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THERMOGRAPHIC ASSESSMENT OF PRESSURE RELIEF VALVE OPERATION

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Abstract: This paper presents a thermographic investigation of the Bowen HR560 coiled tubing unit, used in drilling operations in oilfield applications. The unit enables well interventions using coiled tubing, including pressure control via safety valves. The aim of this study was to assess the operational condition and detect potential malfunctions in the unit, particularly around the pressure relief valve, using thermography as a non-invasive diagnostic method. An infrared camera was employed to identify thermal anomalies, such as localized overheating, which may indicate mechanical faults, inadequate lubrication, or excessive operating pressure.The obtained thermograms were compared with reference thermal profiles to detect deviations and potential indicators of operational issues. The results demonstrate that thermography is an effective tool for early fault detection and for maintaining the operational reliability of coiled tubing units, thereby contributing to safety and uninterrupted performance in well intervention operations.
Key words: Coiled tubing unit, pressure relief valve, thermography.

INTRODUCTION

In modern technical systems, early detection of potential failures represents a key factor in maintaining reliability, safety, and operational efficiency. The application of diagnostic tools and methods enables timely detection of anomalies, thereby preventing failure escalation, reducing the costs of unscheduled maintenance, and minimizing downtime. In this context, the systematic integration of fault detection and diagnostic algorithms—ranging from traditional methods such as Failure Modes and Effects Analysis (FMEA) and Root Cause Analysis (RCA) to advanced AI-driven techniques, has become fundamental for the development of more resilient and self-adaptive technical systems, [1-5].
Complex systems, often operating under functional, safety, and economic constraints, must be equipped with tools that enable continuous monitoring of their condition. Sensor data (vibration, thermal, ultrasonic, etc.), combined with model-based and data-driven approaches, enable not only fault detection but also fault prediction, thereby facilitating the transition from reactive to proactive maintenance, so-called predictive maintenance. Such systems not only extend the operational lifespan of equipment but also enhance safety and optimize the utilization of resources, [6-9].
In the field of technical diagnostics, thermography stands out as a method that enables system inspection under real operating conditions without the need to interrupt processes, thereby minimizing operational losses. The identification of localized zones of elevated temperature often indicates mechanical defects (e.g., faulty bearings, inadequate lubrication), electrical faults (e.g., increased contact resistance, conductor overloading), or inefficient heat transfer processes (e.g., thermal bridges, degraded insulation), [10-12].
The industrial application of thermography encompasses a wide range of sectors and operational scenarios. In power systems, it is used for the preventive detection of anomalies in transformers, disconnectors, circuit breakers, and conductors, thereby reducing the probability of catastrophic failures and extending the service life of components. In the machinery industry, thermographic inspection of power units, rotating machines, and transmission assemblies enables early detection of irregularities in tribological pairs and cooling systems. In the process and chemical industries, it is applied to detect fluid leakages, identify non-uniform temperature distributions in reactors and heat exchangers, and optimize the energy efficiency of facilities.

Within modern predictive and proactive maintenance concepts, thermography is integrated with data acquisition systems, IoT networks, and machine learning algorithms, enabling automated processing of large volumes of thermal data and the development of adaptive models for equipment condition assessment. This approach contributes to increased reliability, reduced life-cycle costs, and enhanced operational safety, making thermography an indispensable diagnostic tool in Industry 4.0 and future smart manufacturing systems.
In addition to protecting pumps, pipes, couplings, and actuator components from overload, pressure relief valves ensure system operational stability by maintaining optimal pressure conditions during load variations or unforeseen operational disturbances.
In modern hydraulic systems, pressure relief valves are designed with a high degree of precision and reliability, often featuring fine pressure adjustment capabilities and integration with electronic monitoring systems. They vary in design and operation—from direct-acting valves, which respond rapidly to pressure spikes, to pilot-operated valves, which provide more stable operation under high flow rates and elevated pressures. Proper selection, sizing, and maintenance of these valves are essential for the longevity and safe operation of hydraulic systems, particularly in high-pressure industries such as oil and gas, construction, and process engineering, [13-16].
The Bowen HR560 is a mobile coiled tubing unit (CTU) manufactured by Bowen, designed for conducting various well intervention operations. This unit is intended for efficient execution of well testing, cleaning, stimulation, and other procedures requiring the use of coiled tubing.The unit is composed of three primary components. The first is a tractor equipped with a hydraulic system, providing the necessary power to operate all systems within the unit. The second component is a trailer containing a control cabin, a tubing reel system, and an injector. The reel system is integrated through the trailer to maintain a legally permissible road transport height, while the injector is mounted on an incline behind the reel, ensuring tubing stability during transport and operational deployment. The third component is a crane with a track, enabling precise handling of equipment and tools during well interventions.This configuration provides a high level of operational flexibility and efficiency, making the Bowen HR560 a suitable solution for modern oil and gas industries that require precise and reliable application of coiled tubing technology.

MATERIAL AND METHODS

For the purposes of this study, the mobile coiled tubing unit Bowen HR560 was employed, equipped with standard hydraulic pressure relief valves that regulate the system’s maximum operating pressure and protect components from overload. The valves were selected according to the manufacturer’s recommendations and included both direct-acting and pilot-operated types, allowing for the examination of various operational characteristics under varying pressures and flow rates. For thermographic analysis, a Testo high-resolution infrared (IR) camera with a temperature range of -20 °C to 500 °C and an accuracy of ±2 °C was used. The camera was calibrated prior to the experiments to ensure reliable and reproducible measurements of the valves’ thermal characteristics. In addition to the IR camera, standard hydraulic instruments for measuring pressure and flow, as well as safety equipment necessary for high-pressure operations in field conditions, were utilized.
Testing was conducted under real operational conditions in a workshop, during which the pressure relief valves of the Bowen HR560 unit were subjected to standard operational cycles. The IR camera was positioned to enable continuous monitoring of the valves’ thermal profiles during load variations and pressure increases.
Thermal images were captured at 10-second intervals, and the collected data were analyzed using a thermography software package, including the generation of temperature maps and the identification of potential overheating zones. This approach enabled the detection of anomalies in valve operation, such as localized temperature increases due to overload or reduced efficiency in pilot-operated valves.
The results were further corrected for ambient temperature and the emissivity of the valve materials, ensuring precise quantification of thermal characteristics. The combination of

thermographic analysis and standard hydraulic measurements allowed for a detailed assessment of valve performance and the identification of potential critical points within the Bowen HR560 hydraulic system.

RESULTS OF INSPECTION AND DISCUSSION

The recording and inspection were conducted over a period of three machine operating hours, during which the gradual heating of all components of the Bowen HR560 system was monitored. Fig. 1 shows the initial temperatures during the so-called cold operation of the machine.

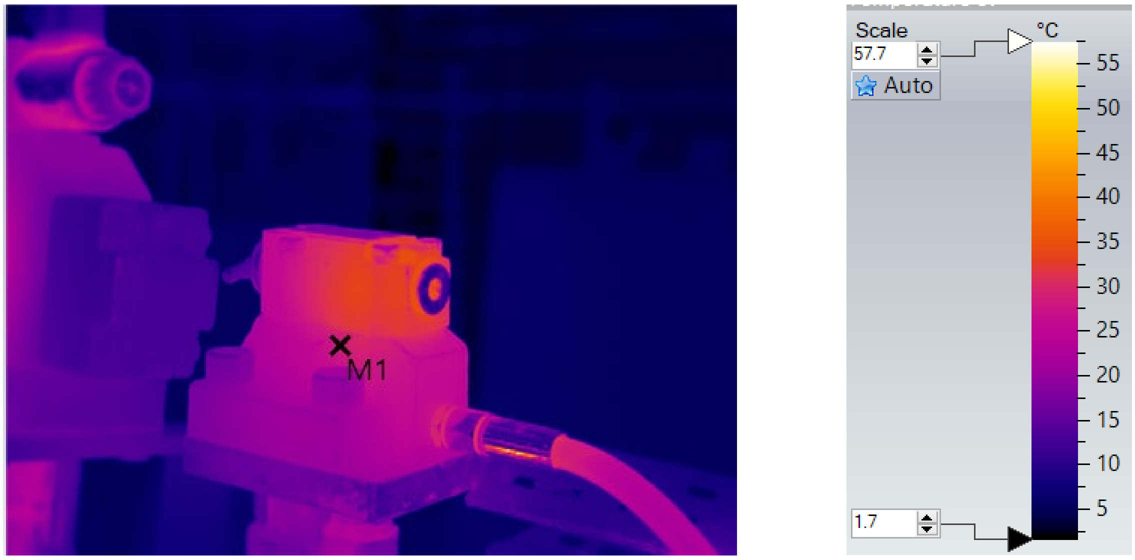

Fig. 1. *The temperatures of the pressure relief valve were recorded during the first hour of diagnostics*

From the figure, it can be concluded that the heating during the first hour of operation was relatively low and that no drastic or concerning changes occurred in the observed valve. The valve temperature was 28.1 °C at the time of recording.

After two hours of machine operation, the temperatures measured on the Bowen valve assembly exhibited variations, with the most significant temperature increase recorded on the pressure relief valve. Fig. 2 illustrates the temperatures observed after entering the second hour of machine operation

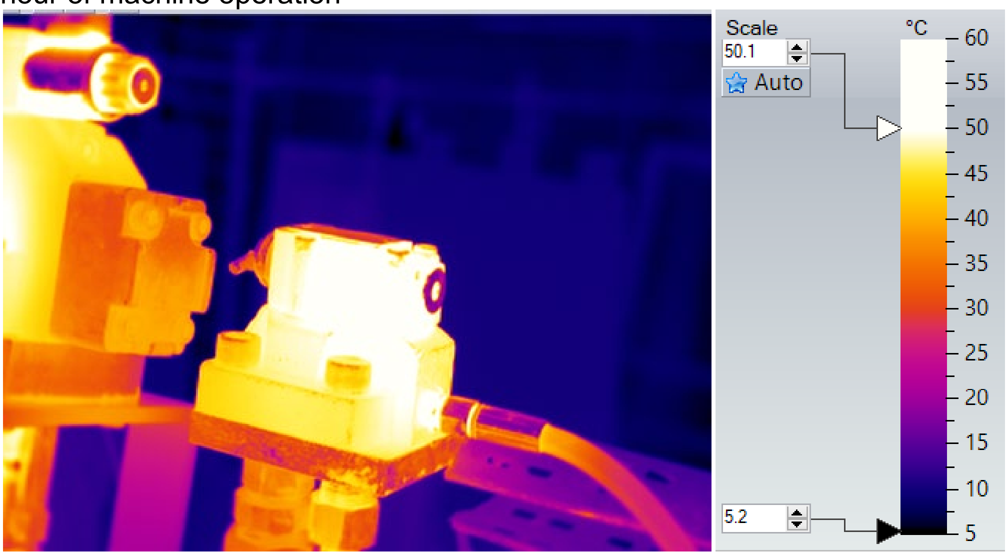

Fig. 2a. *Pressure relief valve temperature after entering the second hour of continuous machine operation*

Fig 2b. *Pressure relief valve*

From the thermal image, it can be observed that, compared to the first hour of machine operation, there has been a noticeable heating of the pressure relief valve, with the thermal image indicating that the temperature of the observed valve has now reached a value of 53.6 °C.

Towards the end of the second hour and at the onset of the third hour, critical heating was observed in the section of the machine connecting the pressure relief valve to the reservoir, as shown in Fig. 3.

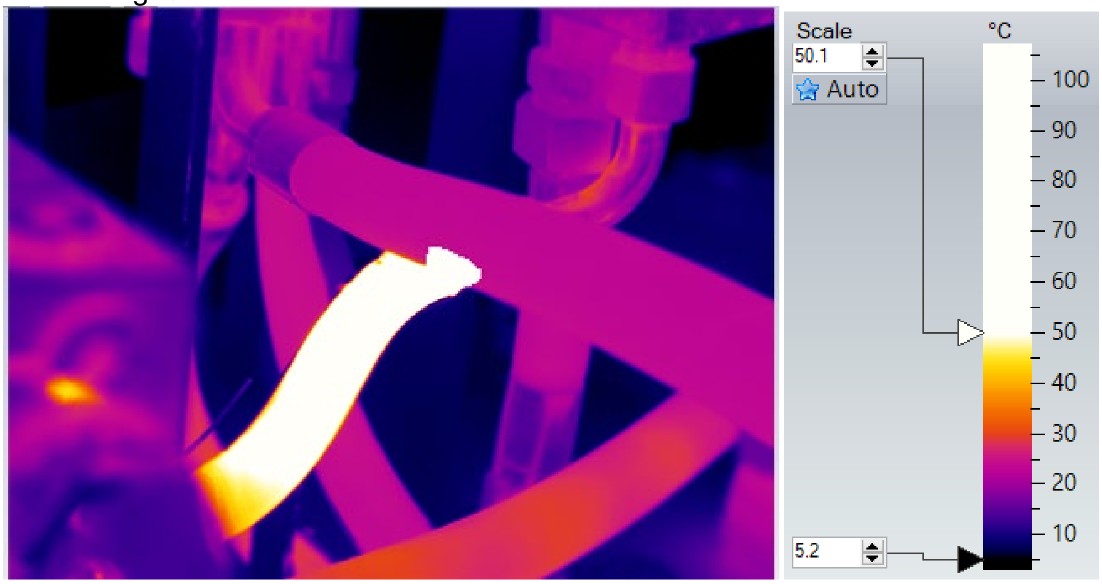

Fig. 3a. *Temperatures after two hours of machine operation on the T-line of the pressure relief valve*

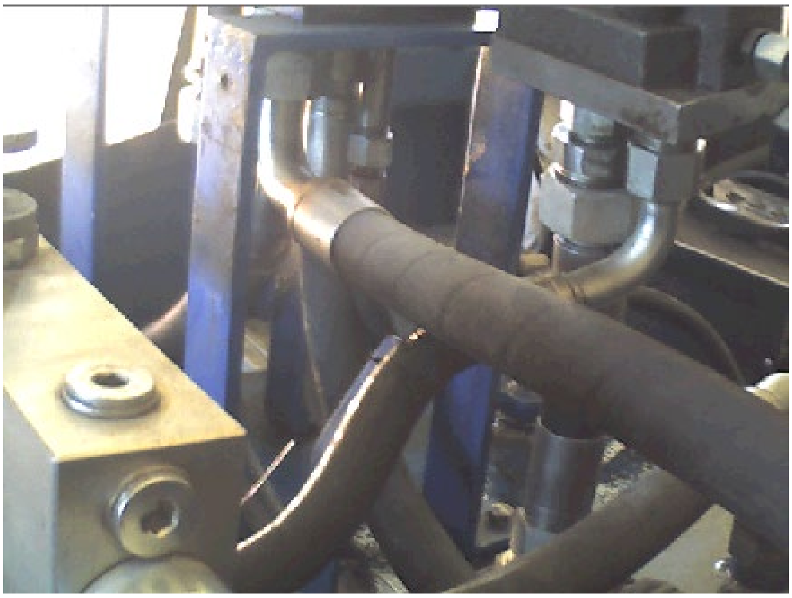

Fig. 3b.*T-line of the pressure relief valve*

After a two-hour period of machine operation, temperatures exceeding the allowable heating limits of the components, i.e., above 50 °C, were observed. The figure shows that on the T-line from the pressure relief valve to the reservoir, a temperature of 96.5 °C was recorded, representing exceptionally high temperatures for this type of system.
Fig. 4 shows the reservoir, which also began to heat up after a two-hour period of operation, with its temperature increasing exponentially. This confirms that the oil in the reservoir cannot cool down sufficiently quickly due to the malfunctioning of the valve.

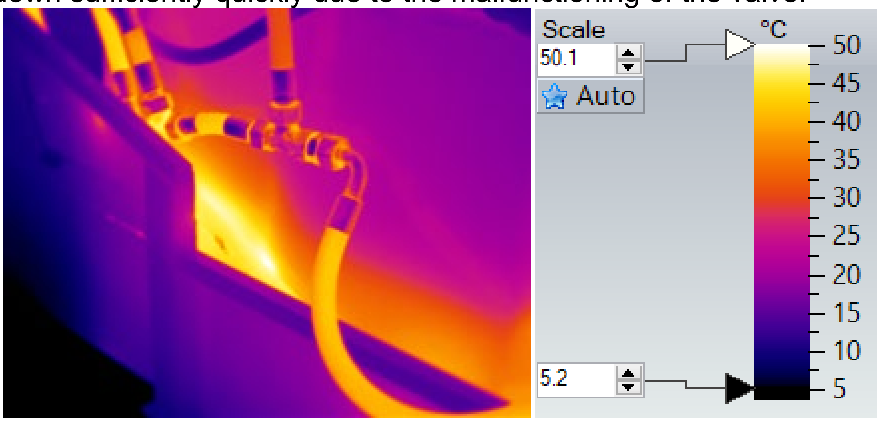

Fig. 4a. *Temperature of the hydraulic system reservoir.*

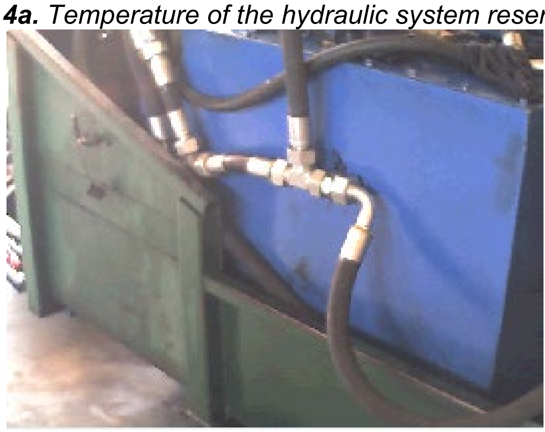

Fig 4b. *Hydraulic reservoir.*

From Fig. 4, it can be seen that the heating poses a potential risk of contamination of the hydraulic oil within the system. After two hours of operation, the oil temperature in the reservoir began to rise, reaching 46.5 °C.
Based on a three-hour monitoring of the pressure relief valve, it can be observed and concluded, from the thermal image obtained through thermographic inspection and diagnostics, that the central issue of the Bowen system is the heating generated by the pressure relief valve, which is definitively malfunctioning. A potential cause of the pressure relief valve malfunction in this system is the weakening of the valve spring, leading to frequent ‘opening’ of the valve, thereby preventing the oil in the reservoir from cooling properly.
The heating of hydraulic components and hydraulic oil in the system should not exceed 50 °C, as it can cause numerous issues, both technical and economic in nature. Temperatures exceeding this threshold generally lead, over time, to contamination of the hydraulic fluid, which results in the degradation of the hydraulic system, pipelines, components, valves, and the pump. Temperature must be maintained within optimal limits, and in order to thoroughly monitor it, thermography should be applied as a diagnostic method.

Table 1. *Analysis of temperature changes of hydraulic system components*

Temperature (°C)	One hour	Two hour	Three hour
Pressure relief valve	28,1	53,6	96,5
Reservoar	22,3	40,5	46,5
Directional valve	20,2	28,9	40,5
Axial – piston pump	25,2	42,9	46,6

The temperature of the pressure relief valve exhibits a pronounced increase, rising from an initial 28.1 °C after one hour of operation to 53.6 °C in the second hour, representing a growth of approximately 90.75%. By the third hour, the temperature reaches 96.5 °C, which corresponds to a cumulative increase of about 243.42% compared to the initial value. This dynamic indicates intense operational loading of the valve and potential energy losses in the form of heat due to high flow rates and pressure drops.
The reservoir demonstrates a milder temperature rise compared to the valve, increasing from 22.3 °C to 40.5 °C after two hours (an 81.61% increase), followed by a moderate rise to 46.5 °C in the third hour, representing a total increase of approximately 108.52% from the starting value. This trend is consistent with the reservoir’s function of absorbing and dissipating part of the system’s thermal load.
For the directional valve, the temperature rises from 20.2 °C to 28.9 °C after the second hour (a 43.07% increase), and subsequently to 40.5 °C in the third hour, corresponding to a cumulative growth of about 100.50%. Such an increase suggests a gradual escalation of friction and internal flow losses within the valve channels during continuous operation.
The axial piston pump records a temperature rise from 25.2 °C to 42.9 °C in the second hour (a 70.24% increase), then reaching 46.6 °C in the third hour, which constitutes a cumulative increase of 84.92%. This outcome suggests stabilization of the pump’s thermal regime following the initial rapid increase, likely due to a thermal balance between the heat generated and its dissipation through the working fluid.
Overall, the observed temperature trends indicate that the pressure relief valve represents the critical point in terms of thermal loading of the system, whereas the reservoir and pump are less exposed to extreme heating, yet still exhibit significant changes that may affect the viscosity of the working fluid and the overall energy efficiency.

CONCLUSION

The thermographic analysis of the Bowen HR560 coiled tubing unit has clearly demonstrated that the pressure relief valve constitutes the most critical thermal stress point within the hydraulic system. Recorded temperature progression from 28.1 °C after one hour to 96.5 °C after three hours of operation significantly exceeds the generally accepted operational threshold of 50 °C for hydraulic components. This abnormal heating pattern is indicative of a malfunction, most likely associated with the weakening of the valve’s return spring, causing frequent and unnecessary opening cycles. Such behavior not only prevents the hydraulic oil in the reservoir from cooling effectively but also accelerates fluid degradation, promotes contamination, and increases the likelihood of premature wear of other hydraulic components.

The operational integrity of the pressure relief valve is paramount, as it governs the system’s maximum operating pressure, protects downstream components from overload, and ensures the safe and efficient performance of the entire hydraulic assembly. Its malfunction compromises the stability of the hydraulic circuit, introduces additional thermal and mechanical loads, and reduces overall system reliability. Moreover, elevated oil temperatures detrimentally affect viscosity, film strength, and lubrication quality, further contributing to the deterioration of pumps, directional valves, and associated pipelines.

Infrared thermography, applied as a non-invasive diagnostic method, has proven to be a highly effective tool for detecting early-stage anomalies under real operating conditions without interrupting the operational cycle. Its ability to identify localized overheating enables targeted maintenance interventions before minor defects escalate into costly and potentially hazardous failures. When integrated with conventional hydraulic monitoring parameters such as pressure and flow rate, thermography supports predictive maintenance strategies, extends component lifespan, and improves operational safety.Given the critical nature of the observed overheating in the pressure relief valve, it is recommended to implement regular thermographic inspections as part of the maintenance routine, alongside thorough mechanical checks and calibration of pressure control components. This approach not only safeguards the reliability and safety of coiled tubing units in demanding oilfield applications but also contributes to optimizing energy efficiency, minimizing unplanned downtime, and ensuring long-term operational sustainability of complex hydraulic systems.

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