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THE INFLUENCE OF HYDRAULIC FLUID TEMPERATURE ON THE ADJUSTMENT CAPABILITIES OF SERVO-MECHANISMS AND CLOSED-CIRCUIT HYDROSTATIC TRANSMISSIONS

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Abstract: *The present article presents the influence of insufficient cooling, the effects of high temperature on the hydraulic fluid and the influence of the fluid temperature on the hydrostatic transmission in the closed loop, with primary adjustment and its servo-mechanism. The hydrostatic transmission was studied with the help of the numerical simulation software AMESim, using the hydraulics library that also takes into account the effects of temperature on the hydraulic fluid.*

Keywords: *closed-circuit hydrostatic transmissions, fluid temperature influence, servo-mechanisms, CAE.*

1. Introduction

High working fluid temperatures are the result of heat generation in the hydraulic system. Because high working fluid temperatures can be so damaging to a hydraulic system, it is important to identify the source of heat generation [1]. Heat generation typically results from fluid flowing from an area of high pressure to an area of low pressure without performing useful mechanical work [2]. When hydraulic fluids are exposed to high temperatures for extended periods of time, they suffer a permanent deterioration in lubrication properties and a severe reduction in kinematic viscosity [3] (Fig. 1). Deterioration of hydraulic fluid leads to oxidation and sludge formation that clogs small flow sections [4]. At the same time, chemical reactions between the degrading additives will occur in the hydraulic fluid, all of which seriously compromise the performance of the fluid and the hydraulic drive and control system [5]. A significant decrease in viscosity, generated by higher working temperatures, also affects the behavior of the hydraulic fluid itself, negatively influencing the performance of the hydraulic system as a whole [6].

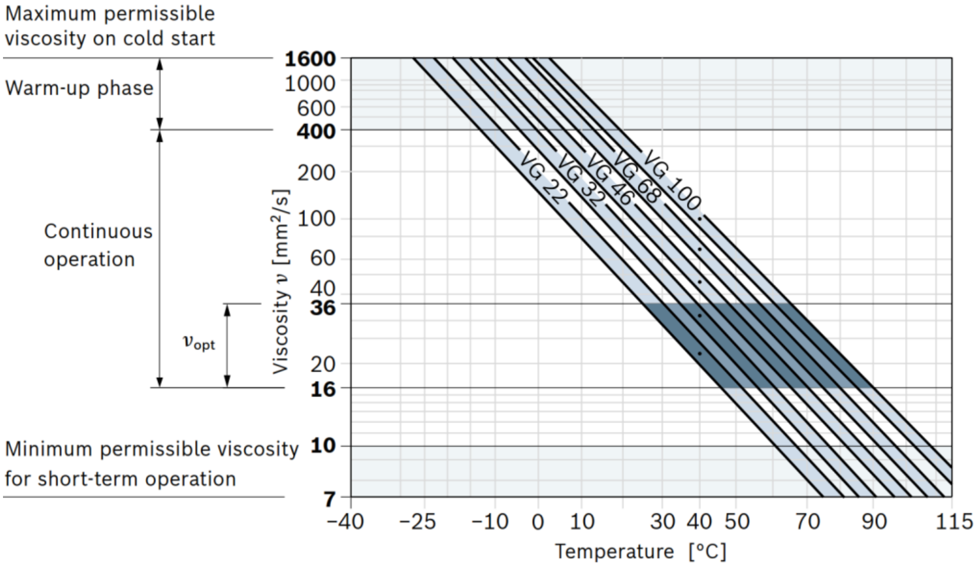

Fig. 1. Kinematic viscosity versus hydraulic fluid temperature and recommended intervals [7]

For an optimal operation of the hydraulic actuation systems, it is necessary that the viscosity of the hydraulic fluid falls within certain limits, between at least 16 and 36 cSt (Fig. 1) [8].

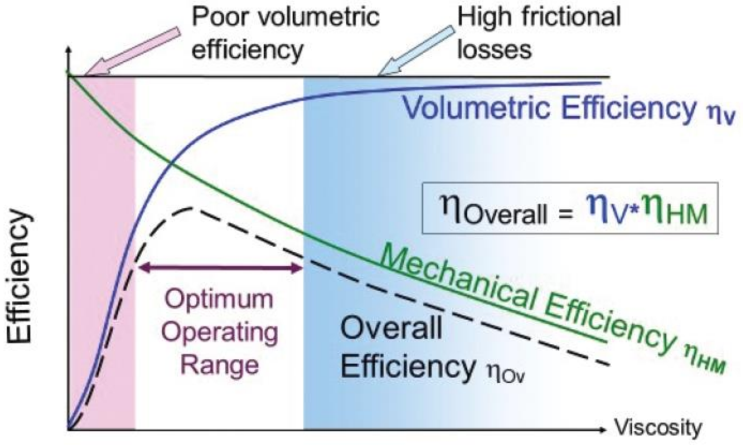

Fig. 2. Effects of Viscosity on Overall Efficiency [9]

The optimal viscosity range, previously mentioned, ensures adequate lubrication of the system, limits volumetric losses and ensures a very good efficiency of the system [10] (as in Fig. 2, too).

2. Material and method

To study the influence of temperature on the system parameters, two numerical simulations were performed in AMESim, the first of which includes a cooling circuit, and the second one does not. The simulation network is represented in Fig. 3; it includes: a closed-loop hydrostatic transmission with primary adjustment, a PID type controller with automatic tuning and feed forward, the transfer box of the truck and the motor truck. This is a multifunctional motor truck; it is used in the field of construction; it moves at normal road speed rates and also at technological speed rates.

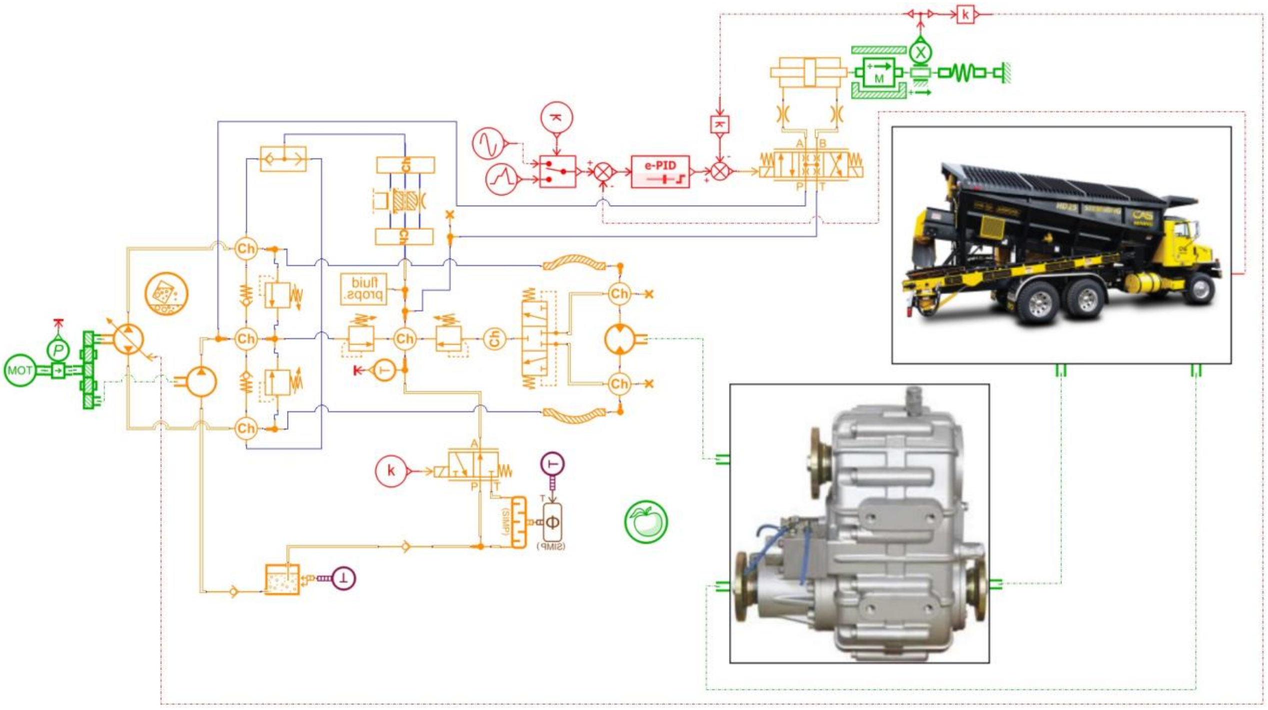

Fig. 3. Simulation network of a motor truck equipped with a closed-loop hydrostatic transmission

The components, operation and initial parameters of the numerical simulation:

- The thermal engine of the truck with a power of 240 kW operates at a constant speed of 1000 rev/min and at this speed it can produce a maximum torque of 1020 Nm; it drives the servo-pump with a displacement of 210 cc/rev and the auxiliary pump with a displacement of 33 cc/rev; the pressure relief valves acting as safety valves in the closed loop circuit are adjusted to 450 bar and the pressure relief valve of the compensating pump is set at 25 bar.
- The hydrostatic motor with radial pistons has a fixed capacity of 1352 cc/rev and is connected to the servo-pump; connected to the same ports, there is also the loop flushing valve, whose pressure relief valve is adjusted to 20 bar.
- The volumetric flow losses of the transmission together with most of the compensation pump flow rate is sent to the heat exchanger in order to cool the hydraulic fluid (ISO VG 46) or directly to the tank.
- The servo-mechanism system of the main pump is composed of a Dn6 proportional control valve, calibrated nozzles with a diameter of 1.1 mm, a spring with an elastic constant of 175 N/mm, a hydraulic cylinder with bilateral rods, with a piston diameter of 50 mm that controls the pump displacement and a PID controller.
- The transfer case of the motor truck has a transmission ratio of 1.652 and the transmission ratio of the two axles is 4.
- The motor truck has all-wheel drive and its velocity can be continuously variable, its total weight is 18 tons and it can carry a payload of 10 tons.

3. Results

After running the numerical simulation model of the hydrostatic transmission with primary adjustment of the motor truck, the following graphs result:

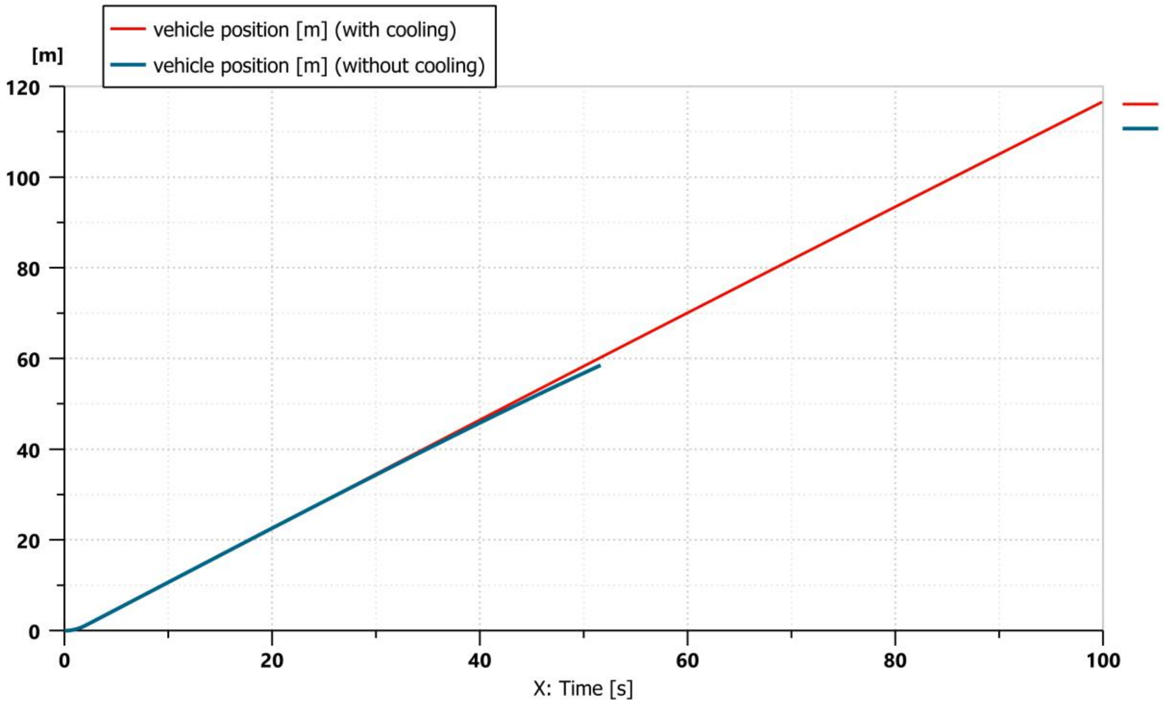

Fig. 4. Time-variation of the motor truck displacement

In Fig. 4 one can see how the displacement in the case of the system that does not benefit from cooling is limited.

In Fig. 5 one can notice that both motor trucks move on a road with the same slope, so the torque at the hydrostatic motor shaft is identical in both cases, as is the pressure of the two hydrostatic transmissions.

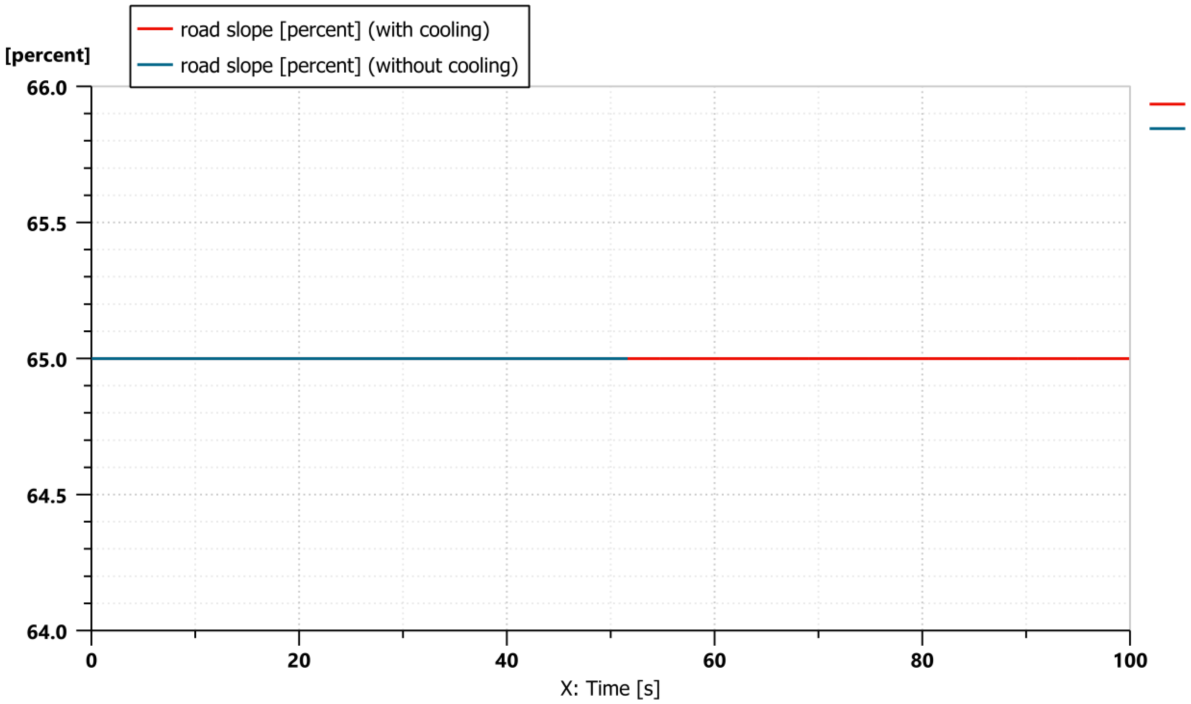

Fig. 5. The slope of the road

Fig. 6 shows how the velocity of the motor truck varies over time.

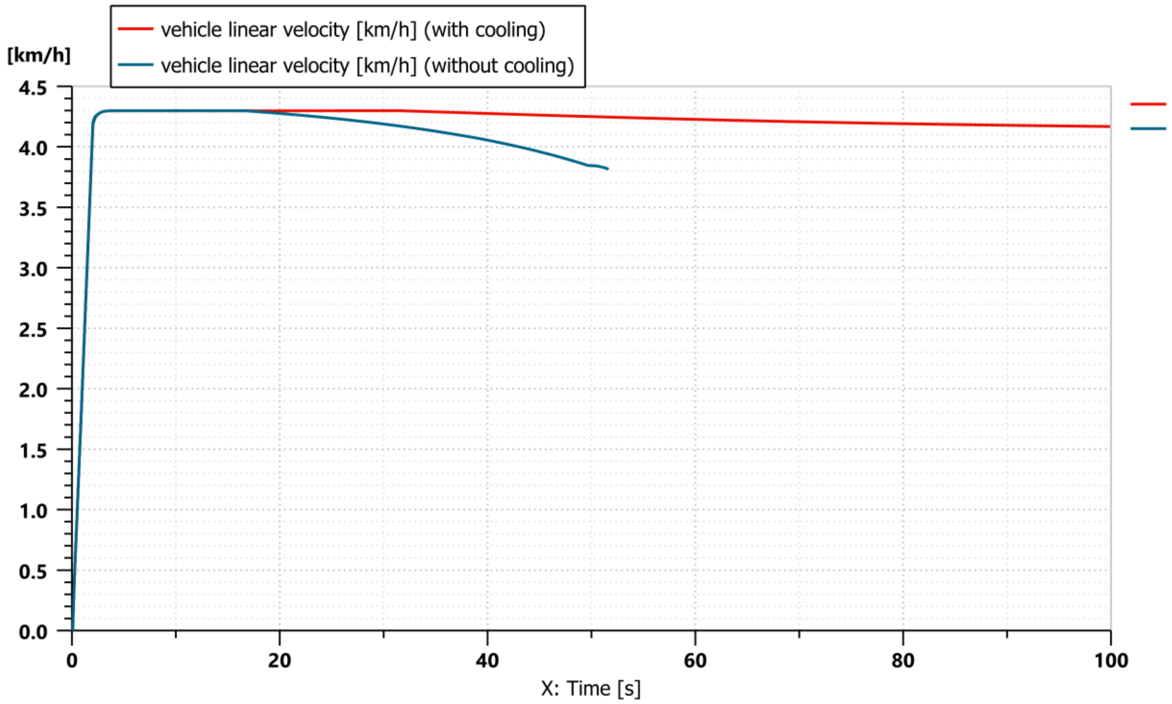

Fig. 6. The velocity of the motor truck

In Fig. 7 one can see how the speed of the hydrostatic motor shaft decreases, proportional to the travel speed; this decrease is due to the increase in volumetric losses (Fig 8.); these losses increase over time because the temperature of the hydraulic fluid increases and simultaneously with this increase, the viscosity of the hydraulic fluid also decreases.

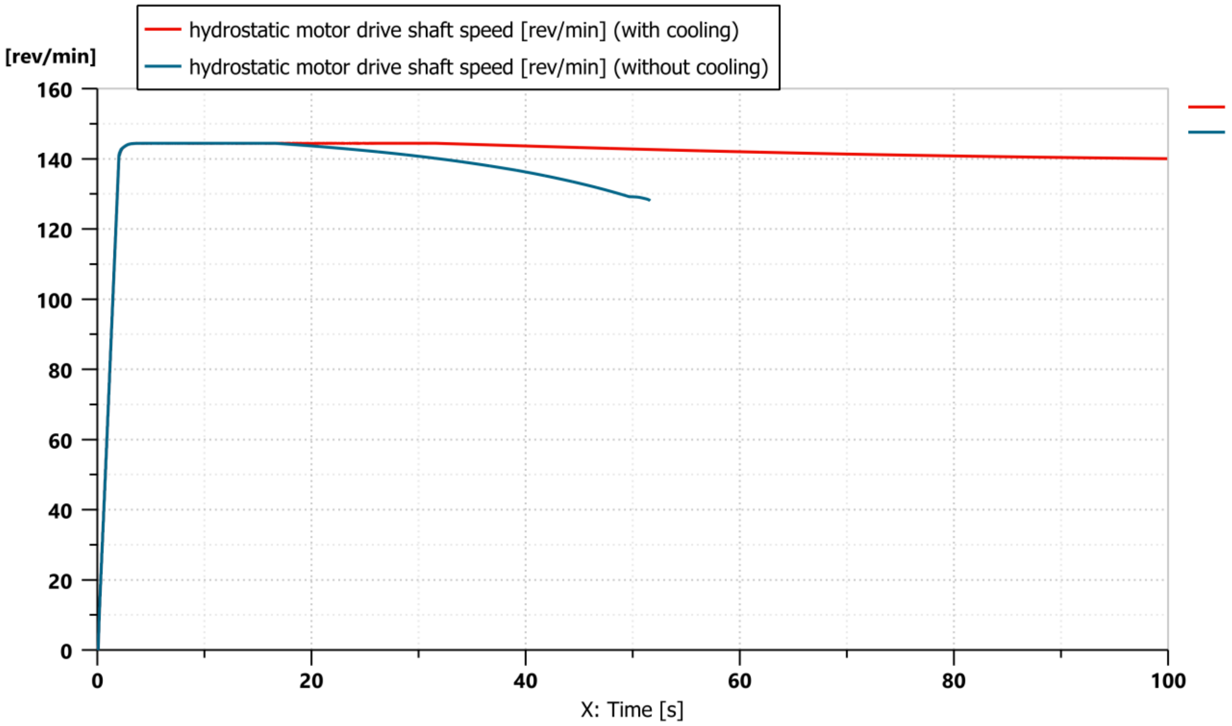

Fig. 7. The shaft speed of the hydrostatic motor

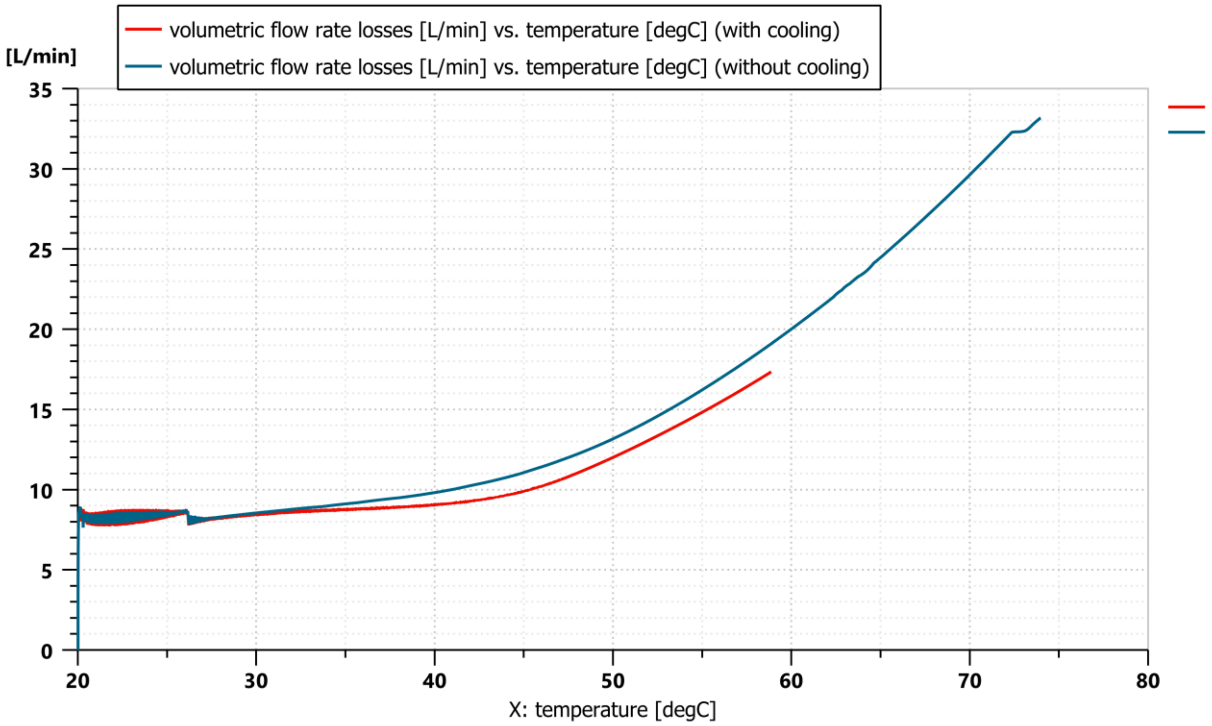

Fig. 8. Transmission volumetric flow rate losses versus hydraulic fluid temperature

Fig. 9 shows that the temperature of the hydraulic fluid affects the maximum speed of the motor truck. This limitation occurs because as the temperature of the fluid increases, the viscosity decreases and the volumetric losses of the transmission increase and a smaller flow rate reaches the port of the hydrostatic motor.

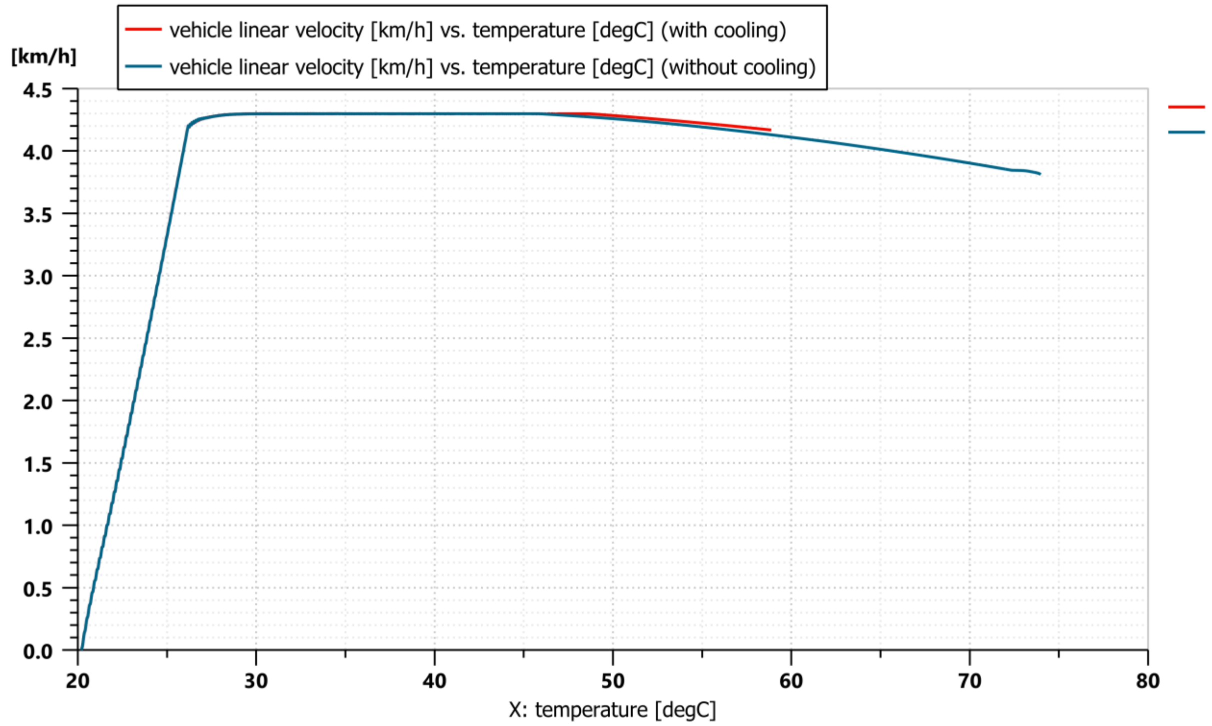

Fig. 9. Variation of the travel speed versus the temperature of the hydraulic fluid

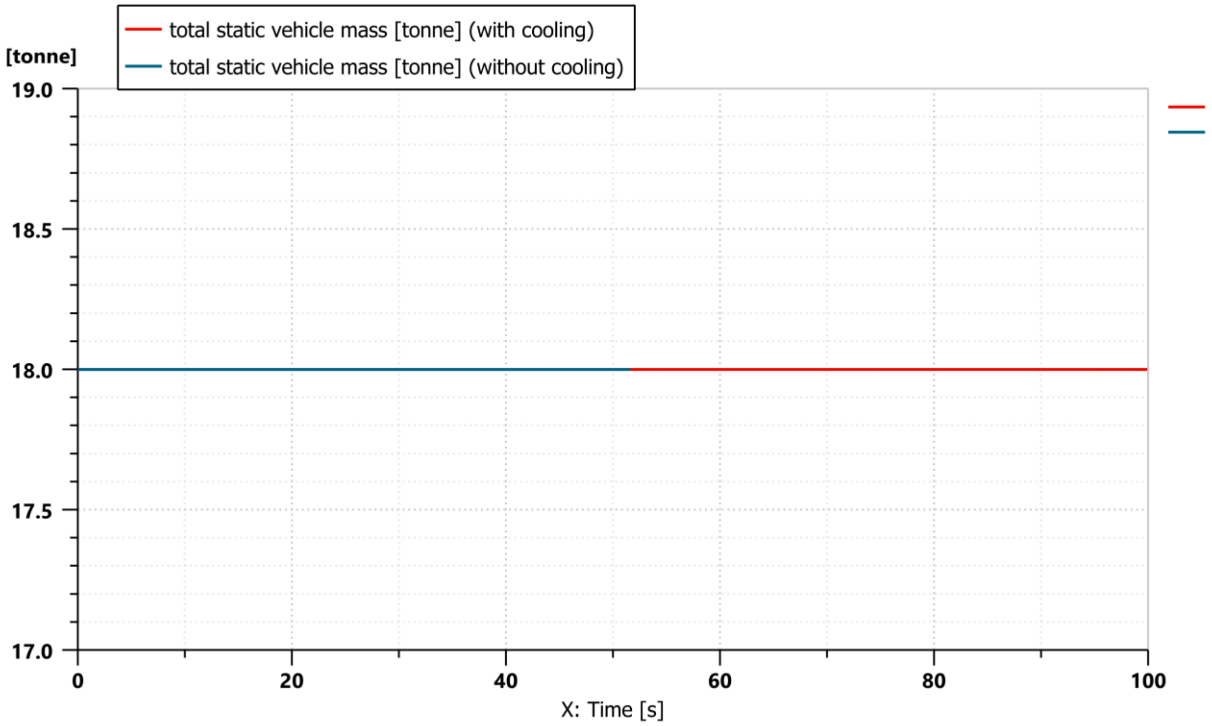

Fig. 10. Total mass of the motor truck

The total mass of the motor truck is constant during simulation (Fig. 10), as is the driving force (Fig. 11) with the exception of the acceleration period from the beginning of the simulation, as well as the torque on the two axles of the motor truck (Fig. 12).

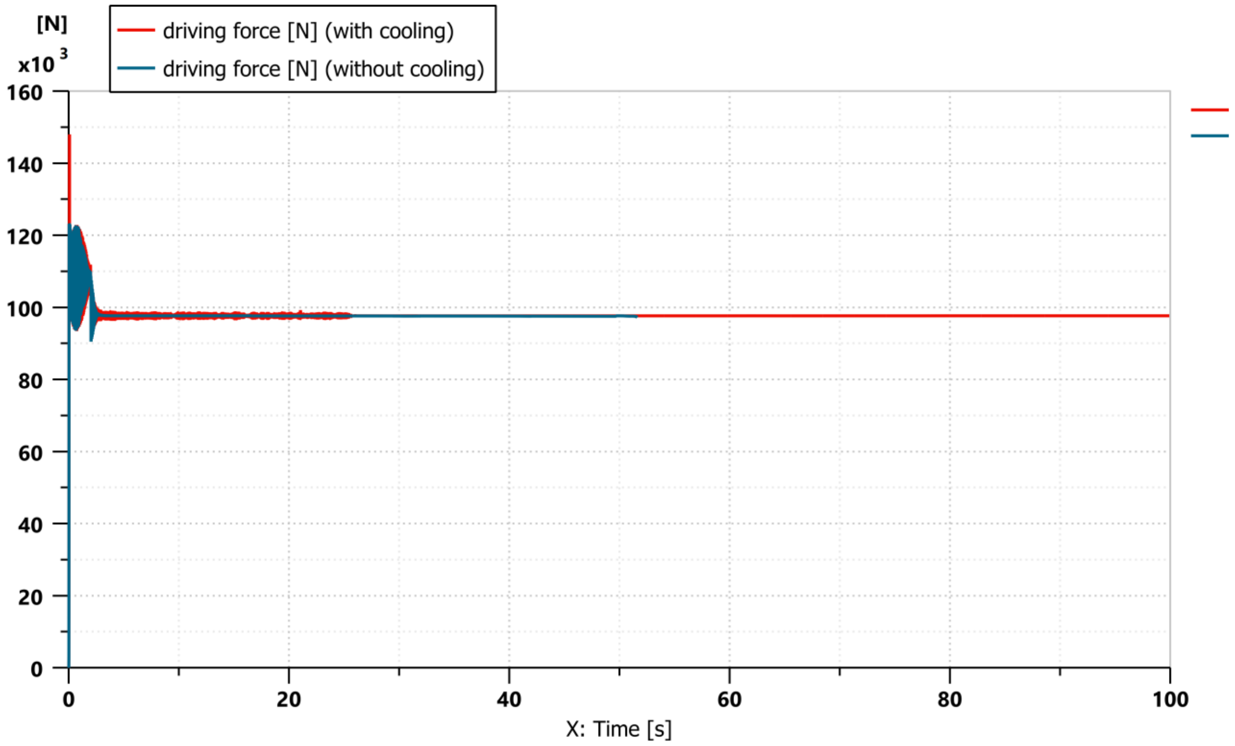

Fig. 11. The driving force of the motor truck

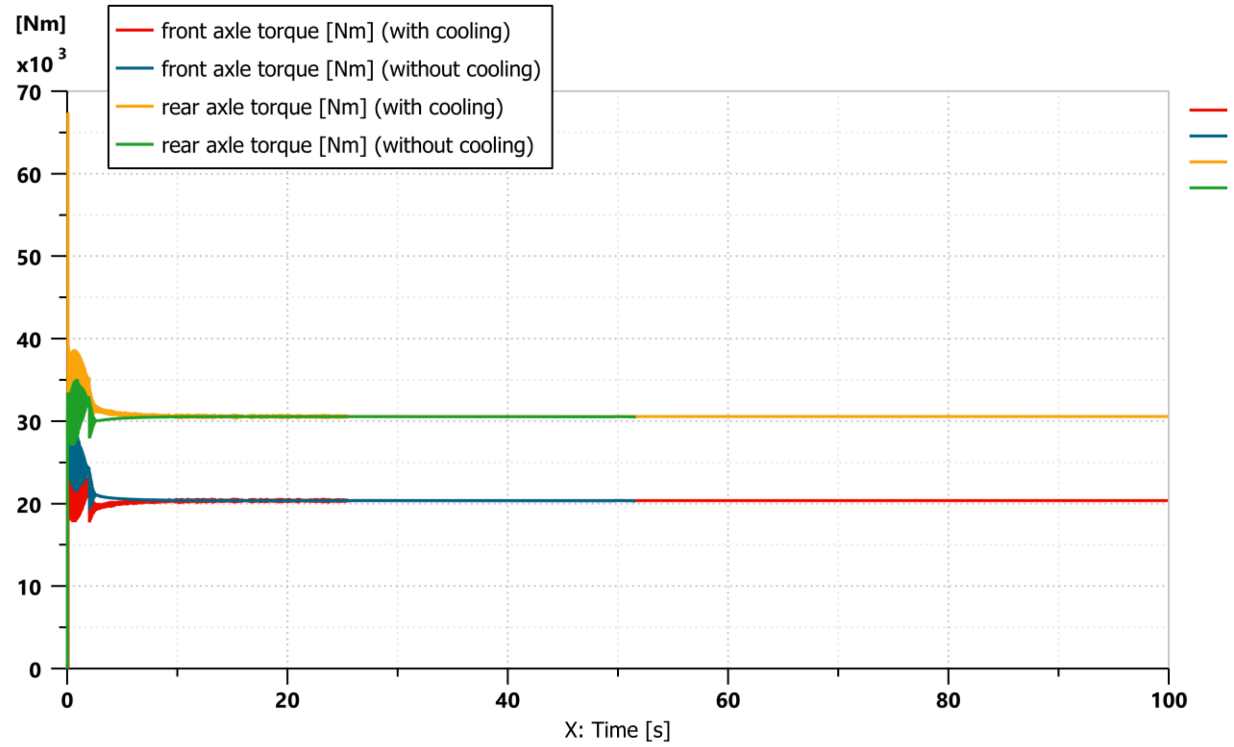

Fig. 12. The torque at the two axles of the motor truck

Fig. 13 shows the variation over time of the pressure at the port of the servo-mechanism for regulating the flow of the servo pump. It can be seen that the hydrostatic transmission that does not benefit from cooling no longer achieves the pressure required to control the flow of the pump because the density of the hydraulic fluid has decreased too much (Fig. 14).

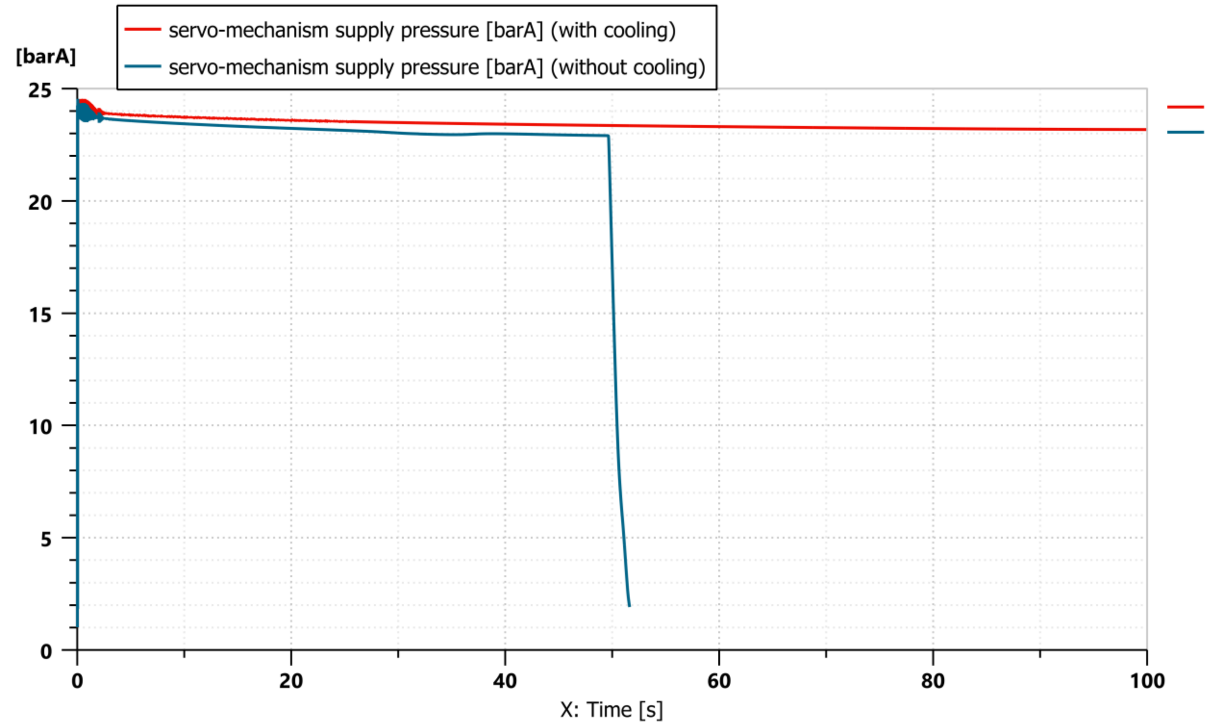

Fig. 13. The pressure at the port of the servo-mechanism for adjusting the displacement of the servo pump

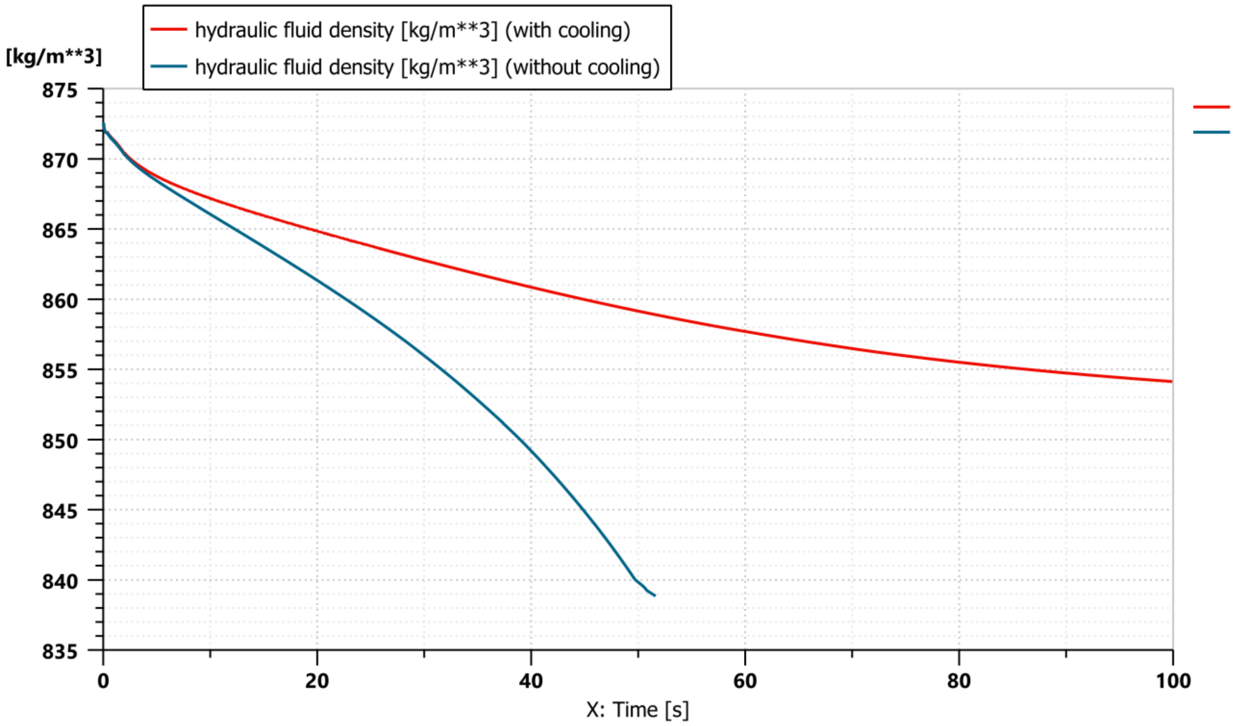

Fig. 14. The time variation of the hydraulic fluid density

The time-variation of the kinematic viscosity of the hydraulic fluid is shown in Fig. 16; this variation occurs due to the increase in the temperature of the hydraulic fluid; likewise, in the case of the void content of the hydraulic fluid (Fig. 15).

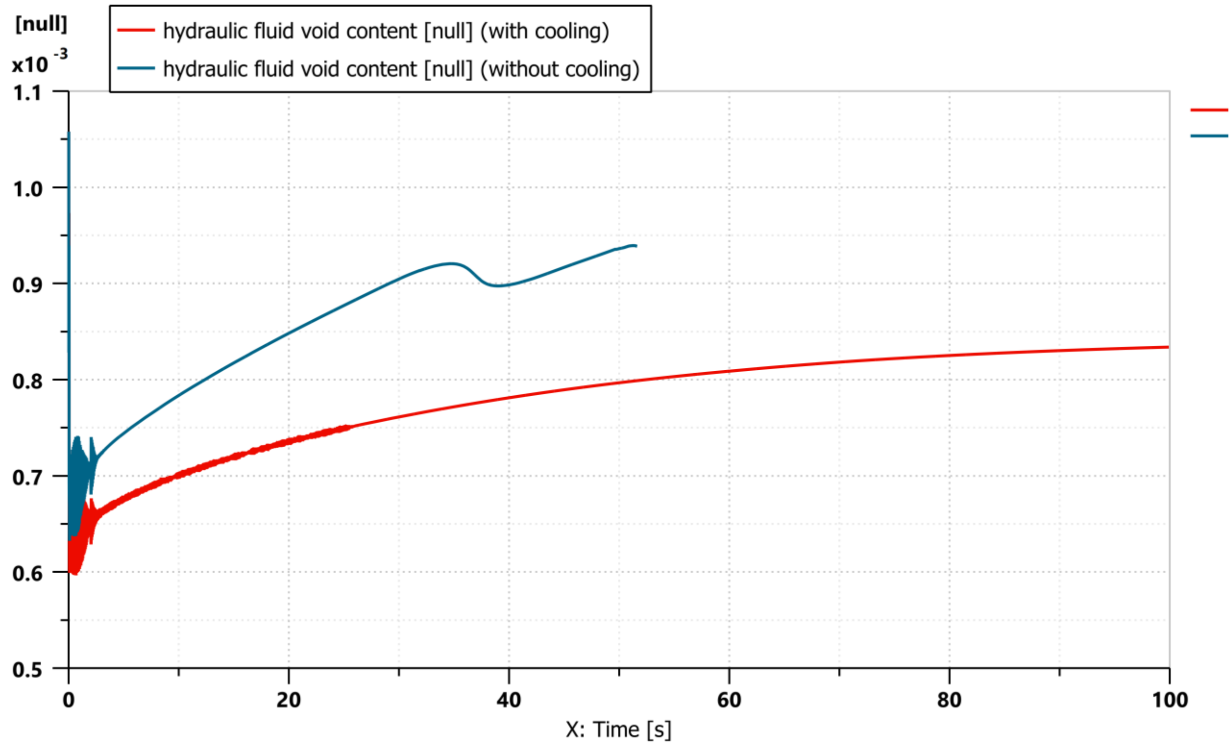

Fig. 15. The void content of the hydraulic fluid

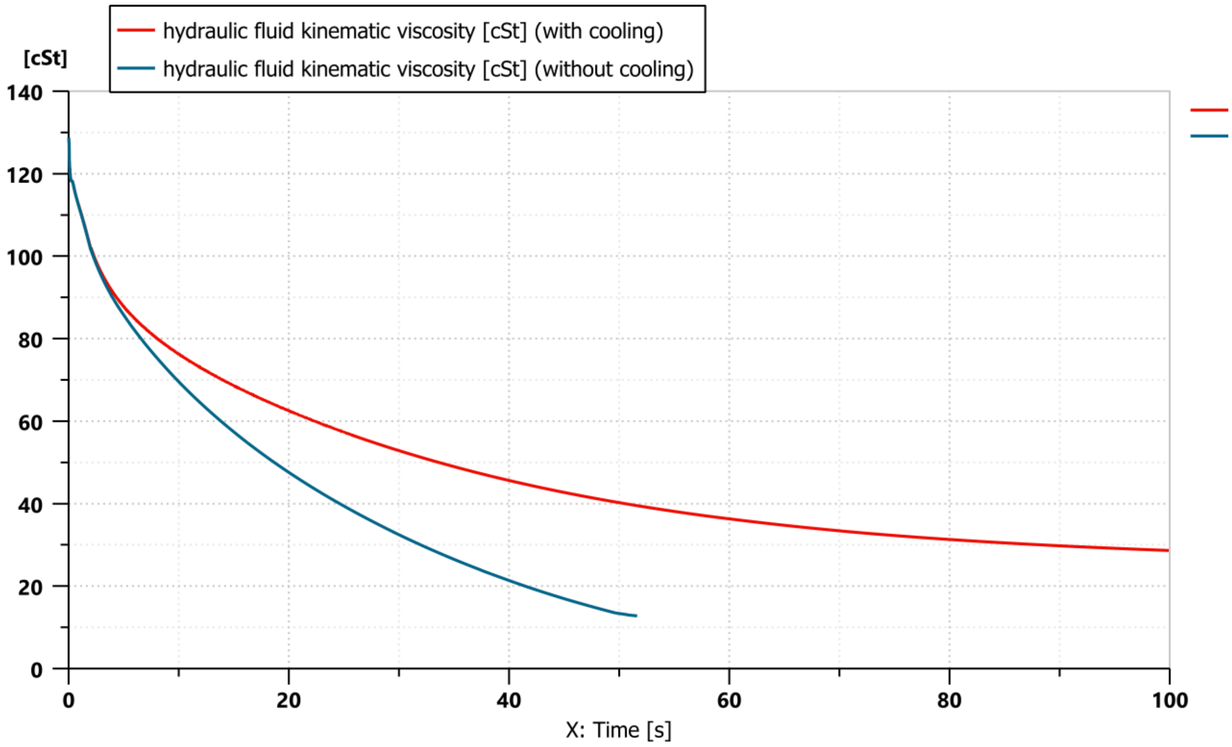

Fig. 16. Kinematic viscosity of the hydraulic fluid

The variation of the kinematic viscosity of the hydraulic fluid depending on the temperature is shown in Fig. 17, where one can see that the transmission that does not benefit from cooling worked up to a temperature of 74 °C and a kinematic viscosity of 12 cSt.

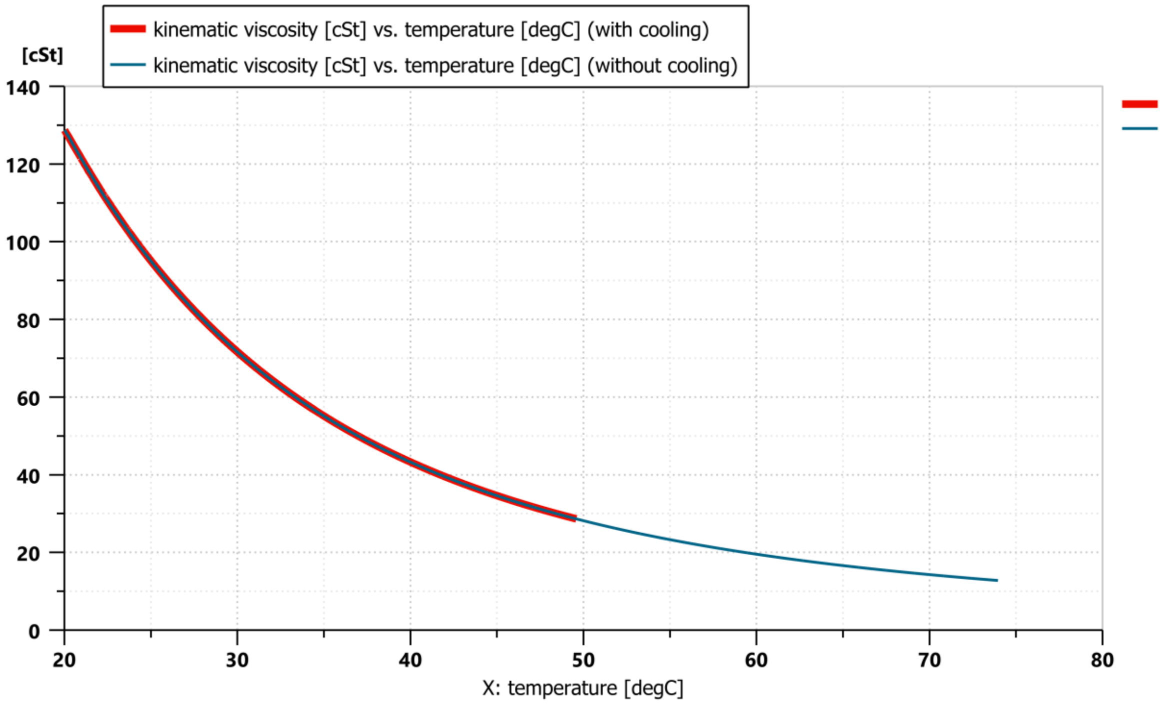

Fig. 17. The kinematic viscosity of the hydraulic fluid depending on its temperature

The heat flow rate between the heat exchanger and the environment is shown in Fig. 18.

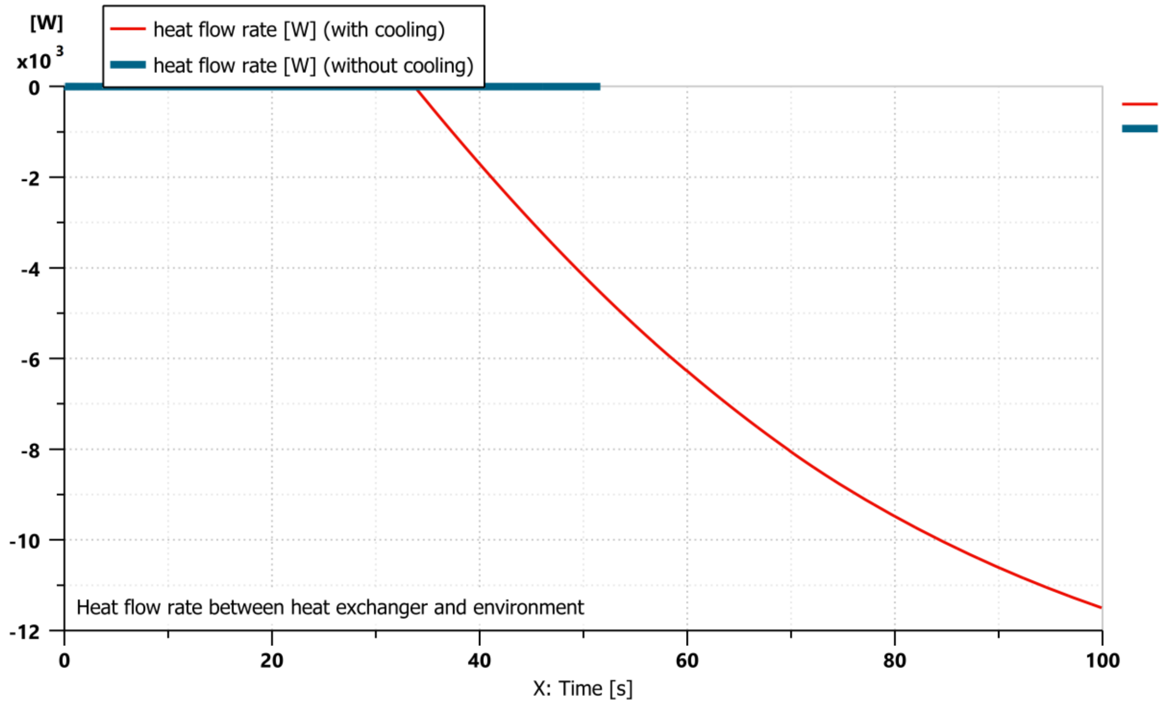

Fig. 18. Heat flow rate between heat exchanger and environment

4. Conclusions

- In the case of servo-mechanisms, the viscosity of the hydraulic fluid must not be strictly controlled, but must be kept within the limits specified by the manufacturer.

- If the cooling circuit of the transmission and the heat exchanger are not sized correctly, in certain situations when the temperature of the environment is very high or the transmission has not been optimized to cope with certain load conditions, the temperature of the hydraulic fluid can increase. Along with this increase, the viscosity decreases, and if it decreases too much, the volumetric losses will be too high and the servo-mechanism will no longer be able to control the flow rate of the pump.

- Unlike open loop transmissions that can operate at the limit even at temperatures of 80 degrees Celsius but with significant volumetric losses and for a short time, closed loop hydrostatic transmissions require a lower hydraulic fluid temperature during operation due to the sensitivity to the viscosity of the hydraulic fluid of the servo-mechanisms.

Acknowledgments

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