ISSN 1454 - 8003
Proceedings of 2019 International Conference on Hydraulics and Pneumatics - HERVEX
November 13-15, Băile Govora, Romania

CONSIDERATIONS REGARDING THE SHOCK ABSORBERS STATIC PERFORMANCES ACCORDING TO HYDRAULIC FLUID WEAR DEGREE

Alexandru Valentin RĂDULESCU[1], Irina RĂDULESCU, Radu Florin MIRICĂ, Daiana Georgiana IVAN

[1] University POLITEHNICA of Bucharest, alexandru.radulescu@upb.ro

Abstract: *The purpose of this paper is to determine the performance of hydraulic shock absorbers in static conditions and to correlate the experimental results with the rheological parameters of the specific fluid, considering its wear degree. The study was performed on two used hydraulic shock absorbers, that were part of a car suspension system. One of them was disassambled, in order to design the component parts and to recuperate the used hydraulic working fluid, and the other one was kept whole, for experimental testing in static conditions. The rheological properties of the used hydraulic fluid were determined, using a Brookfield rotating viscometer CAP 2000+, with cone and plate geometry. Finally, it can observe that the analytical relation for the variation of the static load versus velocity is quite appropriate at low velocities (until 25 mm/s), with the assumption of Newtonian or power law rheological model validity. At higher velocities, the model must be refined, taking into account the real geometry of the hydraulic shock absorber valve.*

Keywords*: Rheology, shock absorber, static test, fluid wear*

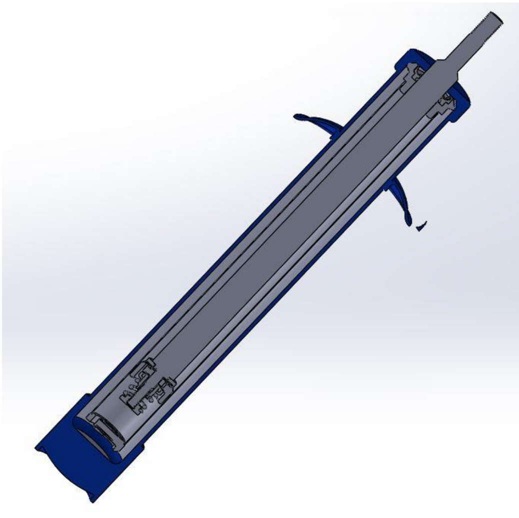
1. Introduction

Hydraulic shock absorbers utilize liquid fluid to convert mechanical energy into thermal energy. The dampening is facilitated by the shock absorber's fluid being moved by a piston displaced by mechanical action that forces the flow of the fluid through orifices or restrictors. The orifices which the fluid passes through limits the velocity or volume flow and converts the mechanical energy of the fluid into thermal energy. The heat energy is then transferred through the fluid and out the devices mechanical mass to the ambient air or environment. These types of absorbers are utilized within automobile, agriculture equipment, motorcycle suspensions, heavy truck, aircraft landing gear, conveyor systems, structural engineering applications and many other custom industrial applications [1 – 3].
Determining the correct hydraulic shock absorber size and performance characteristics requires a complete understanding of the dynamic and static requirements of the mechanical system involved. Performance requirements of a shock absorber system should be accurately estimated, so a functional test should be performed to verify the main technical characteristics: static and dynamic force at hydraulic shock absorber, velocity and stroke of target application, kinetic energy, deceleration rate of shock absorber etc. [4 – 7].
The study was performed on two used hydraulic shock absorbers [8], that were part of a car suspension system. One of them was disassambled, in order to design the component parts and to recuperate the used hydraulic working fluid [9], and the other one was kept whole, for experimental testing in static conditions.
The rheological properties of the used hydraulic fluid were determined, using a Brookfield rotating viscometer CAP 2000+, with cone and plate geometry [10]. It was observed that the used hydraulic fluid segregates in two fractions, according to their density: light fraction and heavy fraction.
A simple analytical expression for the static load of the hydraulic shock absorber was determined, performing also a comparison between theoretical and experimental variation of the static load versus velocity of the piston rod.

2. Theoretical model

The theoretical model is based on the geometry of a hydraulic shock absorber (Figure 1) [8], but assuming a simplified approach of the working area, with the main dimensions presented in Figure 2.

a) General view [8]



b) 3D model

Fig. 1. Hydraulic shock absorber

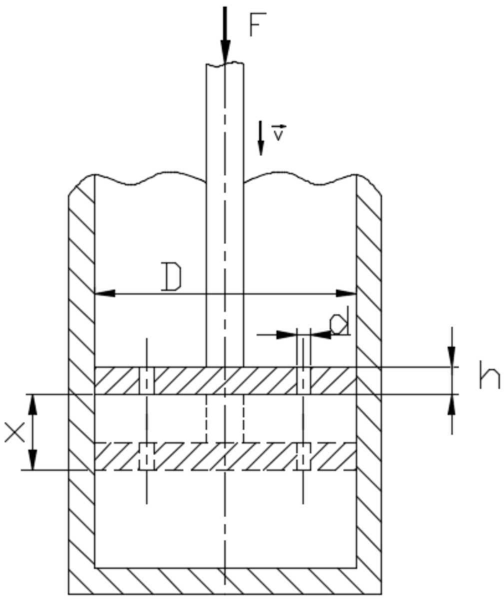


Fig. 2. Detail of the working area

The working area is characterized by piston diameter *D* = 40 mm, holes diameter in the piston *d* = 1 mm, number of holes *N* = 9 and holes length *h* = 10 mm.
In order to obtain the static load of the hydraulic shock absorber, it was assumed that at a downward displacement of the hydraulic piston at distance *x*, the volume of expelled working fluid is forced to flow through the *N* holes in the piston. So, the flow conservation equation has to written, taking into account the flow into the cylinder and the flow through the holes.
The flow of the working fluid into the cylinder, for a displacement *x* of the hydraulic piston, is expressed as:

$$Q = \frac{\pi D^2}{4} v \qquad (1),$$

where: Q – working fluid flow into the cylinder;
v – velocity of the hydraulic cylinder rod;
D – piston diameter.
The flow through the piston holes is calculated with the assumption that the working fluid is modelled with the power law rheological model [11]:

$$\tau = m \left(\frac{du}{dy}\right)^n \qquad (2),$$

where: τ – shear stress;
m – consistency index;
n – flow index;
u – fluid local velocity;
y – local coordinate;
The advantage of using this general model is that when flow index *n* is equal to one, the power law model reduces to the Newtonian fluid model and consistency index *K* has the unit of viscosity.
With assumption, the flow through the piston holes becomes [12]:

$$Q = \frac{\pi\left(\frac{d}{2}\right)^3}{\frac{1}{n}+3} \left[\frac{\Delta p \left(\frac{d}{2}\right)}{2hm}\right]^{\frac{1}{n}} \cdot N \qquad (3),$$

where: Q – working fluid flow through the piston holes;
d – holes diameter;
h – holes lenght;
N – number of holes;
Δp – hydraulic cylinder pressure drop;
The hydraulic cylinder pressure drop can be calculated with the following relation:

$$\Delta p = \frac{F}{\frac{\pi D^2}{4}} \qquad (4),$$

where: F – static load of the hydraulic shock absorber.
The final expression for the static load of the hydraulic shock absorber can be obtained from the flow conservation equation, namely by equalization of the equations (1) and (3) and considering the expression of the pressure drop given by equation (4):

$$F = \frac{2\pi h m D^{2n+2}\left(\frac{1}{n}+3\right)^n}{4^{n+1}\left(\frac{d}{2}\right)^{3n+1} N^n} v^n \qquad (5)$$

If the working fluid is a Newtonian fluid (*n* = 1), the static load of the hydraulic shock absorber will be calculated with a simplified relationship:

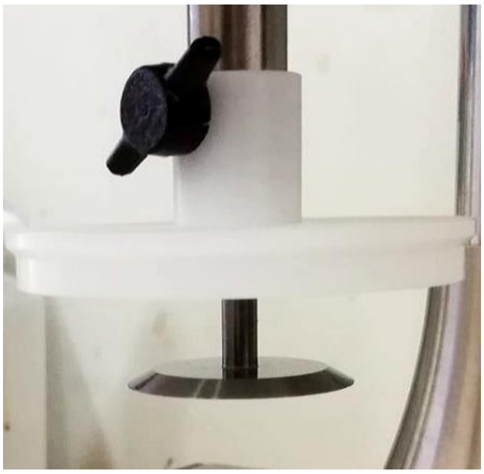
$$F = \frac{\pi h \mu D^4}{2\left(\frac{d}{2}\right)^4 N} v \qquad (6),$$

where: μ – fluid viscosity.

3. Experimental stand and methodology

The rheological measurements were performed on a Brookfield viscometer CAP2000+ equipped with four cone-and-plate geometry and using a Peltier system for controlling the temperature. The CAP 2000+ Series Viscometers are medium to high shear rate instruments with Cone Plate geometry and integrated temperature control of the test sample material [10].
A typical view of the viscometer is presented in Figure 3, with a detail of the working cone number 8 fixed in the coupling device.

a) General view



b) Cone no. 8

Fig. 3. Brookfield viscometer

Concerning the technical parameters of the viscometer, rotational speed selection ranges from 5 to 1000 rpm. Viscosity measurement ranges depend upon the cone spindle and the rotational speed (shear rate). Viscosity is selectively displayed in units of centipoise (cP), poise (P), or Pascal seconds (Pa•s). Temperature control of sample is possible between either 5°C (or 15°C below ambient, whichever is higher) and 75°C or 50°C and 235°C, depending on viscometer model. The viscometer uses a CAPCALC32 software for complete control and data analysis. The tested lubricant is an used hydraulic working fluid, with physical and chemical properties presented in Table 1 [9].

Table 1: Physical and chemical properties of the hydraulic working fluid [9]

Characteristic parameter	Hydraulic working fluid
Colour	light yellow
Odor	characteristic
Flash point [^{0}C]	152 (EN ISO 2592)
Density at 15°C [g/ml]	0.87 (DIN 51757)
Viscosity at 40°C [mm^2/s]	17.1 (DIN 51562)

Concerning the experimental determination of the static load of the hydraulic shock absorber, it was used an worn-out shock absorber, which was fixed in a vise (Figure 4). For the measurement of static load, a range of marked masses were placed on a flange mounted on the end of the shock absorber rod. There were used successively marked masses of 5, 10, 15, 20, 25 and 30 N.

The displacement time of the rod was established by timing, the timing starting from the moment when the flange was released. Knowing the shock absorber stroke and observing that the movement is uniform, the velocity of the hydraulic cylinder rod can be easily calculated.

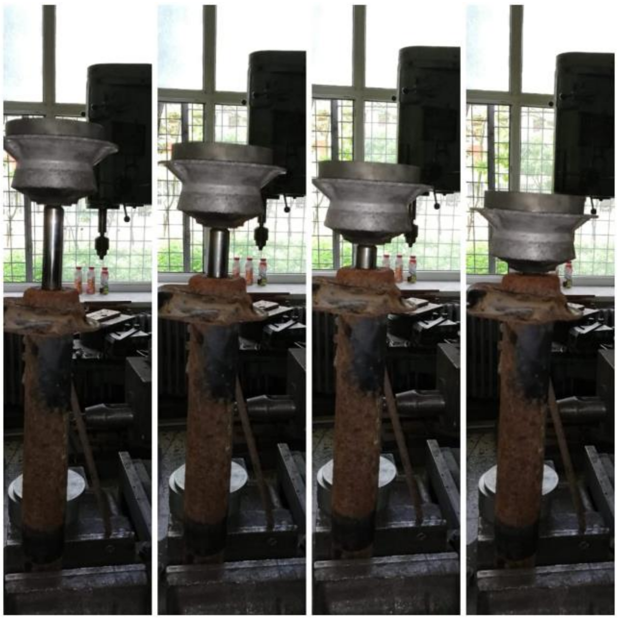


Fig. 4. Experimental setup for shock absorber testing

Using the rheological parameters determined for the working fluid with Brookfield viscometer, the theoretical values of the static load for the shock absorber were obtained. These values were compared with the experimental ones, measured on the real worn-out shock absorber.

4. Results and discussions

The experimental rheological tests were performed in two stages:

- tests for fluid stability - determination of the homogenization time (soaking time) of the samples, at five different shear rates: 200, 400, 600, 800 and 1000 s^{-1}
- tests for rheological parameters - consist of a load from 200 s^{-1} to 1200 s^{-1} shear rate gradient and measuring the shear stress, at a constant temperature of 20 ^{0}C.

During the experimental tests, it was observed that the used hydraulic fluid segregates in two fraction, according to their density: light fraction and heavy fraction. So, the results will be presented for these two fractions, and also for the mixture between them, called mixed fraction.
Figures 5, 6 and 7 present the results from the stability tests, where from it can determine the soaking time. This time represents an input data for the data acquisition program, request by Capcalc 32 software specific for the viscometer. Analysing these results, it can observe that working fluid viscosity decrease with the increasing of shear rate, for all three types of fractions: light, heavy and mixed. Regarding the soaking time (the time after which the fluid flow stabilizes), the curves presented in Figures 5, 6 and 7 show the stabilization of the movement after time intervals depending on the type of analyzed working fluid fraction (Table 2).

Table 2: Soaking time for different fraction of the hydraulic working fluid

Type of fraction	Soaking time [s]
light	50
heavy	70
mixed	60

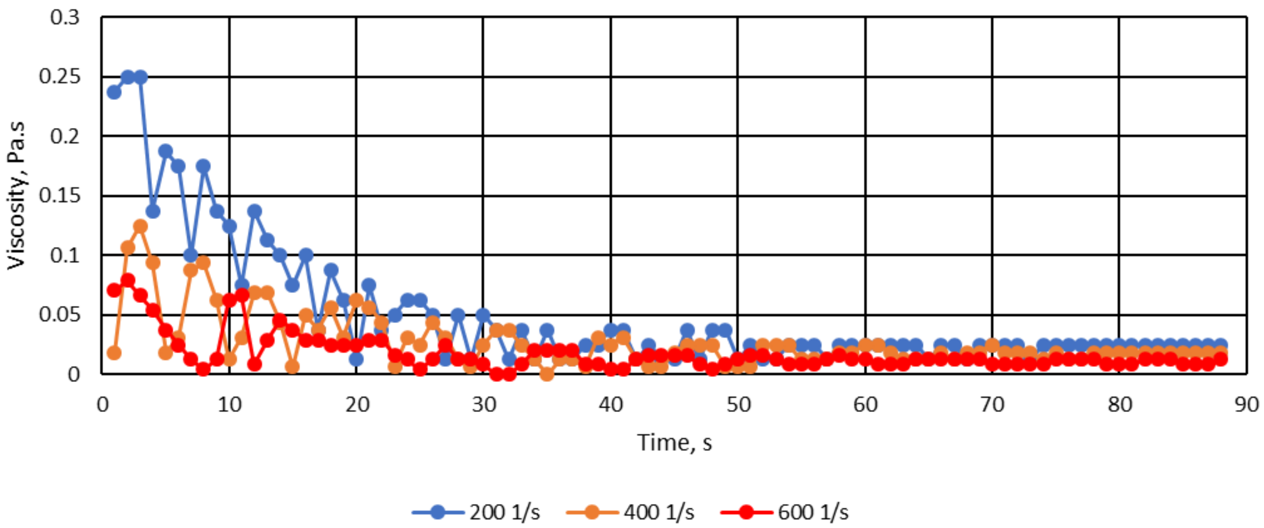


Fig. 5. Variation of the viscosity versus time for light fraction of the working fluid, at different shear rates

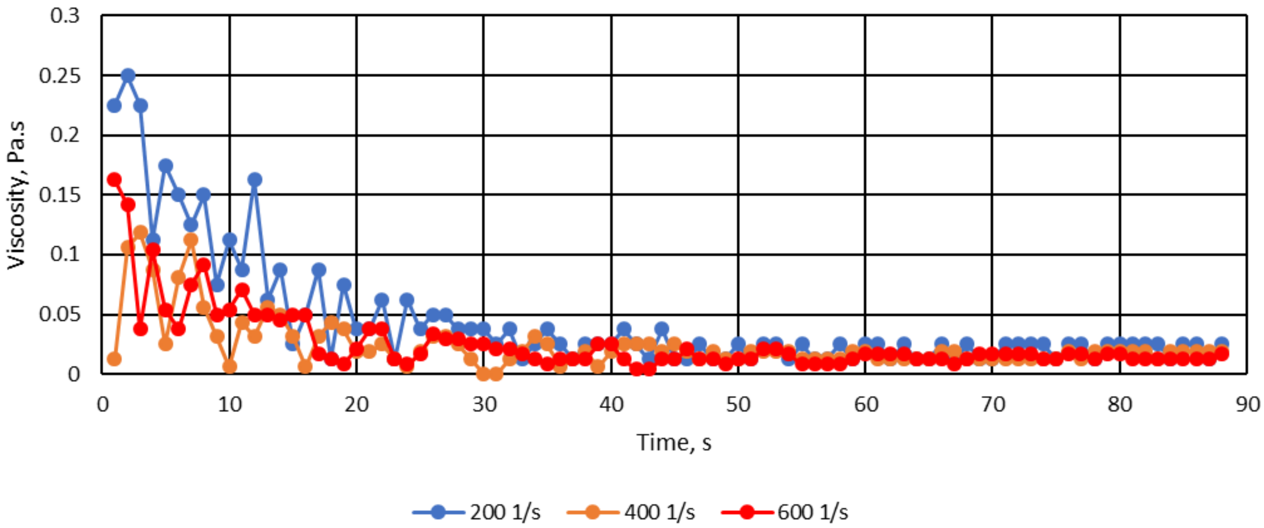


Fig. 6. Variation of the viscosity versus time for heavy fraction of the working fluid, at different shear rates

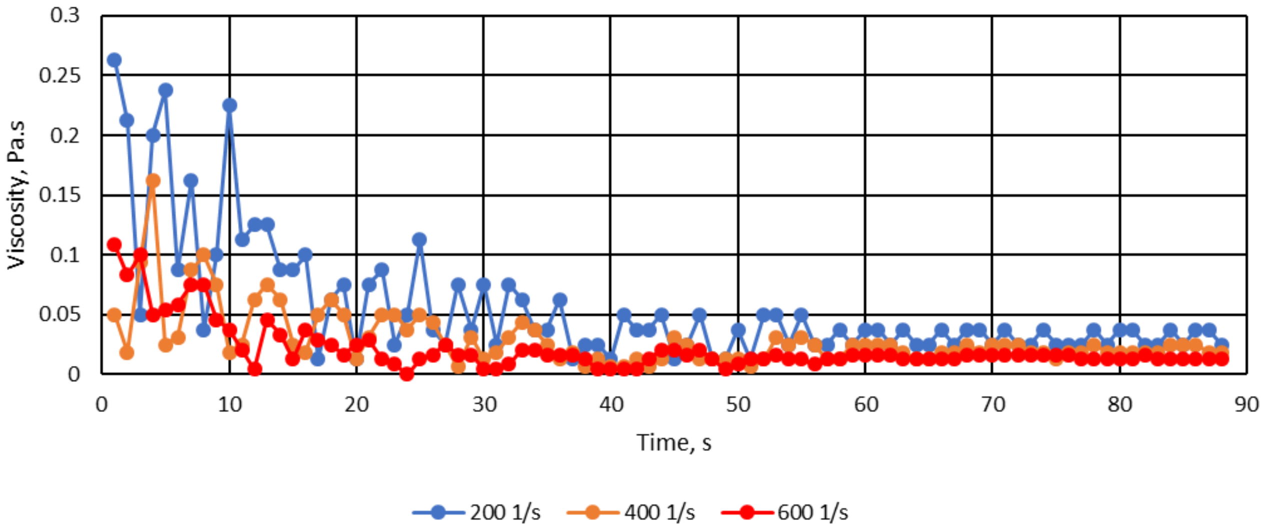


Fig. 7. Variation of the viscosity versus time for mixed fraction of the working fluid, at different shear rates

Figure 8 presents the specific rheograms for the hydraulic working fluid, corresponding to those three type of fractions (light, heavy and mixed). Based on these results, the rheological models of the analyzed fractions can be obtained, using the regression analysis method with MathCAD software.

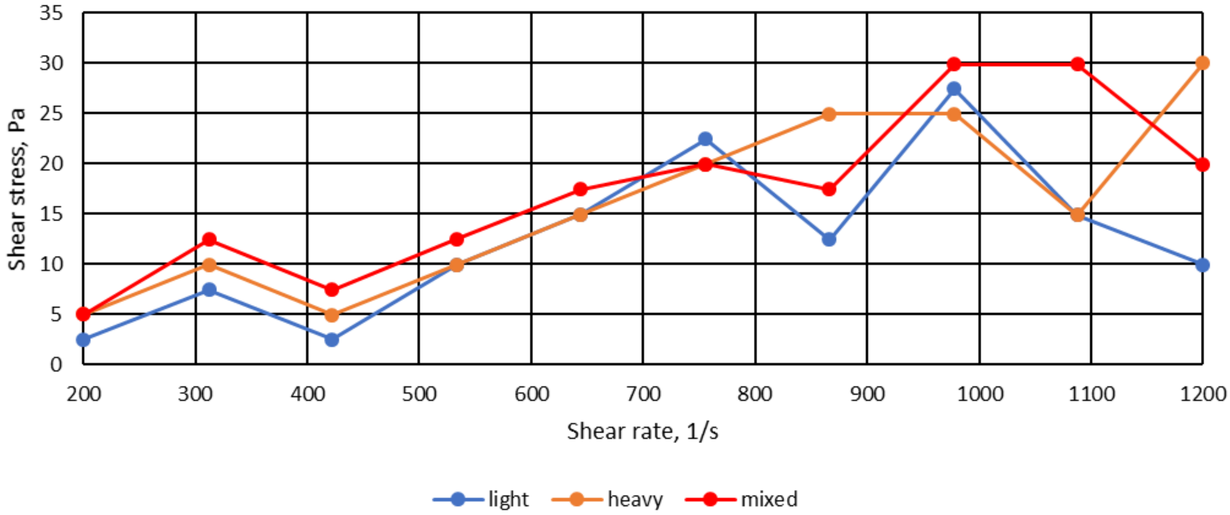


Fig. 8. Rheograms for different fractions of the working fluid, at 20 ^{0}C

Table 3 presents the values of the rheological parameters for the three types of working fluid fractions. Analyzing these results and considering the magnitude of the correlation coefficient, it can observe that power law rheological model is more appropriate for light fraction, while Newtonian model corresponds better for heavy and mixed fraction.

Table 3: Rheological parameters of hydraulic fluid different fractions

Lubricant	Newtonian model		Power law model		
	Viscosity, Pa·s	Corr. coeff., %	Consistency index, Pa·s^n	Flow index	Corr. coeff., %
Light fraction	0.0172	33.55	0.010	1.07	51.41
Heavy fraction	0.0227	73.70	0.029	0.96	72.23
Mixed fraction	0.0240	80.43	0.053	0.88	78.80

The results concerning the experimental determination of the static load of the hydraulic shock absorber are presented in Table 4.

Table 4: Experimental results for static load

G [N]	12.8	17.8	22.8	27.8	32.8	37.8	42.8
t [s]	25.60	14.26	9.49	6.96	4.98	4.13	2.75
v [mm/s]	3.75	6.73	10.12	13.79	19.28	23.25	34.91

Finally, the comparison between theoretical and experimental variation of the static load versus velocity of the piston rod, for all three fractions of the hydraulic working fluid, is presented in Figure 9.

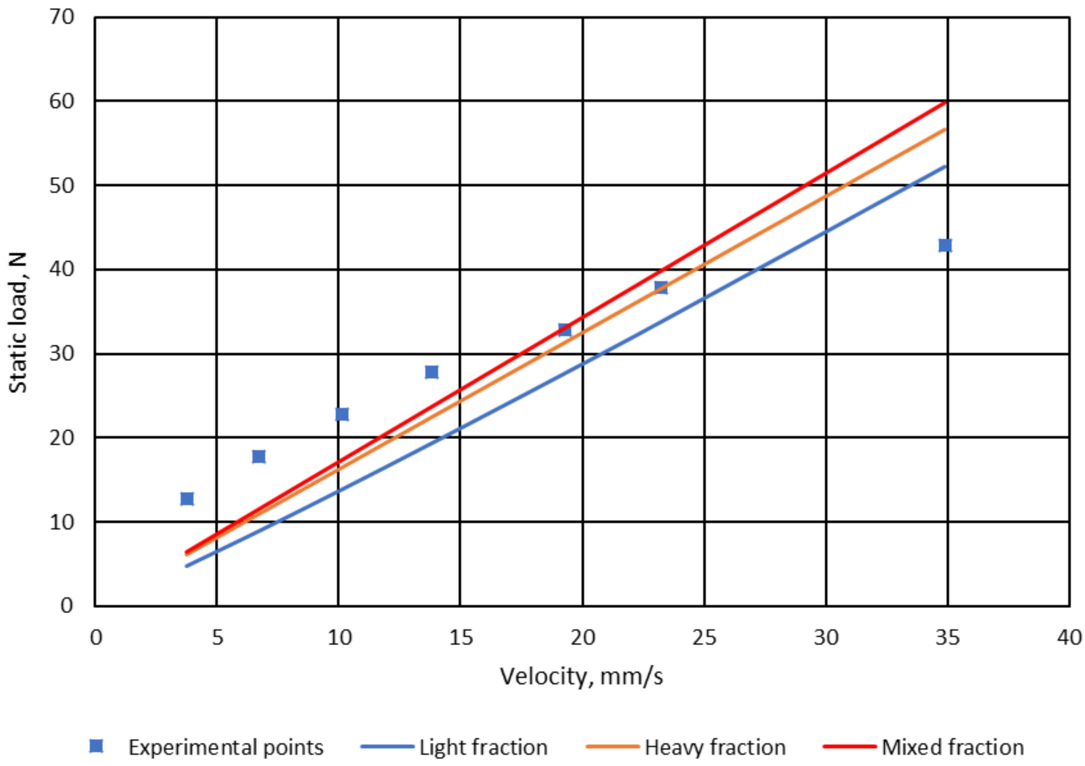


Fig. 9. Variation of static load versus velocity of the piston rod: comparison theory - experiment

5. Conclusions

The purpose of this paper was to determine the performance of hydraulic shock absorbers in static conditions and to correlate the experimental results with the rheological parameters of the specific fluid, considering its wear degree.
During the experimental tests, it was observed that the used hydraulic fluid segregates in two fraction, according to their density: light fraction and heavy fraction. From rheological point of view, it was found that power law rheological model is more appropriate for light fraction, while Newtonian model corresponds better for heavy and mixed fraction.
Finally, a simple analytical relation was proposed, for the variation of the static load of the shock absorber versus velocity of the piston rod. This calcul relation is quite appropriate at low velocities (until 25 mm/s), with the assumption of Newtonian or power law models validity.
At higher velocities, the theoretical model has to be refined, taking into account the real geometry of the hydraulic shock absorber valve.

References

[1] Singh, Manpreet, Singh, Jasvinder and Singh, Gurpreet. "Review on shock absorbers & suspension system". *International Research Journal of Engineering and Technology,* Vol. 4, No. 4 (Apr. 2017): 1521-1527.
[2] Morettini, Giulia, Bartolini, Nicola, Astolfi, Davide, Scappaticci, Lorenzo, Becchetti, Matteo and Castellani, Francesco. "Experimental diagnosis of cavitation for a hydraulic monotube shock absorber". *Diagnostyka*, Vol.17, No. 3 (2016):75-80.
[3] Czop, Piotr and Gnilka, Jacek. "Reducing aeration and cavitation effect in shock absorbers using fluid-structure interaction simulation". *Computer Assisted Methods in Engineering and Science,* Vol. 23 (2016): 171-189.
[4] Wieckowski, Dariusz, Dabrowski, Krzysztof and Slaski, Grzegorz. "Adjustable shock absorber characteristics testings and modelling". *IOP Conf. Series: Materials Science and Engineering,* 421 (2018) 022039: 1-10.

[5] Titurus, Branislav, du Bois, Jonathan, Lieven, Nick and Hansford, Robert. “Model uncertainty in identification of the static characteristics of the hydraulic damper”. *10th International Conference RASD 2010*, Southampton (12-14 July 2010): 170-180.
[6] Ferdek, Urszula and Luczko, Jan. “Modeling and analysis of a twin-tube hydraulic shock absorber”. *Journal of Theoretical and Applied Mechanics,* Vol. 50, No. 2 (2012): 627-638.
[7] Krakov, Mikhail. “Influence of rheological properties of magnetic fluid on damping ability of magnetic fluid shock-absorber”. *Journal of Magnetism and Magnetic Materials,* Vol. 201, No. 1-3 (Julay 1999): 368-371.
[8] https://www.engineersedge.com/hydraulic/hydraulic-shock-absorbers.htm (accessed on 26.09.2019).
[9] https://cdn.partsfinder.bilsteingroup.com/pf-document/CLP02615_GB.PDF (accessed on 03.10.2019).
[10] http://www.brookfieldengineering.com/-/media/ametekbrookfield/manuals/ lab%20viscometers/cap2000%20instructions.pdf?la=en (accessed on 29.09.2019).
[11] Balan, Corneliu. *The rheology of lubricating greases.* NLGI ed., 2000.
[12] Chhabra, Raj and Richardson, John, Francis. *Non-Newtonian flow and applied rheology: engineering applications.* Butterworth-Heinemann ed., 2011.