Agata BIEŃCZAK
Industrial Institute of Agricultural Engineering
ul. Starołęcka 31, 60-963 Poznań, Poland
e-mail: office@pimr.poznan.pl

THE EFFECT OF FLUID VISCOSITY ON THE CHARACTERISTICS OF GEAR PUMP OF DECLARED CAPACITY OF 2.5 $m^3 \cdot h^{-1}$

Summary

The paper presents selected characteristics of gear pump of declared volume flow rate of 2.5 $m^3 \cdot h^{-1}$. The effect of viscosity on among others: volume velocity and power of the pump shaft has been determined. It has been found that the viscosity significantly influences the characteristics of the pump.
***Key words**: gear pump, viscosity, pump characteristics*

WPŁYW LEPKOŚCI POMPOWANEJ CIECZY NA CHARAKTERYSTYKI PRZEPŁYWOWE POMPY ZĘBATEJ O DEKLAROWANEJ WYDAJNOŚCI 2,5 $m^3 \cdot h^{-1}$

Streszczenie

W artykule przedstawiono wybrane charakterystyki pompy zębatej o deklarowanej wydajności 2,5 $m^3 \cdot h^{-1}$. Określono wpływ lepkości m.in. na strumień objętości oraz moc na wale pompy. Ustalono, że lepkość znacząco wpływa na charakterystyki przepływowe pompy.
***Słowa kluczowe**: pompa zębata, lepkość, charakterystyki pomp*

1. Introduction and aim

Properly determined pump characteristics constitute major criteria of selection of pump systems in manufacturing plants. In food processing industry, positive displacement pumps as well as rotodynamic pumps are widely used. The type of pump primarily depends on the properties of the fluid to be displaced and on its viscosity. Generally, positive displacement pumps are mainly used for medium and high-viscosity fluids, such as chocolate (2.5-16 Pa·s), whereas rotodynamic pumps are used for low-viscosity fluids such as milk (0.002-0.004 Pa·s) [4]. In the subject literature, the available information pertains to research on operation of pumps depending on the viscosity of the pumped fluid. The research, however, was carried out repeatedly with several types of oil of various viscosity (below 0.5 Pa·s). Publication [8] presents the results of positive displacement pumps using viscous fluids (10-41 Pa·s). The tests run with a rotary cam pump proved that increased viscosity significantly influences its characteristics [8]. Such information regarding gear pumps is rather scarce and pertains mostly to hydraulic pumps. The body of research into the effect of fluid viscosity in hydraulic pumps is vast. It includes numerous phenomena occurring when the pump operates, e.g. the pulsating capacity [7] or the impact of the operating parameters on the efficiency of the pumps, which was studied using hydraulic oil of viscosity ranging from <0.015 to 0.2> Pa·s [6]. When testing gear pumps used in the food industry, it is important to carry out tests with fluids of substantially higher viscosity (several dozen Pa·s). The flow characteristics of gear pumps are presented mainly in technical documentation provided by their manufacturers (Pomac Pumps, All Pumps, Tapflo) and are not generally accessible. Consequently, there is a need to work out the characteristics of gear pumps depending on the viscosity of the fluid they displace. The above statement encouraged the researchers from Industrial Institute of Agricultural Engineering and, specifically, its Department of Research and Development of Foodstuff Machinery and Devices to address the said problem.

The aim of this work is to present selected characteristics of a gear pump of declared capacity of 2.5 $m^3 \cdot h^{-1}$, depending on the viscosity of the pumped fluid [1]. The detailed aims include defining the following characteristics:

- volumetric capacity depending on the pump rotational speed Q(n),
- power needed to energize the pumps depending on their rotational speed P(n),
- pressure difference across the pump depending on its rotational speed Δp(n).

2. Methodology and materials

The subject of the research was a gear pump of declared capacity of 2.5 $m^3 \cdot h^{-1}$ presented in fig. 1.

Photo: A. Bieńczak

Fig. 1. Gear pump of declared capacity of 2.5 $m^3 \cdot h^{-1}$ with the electric motor fitted
Rys. 1. Pompa zębata wraz z napędem o deklarowanej wydajności 2,5 $m^3 \cdot h^{-1}$

The parameters of the pumping system are presented in table 1.

Table 1. Selected parameters of the pump and its electric drive [5]
Tab. 1. Wybrane parametry pomp i napędu elektrycznego [5]

Parameter	P25
Declared capacity of the pump [$m^3 \cdot h^{-1}$]	2.5
Intertooth space [m^2],	0.0000407016
Number of teeth [pcs.]	6
Nominal rotary speed of the pump [rpm^{-1}]	150
Motor power of [kW]	1.5

The research was carried out on a test bench located in Industrial Institute of Agricultural Engineering in Poznań (fig. 2). The test bench consisted of the pump, its driving motor, a mixing tank with a double heating mantle, pipelines of the diameter of 0.05 [m] with a coiled heating cable, a mass flow-meter and a number of pressure and temperature recording sensors [2].

The tests were run using vegetable oil, high sugar content glucose syrup (SW) and low sugar content glucose syrup (SN). The temperature of the vegetable oil was 24°C. The tests using the glucose syrup were run at various temperatures, which allowed obtaining various viscosities (table 2).

Table 2. Selected physical properties of the pumped fluid [1]
Tab. 2. Wybrane właściwości fizyczne przetłaczanej cieczy [1]

No	Name	Temperature [°C]	Viscosity [Pa·s]	Density [$kg \cdot m^{-3}$]
1.	Vegetable oil	24	0.08	889
2.	SW	50	1.00	1393
3.	SW	35	2.60	1394
4.	SW	25	5.40	1400
5.	SW	22	10.00	1410
6.	SN	50	12.00	1410
7.	SN	38	20.00	1413
8.	SN	42	30.00	1414

The fluid was poured into the mixing tank whose bottom valve was then open so that the fluid could flow into the pump. Subsequently, the pump was started in order to remove the initial part of the fluid mixed with water that remained after rinsing the test bench. The pump moved the fluid in a closed system. After the temperature in the system reached the desired value, the tests were initiated. Volume velocity, suction and discharge pressures, rotational speed, power consumption of the pump, temperature and viscosity of the displaced fluid were recorded at the time of testing [1, 3]. Based on the test results, the characteristics of the pump under examination were defined.

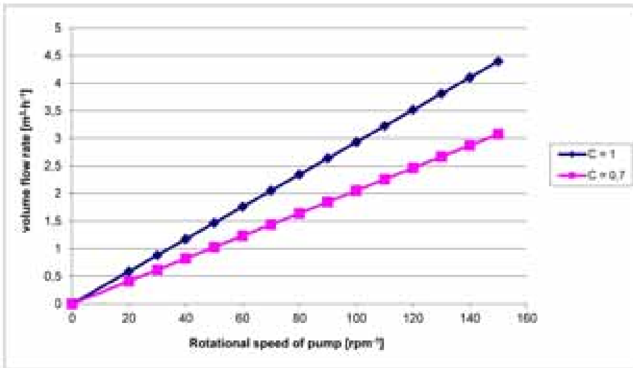
3. Results of research

The flow of fluid in gear pumps is defined by equation (1). The volume flow rate of the pump was calculated based on the equation:

$$V = C \cdot 2v \cdot n \cdot z, \quad (1)$$

where:
V – volume flow rate (capacity) [$m^3 \cdot min^{-1}$],
C – the pump constant resulting from its design (volumetric efficiency),
v – intertooth space volume [m^3],
n – rotational speed [rpm],
z – number of teeth.

According to equation (1), theoretical linear characteristics for fluids were obtained (for C = 1, and C = 0.7) fig. 3. They were subsequently validated on the test bench [5].



Source: own study, *źródło: opracowanie własne*

Fig. 3. Theoretical characteristics of volume velocity for the pump of declared volume flow rate of 2.5 $m^3 \cdot h^{-1}$
Rys. 3. Teoretyczna charakterystyka strumienia objętości przepływu dla pompy o deklarowanego wydajności 2,5 $m^3 \cdot h^{-1}$

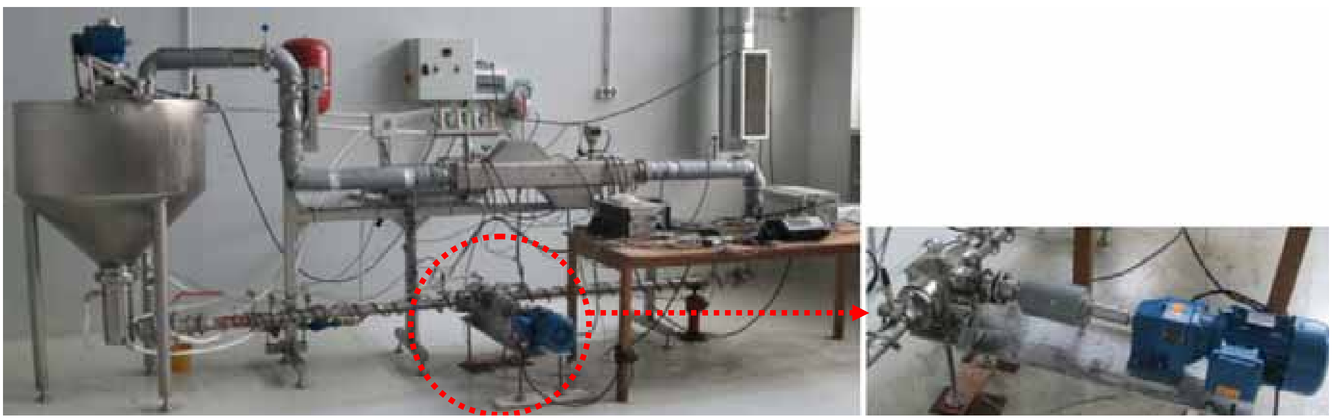
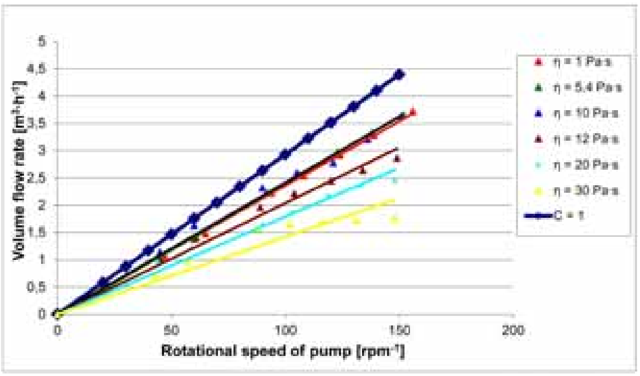


Fig. 2. The gear pump test bench [2]
Rys. 2. Stanowisko do badań charakterystyk przepływowych pomp zębatych [2]

Fig. 4. presents the flow characteristics for fluids of the following viscosities: 1.0; 5.4; 10.0; 12.0; 20.0 and 30.0 Pa·s. Fig. 4 also presents a theoretical curve for C=1.



Source: own study, *źródło: opracowanie własne*

Fig. 4. The effect of rotational speed of the pump on the volume flow rate for fluids of various viscosities
Rys. 4. Wpływ prędkości obrotowej pompy na strumień objętości dla cieczy o różnych lepkościach

The research showed that the pump obtained its declared volume flow rate of 2.5 $m^3 \cdot h^{-1}$ at various rotational speeds of the pump. Table 3 presents the values of rotational speeds at which the pump obtained its declared capacity.

Table 3. The value of rotational speed of the pump for volume flow rate of 2.5 $m^3 \cdot h^{-1}$ depending on the viscosity of the displaced fluid
Tab. 3. Wartość prędkości obrotowej pompy dla strumienia objętości 2,5 $m^3 \cdot h^{-1}$ w zależności od lepkości przetłaczanej cieczy

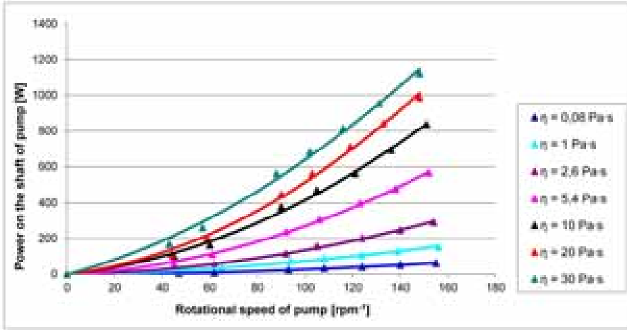
No.	Viscosity [Pa·s]	Pump rotational speed [rpm^{-1}]
1.	1	108
2.	5.4	106
3.	10	105
4.	12	120
5.	20	148
6.	30	Does not reach the value

Source: own study, *źródło: opracowanie własne*

It was observed that the increase in viscosity above 10.0 Pa·s resulted in the increase of the rotational speed at which the pump reached its declared volumetric flow rate. For the viscosity of 30.0 Pa·s, however, the declared capacity could not be reached. The maximum obtained volume flow rate reached 1.8 $m^3 \cdot h^{-1}$.

Fig. 5. presents the characteristics of the pump output for fluids of the following values of viscosities 0.08; 1.0; 2.6; 5.4; 10.0; 20.0; 30.0 Pa·s.

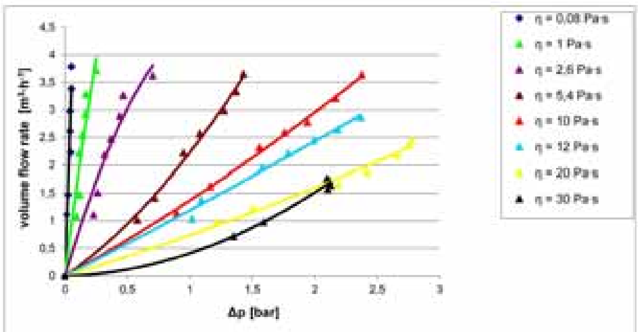
It was observed that, along with increasing viscosity of the fluid, the power consumption of the pump increased. With fluids of the viscosity of 30.0 Pa·s, the power consumption was close to the of maximum power electric motor. Consequently, the pump was unable to displace fluid of higher viscosity.



Source: own study, *źródło: opracowanie własne*

Fig. 5. The effect of rotational speed of the pump with declared volume flow rate of 2.5 $m^3 \cdot h^{-1}$ on its power consumption for various viscosities of the displaced fluid
Rys. 5. Wpływ prędkości obrotowej pompy o deklarowanej wydajności objętościowej 2,5 $m^3 \cdot h^{-1}$ na jej pobór mocy na wale dla różnych lepkości przetłaczanej cieczy

Fig. 6. shows the relation of capacities with respect to pressure differences created upstream and downstream of the pump for fluids of the following viscosities 0.08; 1.0; 2.6; 5.4; 10.0; 12.0; 20.0; 30.0 Pa·s.



Source: own study, *źródło: opracowanie własne*

Fig. 6. The effect of suction and discharge pressure differences on the volume flow rate for various fluid viscosities
Rys. 6. Wpływ różnicy ciśnień na ssaniu i tłoczeniu w zależności od wydajności dla różnych lepkości przetłaczanej cieczy

It was observed that the value of pressure difference increased with the increase in viscosity. For fluids of up to 2.6 Pa·s and volume velocity of 2.5 $m^3 \cdot h^{-1}$ the pressure difference was below 0.5 bar. For the viscosity of 5.4 Pa·s, it doubled to reach 1 bar and a fourfold increase in viscosity caused a triple increase in the value of the pressure difference.

4. Conclusions

The research showed that viscosity ranging from 0.08 to 30 Pa·s significantly influences the pump characteristics. The increase in viscosity of the displaced fluid caused a drop in the pump volumetric efficiency and an increase in the pump power consumption. At 1 Pa·s, the power consumption was several times lower than for fluids of the viscosity of 20 Pa·s. The tested pump did not reach its declared capacity of 2.5 $m^3 \cdot h^{-1}$ when displacing fluids whose viscosity value was 30 Pa·s due to inadequate power of the electric motor. Based on the above research, it was confirmed that viscosity constitutes a key factor influencing the operation of the pump and its characteristics and that tests carried out using exclusively vegetable oil do not fully reflect the phenomena that take place inside the pump. The conclusions of this research are in accordance with [8]. Based on the analysis of equation (1) and the tests, parameter C depends on the viscosity of the displaced fluid, which needs to be further studied.

5. References

[1] Bieńczak A., Chruściński W., Dembicki D., Dudziński P., Marcinkiewicz J., Szczepaniak J.: Badania eksperymentalne parametrów wydajności i trwałości typoszeregu niekomercyjnego prototypu pomp. Badania trwałości powłok ochronnych kół zębatych z wykorzystaniem analizy obrazu, Poznań, PIMR, 2013.

[2] Bieńczak A., Rak-Urbaniak L., Pera A.: Stanowisko do badań pomp zębatych. Technika Rolnicza Ogrodnicza Leśna, 2012, 6: 22-24.

[3] Bieńczak A., Szczepaniak J.: Studium i badania charakterystyk reologicznych wybranych płynów nienewtonowskich pod kątem ich właściwości przepływowych. Opracowanie modelu matematycznego przepływu w typoszeregu pomp dla celów aproksymacji charakterystyk obliczeniowych, Poznań, PIMR, 2012.

[4] Bieńczak A., Szczepaniak J., Wilkońska M.: System transportu cieczy o różnych lepkościach w spożywczych zakładach produkcyjnych. Technika Rolnicza Ogrodnicza Leśna, 2012, 6.

[5] Marcinkiewicz J., Bieńczak A.: Opracowanie modelu obliczeniowego MES na podstawie modeli komputerowych CAD 3D. Implementacja obciążeń z uwzględnieniem analizy przepływu cieczy nienewtonowskich. Symulacje przepływów. Analiza wyników obliczeń, Poznań, PIMR, 2012.

[6] Kollek W.: Wpływ parametrów eksploatacyjnych na sprawność pomp zębatych. Sterowanie i Napęd Hydrauliczny, 1983, Zeszyt 3: 76-78.

[7] Osiński P., Kollek W.: Pulsacja wydajności pomp zębatych o zazębieniu zewnętrznym. Hydraulika i Pneumatyka, 2000, 2: 24-26.

[8] Ratajczak W.: Charakterystyki energetyczne pomp wyporowych transportujących ciecze spożywcze. Inżynieria Rolnicza, 2013, nr 1 (141), s. 207-214.