and time  $t$  was interpolated by dependence:

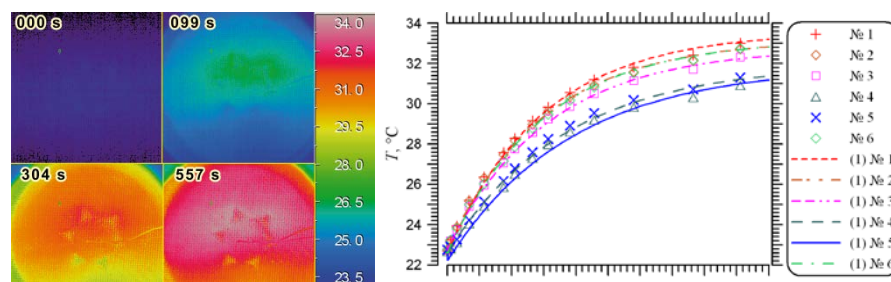
$$T(t) = T_0 + \Delta T \cdot \left[ 1 - \exp\left(-\frac{t}{\tau}\right) \right] \quad (1)$$

where  $T_0$  is initial temperature,  $\Delta T$  is temperature difference,  $\tau$  is typical scale time.

### 3. Discussion of results

The 2D thermographic method has been tested for determining the temperatures fields of the gas flow for stationary and non-stationary conditions of heating in cylindrical gas heaters at various air flow rates. Processing the thermograms allow us to receive the information about the temperature field in the gas flow at each passage section of minichannels.

Figure 2 shows four typical thermograms of samples at different times after the burst of thermal load of 4.8 W on the central heater with total air flow rate of 0.45 g/s and temperature-time graph of the average temperature in each of six channels. The temperature non-uniformity is caused by natural convection in the heating assembly and variation in individual gas flows in the channels, caused by differences in their areas of flow.

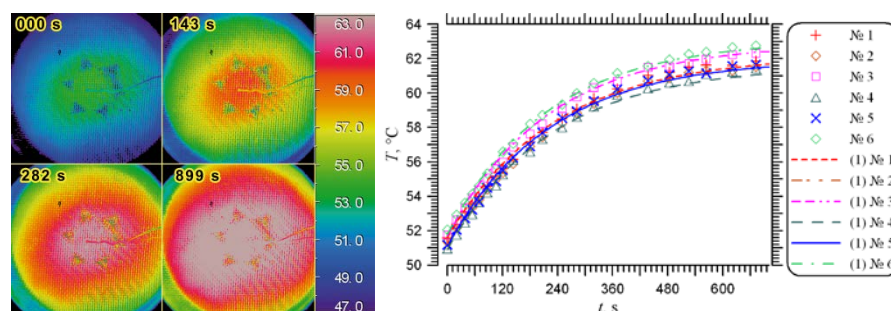


**Figure 2.** The thermograms of a wire mesh in the outlet cross-section after the heat load surge on central heater in the assembly and time graph of the average temperature in each of six channels.

**Table 2.** Parameter values for ‘equation (1)’ under the conditions in figure 2.

No. →	1	2	3	4	5	6
$T_0$ , °C	22.6	22.6	22.6	22.6	22.6	22.6
$\Delta T$ , °C	11.0	10.4	10.0	9.4	9.7	10.6
$\tau$ , s	180	180	190	220	230	180

Figure 3 shows thermograms for the case of a decrease in the total air flow rate from 0.45 g/s to 0.26 g/s, under heat load of 33.6 W proportioned uniformly on all the heaters. Sampling starts from the moment of a decrease in the total flow rate of gas. It is easy to see that after the decrease in the total air flow rate the increase of temperature in the outlet cross-section takes place due to the gain of heating up of air in quasitriangular minichannels.



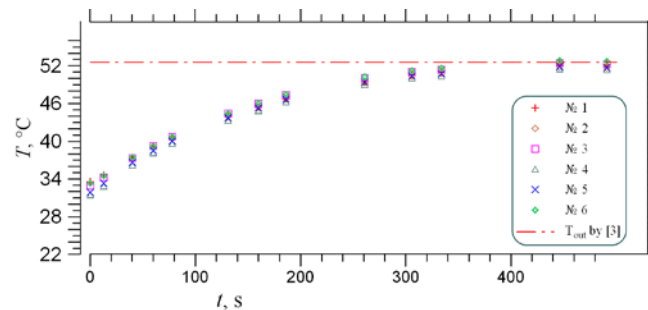
**Figure 3.** The thermograms of a wire mesh in the outlet cross-section after a decrease in the total flow rate of air and time graph of the average temperature in each of six channels.

**Table 3.** Parameter values for ‘equation (1)’ under the conditions in figure 3.

No. →	1	2	3	4	5	6
$T_0$ , °C	51.6	51.2	51.7	50.9	51.1	51.8
$\Delta T$ , °C	10.6	10.8	11.2	10.7	10.9	11.3
$\tau$ , s	232	225	221	226	223	218

Figure 4 presents the variation in time of average temperature  $T_{out}(t)$  in each of quasitriangular channels (marker) in comparison with calculated value of stationary temperature  $T_{out}$  (line). Calculation takes into account the redistribution of gas flow rate for each of the channel passage sections due to the difference of the area of passage section of the channels [3]. Thus, it takes into account the changing in the conditions of heat exchange along the length of the channel. In the present experiment the total air flow rate is 0.45 g/s, heat load on central heater is 4.8 W, surge of heat load on six peripheral heaters is 28.8 W. Sampling starts from the moment of the surge of heat load on peripheral heaters in the model assembly. Processing the thermograms has shown that after transition

to the stationary conditions, the temperature of air at the outlet of assembly corresponds to the calculated value for the stationary flow.



**Figure 4.** Time graph (upper axis) of the average temperature in each of six quasitriangular channels  $T_{out}(t)$  after the heat load surge on peripheral heaters in the assembly. Calculated value of air temperature  $T_{out}$  by [3].

**Table 4.** Parameter values for ‘equation (1)’ under the conditions in figure 4.

No. →	1	2	3	4	5	6
$T_0, ^\circ\text{C}$	33.4	33.3	32.8	31.5	31.9	32.7
$\Delta T, ^\circ\text{C}$	20.3	20.5	20.7	21.3	21.5	21.5
$\tau, \text{s}$	173	175	157	160	175	180

The measured value of typical time scale  $\tau$  is in good agreement with an estimate of time necessary for warming up the assembly to the stationary temperature field and it is determined by the heat release rate with the heat loss from the assembly taken into account. The thermograms allow us to see the 2D patterns of nonsteady preheating of gas in quasitriangular minichannels, and dynamics of preheating of model assembly in full detail. Let us note that it is necessary to use the infrared imagers with smaller wavelength  $\lambda$  for increasing accuracy of measurements in operations with channels of a smaller size.

#### 4. Conclusion

Testing the 2D thermographic method for determining the thermal structure of gas flow using fast-response fine-meshed wire, at the outlet of the model of multi-channels assembly has shown the sufficient time resolution. Qualitative and quantitative characters of temperature changes in thermograms are consistent with modern physical understanding of the gas flow in channels.

The thermographic method is universal for studying the processes of stationary and non-stationary heat exchange. Accuracy of the method is determined by characteristics of the studied object and the equipment used for thermal imaging.

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#### References

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