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DETERMINATION OF PRESSURE LOSS IN PIPE DURING FLOW OF ECOLOGICAL PLASTIC LUBRICANT MOGUL EKO L1

STANOVENÍ TLAKOVÉ ZTRÁTY V POTRUBÍ PŘI PROUDĚNÍ EKOLOGICKÉHO PLASTICKÉHO MAZIVA MOGUL EKO L1

Abstract

The article deals with determination of pressure loss in steel pipe during flow of ecological plastic lubricant MOGUL EKO L1. For pulsing flow of lubricant through pipe is experimentally determined pressure loss in pipe to the mean flow velocity. This relation is compared to a calculated relation of pressure loss in pipe at mean flow velocity for steady flow mentioned lubricant according Bulkley–Herschell rheological model and according Bingham rheological model.

Abstrakt

Příspěvek se zabývá stanovením tlakové ztráty v ocelovém potrubí při proudění ekologického plastického maziva MOGUL EKO L1. Pro pulzující proudění maziva trubkou je experimentálně stanovena závislost tlakové ztráty v potrubí na střední rychlosti proudění. Tato závislost je porovnána s vypočtenou závislostí tlakové ztráty v potrubí na střední rychlosti proudění pro ustálené proudění uvedeného maziva dle Bulkley – Herschellova reologického modelu a dle Binghamova reologického modelu.

1 Introduction

For fine lubricating system design is important to determine pressure loss. A significant group of lubricants present the plastic lubricants, which are ranked to non-Newtonian fluids. For non-Newtonian fluids is a ratio of shear stress τ and shear deformation velocity $d\gamma/dt$ variable quantity – apparent viscosity. Calculation of pressure loss for non-Newtonian fluids is different from calculation of pressure loss for Newtonian fluids. For determination of pressure loss of non-Newtonian fluid flow is important a course of relations between shear stress τ and shear deformation velocity $d\gamma/dt$, which is called the flow curve or rheogram. The flow curve of lubricant is determined experimentally using rheometer. We can classify Lubricant MOGUL EKO L1 with regard to course of its flow curve as true viscoplastic non-Newtonian fluids. Measured rheograms are approximated by rheological model.

2 A steady flow of plastic lubricant in the pipe, Bulkley – Herschell model

For description of rheological properties of a real viscoplastic fluid is known Bulkley - Herschell model:

$$\tau = \tau_0 + K \cdot (\dot{\gamma})^n , \tag{1}$$

where τ_0 (Pa) is initial shear stress, K (Pa.s^n) – consistency coefficient, n – flow index.

Rheological parameters for molded plastic lubricant MOGUL EKO L1 at temperature ϑ =25°C are as follows [4]: τ_0 = 188.78 Pa, K = 43.77 Pa.s^n, n = 0.3979.

We can determine dependency of mean flow velocity v_s on pressure gradient p_z for steady flow of plastic lubricant in pipe with length L and inner diameter d. The dependency is calculated for Bulkley - Herschell rheological model by following equations [1] [2]:

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$$v_s = \frac{1}{\eta_0} \cdot \left(\frac{p_z \cdot R}{2 \cdot L} \right)^m \cdot R \cdot \phi \tag{2}$$

where:

$$\eta_0 = K^m \tag{3}$$

$$m = \frac{1}{n} \tag{4}$$

$$\phi = \left[\frac{(1-\alpha)^{m+1}}{m+1} - \frac{2 \cdot (1-\alpha)^{m+2}}{(m+1) \cdot (m+2)} + \frac{(1-\alpha)^{m+3}}{(m+1) \cdot (m+2) \cdot (m+3)} \right] \tag{5}$$

$$\alpha = \frac{r_0}{R} \tag{6}$$

$$r_0 = \frac{2 \cdot L}{p_Z} \cdot \tau_0 \tag{7}$$

$$R = \frac{d}{2} \tag{8}$$

For steady flow of ecological plastic lubricant MOGUL EKO L1 was calculated dependency of pressure gradient p_z on the mean flow velocity v_s taking advantage of Herschell–Bulkley software, which is available at Department of Hydromechanics and Hydraulic Equipment FS VŠB-TU Ostrava.

3 A steady flow of plastic lubricant in pipe, Bingham model

We can use Bingham model for description of rheological properties of ideal viscoplastic fluid:

$$\tau = \tau_0 + \eta_B \cdot \dot{\gamma} \tag{9}$$

where τ_0 (Pa) is initial shear stress, η_B (Pa.s) – Bingham viscosity .

Rheological parameters for molded plastic lubricant MOGUL EKO L1 at temperature ϑ =25°C are as follows [4]: τ_0 = 239.18 Pa, η_B = 5.14 Pa.s.

We can determine dependency of pressure loss p_z on mean flow velocity v_s for steady flow of plastic lubricant in pipe of length L and inner diameter d. The dependency is calculated for Bingham rheological model by Darcy-Weisbach equation [1] [3]:

$$p_z = \lambda \frac{L}{d} \cdot \frac{v_s^2}{2} \cdot \rho \tag{10}$$

Friction coefficient λ is determined from equation:

$$\lambda^4 - \left(\frac{64}{\mathrm{Re}_B} + \frac{64}{6} \cdot He_1 \right) \cdot \lambda^3 + \frac{64^2}{3} \cdot He_1^{\ 4} = 0 \tag{11}$$

where Reynolds number Re_B and Hedström number He is established according relation:

$$\mathrm{Re}_B = \frac{v_s \cdot d \cdot \rho}{\eta_B} \tag{12}$$

$$He = \frac{\tau_0 \cdot d^2 \cdot \rho}{\eta_B^{\ 2}} \tag{13}$$

for criterion He_1 is valid:

$$He_1 = \frac{He}{\mathrm{Re}_B^{\ 2}} = \frac{\tau_0}{\rho \cdot v_s^{\ 2}} \tag{14}$$

For steady flow of ecological plastic lubricant MOGUL EKO L1 was calculated relation of pressure gradient p_z on the mean flow velocity v_s taking advantage of Bingham software, which is available at Department of Hydromechanics and Hydraulic Equipment FS VŠB-TU Ostrava.

4 An experimental verification of pressure loss

The scheme of measuring apparatus for experimental determination of pressure loss in the pipe in dependency on a mean flow velocity at pulsing flow of plastic lubricant displays Fig.1. Measuring equipment allows experimentally determine a stress modulus of lubricant in steel pipe and a spreading wave phase velocity at pulsing flow of plastic lubricant.

Specification of components and apparatus:

lubricant MOGUL EKO L1 with density ρ= 900 kg.m^{-3},

LA- lubricating aggregate Tribos ACF 02, T – tank,

l_1 – steel pipe: length l_1= 4.2m, inner diameter d, outer diameter D,

l_2 – steel pipe: length l_2= 5.3m, inner diameter d, outer diameter D,

V1, V2, V3, closing valves, C1, C2, C3, C4, C5 – cubes with Minimess connections,

HM – linear hydro motor, piston diameter D= 12mm, piston rod diameter d= 6mm,

TR1, TR2, TR3 – original pressure transducers Hydrotechnik,

TR4 – inductive position transducer Megatron, model RC13-100-M, output connected to voltage input of measuring station Hydrotechnik,

TR5 – original temperature transducer Hydrotechnik,

M 5000 – original measuring station M5000 Hydrotechnik.

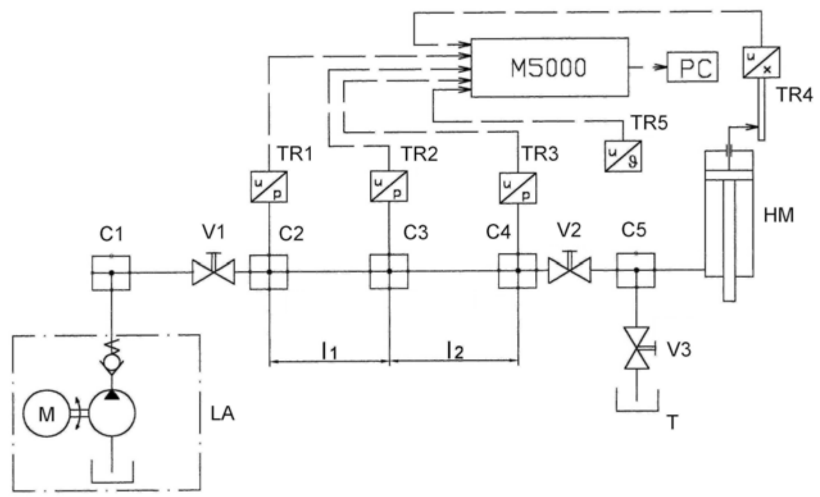

Fig.1 Scheme of experimental apparatus

The apparatus allows to measure pressure loss in three points on the transducers TR_1, TR_2, TR_3 for variants with one or two pipes l_1, l_2. The measurement was made for variant with one pipe l_1 of length L_1 = 4.16 m, inner diameter d= 3.6 mm and outer diameter D = 6 mm. The pipe l_2, connecting cube C_4 and transducer TR_3 were not included in the system. The cube C_3 is connected directly to the valve V_2. There were measured a course of pressure p_1 on the transducer TR_1 and pressure p_2 on the transducer TR_2. For measurement of pressure was used an original pressure transducers PR15 Hydrotechnik, accuracy 0.5%. A change of piston rod position of hydro motor HM was measured using position transducer TR_4 with output voltage U. For the purpose of conversion of output voltage U from position transducer to position size in mm was position transducer standardized using dial gauge. The temperature ϑ was measured using temperature transducer TR_5. After transfer of received data files from inner memory of measuring station M5000 Hydrotechnik to PC the data were processed using software HYDROcomsys/win. The pressure loss p_z was determined as difference of average value of pulsing pressure p_1 and average value of pressure p_2. At known diameter of piston, diameter of piston rod and measured position of piston rod in time t of linear hydro motor HM is calculated a volume of lubricant ejected from pipe in time t and average flow velocity $v_{s.}$

The Fig. 2 shows an example of measured courses of pressure p_1 on transducer TR_1, pressure p_2 on transducer TR_2 and output voltage U of position transducer TR_4 for a pulsing flow. Interval of scanning is 20 ms, temperature of lubricant is ϑ=24.2°C.

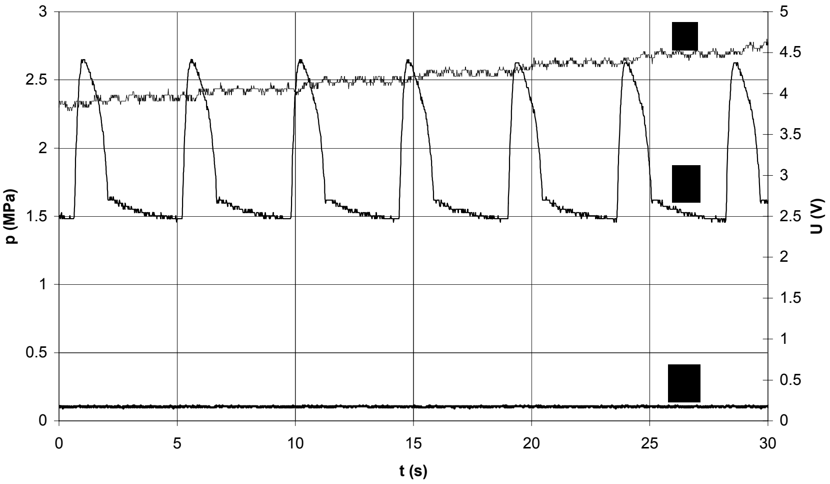

Fig.2 The courses of pressure p_1 on the transducer TR_1, pressure p_2 on transducer TR_2 and output voltage U of position transducer TR_4 for pulsing flow

Fig.3 compares calculated relations of pressure loss in pipe on mean flow velocity according Bulkley–Herschell rheological model and according Bingham rheological model with experimental pressure loss for pulsing flow.

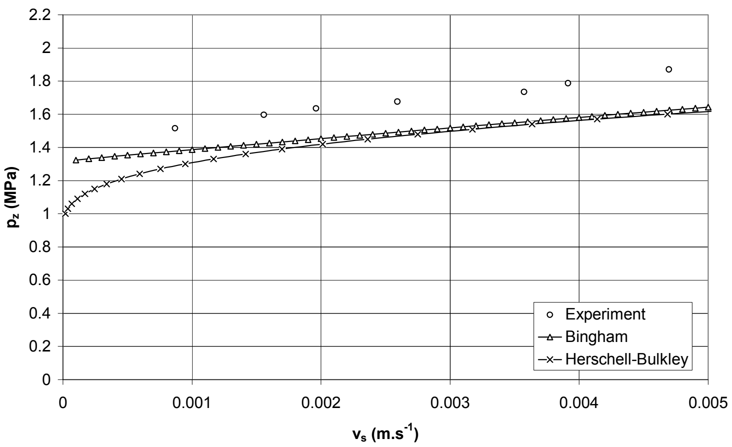

Fig.3 Dependency of pressure loss p_z in pipe on mean flow velocity v_s, pipe length L_1 = 4.16 m, inner diameter d= 3.6 mm

5 Conclusion

This study determines pressure loss in pipe during flow of plastic ecological lubricant MOGUL EKO L1 experimentally for pulsing flow and numerically for steady flow according Bulkley-Herschell rheological model and according Bingham rheological model. From the Fig. 3 is clear, that course of measured values of pressure loss approaches well the curve tendency of calculated data. Calculated values of pressure loss are approx. 0.2 MPa lower in comparison to measured ones, that is most probably caused by different level of lubricant molding in the lubricant aggregate and pipe compare to lubricant molding level used for the calculating process. The pressure loss is influenced by tixotropy of lubricant, when by shear stress rheological properties of lubricant are changed. Higher values of experimentally established pressure loss, compared to the calculation, indicate less molded lubricant during an experiment in comparison with molding of lubricant, which was use for calculation. Tixotropic behavior of lubricant significantly influence the value of pressure loss. Since solving practical problems the level of lubricant molding in lubricating aggregate and in the pipe does not have to correspond exactly with level of lubricant molding used for calculation, results are sufficiently precise for determination of pressure loss.

Dependency of pressure loss in pipe on mean flow velocity for pulsing flow was measured and compared with calculated pressure loss for steady laminar flow. It is also advisable to measure the pressure loss for steady flow of lubricant and to compare it with value of measured pressure loss at pulsing flow. The steady flow is ensured using hydraulic accumulator at output of lubricating aggregate. According [1] are relations $v_s - p_z$ derived for steady flow, but experiments show, that relations are usable for pulsing flow, as far as the amplitude of pulsations is essentially lower then value of direct component of flow.

Literature Review

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