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EXPERIMENTAL DETERMINATION OF HEAT LOSSES FOR A BURIED TRANSPORT PIPELINE IN NON-ISOTHERMAL STATE

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Abstract: *In the thermotechnics laboratory of the Petroleum – Gas University of Ploiesti an experimental stand consisting of a 60 meter buried pipeline was built. Sensors were placed to measure the temperature field around the pipeline. In order to determine the heat loss over the entire length of the pipeline a 3D model was created, model which was calibrated based on experimental data. At the end of the paper the heat loss determined over the entire length of the pipeline at different moments in time is presented.*

Key words: *heat, oil, transport, non-isothermal, transducers*

1. Introduction

In the laboratory from the Petroleum – Gas University of Ploiesti an xperimental stand for transporting viscous oil in non-isothermal state was realized. On the stand heat loss in the case of viscous oil transport was studied by determining the temperature gradient at the wall pipe. This was possible by measuring the real-time temperature field around the pipeline.

2. Description of the experimental stand

For experimental testing of viscous oil transport in non-isothermal state heated with a ground-water heat pump, a transportation mini-system whose configuration is shown in Figure 1 was made.

It consists of a heat pump, four systems that extract heat from soil, two tanks for storing viscous oil, a pipeline, a pipe manifold and monitoring and a real time data acquisition system.

In Figure 2 one can see the two tanks, the tank R1 where the oil is heated before being transported and the R2 tank, that is a landing tank.

The transport system also includes an insulated steel pipe buried at a depth of 1 m. The total length of the transport pipeline is 60 meters and a detail of it can be seen in Figure 3. The pumping control is done with the pipe manifold assembled in the laboratory (Figure 4).

The design of the system is based on two pumps, straightway valves and an electric on/off pumps system. Pump P1 is used for pumping the heated oil from tank R1 through the transport pipeline into the R2 tank. Pump P2 is used to restore the original state. This pumps the oil from tank R2 to R1. When a pump is actuated, the oil flow by-passes the other pump. The used pumps are GRUNDFOS UPS 25-80 180 and they allow the functioning in stationary regime at three different rotative speeds.

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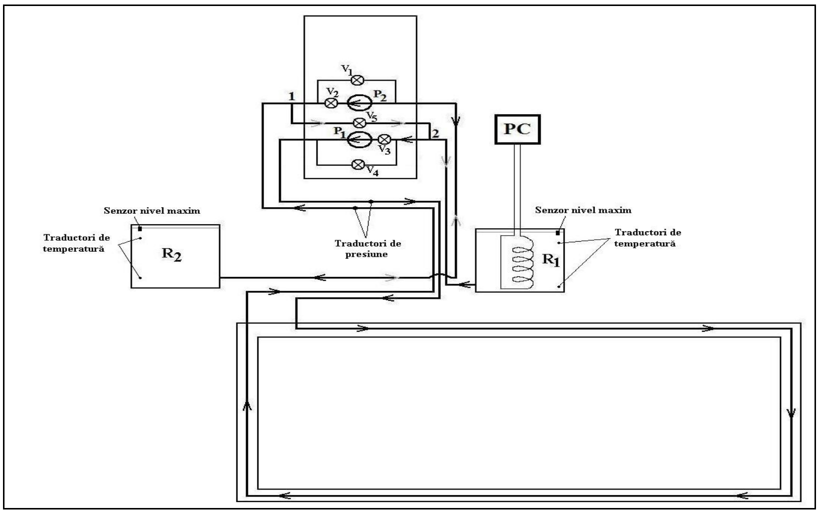

Fig. 1. *Experimental test stand*

Fig. 2. *The two tanks*

Fig. 3. *Detail of the transport pipeline*

Thermal interaction between the heated oil pipe transport and soil from the neighborhood is monitored by a system of twenty four temperature transducers. Location of temperature transducers is shown schematically in Figure 5.

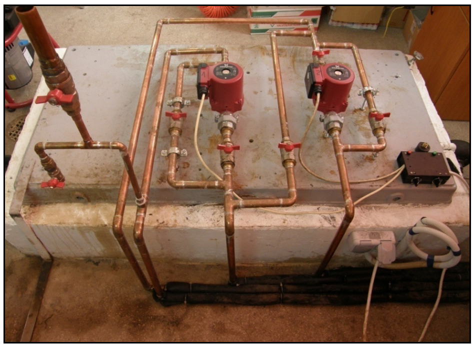

Fig. 4. *The pipe manifold*

The signal from these temperature transducers mounted in the soil is taken through the connection boxes and led to a system of automatic data acquisition (Figure 6).

The system of automatic data acquisition is able to monitor forty temperature sensors with a sampling rate of 20 seconds, to memorize data for a period of two months and communicate with PC via RS 485 bus.

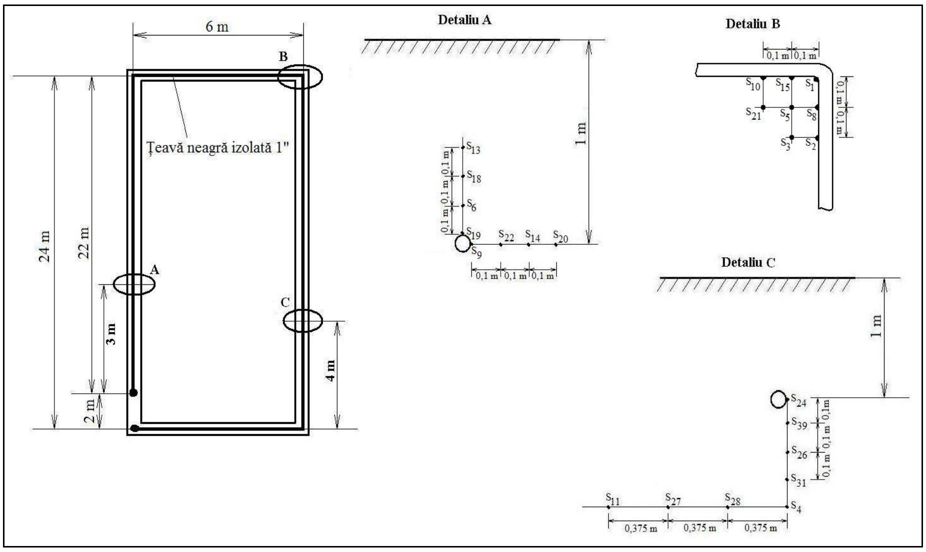

Fig. 5

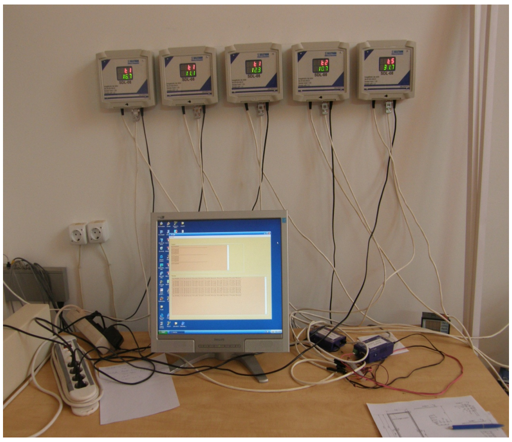

Fig. 6.

3. Numerical model

Starting from the heat diffusion equation (1) integrated numerically using finite volumes method in three-dimensional space around the transport pipe, an original program in Delphi was created.

$$\frac{\partial}{\partial t}\left(\rho \cdot c_p \cdot T\right) + \nabla J = 0 \qquad (1)$$

where: t is time, ρ - density, c_p - specific heat, T - temperature, J - heat flow (2), λ - the coefficient of conductivity

$$J = \kappa \cdot \nabla T \,. \qquad (2)$$

With the numerical model and based on the temperature values at the entry and exit of the pipe obtained experimentally, the variation of temperature of oil along the pipeline and in soil vicinity can be calculated.

The results of such test are shown numerically in Figure 7.

4. Presentation of results

The numerical model is able to calculate the variation of temperature field around the pipeline taking into account the real geometry of the system.

The problem that had to be resolved was related to determination of soil properties and in particular the coefficient of conductivity.

This was done indirectly through successive attempts made with the numerical program for different values of the coefficient of conductivity.

a. Calibration of numerical model

When the calculated values of the temperature field coincided with the experimental values determined in the concentration areas of transducers (Tables 1 and 2), the coefficient of conductivity was assumed to be correct.

11	11,07	12,67	33,75	12,67	11,07	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11,04	12,06	25,67	12,06	11,04	11
11	11,07	12,68	33,81	12,68	11,07	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11,04	12,05	25,61	12,05	11,04	11
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11	11,07	12,78	35,12	12,78	11,07	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11,04	11,95	24,29	11,95	11,04	11
11	11,07	12,79	35,19	12,79	11,07	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11,04	11,95	24,23	11,95	11,04	11
11	11,07	12,79	35,25	12,79	11,07	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11,04	11,94	24,17	11,94	11,04	11
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11	11	11,05	11,73	11,76	11,76	11,77	11,77	11,78	11,78	11,79	11,79	11,8	11,8	11,81	11,81	11,81	11,82	11,82	11,83	11,83	11,84	11,84	11,85	11,88	12,66	23,1	11,86	11,03	11
11	11,03	11,7	21,6	21,66	21,73	21,79	21,85	21,91	21,98	22,04	22,1	22,16	22,23	22,29	22,35	22,41	22,48	22,54	22,6	22,67	22,73	22,79	22,85	22,92	22,98	23,04	11,83	11,03	11
11	11	11,05	11,73	11,76	11,76	11,77	11,77	11,78	11,78	11,79	11,79	11,8	11,8	11,81	11,81	11,81	11,82	11,82	11,83	11,83	11,84	11,84	11,85	11,85	11,86	11,83	11,06	11	11
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11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11

Fig. 7

Experimental values of temperature in zone 2 Table 1

T_3	T_2	T_1	T_{cond}	T_1	T_2	T_3
11	11	11	11	11	11	11
11,15	11,05	11,2	11,1	11,1	11	11
12,55	12,45	12,5	12,25	11,5	11,1	11
29,22	**29,2**	**29**	**28,83**	12,24	11,3	11
12,5	12,4	13,1	**28,79**	12,3	11,15	11
11,15	11,35	12,35	**28,75**	12,2	11,1	11
11	11	12,3	**28,75**	12	11,1	11

The calculated temperature in zone 2 Table 2

T_3	T_2	T_1	T_{cond}	T_1	T_2	T_3
11	11	11	11	11	11	11
11,05	11,05	11,05	11,05	11	11	11
12,32	12,32	12,31	12,26	11,1	11	11
29,18	**29,11**	**29,05**	**28,99**	12,26	11,05	11
12,32	12,37	13,51	**28,93**	12,3	11,05	11
11,05	11,11	12,35	**28,86**	12,3	11,05	11
11	11,05	12,29	**28,8**	12,29	11,05	11

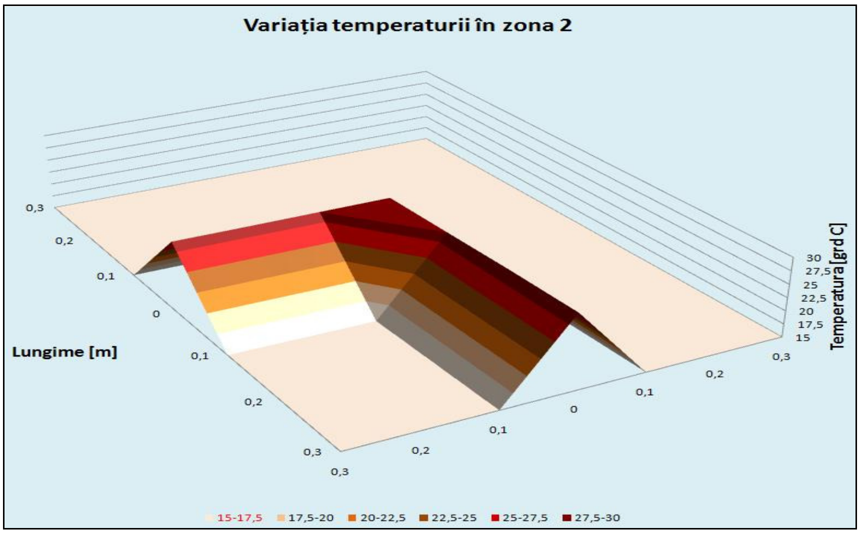

Fig. 8.

b. Simulation with the calibrated model

During the pumping process the variation of temperature field around the pipeline is essential for the heat loss and temperature variations of oil along the pipeline.

Figure 9 presents the variation of soil temperature in a horizontal plane containing the pipeline. The highest values represent the temperature on the pipe wall. With time, the soil in the vicinity of pipe is heating, which causes changes in the configuration of the surface which represents soil temperature.

The process of transport is limited by the amount carried. In our case it is 800 l in 45 minutes.

On the basis of the experimental values and numerical model, the developments of oil temperature through pipeline and soil temperature for a transmission of a greater quantity of oil can be predicted.

c. Analysis of heat loss

Knowing the coefficient of thermal conductivity of soil and using in the numerical program the original and limit conditions resulted from the experimental tests, one could determine, at any time and for each point on the pipe, the quantity of thermal power transferred to environment.

The thermal power lost per 1m of pipe based on the gradient of temperature field at the pipe wall was calculated for the heat loss.

Figure 10 presents in a graphical form, reflecting the geometry of the xperimental system, the thermal power lost on the pipe after five minutes from starting

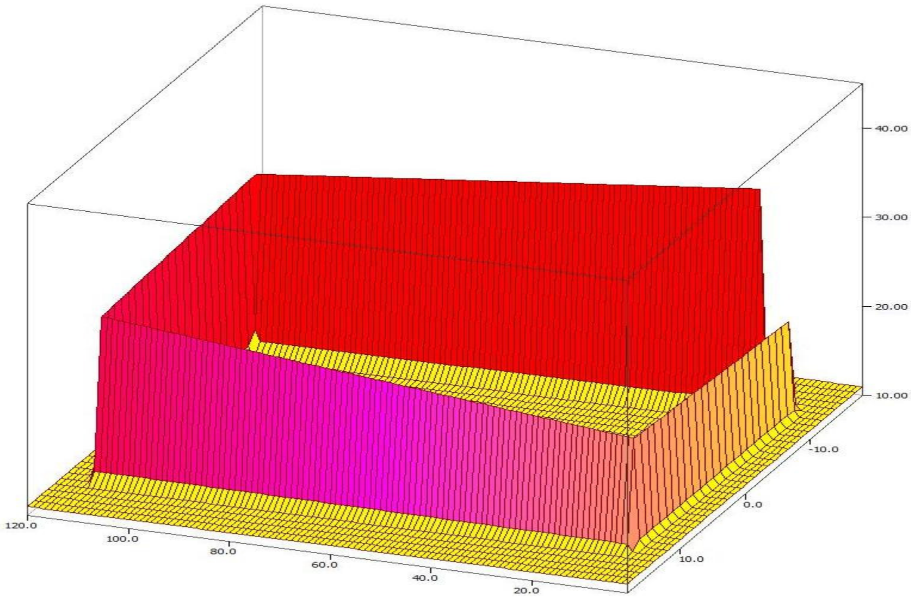

Fig. 9. *Time* = 30 *minutes*

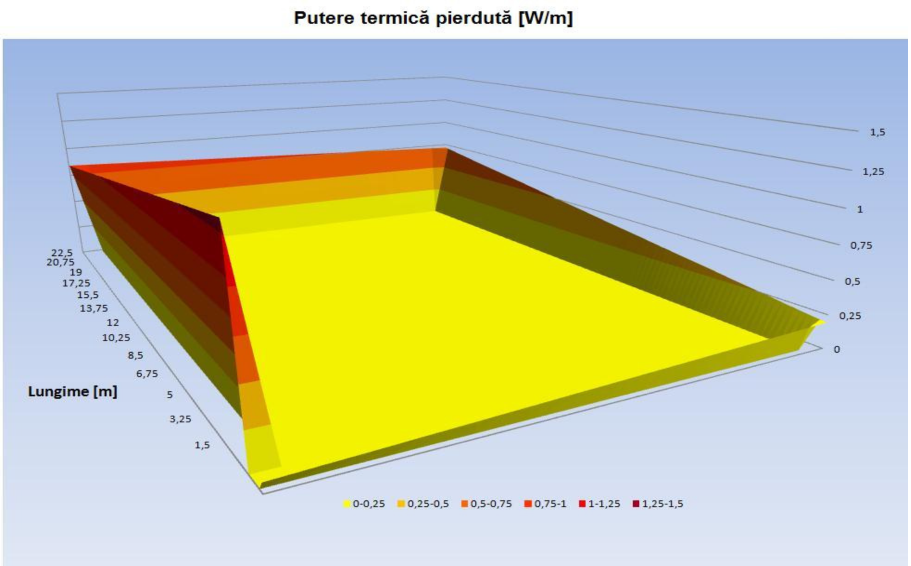

Fig. 10. *Thermal power lost on the pipeline after five minutes*

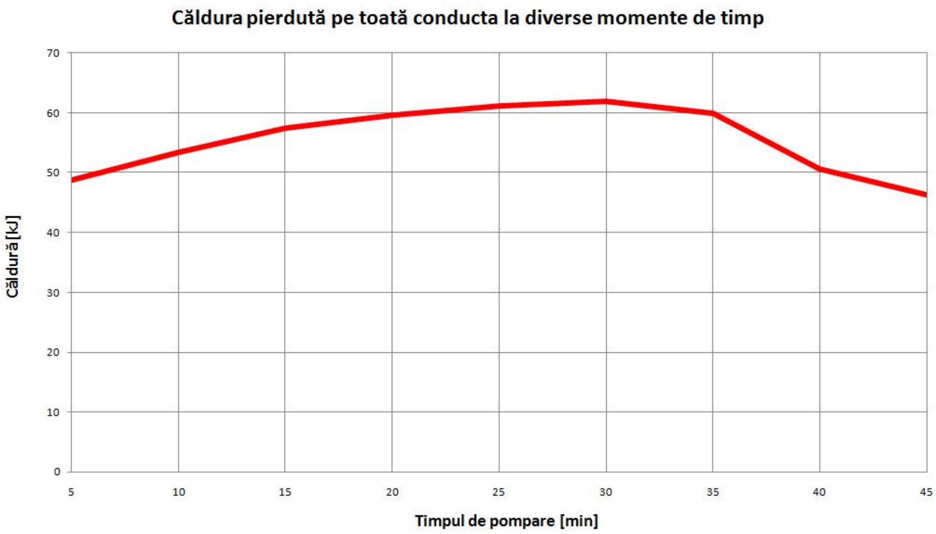

Fig. 11. *Heat lost over the entire duct*

In the graph above, the total heat lost over the entire duct at different moments of time is presented.

5. Conclusions

The monitoring device of the transport process has enabled, for the first time, to obtain complete data in the case of a pipeline buried in the soil.

A numerical model in the development medium DELPHI defined on the geometry of the experimental system for analyzing the thermal interaction between the transport pipe and soil was achieved.

We are able to monitor, during the transport process in several areas, the temperature field around the pipeline for the purpose of determining heat losses.

We obtained a 3D image of the dynamics of temperature field around the pipe through the derivative of temperature field at pipe wall, with the purpose of experimental determining of thermal power lost on various segments of the pipeline.

The results analysis shows that in the process of pumping the hot oil, there are two phases: the first phase in which the lost heat on the pipe increases, reaching a maximum and then the second phase of the heat lost when thermal power begins to decline.

The decrease of thermal power lost on the pipeline in phase II is due to, according to the experimental results, the warming of the soil around the pipeline and reducing the thermal gradient at the wall pipe.

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