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POSSIBILITIES OF USING THERMAL IMAGING TO DIAGNOSE FUEL INSTALLATIONS AND DISTRIBUTION EQUIPMENT IN AVIATION UNITS

MOŻLIWOŚCI WYKORZYSTANIA TERMOWIZJI DO DIAGNOSTYKI INSTALACJI PALIWOWYCH I SPRZĘTU DYSTRYBUCYJNEGO W JEDNOSTKACH LOTNICZYCH

Abstract

The fire hazard is one of the main threats occurring in the process of securing military units' liquid fuels. Due to the quantity and intensity of fuel consumption, aviation is the branch of the Armed Forces where this threat occurs. In order to reduce the occurrence of this hazard, it was assumed that the use of a thermal imaging camera for diagnostics and assessment of the efficiency of equipment and fuel infrastructure at military airports is possible. Based on the conducted research using this type of camera at two airport facilities, the possibility of carrying out diagnostics and assessing equipment efficiency has been confirmed.

Keywords: termovision, fire safety, fuel instalation, distribution equipment, diagnostics

Streszczenie

Zagrożenie pożarowe to jedno z głównych zagrożeń występujących w procesie zabezpieczenia jednostek wojskowych w paliwa płynne. Ze względu na ilość i intensywność zużywanego paliwa rodzajem Sił Zbrojnych, gdzie to zagrożenie występuje, jest lotnictwo. W celu ograniczenia wystąpienia tego zagrożenia przyjęto założenie, że zastosowanie kamery termowizyjnej do diagnostyki i oceny sprawności sprzętu i infrastruktury paliwowej na lotniskach wojskowych jest możliwe. Na podstawie przeprowadzonych badań przy użyciu tego typu kamery na dwóch obiektach lotniskowych potwierdzono możliwość realizacji diagnostyki oraz oceny sprawności sprzętu.

Słowa kluczowe: termowizja, bezpieczeństwo pożarowe, instalacje paliwowe, sprzęt dystrybucyjny, diagnostyka

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1. INTRODUCTION

Recently, especially during the pandemia of coronavirus, the use of thermal imaging cameras in everyday life has significantly increased. The development of technology enabling non-contact measurement of the temperature of the tested object has resulted in greater availability and popularity of the devices. Measuring temperature by this method does not require direct contact with the measurement object and does not need of installation additional sensors on the tested object. It opens up many possibilities of use. Especially where the increased temperature of the object may have an impact on the safety of the facility or environment. Early detection of excessive temperature rise of the device will prevent costly failures, downtime or fire.

The Armed Forces are a formation in which, due to the existing threats, this technology may be used for diagnostics of infrastructure or military technique. One of the logistics services where fire issues are extremely important for the safety of personnel, stored materials and the natural environment is the Propellants and Lubricants service. The research carried out attempted to confirm that it is possible to use a thermal imaging camera for diagnostics and assessment of the efficiency of the service's distribution equipment.

2. SPECIFICITY OF THERMAL IMAGING MEASUREMENTS

Thermal imaging is closely related to the discovery of infrared radiation in 1800 by the English astronomer Friedrich Wilhelm Herschel. This radiation is a type of electromagnetic radiation with a frequency lower than visible light in the range below 1000 µm.

Thermal imaging examination involves non-contact measurement of the temperature of the examined object. The operating range of thermal imaging devices is in the range from 780 nm to 14 µm (Fig. 1).

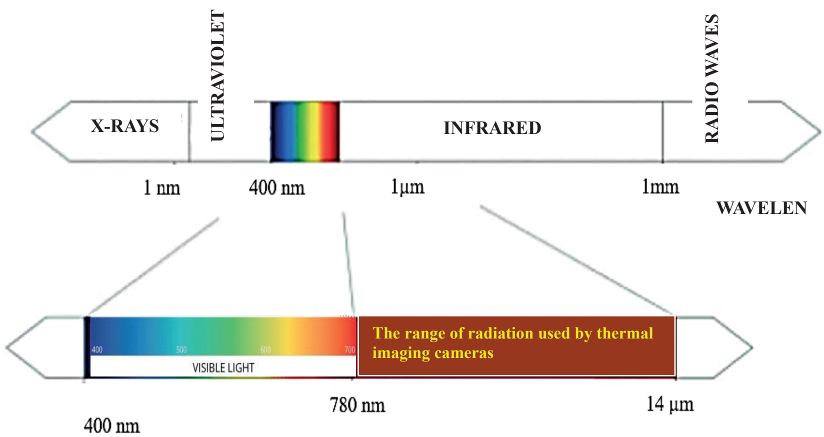

Fig. 1. Infrared radiation range

Source: S. Ling, W. Moebs, J. Sanny, Physics for higher education, Volume 3, 16.5 Spectrum of electromagnetic radiation.

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Every element whose temperature is higher than absolute zero - 0 K (− 273°C), is a source of infrared radiation. The intensity of infrared radiation depends on the temperature and surface features of a given body. Even when an object is not hot enough to emit visible light, most of its energy will be emitted in the infrared range[1].

Thermal imaging devices generate an image of infrared or "thermal" radiation that is invisible to the eye. In the infrared image, there are no colours or even "shades of gray", but only radiation of varying intensity. The camera converts this radiation into a visible image generated on the display (Fig. 2).

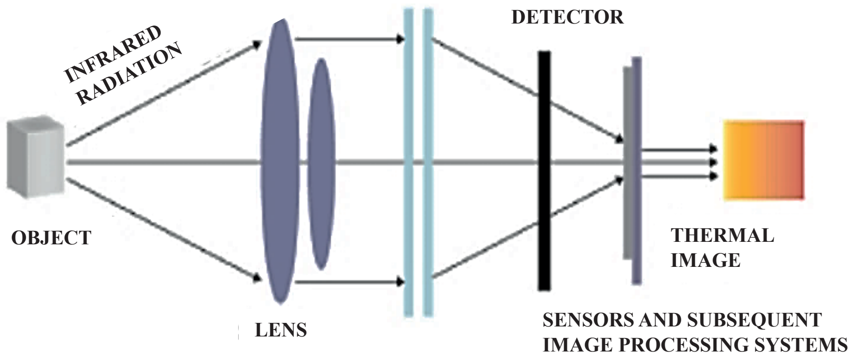

Fig. 2. Thermal image registration process

Source: G. Rudkowski, Thermal imaging and its applications, Transport and Communication Publishers, Warsaw 1978.

The radiation value is a function of the object's surface temperature, which allows to perform calculations and displays temperature. The radiation received by the camera depends not only on the temperature of the examined object, but also on its emissivity function. Radiation also comes from the environment and is reflected by the tested object. The resultant radiation of an object is the radiation of the object itself and the reflected radiation and absorption of the atmosphere. Accurate temperature measurement requires compensation of the influence of other radiation-generating sources. Compensation is performed by the camera automatically, but it requires the prior introduction of the emissivity value of the tested object. The radiation generated by the object passes through an optical system that focuses the infrared energy on a detector system (sensor matrix) composed from the thousands of pixels in the form of a grid. A single pixel converts infrared energy into an electrical signal. The camera processor creates a map of the apparent temperature of the examined object. Each radiation value is presented in a different colour[2]. Modern thermal imaging cameras have the ability to absorb visible light, thanks to

[1] G. Rudkowski, Thermal vision and its applications, Transport and Communication Publishers, Warsaw 1978, pp. 31–39, 51–55.

[2] Ibidem.

which a digital image is also recorded. It allows the infrared image to be linked to the real image of the object (Fig. 3).

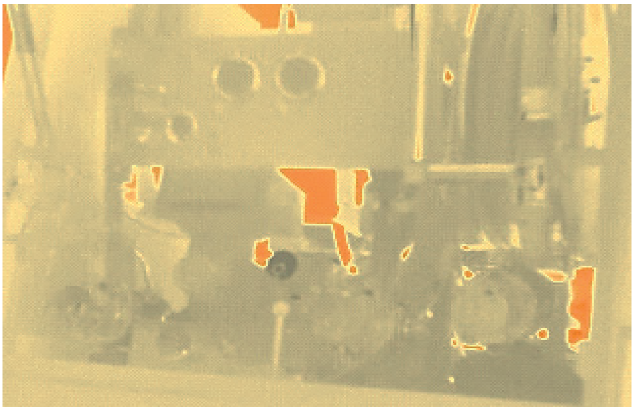

Fig. 3. Temperature image of the distribution node of the CND-33 tanker dispenser of aviation fuel
Source: authors.

The measurement results using a thermal imaging camera are significantly influenced by a number of different factors, which may be caused by external influences or the human factor. It is important to reduce or remove factors influencing measurement error. It is necessary to correctly determine the emissivity of the tested object, perform the measurement from an appropriate distance and use the appropriate angle of measurement.

The most common mistake is improper setting of the measurement temperature range. Another common mistake is incorrect setting of the emissivity and the apparent reflected temperature. The emissivity is influenced by the physical and chemical parameters of the examined object; it is a unique parameter that distinguishes a given object. If the value of this parameter is high, it makes the measurement easier, but if the value is close to zero, it is more difficult to perform the correct measurement. The efficiency of the object's thermal radiation determines the emissivity. It is determined on a scale from 0 to 1, the value 0 is assigned to a object with mirror properties (reflecting radiation), while the value 1 describes an object absorbing all the energy, the so-called black object. Both values are theoretical values, both are unattainable. An object acting as a mirror reflects the ambient temperature - the camera will show the result relating to the objects surrounding the examined object. However, when measuring an object with higher emissivity, in order to reduce these differences, it is necessary to set the appropriate emissivity and reflected temperature as the ambient temperature.

The observation angle and distance from the object have a significant impact on the measurement accuracy. The appropriate measurement angle allows to obtain

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a reliable result. Carrying out measurements at an angle other than the permissible angle may lead to incorrect measurement and erroneous result. Equally important is the distance of the measuring device from the tested object, which reduces the radiation density and may increase the measurement error. Atmospheric conditions like rain, sun, fog, dust, strong wind[3], also effect on the accuracy of the measurement. The difference between the environmental temperature and the temperature in which the thermal imaging camera was stored is important for the accuracy of the measurement. In case of large differences in these temperatures, it is necessary to to compensate them by acclimatizing the device to the temperature at which the measurement will be used by a period of 10 to 60 minutes[4].

For the research the Testo 882 thermal imaging camera was used. The camera is designed to detect thermal anomalies and weak points in materials (Fig. 4).

Fig. 4. Testo 882 thermal imaging camera
Source: authors.

This version of the camera is characterized by a high detector resolution, i.e. 320 x 240 pixels, thanks to which the matrix can measure the temperature of 76,800 points simultaneously. The camera is equipped with a solar module that allows you to enter the solar radiation parameter and a 32-degree wide-angle lens that facilitates the recording of large sections of objects. The camera allows to measure temperatures in a wide range, up to 550°C[5]. The Testo IrSoft program version 5.0, designed for the interpretation of infrared images, was used to correctly read and process the images. The program allows to visualize the maximum and minimum temperature values, as well as the ability to set multiple measurement points and make temperature corrections, which to change the emissivity of the tested material and select the hottest or coldest place in the image. It is also possible to change the setting of ambient

3 A. Hulewicz, Thermal imaging diagnostics in electrical engineering, Poznań University of Technology Academic Journals No. 89, Electrical Engineering 2017, pp. 259–262.
4 Ibidem.
5 Testo 882 thermal imaging camera manual.

temperature, external or internal temperature, humidity, reflected temperature or emissivity (software IRSOFT, 2019)[6].

2. FIRE HAZARDS OCCURRING IN THE PROPELLANTS AND LUBRICANTS SERVICE

It is one of the services of the material subsystem of the Polish Armed Forces, dealing with, among other things, the collection, maintenance and distribution of liquid fuels, oils, lubricants and special products. Liquid fuels, some oils and some special products are products that can be classified into one of three classes of petroleum products based on their ignition temperature (Table 1). The ignition temperature is defined as the lowest temperature at which fuel heated under standard conditions will release a sufficient amount of vapor to produce a mixture with air that ignites near a flame with an energy of 5 mJ[7].

Table 1. Division of petroleum products according to the flash point of the liquid

Class	Petroleum product	Flash point °C
I	Crude oil and its derivatives	down 21
II	Petroleum products	21 ÷ 55
III	Petroleum products	55 ÷ 100

Source: own study based on K. Górska, W. Górski, Propellant materials and lubricants, Transport and Communication Publishers, Warsaw 1986.

The affiliation of individual petroleum products to one of three groups determines the risk of fire hazard, which affects storage conditions, the location of storage tanks and the procedures for transporting and distributing these products. Class I and II products pose the greatest fire risk and pose the strictest requirements for storage and distribution. The following liquid fuels stored in military units, especially aviation units, qualify for these groups: aviation fuel, diesel oil and automotive gasoline (Table 2).

Table 2. Ignition temperature of selected liquid fuels stored in military fuel depots

Fuel Type	Flash point, °C
Automotive gasoline	– 40 ÷ – 20
Aviation fuel	28 ÷ 47
Diesel fuel	35 ÷ 75
Ship fuel	min. 65

Source: own study based on K. Górska, W. Górski, Propellant materials and lubricants, op. cit.

6 https://www.testo.com/pl-PL/kamery-termowizyjne/oprogramowanie-irsoft [access: 5.03.2023].
7 K. Górska, W. Górski, Propellants and lubricants, op. cit.

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Due to the decreasing share of vehicles and equipment equipped with gasoline-powered engines, consumption and stored quantities in fuel depots are decreasing. Most often, there are single, small-capacity storage tanks that allow for maintaining a supply of gasoline to meet the current needs of a military unit. Depending on the type of military unit, the dominant fuel stored and consumed may be diesel or aviation fuel.

Diesel oil, despite having a composition of hydrocarbon groups similar to aviation fuel, is a fuel with a lower fire risk. Moreover, the intensity and volume of aviation fuel demand for one piece of military equipment (aircraft) determines this type of liquid fuel to be of particular interest in terms of compliance with distribution and storage procedures, but also fire safety.

In order to reduce the risk of fire when storing liquid fuels in military fuel depots, underground and semi-underground tanks are used. An underground tank is a tank placed below the ground level and covered with an appropriate layer of soil.

However, semi-underground tanks used in military fuel depots are located below ground level (in a trench), while the remaining part above ground level is also covered with a layer of soil. This solution significantly reduces the impact of ambient temperature on stored fuels. This results in smaller fluctuations in the temperature of the stored fuel, which contributes to lower emissions of fuel vapours into the atmosphere. Lower emissions of fuel vapours mean less pollution of the natural environment but also reduce the risk of fire at the fuel depot.

Fig. 5. Pumping units for fuel manipulation at the air base fuel depot
Source: authors.

Due to the above, the scope of the research included devices (pump units) used to manipulate aviation fuel at the airbase fuel depot (Fig. 5), elements of the tanker-dispenser distribution node (c-dl) (Fig. 6) and stationary dispensers for dispensing fuel for vehicles and ground equipment at a military fuel station (Fig. 7).

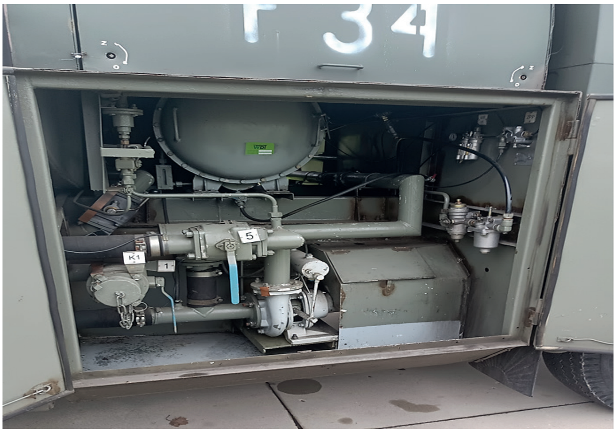

Fig. 6. Fuel installation on the CD-7.5 B tanker-dispenser

Source: authors.

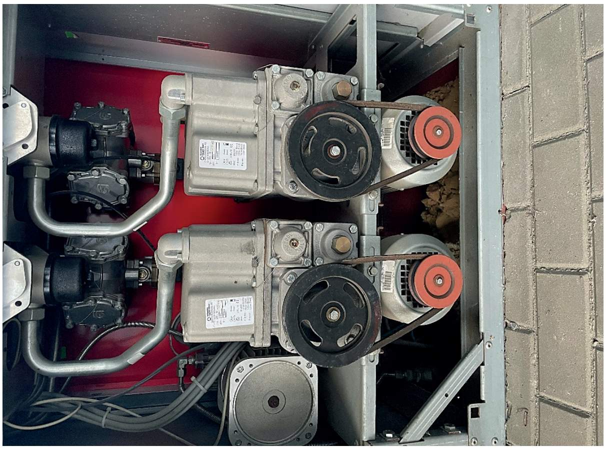

Fig. 7. Fuel pumps of a stationary fuel dispenser

Source: authors.

The measurements covered representative stationary and mobile devices of the MPS service intended for pumping and distributing liquid fuels. In the case of stationary equipment, elements which, due to their structure and operating characteristics, may be prone to heating up include the following elements (Fig. 8):

− stuffing boxes and bearings of the pump drive shafts;
− electric drive engines;
− power transmission components.

Pump sets used at air base fuel depots (as in Fig. 3) are used to receive liquid fuels from rail or road transport into storage tanks, dispense them from these tanks to the tankers-distributors or perform manipulation (pushing) of fuel between individual

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tanks. The operation of these sets is usually characterized by long operating times, which contributes to the heating of the working elements despite being cooled by the pumped product. Whereas, in the case of mobile distribution equipment, the operating time of these devices is much shorter than that of stationary devices, however, these devices are exposed to higher ambient temperatures (especially in summer) and pumping liquid fuels at higher temperatures in the summer due to the impact of sunlight on the main tank of the tanker distributor. In such a case, a slight increase in temperature of the elements in contact with the fuel may significantly increase the fire hazard for the device and for objects in the close vicinity.

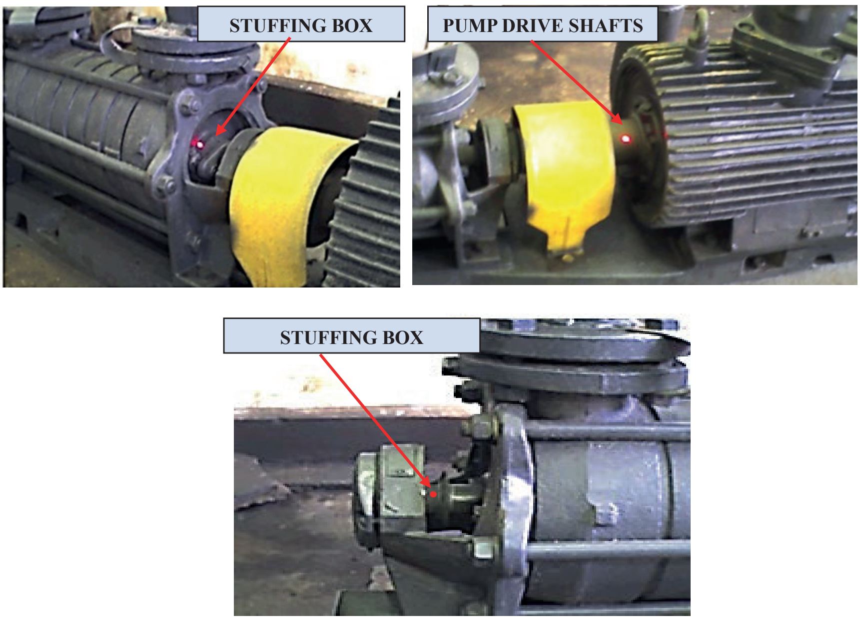

Fig. 8. Structural elements of the pumping set of the air base pumping station potentially exposed to excessive heating

Source: authors.

3. TESTS OF TEMPERATURE CHANGES OF DISTRIBUTION EQUIPMENT COMPONENTS

The research was conducted on air base facilities and distribution equipment of two air bases in the period from September to December 2022. The ambient temperatures during the measurement period ranged from–2.7°C ÷ + 17°C. The measurements were carried out according to the following scheme:

- measurement of ambient temperature;
- measurement the temperature of individual structural elements (control points), particularly exposed to temperature increases during operation;

– measurements the temperature at the above points during device operation at specified time intervals;
– measurement the temperature at the above-mentioned points after completion of operation of the device.

The operating time for individual devices was different due to the purpose of the tested device and its specific operation.

A. Pump sets for handling aviation fuel at airport depots are most often used with two different pump sets in terms of efficiency (Fig. 9).
   - Sets with high capacity exceeding 1.500 l/min, equipped with centrifugal pumps used to pump fuel from transport vehicles (road tankers, railway tanks) to storage tanks, manipulation between individual storage tanks and to pump fuel to the transport vehicles. For this last operation, depending on the needs (the capacity of the tanks of the transport vehicles) and the design of the pumping station, pump sets with lower efficiency may be used.
   - Sets with low capacity not exceeding 800 l/min, equipped with multi-stage axial rotor pumps, used to manipulate fuel between tanks or the tank and the transport vehicle. These sets most often empty storage tanks of the so-called the residual part of the tank or when emptying the fuel system of an air base depot.

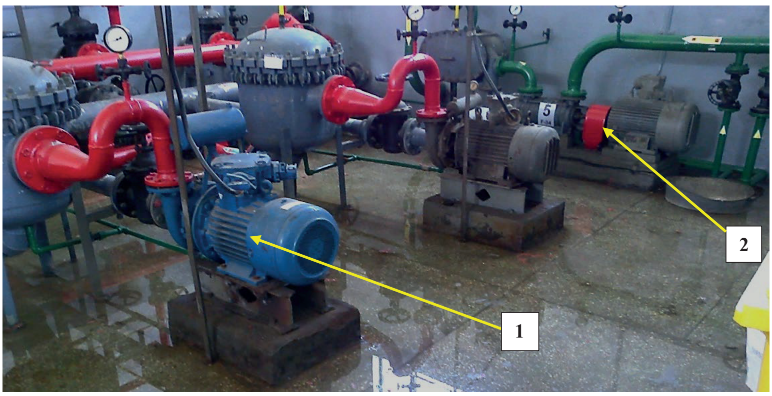

Fig. 9. Pumping sets of the airport pumping station: 1 – set equipped with a centrifugal rotor pump, 2 – set equipped with a multi-stage axial rotor pump
Source: authors.

B. (distribution node) on a truck chassis, intended for transporting, storing and dispensing liquid fuels to aircraft. Depending on the design, the capacity of the distribution node may be from 700 l/min. up to 1.000 l/min. Depending on the capacity of the main tank, tankers-dispensers equipped with tanks with a capacity of more than 20.000 liters are equipped with pumps with higher efficiency ensuring quick delivery of fuel to the aircraft. In both cases, centrifugal rotor pumps are used, the significant difference is the pump drive. In older designs, it is

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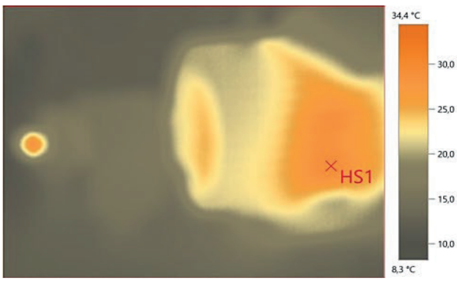
a mechanical drive, via a belt transmission or cardan shaft from the power transmission gears. However, for newer designs, the fuel pump is driven by a hydraulic motor powered by a hydraulic pump driven by the power transmission gears.

C. Stationary dispensers for dispensing automotive fuels for military equipment. Depending on the intended use, the capacity of individual dispensers ranges from 40 – 120 l/min. The pumps in the dispensers are driven by electric motors via a belt transmission.

The results of measurements performed on individual devices according to the assumed procedure, most of the measurement points did not show values that fell into the temperature range posing a risk of fire or indicated improper operation of components cooperating with each other. However, in the case of measuring the temperature of the measuring points of the pump set, after 15 min. operation, there was an increase in temperature at two measurement points, casing of the electric motor up to 29.0°C (Fig. 10) and the pump stuffing box on the side of the electric motor up to 28.6°C.



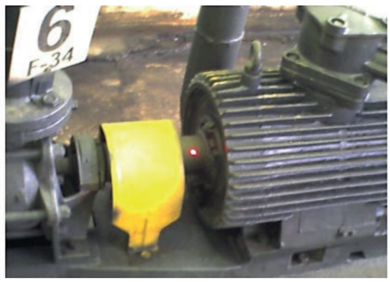


Photo parameters:
Emissivity 0,98
Temperature reflected from an object [°C] 17,0

Markings in the photos:			
Measurement objects	Temperature [°C]	Emissivity	Reflected temperature
The warmest point	29,0	0,98	17,0

Fig. 10. Measurement after 15 minutes of operation, pump stuffing box and electric motor housing

Source: authors.

After 30 min. of operation, the engine housing temperature reached 33.6°C, the pump stuffing box temperature reached 34°C (Fig. 11), the temperature of both measurement points creates a fire hazard.

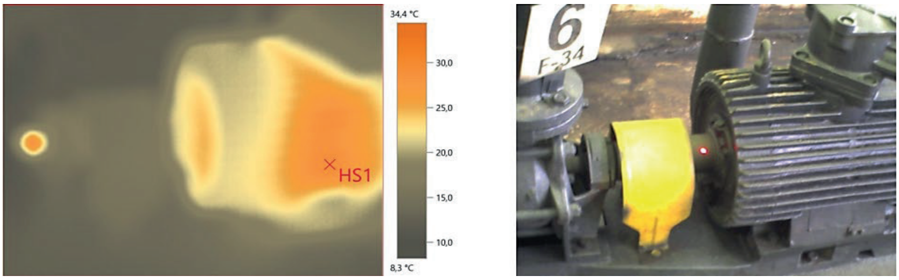


Photo parameters:
Emissivity 0,98
Temperature reflected from an object [°C] 17,0

Markings in the photos:			
Measurement objects	Temperature [°C]	Emissivity	Reflected temperature
The warmest point	29,0	0,98	17,0

Fig. 11. Measurement after 30 minutes of operation, pump stuffing box and electric motor housing

Source: authors.

The increase in temperature on the pump stuffing box may be related to the thermal conductivity of the elements transmitting power from the electric motor (drive shaft), however, the pump stuffing box is cooled from the pump side by the pumped aviation fuel, which temperature was 11.3°C. Therefore, the pump element (stuffing box) should not reach a temperature comparable to the engine temperature. This may indicate that the stuffing box sealing elements are heating up. This may indicate excessive tightening of the screws regulating the pressure of the seals on the pump shaft; if the pump is operated for a longer period of time, it could cause the stuffing box to seize and, in the worst case, cause the pump to leak and ignite the leaking fuel. After completing the measurements, a preliminary analysis of the results was made and the staff of the airport fuel depot were informed about the threat. Information was obtained that this pump had already experienced a case of excessive stuffing box overheating. The incident was noticed by the pump station staff when a plume of smoke appeared from the stuffing box.

It was the stuffing box on the outside of the set. After turning off the set and loosening the screws adjusting the stuffing box seal, this element no longer overheated, as was found during measurements. The stuffing box reached max. temp. 16.8°C after 15 min. of operation, this temperature was maintained until the end of the set's operation.

4. SUMMARY

The obtained test results and interviews with staff confirm the assumption that a thermal imaging camera can be an effective tool for quick diagnostics and assessment of the efficiency of distribution equipment for propellants and lubricants. Analysing the

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case of the pump set at the airport fuel depot, especially its previous work intensity and the period since the last service, it was found that the pump had not been used for a long period. This could result in leaks from the pump stuffing box, in which case the staff tightens the box adjustment screws to reduce leaks and fuel losses. Starting the set and increased work intensity led to the stuffing box overheating.

It comes to the conclusion that after a long period of non-use of pump sets or after performing maintenance work, the first start-up should be subject to checking the temperature distribution on such elements as: pump stuffing box, bearings of the pump and electric motor, electric motor housing.

This becomes particularly important during periods of high ambient temperatures, which will result in increased fuel temperature and then any excessive overheating of fuel infrastructure elements may pose a risk of fire outbreak and environmental pollution.

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