MINISTRY OF EDUCATION AND SCIENCE
NATIONAL TECHNICAL UNIVERSITY
«KHARKIV POLYTECHNIC INSTITUTE»

METHODOLOGICAL INSTRUCTIONS

to the laboratory work «Estimation of Thermal Conductivity of Heat Insulation of a Pipeline» of discipline «Theoretical Fundamentals of Heat Engineering»

for students of specialty
141 «Electric Power Engineering,
Electrical Engineering and Electromechanics»

Kharkiv 2021

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Methodological instructions to the laboratory work «Estimation of Thermal Conductivity of Heat Insulation of a Pipeline» of discipline «Theoretical Fundamentals of Heat Engineering» for students of specialty 141 – «Electric Power Engineering, Electrical Engineering and Electromechanics» / compiler V.V. Pylyov. – Kharkiv: NTU «KhPI», 2021. – 12 p.

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Reviewer O.M. Tarasenko

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PREFACE

The intensity of conduction, which is a mode of heat transfer innate to solid bodies, is determined by the temperature gradient and the value of the thermal conductivity. The latter is a thermophysical characteristic of the substance, which in the general case depends on temperature and is usually found experimentally.

The goal of the laboratory work is deepening knowledge of the theory of thermal conduction, obtaining the skills of carrying out experimental work to determine the thermal conductivity of materials. It is an important part of training of students regarding heat engineering.

1. PROBLEM STATEMENT

When operating heat supply systems of industrial enterprises, in order to check the state of the insulation of pipelines it is necessary to experimentally evaluate the amount of heat loss and the thermal conductivity of the insulation material using nondestructive measurement methods, preferably of the kind that doesn't interrupt operation of the pipeline. For cylindrical bodies in this case, the heat resistance measuring band method is most often used.

The measuring band is additional layer of cylindrical wall with known thickness δ_b and thermal conductivity λ_b with built-in temperature detecting devices on both its surfaces. If placed on a pipeline with a diameter d, the linear heat flow of heat losses through it can be found according to the formula

$$q_l = \frac{\Delta t}{\frac{1}{2\pi\lambda_b}\ln\frac{d + 2\delta_b}{d}}, \tag{1}$$

where Δt is the difference of measured temperatures on outer and inner sides of the band.

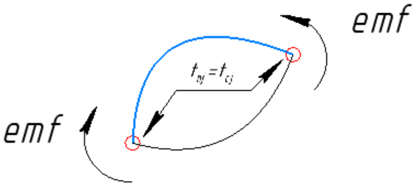
It should be noted that as far as the measuring band creates additional heat resistance on the body of the pipeline, the heat losses value q_l has been found is going to be slightly less than the one outside the range of band applied. Usually this difference is no more than a few percent and so is admissible to neglect for the practical goals. In the laboratory work the improved value is going to be found on the basis of additional measurements of temperature by sensors placed outside the band.

The essential part of the laboratory work is students becoming accustomed with the method of measuring the temperatures with thermocouples – the thermoelectric thermometers.

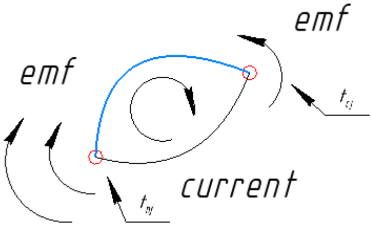
They consist of two thermoelectrodes made of dissimilar material that have two junctions. The electromotive forces (emf) that emerge in the junctions depend on the local temperatures and have opposite directions, as it's shown in Fig. 1, *a*. If the temperatures of the junctions are the same, the values of emf are equal and compensate each other.

If the temperature of one junction is higher than the temperature of the other one, the corresponding emf exceeds its counterpart, and a circular electric current in the circuit arises, as in Fig. 1, *b*. If the circuit is broken, the current in it is impossible, but there is going to be a potential difference on the loose ends of conductors. It can be measured by millivoltmeter according to Fig. 1, *c*.

The values of emf that correspond specified temperatures are known for standard thermoelectrodes and used to create calibration charts. They are usually built for the case, when the temperature of cold junction t_{cj} equals 0°C, and contain dependency of adjusted value of emf of hot junction $E(t_{hj}, 0)$, which equals millivoltmeter readings $E(t_{hj}, t_{cj})$, on hot junction temperature t_{hj} itself.



a



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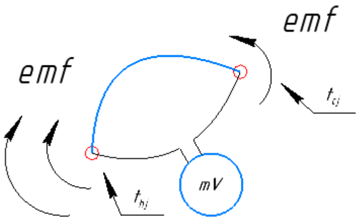

c

Figure 1 – Principle of operation of a thermocouple:
a – with both joints having the same temperature;
b – with joints having different temperatures; *c* – open-loop circuit

To maintain a constant temperature t_{cj} = 0°C the cold junction of the thermocouple can be placed in a special thermostat. The other approach in absence of such thermostat presupposes measuring the temperature of cold junction t_{cj} by a customary expansion thermometer. The adjusted value of cold junction emf $E(t_{cj}, 0)$ can be found from the calibration chart for that temperature. After that the adjusted value of hot junction emf in a general case

$$E(t_{hj}, 0) = E(t_{hj}, t_{cj}) + E(t_{cj}, 0) \tag{2}$$

is used to get sought hot junction temperature t_{hj} value from the chart.

Thermocouples are widely used because they are self-powered and able to measure a wide range of temperatures. The main limitation with thermocouples is accuracy. To measure small temperature differences, such as between the sides of the measuring band, the thermocouples battery is applied. It consists of multiple thermoelectrodes in-series. Their junctions are placed in the measuring zones by turns, so that all hot junctions are on the inner side of the band, and all cold junctions are on the outer one, as shown in Fig. 2.

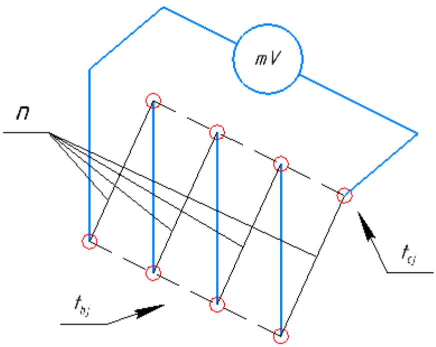

Figure 2 – A battery of thermocouples

If there are n pairs of junctions, the potential difference measured by millivoltmeter E_{tb} is going to be n times greater, accuracy increasing respectively.

To found the potential difference of a one thermocouple in the battery the following formula is used

$$E\left(t_{hj}, t_{cj}\right) = \frac{E_{tb}}{n}. \qquad (3)$$

It has to be noted that, as far as the temperature of the battery cold junctions is not the temperature of surroundings, the temperature of the hot junctions that's used as a reference point instead requires measuring by a separate thermocouple, while the temperature of the cold junctions is sought via the measurement.

2. LABORATORY INSTALLATION DESCRIPTION

A diagram of the experimental installation that is used in the laboratory work is shown in Fig. 3.

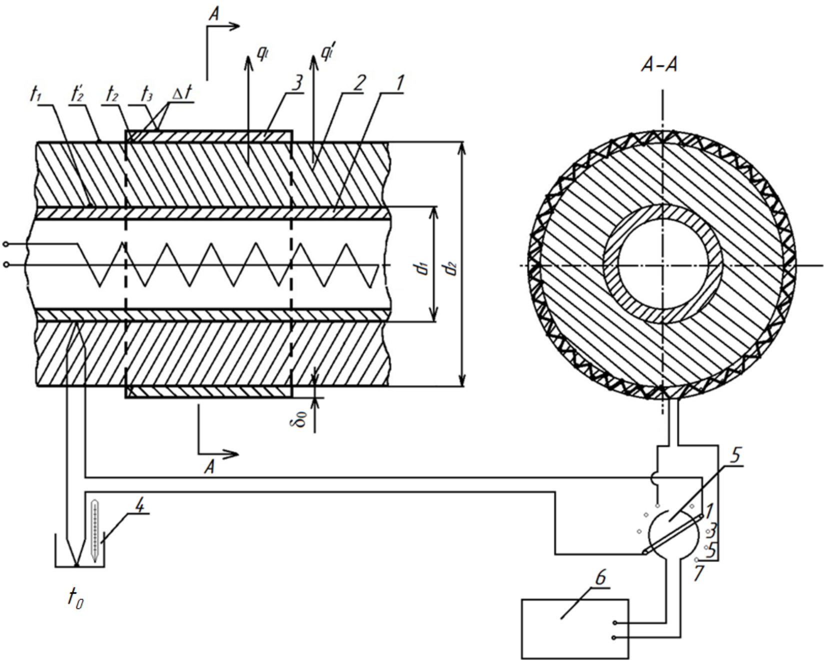

Figure 3 – Experimental installation schematic diagram

The section of an insulated pipeline 1, heat losses from which are studied, has outer diameter d_1 = 25 mm. The passage of a heat carrier in it is imitated by an electric heater set inside. There is a layer of heat insulation 2 on its surface, which covered with aluminum foil protective layer on its own; its outer diameter is d_2 = 60 mm. The measuring band 3, made of microcellular rubber, is put on over it. The band has thickness δ_0 = 4 mm and known thermal conductivity λ_0 = 0.16 W/(m·K).

The hot junctions of chromel-kopel thermocouples are installed at the suitable points for temperature measurement: on the outer surface of the pipeline under the insulation t_1, on the outer surface of the insulation under the measuring band t_2 and outside it t'_2. The cold junctions 4 of these three thermocouples are integrated in switch 5 and have the temperature of surroundings t_0, which has to be measured with a liquid thermometer. The switch commutates thermocouples with a digital millivoltmeter 6, one at a time. The last position of the switch connects it to the battery of n = 30 thermocouples inside the measuring band. The themperature t_2 gotten with the foregoing thermocouple under the band serves in capacity of the hot junction temperature for this thermocouples battery.

3. TEST PROCEDURE

The condition for carrying out a correct thermal engineering experiment is the stationarity of the thermal state, when the temperature values at different points of the object don't change over time.

While performing measurements on full-sizes pipelines, this condition is always fulfilled, as far as the temperature state of heat insulation doesn't change in operation. In the laboratory work reaching the entirely stationary thermal state of the system takes several hours, what isn't completely acceptable. The test procedure lets measurements to be started in 20-30 minutes after the installation was turned on; a procedural error related to that temperatures continue changing leads to the roughness of measurement results and absence of their repeatability from one experiment to other.

Therefore the millivoltmeter readings for all switch positions need to be taken in short period of time to keep them as mutually consistent as possible. They are registered in the laboratory work report in the form similar to Table 1.

Table 1 – The table blank for results of the measurement

Switch position	Quantity	Unit	Value
1	$E(t_1, t_0)$	mV	
3	$E(t_2, t_0)$	mV	
5	$E(t'_2, t_0)$	mV	
7	E_{tb}	mV	
	t_0	°C	

4. PROCESSING THE DATA

First thing, to be able to find the temperatures corresponding the readings of the thermocouples, the adjusted emf of their cold junctions $E(t_0, 0°C)$ has to be ascertained using the calibration chart in the form of Table 2.

After that adjusted values of the measuring junction emf of the thermocouples are found according to (2), mV:

$$E(t_1, 0) = E(t_1, t_0) + E(t_0, 0); \tag{4}$$

$$E(t_2, 0) = E(t_2, t_0) + E(t_0, 0); \tag{5}$$

$$E(t_2', 0) = E(t_2', t_0) + E(t_0, 0); \tag{6}$$

$$E(t_3, 0) = -E(t_3, t_2) + E(t_2, 0), \tag{7}$$

where t_3 is the temperature of outer surface of the measuring band;

$E(t_3, t_2)$ is the potential difference of a one thermocouple in the thermocouple battery, mV:

Table 2 – Dependence of emf of chromel-kopel thermocouple on the temperature of its hot junction if the temperature of the cold one is 0°C

°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	0	0.07	0.13	0.20	0.26	0.33	0.39	0.46	0.52	0.59
10	0.65	0.72	0.78	0.85	0.91	0.98	1.05	1.11	1.18	1.24
20	1.31	1.38	1.44	1.51	1.57	1.64	1.71	1.77	1.84	1.90
30	1.97	2.04	2.11	2.17	2.24	2.31	2.38	2.45	2.51	2.58
40	2.65	2.72	2.79	2.86	2.93	3.00	3.06	3.13	3.20	3.27
50	3.34	3.41	3.48	3.55	3.62	3.69	3.75	3.85	3.89	3.96
60	4.03	4.10	4.17	4.24	4.31	4.38	4.45	4.52	4.59	4.66
70	4.73	4.80	4.87	4.95	5.02	5.09	5.16	5.23	5.31	5.38
80	5.45	5.52	5.59	5.67	5.74	5.81	5.88	5.95	6.03	6.10
90	6.17	6.24	6.32	6.39	6.46	6.54	6.61	6.68	6.75	6.83
100	6.90	6.97	7.05	7.12	7.20	7.27	7.34	7.42	7.49	7.57

$$E\left(t_3, t_2\right) = \frac{E_{tb}}{n} \,. \qquad (8)$$

On the basis of emf (4)-(7) the values of the local temperatures t_1, t_2, t'_2, t_3 are found using the dependence in the Table 2.

After that it becomes possible to found the linear heat flow through the measuring band, W/m:

$$q_{lb} = \frac{t_2 - t_3}{\dfrac{1}{2\pi\lambda_0} \ln \dfrac{d_2 + 2\delta_0}{d_2}} \,. \qquad (9)$$

The pipeline heat insulation thermal conductivity can be obtained from a similar equation for linear heat flow through it, W/(m·K):

$$\lambda_{hi} = \frac{q_{lb} \ln \frac{d_2}{d_1}}{2\pi(t_1 - t_2)} . \qquad (10)$$

The improved value of heat losses found as a linear heat flow through heat insulation in a place where the measuring band doesn't create an additional heat resistance, W/m:

$$q_l = \frac{t_1 - t_2'}{\frac{1}{2\pi\lambda_{hi}} \ln \frac{d_2}{d_1}} . \qquad (11)$$

The conclusions to the work must contain a guess of what the material of the pipeline heat insulation from Table 3 is; the finding over it condition; assessment of inaccuracy of the heat losses value obtained with the heat resistance measuring band.

Table 2 – Parameters of heat insulation materials

Material	Thermal conductivity, W/(m·K)	Limiting temperature of using, °C
Asbestos	0.13	700
Mineral wool	0.058	500
Slag wool	0.06	750
Base felt	0.05	90
Foamed glass	0.16	600..800

5. CONTROL QUESTIONS

1. What are the three modes of heat transfer?
2. What does the Fourier's law state, what is the heat diffusion equation?

3. What is thermal conductivity? Compare its values for substances in different states.

4. Compare specific and linear heat flows. For what purposes are they convenient to use?

5. What are expressions for heat flow through flat and cylindrical walls?

6. What is thermocouple? How is it used for temperature measurements?

7. What is a purpose of using a thermocouple battery?

8. Why the potential difference for a thermocouple of the measuring band in formula (7) is subtracted from the temperature of a junction unlike all others?

9. Why the improved value of heat losses is large than the one obtained with the measuring band?

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CONTENTS

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