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Methods and Means of Heat Losses Monitoring for Heat Pipelines

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Abstract
The structural features of laying the pipelines of thermal networks (underground and aboveground) are considered. The technical characteristics of modern UAVs are investigated and the possibility of their application for monitoring of heat losses in the main heat pipelines is considered. The possibilities of thermal aerial photography for detecting different types of defects on pipelines in a functioning state are explored. The characteristics and capabilities of the proposed set of devices for monitoring thermal losses in pipelines based on quadrocopters are considered.

Keywords: unmanned aerial vehicles, heat loses, heat pipelines, thermal aerial photography

1. Introduction

The urgency of the problem of diagnosing the technical condition of hazardous production facilities becomes more and more obvious every year. This is especially true for those objects, the destruction of which, even partial, can lead to anthropogenic catastrophe or significant material damage. Such facilities include constructive elements of the energy industry, oil refining and chemical industries: units, tanks, columns, pressure vessels, pipelines.
Wear and aging of the equipment make its operation dangerous, and periodic monitoring by standard monitoring tools often can't provide an adequate level of operational reliability, or its conducting is associated with a large loss of time for preparatory work.
The dangers threatening to the pipeline systems can be combined into two categories: accidents and sabotage. Many accidents are caused by excavations, inadequate system capacity, corrosion, weather conditions, mechanical failures, damages of the control system, operator errors, and natural disasters. Therefore, the tendency of the transition from periodic monitoring of such objects to their continuous monitoring becomes more and more noticeable.
Unmanned aerial vehicles (hereinafter referred to as UAVs), also known as drones, are already firmly entrenched in many areas of human activity. With the development of the aviation industry, the number of UAVs is growing at a high rate, as well as the range of tasks that they can solve. UAVs today are widely used by military, police and civilian services, including search and rescue, land management or topographic surveys.
The using of UAV for monitoring the technical condition of heat networks is also promising. Improvement of the monitoring system of the condition of heat pipelines on the basis of the UAV will allow to locate the places of possible pipeline ruptures or leakage of the coolant under the surface layer of the soil quickly.

2. Source analysis and problem statement

In Ukraine, many organizations and scientists are involved in the using of UAV for monitoring energy facilities. However, these works, in general, are taking a theoretical nature, or aiming at creation the software products for UAVs. This is due to the high cost of both: the UAV and the services of the UAV operators.

In Ukraine, the most significant contribution to the development of UAV belongs to the Igor Sikorsky Kiev Polytechnic Institute, the National Aviation University, a number of enterprises of the Ukroboronprom, and other enterprises and scientific institutions.
Among the scientists who made the greatest contribution to the development of UAV in Ukraine, it should be noted V.P. Babak [1-2], V.P. Kharchenko [3-4], O.V. Zbrutsky [5], O.I. Lysenko [6] and others.
One of the most relevant areas at the moment is the using of UAVs for monitoring and regulating traffic [7], the construction of navigational charts [8], creating the wireless communication systems [9] and others.
One of the areas of application of UAV is ecology. UAVs equipped with different sensors have been introduced for in-situ air quality monitoring, as they can offer new approaches and research opportunities in air pollution and emission monitoring, as well as for studying atmospheric trends, such as climate change, while ensuring urban and industrial air safety. The aims of this review were to: (1.) compile information on the use of UAVs for air quality studies; and (2.) assess their benefits and range of applications [10].
At the moment, there is no detailed study of the possibility of monitoring thermal facilities using UAV in the literature. Only some works testify to the possibility of using UAVs with television cameras for pipelines controlling, but they have a weak scientific component [11,12]. This indicates that we are at an early stage of using UAVs in order to diagnose different equipment.

3. Purpose and tasks of the study

The conducted studies were aimed at establishing approaches to monitoring the technical state of thermal networks (underground and aboveground) in the conditions of their operation without disconnecting consumers.
To achieve this goal, the following tasks were set:
- to explore the features of heat networks' constructions;
- to explore the technical characteristics of modern UAVs;
- to investigate approaches for the selection of optimal characteristics of the route of the UAV fleet;
- to offer an optimal method for monitoring the technical condition of the main heat networks;
- to offer technical means for monitoring the technical condition of the main heat networks.

4. Main part

4.1. Features of heat networks' construction

In district heating systems, the heat energy in the form of hot water or steam transports from the thermal power plant (TPP) or boiler houses to the consumer by special pipelines, which are called heat networks [13].
Heat networks are divided according to their intended purpose into:
- main – from the source of heat production to each microdistrict or enterprise;
- distributive or quarterly – from main networks to city blocks;
- intraquarter networks – up to separate buildings;
- branches from distribution (or trunk) networks to heat points of heat consumers.

The schemes of transportation of heat from the source to consumers depend on the type of coolant, the mutual location of production sources and consumers of thermal energy, as well as the nature of the change in heat load. The design of heat networks is significantly affected by

the thermal capacity of the thermal energy source and the prospects for the development of the district heating. The scheme of heat networks, in addition to high cost-effectiveness, must meet modern requirements for service life and reliability of operation. Depending on the configuration of the scheme, the heat networks are divided into radial and circular.
If short-term interruptions in heat consumption are permissible, sufficient to eliminate accidents on heating networks, then the use of radial schemes of heat networks is recommended (Fig. 1).

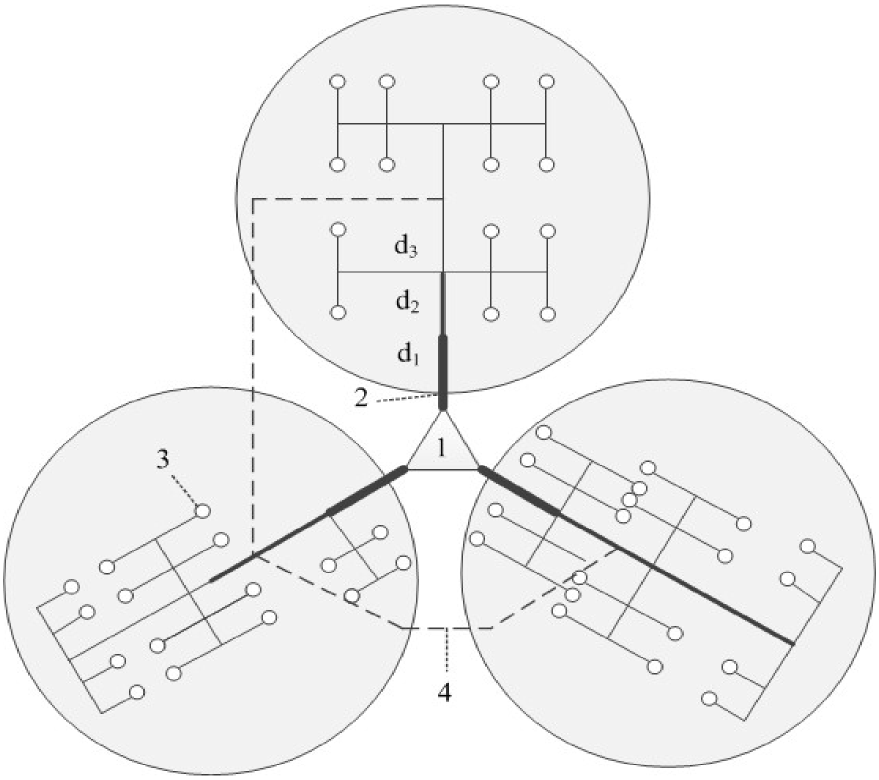


Figure 1. Structural diagram of radial heat networks:
1 – TPP; 2 – main pipelines (d – pipe's diameter, $d_1 > d_2 > d_3$);
3 – thermal energy consumers; 4 – jumper

Radial heat networks are constructed with a gradual decrease in the diameter of the pipes from the heat source. Such heat networks are also called dead-end, they have a lower cost than the circular ones, and they are also easy to operate. In case of accidents on the main sections of heat networks, the heat supply outside the emergency area is terminated.
If heat supply can't be stopped, heat radial-circular networks may be used to reserve heat in an emergency area, which differ from radial ones by using jumpers between the lines. Redundancy by jumper in most cases is ineffective due to the insufficient throughput of the jumpers, which have a smaller diameter than the diameter of the main pipes.
Circular heating networks (Fig. 2) have a high cost and combine several sources of thermal energy production for the purpose of optimally distributing heat load through heat stations and loading the most powerful and economical boiler units. Technical and economic studies have shown that the additional costs for the construction of a circular heat network of constant diameter pipes are most often compensated by a reduction in capital investments for the installation of smaller total reserve thermal capacities at the TPP.

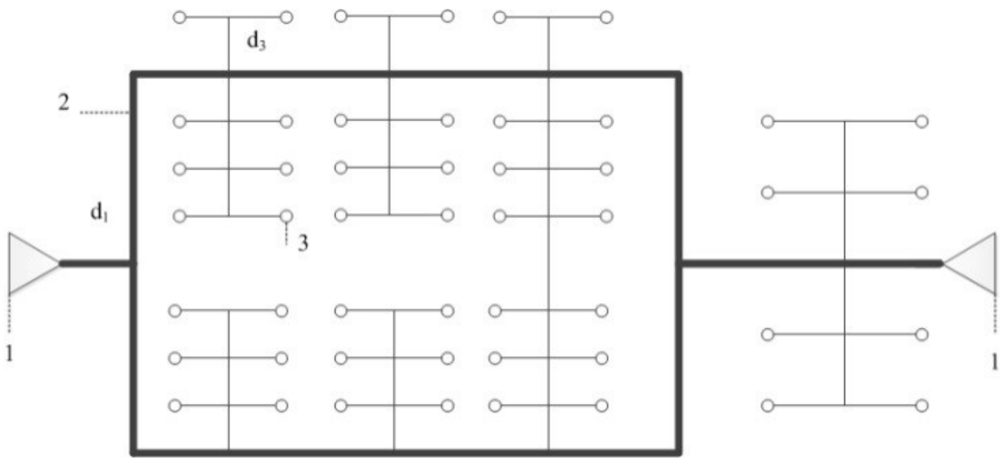


Figure 2. Structural diagram of annular heat networks:
1 – TPP; 2 – main pipelines (d – pipe diameter, $d_1 > d_3$);
3 – thermal energy consumers

Steam networks are designed mainly radial on the territory of industrial enterprises, where the thermal load is concentrated at a short distance and short breaks in heat supply are allowed. Laying of condensate lines for return of condensate to a source of thermal energy is carried out proceeding from local conditions and features of technological process.

4.2. UAV's characteristics

According to the international classification proposed by UVS International [14], all UAVs are divided into tactical UAVs with sublevels in range and altitude of action (Table 1), as well as strategic and special UAVs.

Table 1. Classification of tactical UAV

Name	Range, km	Maximum take-off weight, kg
Nano	<1	<0,025
μ	1-10	0,025-5
Mini	1-10	5-150
CR (Close Range)	10-30	25-150
SR (Short Range)	30-70	50-250
MR (Medium Range)	70-200	150-500
MRE (Medium Range Endurance)	>500	500-1500
LADP (Low Altitude Deep Penetration)	>250	250-2500
LALE (Low Altitude Long Endurance)	>500	15-25
MALE (Medium Altitude Long Endurance)	>500	1000-1500

Division into UAV's of aircraft, helicopter and other types in this classification is not provided. The United States of America and Israel are leaders in the development and production of UAV's. At this moment, countries such as South Korea, China, South Africa are entering the market of unmanned civilian systems.

For monitoring the environmental parameters of power objects, it is sufficient to have a practical flight altitude of up to 1 km, but modern small unmanned aerial systems (UAS) can be raised to a height of 2.5-3 km, which can be useful in case of accidents at energy facilities for obtaining panoramic images of the environment around the epicenter of the accident or for analyzing air quality at certain altitudes. The characteristics of some UAV's are shown in Table 2.

Table 2. Technical characteristics of UAV

Name	Micro B	MASS	SkybladeIII	Boomerang 1.3m	Jackaroo 1.5 m	SmartOne
Take-off weight, kg	1	5	2.4	2	2.5	1.1
Payload weight, kg	0.2	–	–	0.25	0.75	–
Wingspan, m	1	2.6	1.5	1.4	1.5	1.2
Lengh, m	–	1.4	1.3	1.3	1.5	–
Speed (max), km/h	80	130	80	105	105	50
Flight altitude, km	–	0.5	–	3.5	3.5	0.6
Action radius, km	10	8	10	25	25	2.5
Flight duration (max), h	1	1	1	1.5	2.5	1

Thus, based on previous studies [13], for monitoring the environmental parameters of energy facilities, it is recommended to use a UAS with two UAVs of aircraft and helicopter type of mini class, with mass up to 10 kg, flight range up to 50 km, low altitude (practical altitude up to 2 km), electric motor, remotely piloted, but with the functions of automatic flight along a given route, vertical take-off and landing (for a multi-rotor platform) and starting from a hand and landing (for aircraft-type of UAV), with data transfer in real time and the accumulation of data on board (for different types of sensors).

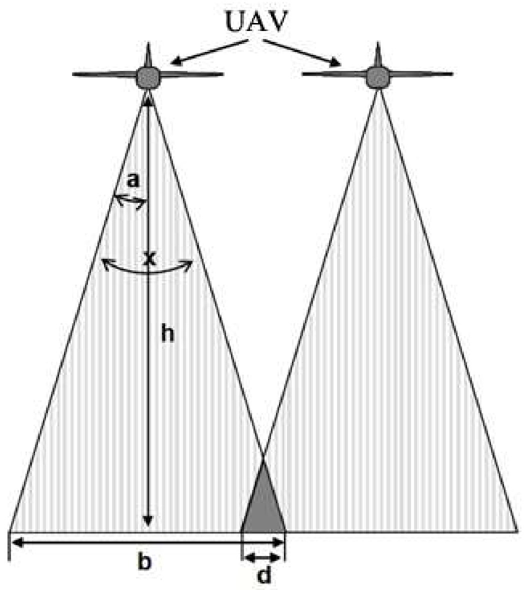
4.3. Optimal characteristics of the UAV route

The choosing of the route option depends on the task, the method of searching for objects, their mobility, size, visibility and density of location on the ground.

For general review of the territory, the most expedient is the circular closed route. The main advantages of this method are coverage of a large area, speed and speed of monitoring, the possibility of examining hard-to-reach areas of the terrain, a relatively simple flight task planning and operational processing of the results obtained. The route should provide an overview of the entire work area. For the rational using of UAV energy resources, it is advisable to route the flight route with the expectation that the first half of the UAV flight will take place against the direction of the wind.

Straight parallel mutually parallel routes are used for detailed inspection of individual sections of the terrain within the working area.

A parallel route is recommended for aerial surveying of terrain areas. During preparing a route, the operator must take into account the maximum width of the UAV camera's field of view at a given altitude of its flight. The route is laid so that the border areas of the field of view of the camera overlap neighboring fields by at least 15-20% (Fig. 3).



a – the half of the viewing angle of the UAV camera,
x – the aperture of the UAV camera,
h – the UAV flight height,
b – the UAV survey width,
d – the UAV inspection overlap area

Figure 3. UAV's layout with parallel aerial survey route

Calculating the distance between the neighboring edges of the field of view of the camera in a parallel passage, taking into account the 15% overlap, the operator for turning the UAV to the required radius and the UAV exit to the straight line until the next turning point, places an additional turning point equal to the scale of the X meter map (Fig. 4).

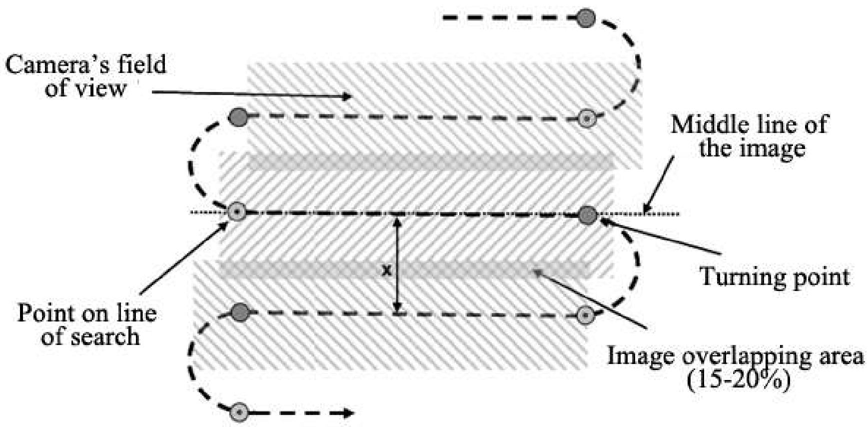


Figure 4. Scheme of flying around a monitoring object using a UAV

Aerial photography of areas of the terrain is expedient to spend in the morning and evening time of the day in the absence of ascending and descending air currents affecting the horizontal flight of the UAV.

4.4. Possibilities of thermal aerial photography

Thermal aerial photography at this moment is the only way, which in short time intervals allows to identify emergency and potentially defective parts of pipelines of heating networks. With its help it is possible to quickly investigate significant areas of the urban landscape and with high reliability to fix abnormal sections of the temperature field on the ground surface.

Usually thermal aerial photography is performed at an altitude of 300-400 m along a system of parallel routes with an inter-route distance of 300-500 m, which provides at least 40% overlap of the image to obtain a picture of the distribution of thermal energy in the plane. Thermal aerial photography is performed in the early spring or late autumn in the absence of snow cover, when the heating networks function in the operating mode. To eliminate the distorting thermal effects from solar insolation, aerial photography should be carried out at night, less often in the daytime with high continuous clouds. Aerial photography is not carried out with fog, precipitation and wind speed exceeding 10 m/s.
Hidden places of leakage of the heat carrier, zones of destruction of thermal insulation, areas of flooding of heat pipes are confidently fixed on thermograms obtained during thermal aerial photography (Fig. 5).

Figure 5. A snapshot of the residential area obtained during the thermal aerial photography

Experimentally established the possibility of assessing the state of thermal networks in 4 grades, which can be indicated by different shades on the thermogram [15]:
1) normalized heat losses (characterized by dry and integral insulation of pipelines and minimum heat flow from the coolant to the earth's surface).
2) increased heat loss (characterized by wet or broken heat insulation of pipelines, which contributes to the nucleation of foci of corrosive destruction, a clear anomaly of the average brightness level and a slightly enlarged width of the thermal trace can be displayed in the thermal field).
3) high heat losses (characterized by broken and wet insulation of pipelines, the channel is often filled with water from neighboring water-bearing communications, ground or meltwater, in the thermal field it shows like a high-contrast anomaly with a width in several times greater than the norm).
4) emergency condition (characterized by a violation of the integrity of the pipeline with a spill of heat carrier. The anomaly of the thermal field has a very high contrast and a wide diffuse shape, due to the peculiarities of the microrelief).
The main task of thermal aerial photography is reduced not only to the detection of emergency areas. As a rule, in case of a pipeline rupture, such places are quickly localized and the necessary measures are taken. One of its tasks is to predict the development of emergency situations for preventing their occurrence. Moreover, the structures of building heat networks are suitable for conducting thermal aerial photography.

4.5. Means for thermal aerial photography

Within the framework of the scientific research work of the National Academy of Sciences of Ukraine "Development of the methodology for monitoring the thermal state of the main heating systems on the basis of quadrocopters" the scientists of the Institute of Technical Thermophysics have proposed a set of modules for monitoring the technical condition of the main thermal pipelines. The complex consists of a Nokia 6 smartphone based on the Android operating system with preinstalled software and a compact thermal imager manufactured by Seek Thermal. The complex is located inside the shockproof case and is attached to the bottom of the quadrocopter.
Some technical characteristics of the proposed complex are given in Table 3.

Table 3. Technical characteristics of the proposed complex

Parameter	Value
Screen resolution	206x156
Field of view, °	20
Frame rate, Hz	<9
Detection distance, m	≤500
Temperature range, °C	-40…330

Figure 6 shows an example of a thermal imaging pattern obtained with the aid of the proposed complex.

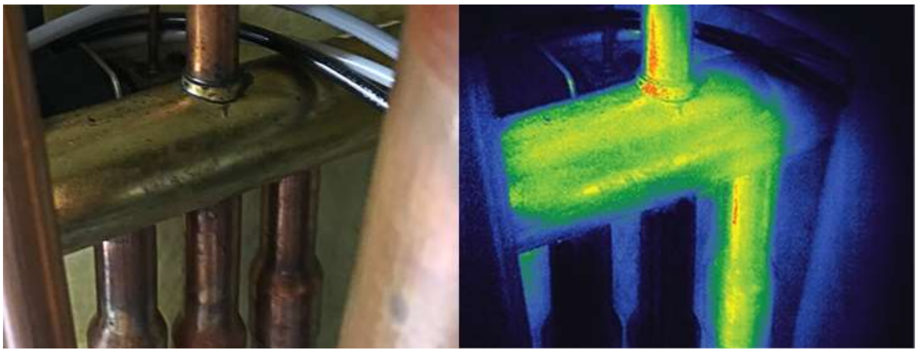


Figure 6. Thermal photo taken during the diagnosis of faulty valves

In the near future, it is planned to conduct a comprehensive monitoring of the technical condition of the main heating network site in Kiev with the help of the proposed complex.

5. Conclusions

On the basis of normative documentation and open sources, the features of constructing thermal networks (underground and above-ground ones) are investigated. It is shown that the basic structural schemes of laying pipelines are radial and annular. For radial heating networks, territorial zones for the investigation of individual sections of the pipeline have been identified. The conducted researches showed that at present there is no universal method for monitoring the technical condition of pipelines of heating networks. The results of the analysis of regulatory documentation indicate that for heating systems in the state of operation, there are no descriptions of control techniques based on the integrated use of modern non-contact methods. It is shown that one of the perspective methods of diagnosing the condition of pipelines of thermal networks is thermal aerial photography based on modern unmanned aerial vehicles. World practice of widespread using of UAVs for monitoring environmental characteristics indicates their effectiveness, economy, and high reliability of control results.

The proposed complex for monitoring the technical condition of main heating networks is the only alternative for the timely detection of emergency sections of heating networks. This development will significantly reduce the cost of repair work, preventing emergencies.

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