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Decreasing the Oil Temperature in the Hydraulic Circuits by Using the Removable Finned Cooler

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Abstract The paper is focused on the research of decreasing the oil temperature in the hydraulic circuit by the finned cooler. The experimental setup is used to investigate the oil temperature and the surface temperature of the hydraulic pipe at the inlet and outlet of the cooler. The data are compared with respect to the hydraulic circuit without the cooler used. In addition, the influence of the oil pump on and off on the temperatures is evaluated. The finned surface of the cooler ensured a decrease in oil temperature at the cooler outlet of 3.65 °C and 4.24 °C with the pump on (at 5 minutes) and with the pump off (at 10 minutes). With the pump off and not circulating oil in the circuit, the significance of the cooler was most pronounced. The distribution of temperature fields obtained by numerical simulation confirmed the advantageous importance of the demountable fin cooler for the experimental hydraulic circuit. Finned cooler providing enhanced heat dissipation and thus the hydraulic oil is protected from degradation. The design of the fin cooler enables simple installation without shutting down the hydraulic circuit.

Keywords Cooler, hydraulic pipe, heat, oil, temperature

1. INTRODUCTION

Hydraulic pipes are components of hydraulic circuits used e.g. in the fields of engineering, agriculture, waste management, forestry and transport technology, construction industry [1]. In order to handle heavy loads or to compress material, a closed hydraulic circuit is used in which hydraulic oil flows through a pressure pump [2]. The oil coolers in the assembly keep the hydraulic oil within the required temperature range, as the pressure and viscosity of the oil depend on the operating temperature [3, 4]. The oil cooling is an important part of hydraulic systems to ensure their correct operation and failure-free operation. Keeping the oil within operating temperature range has a positive impact on the life of the hydraulic oil and hydraulic circuit components, reducing maintenance and repair expenses, reducing downtimes [5]. Oil coolers are also used in high-performance internal combustion engines, where the oil absorbs the heat generated by the piston movement in the cylinder and dissipates it through the manifold and cooler to the ambient environment. Here the engine oil performs the function of heat dissipation, friction reduction, abrasion reduction, detergency, sealing of critical parts necessary for correct operation of the engine [6].
The two basic methods of cooling oil coolers are cooling by air and water, which allow the thermal energy to be dissipated into a secondary medium, usually air or liquid [7, 8]. In the air-cooling process, the inflow of cold air cools the hot walls of the cooler core. The advantage of this method is the simplicity of maintenance ensuring low operating costs, but the main disadvantage is that the cooling performance is significantly affected by the change in ambient temperature. Water-cooled systems use a hot and cold medium separated by a wall to dissipate heat. Here, higher cooling efficiency is assured because air temperature changes have negligible effect on cooling performance. A water-cooled cooler consists of a series of finned tubes through which the hot medium flows [9, 10]. The coolant absorbs heat from the oil and transfers it from the cooler to the ambient environment.

External finned coolers are most commonly used to heat transfer from the hot medium to the ambient air. Several researchers have investigated the intensification of heat transfer to the ambient environment through finned surfaces. By increasing the external heat exchange surface area, more intensive heat transfer from the heated surface to the ambient air can be achieved [11, 12]. For the mentioned method of heat dissipation by conduction, convection and radiation, it is also important to investigate the geometrical parameters and materials of finned coolers [13, 14]. The effect of fin thickness, spacing and height on the thermos-hydraulic properties of the enlarged heat exchange surfaces has been discussed in the literatures [15, 16].

In the case of machines and equipment, the hydraulic oil is overheating despite the oil cooler mounted in the hydraulic circuit. Overheating occurs especially in the summer months and in closed systems, as well as with high loads on machines and equipment, which is why the application of a supplementary demountable cooler is reasonable. Currently commonly used additional coolers for hydraulic pipes work on the principle of an insertion between the two ends of the pipes, which brings several negatives. It is necessary to shut down the machine or equipment for the installation of such coolers and also to deal with some leaks. The demountable finned cooler designed and investigated in this paper solves these negatives, whereby the number of heat exchange segments can be added or removed as necessary depending on the dimensional capabilities of the machines and equipment. Also, the size adaptability of the cooler in terms of adjusting the internal diameter of the clamp provides the possibility of use for different diameters of hydraulic pipes. In the presented paper, a disassembled cooler is designed and investigated in terms of the oil temperatures at the inlet and outlet of the cooler, and the surface temperatures of the hydraulic hose. The hydraulic circuit with and without the cooler installed is compared. Simulations of the temperature fields are presented to compare the heat conduction in the materials when six segments and one segment of the cooler are used.

2. MATERIAL AND METHODS

The hydraulic circuit was designed and constructed for the realization of experimental measurements (Fig. 1). The heated oil circulated through the hydraulic pipe (1) and was cooled by a demountable finned cooler (2), which consisted of six segments of heat exchange surfaces. The oil temperature at the inlet and outlet of the cooler was measured by NTC temperature sensors ZA 9040-FS (3, 4) connected to the Almemo 2590 value logger. The measuring range of the resistance temperature sensors was -50 °C to 125 °C with measurement accuracy ±0.01 °C. The cooled oil flowed into the oil tank (5) and recirculated by means of a driven hydraulic pump (7) through the oil filter (6) and cooler (2). The fluid in the hydraulic circuit is continuously heated to the operating temperature during the operation of the machine or equipment, which is variable depending on the load. The optimum operating temperature of hydraulic oil used in construction machinery ranges from 40°C to 70 °C. The most suitable operating temperature is 50 °C. When hydraulic oil is heated above 90 °C, the negative hygroscopic properties of the oil increase significantly, causing degradation [17].

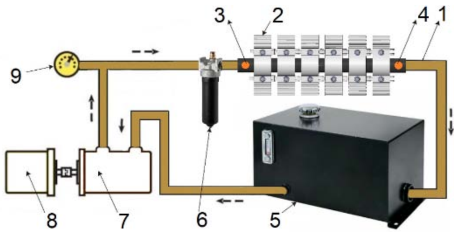


Figure 1 Experimental hydraulic circuit with installed demountable cooler. 1 – hydraulic pipe, 2 – demountable cooler, 3 – oil temperature sensor and pipe surface temperature sensor at the inlet to the cooler, 4 – oil temperature sensor and pipe surface temperature sensor at the cooler outlet, 5 – oil tank, 6 – oil filter, 7 – hydraulic pump, 8 – hydraulic pump drive, 9 – pressure gauge, arrows represent the direction of oil flow.

The pipe surface temperature at the inlet and outlet of the cooler T_{sin}, T_{sout} was measured by NiCr-Ni FTA 8068 contact temperature sensors, which have fixing clamps with springs in order to fix the sensor to the pipe. The oil temperature at the inlet and outlet of the cooler T_{oin}, T_{oout}. The oil temperature at the inlet and outlet of the cooler was measured by NTC ZA9040 resistive temperature sensors mounted directly in the pipe (Fig. 1). The sensors were connected to the Almemo 2590 value logger. The contact surfaces of the pipe and the cooler were coated with a copper-based thermally conductive paste with a thermal conductivity of 3.1 W/(m.K). The hydraulic pipe material was EPDM (ethylene propylene diene monomer) with a thermal conductivity of 0.29 W/(m.K) and the cooler was aluminium with a thermal conductivity of 237 W/(m.K). The 60 W hydraulic pump achieved a suction capacity of 3 l/min at an operating temperature of 40 °C to 70 °C. The Wika 7075643 pressure gauge was used to measure the operating pressure in the system. Type HL32 oil with a density of 875 kg/m^3 was circulated in the hydraulic pipe.

The demountable finned cooler is composed of an upper finned flange (2) and a lower flange (4) which encloses the outer wall of the hydraulic pipe (1). For the research, six segments were used for heat removal from the pipe (Fig. 2). The flanges are joined with the allen screws (3) to form a clamping joint. The individual segments are joined by means of pins with counter-nuts (5) into which brass connecting pins (6) are inserted. The number of cooler segments can be varied depending on the length of the hydraulic pipe. The hot hydraulic oil (A) flows through the hydraulic hose (1) and out of the partially cooled hydraulic hose (B) towards the oil tank and pump.

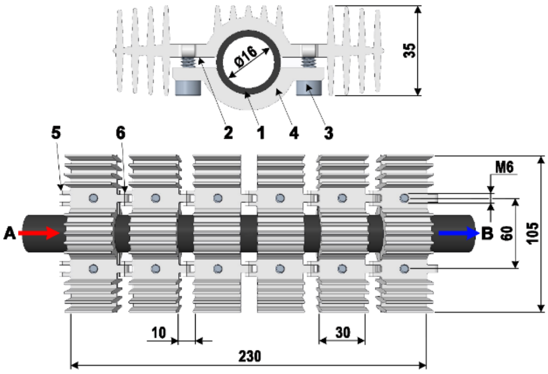


Figure 2 The basic dimensions and design of a demountable cooler. 1 – hydraulic pipe, 2 – upper finned flange, 3 – allen screw, 4 – lower flange, 5 – hinge, 6 – connecting pin, A – oil inlet, B – oil outlet.

In the machines and equipment mentioned above, the negative is the limited mounting space around the individual components. The hydraulic pipes are generally not only straight, but are mostly curved and turned at different angles. In the case of metal tubes, it is a direct attachment to the machine skeleton. This led to the design of a continuously adjustable cooler composed of the required number of cooling segments, given the location and difficulty of installation (Fig. 2). The rotation of the group of segments provided by means of pins with housings and coupling pins. This design also allows the pipe to change its length during the operation due to temperature changes.

3. RESULTS

The course of temperatures measured on the pipe surface at the inlet and outlet of the cooler when the hydraulic pump is switched on is shown in Fig. 3. The measurement points were identical with and without the cooler installed on the pipe. Subsequently, it was possible to compare and evaluate the effect of the additional cooler on the cooling efficiency. The cooling time was 5 minutes and the cooler reduced the outlet temperature by 1.7 °C compared to the state without cooler. In the starting cooling time from 0 to 1 minute, the highest efficiency of the installed cooler can be observed (difference of 5.3 °C to 8.3 °C at the outlet compared to the uninstalled cooler).

The oil temperature measured directly in the hydraulic line was recorded with the pump on for 5 minutes and subsequently from 5 to 10 minutes with the pump off (Fig. 4). The pump shutdown is also evident from the temperature courses at the inlet and outlet of the T_{oin}, T_{oout} cooler, where temperatures dropped in steps over a period of 5 minutes. Also, from the courses in Fig. 4, a positive effect of the installed cooler can be observed, by which the heat dissipation from the hydraulic line was increased, as evidenced by the lower oil temperatures at the outlet of the cooler T_{oout}. The installed cooler ensured a reduction in T_{oout} of 3.65 °C and 4.24 °C in a time of 5 minutes and 10 minutes with the pump on and pump off, respectively. When the pump is switched off and the oil is not circulating, the temperature differences between the installed cooler and the cooler without it are higher due to oil stagnation in the cooler area, which results in a more intensive heat dissipation through the cooler to the ambient environment. This condition commonly occurs in practice when the hydraulic control valve does not allow oil under pressure from the hydraulic pump and the required cylinder movement is counteracted by drag from the working environment (e.g. digger arms, hydraulic arms). The significance of the additional cooler is also evident from the T_{oin} values, as the circulation of the cooled oil in the hydraulic circuit causes a gradual decrease in the inlet temperature of the cooler. The cooler ensured a T_{oin} reduction of 3.42 °C and 3.27 °C in 5 minutes with the pump on and 10 minutes with the pump off. This has a positive effect on the long-term and more load-intensive operation of machines and equipment operating with hydraulic circuits.

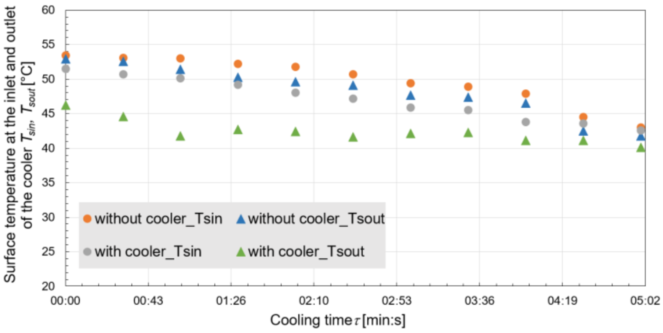


Figure 3 The pipe surface temperatures at the inlet and outlet of the cooler with the pump switched on.

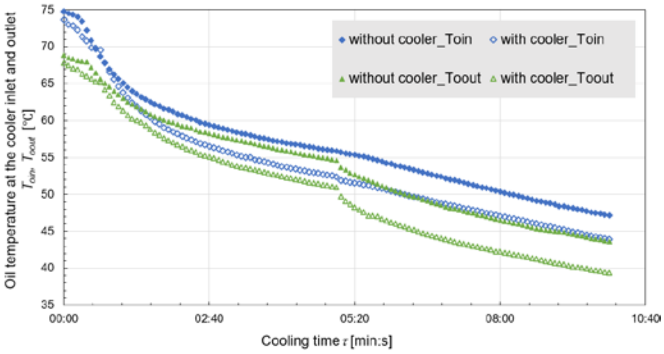


Figure 4 The course of oil temperatures at the inlet and outlet of the cooler.

Fig. 5, 6 shows the courses of the oil temperature differences Δ*T* at the inlet and outlet of the cooler, firstly when the pump is switched on for 5 minutes and then when the pump is switched off between 5 and 10 minutes. When the pump was switched on, it caused a gradual decrease in temperature differences (Fig. 5) and when it was switched off, the temperature differences increased and gradually stabilized (Fig. 6). Higher temperature differences between the inlet and outlet in this application indicate higher heat dissipation by the cooler. The significance of the installed cooler with the pump switched on became more pronounced from time 2:15, when a number of oil circulations in the hydraulic circuit had already occurred, thus gradually decreasing the temperature of the oil also at the inlet to the cooler. The difference between the Δ*T* values was 0.23 °C at the time of 5 minutes with the pump on.

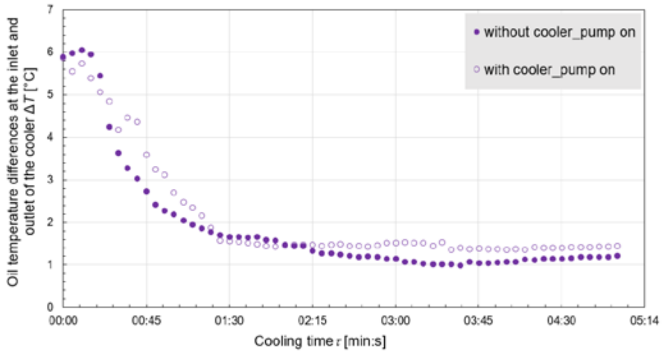


Figure 5 The course of the oil temperature differences at the inlet and outlet of the cooler with the pump switched on.

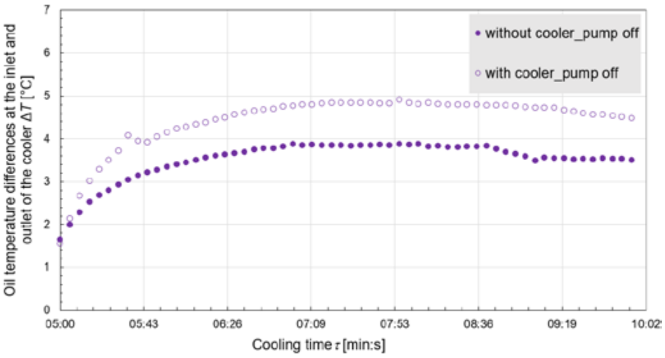


Figure 6 The course of the oil temperature differences at the inlet and outlet of the cooler with the pump switched off.

By switching off the pump, the temperature differences increased significantly and it was the importance of the installed cooler that became most pronounced here. At 10 minutes, the difference between the Δ*T* values was 0.98 °C and the installed cooler caused higher temperature differences, which means more intensive heat dissipation. From 06:30 onwards, the differences between Δ*T* values were of approximately the same range from 0.90 °C to 1.24 °C. In the case of the machine and equipment connected to the hydraulic circuit, the heat from the oil is dissipated more effectively through the cooler to the ambient environment.

The temperature distribution on the surface of the top and bottom flanges of the demountable cooler was solved numerically with Creo Simulate 7.0.1.0 (Fig. 7, 8). For the numerical simulations, the condition without the pump used was assumed for the maximum load of commonly used hydraulic circuits in practice, when the highest temperature of 70 °C is reached (overheating condition). Steady State Thermal Analysis was used for the computation. The Single-Pass Adaptive convergence criteria were setup using the Analysis Definition data form. The cooler was of Aluminium alloy (Al-Cu 2014) with a thermal conductivity of 192.163 W/(m.K) and a specific heat capacity of 9.63753e+08 J/(kg.K). The surface of the cooler was heat loaded to Q = 5,000 W with a surface temperature of 70 °C and a bulk temperature of 25 °C. The heat transfer coefficient on the horizontal surfaces and vertical surfaces was set to 25 and 50 W/(m^2.K), respectively.

From the distribution of the temperature fields of the six segments of the cooler, a gradual decrease of the temperatures in the z-axis direction can be observed, because in this direction the oil flow in the hydraulic pipe (Fig. 7). The temperature gradient between the first and sixth segments was 10 °C at the centre fins of the top flanges. The condition is simulated after the oil supply is shut off by the hydraulic manifold, when the additional cooler enables the temperature of the hydraulic oil in the pipe to be decreased. There was also a gradual heat transfer in the x-axis direction by conduction in the material up to the lateral fins of the individual segments. The lateral fins ranged in temperature from 50.90 °C to 42.71 °C. As the temperature of the oil in the hydraulic manifold gradually decreased due to cooling, the surface temperature on the lower flanges of the individual segments also gradually decreased from a maximum temperature of 70.00 °C to 42.71 °C.

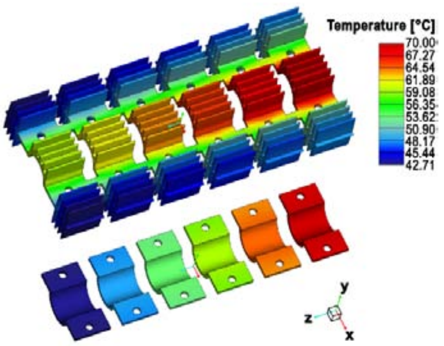
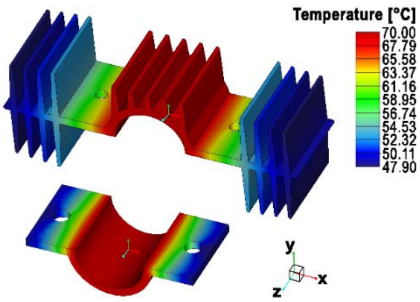
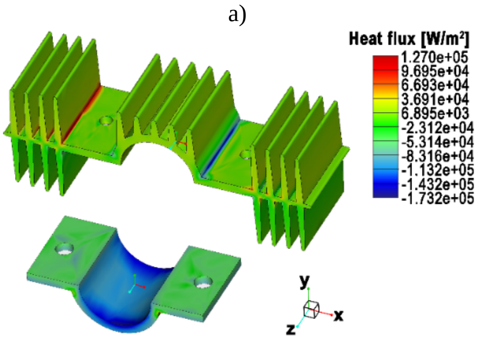


Figure 7 Distribution of temperature fields on the surface of the top flanges (finned) and bottom flanges of a demountable cooler with the pump switched off.

In the case of using only one segment as a cooler on the pipe, the temperature distribution is different especially on the lateral fins of the segment and the bottom flange of the segment (Fig. 8a). The application of the single segment would not be sufficient for efficient heat dissipation along the length of the hydraulic pipe.



a)



b)

Figure 8 Numerical simulations of one segment of a demountable cooler with the pump off. a) the distribution of temperature fields on the surface of the top and bottom flange, b) the distribution of heat flux on the surface of the top and bottom flange.

The distribution of heat fluxes on the surface of top and bottom segments is shown in Fig. 8b. The heat flux on the surface of the top flange and fins of the cooler reached values up to 36,910 W/m^2. At singularity points between the horizontal surface of the cooler and the vertical surface of the fins, this means that the maximum and minimum values are not taken into consideration.

4. CONCLUSION

The designed demountable cooler allows to reduce the temperature of the hydraulic oil circulating in the hydraulic systems of a wide range of machines and equipment. If the oil is excessively heated, the rubber seals can be damaged, which also reduces the operating pressure and increases the heat of the oil. Simultaneously, if the oil is loaded with high temperature for a long time, oxidation products are formed which negatively affect the pump. Up to 85% of hydraulic system failures are related to the adverse condition of the oil. In some cases, conventional oil coolers are not sufficient, so this problem can be solved by dissipating heat from the hydraulic hoses via a demountable cooler.

Experimental measurements showed that our designed cooler achieved a reduction of 3.65 °C and 4.24 °C in the oil temperature at the cooler outlet for 5 minutes and 10 minutes with the pump on and pump off, respectively. With the pump off and not circulating oil in the circuit, the significance of the cooler was most pronounced. This condition occurs in practice in the operation of machines and equipment when the movement of the hydraulic cylinder is counteracted by the operating environment. By circulating the oil in the hydraulic circuit for several times, the temperature of the oil at the inlet to the cooler gradually decreased. The finned cooler achieved a reduction of 3.42 °C and 3.27 °C in the oil temperature at the inlet of the cooler for 5 minutes and 10 minutes with the pump on and pump off, respectively. This has positive effects on the long-term and more stress-intensive operation of machines and equipment operating with hydraulic circuits. From simulations of temperature fields and heat fluxes, it is observed that the increase in cooler surface area by the fins contributes to improved heat dissipation and thus the hydraulic oil is protected from degradation.

The application of the demountable cooler is especially significant in the summer months or in locations with higher ambient temperatures all the year round. The extended surface of the cooler ensures that the heat is dissipated from the hydraulic oil before it enters the hydraulic pump while the machines and equipment are being operated. The advantage of our designed cooler is its constructional flexibility, as it allows mounting on different diameters of pipes and hoses, not only straight but also bent at a specific angle. The installation of the cooler does not require the machine or equipment to be shut down, nor is its structural integrity compromised, which could result in hydraulic oil leakage or aeration of the hydraulic circuit.

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