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The Influence of the Fluid Nature on the Driving Power of a Rotating Volumetric Pump with Profiled Rotors

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Abstract: *The term rotating volumetric machine with profiled rotors refers to the following:*
- The constructive solution of the rotating machine can be used as a force machine (steam engine, pneumatic engine);
- Or it can be used as a working machine (pump, fan, and compressor).
The constructive solution and the operation mode of the volumetric pump with profiled rotors are presented, and based on the functional parameters (speed and flow rate) the correlation between the driving power and the conveyed fluid nature is established.
The data obtained theoretically are verified by means of an experimental installation built for this purpose.

Keywords: *Volumetric pump, profiled rotors.*

1. The constructive solution and the operation of a volumetric pump with profiled rotors

The rotating machine can convey clean or suspended liquids, multiphase fluids, wastewater, rheological fluids, gases, vapours, etc.
In this paper it was considered that the machine functions as a rotating volumetric pump with profiled rotors that convey water, engine oil.
The rotating volumetric pump with profiled rotors is composed (figure 1) of two profiled rotors (2), which rotate at the same speed inside a case (1); the profiled rotors are engaged by two gear wheels (7), thus ensuring their synchronization. The gear wheels are mounted on the outside of the pump on the shafts of the two rotors [1] [2].

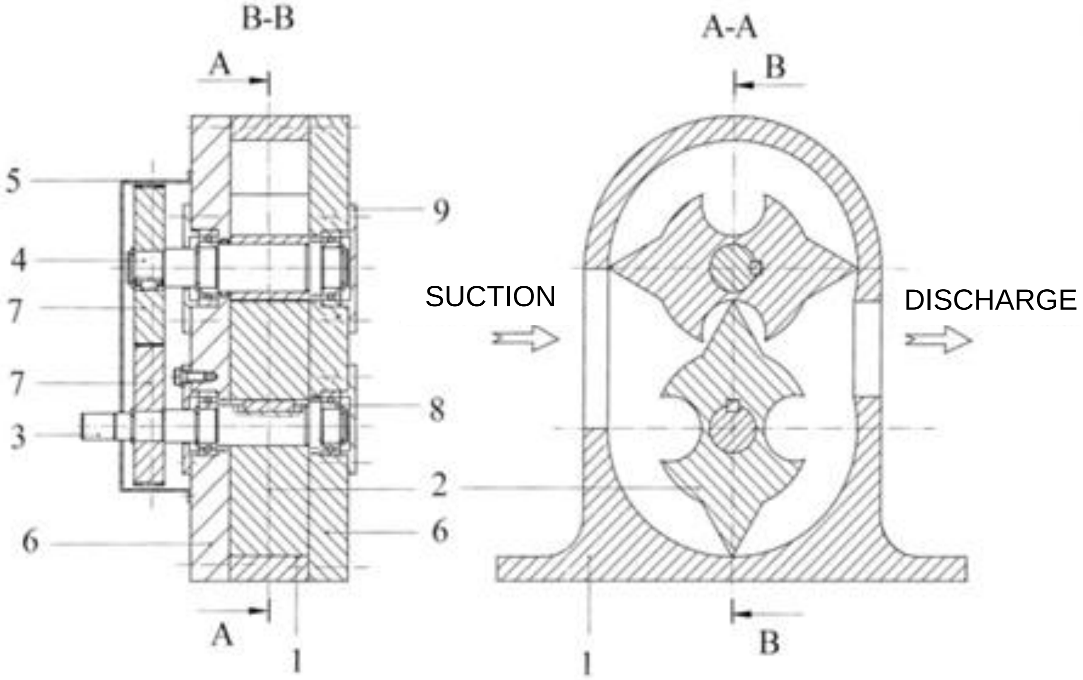

Fig. 1. Constructive solution of the rotating volumetric pump with profiled rotors
1 - oval case; 2 - profiled rotor; 3 - driving shaft; 4 - driven shaft; 5 - oil box; 6 - side wall; 7 - gear wheel; 8 - bearing; 9 - bearing cover

Figure 2 shows the operating mode of the rotating volumetric pump with profiled rotors. One can observe that after a rotation of 180 ° the useful volume of the transported fluid (V_u), is discharged into the chamber (8).

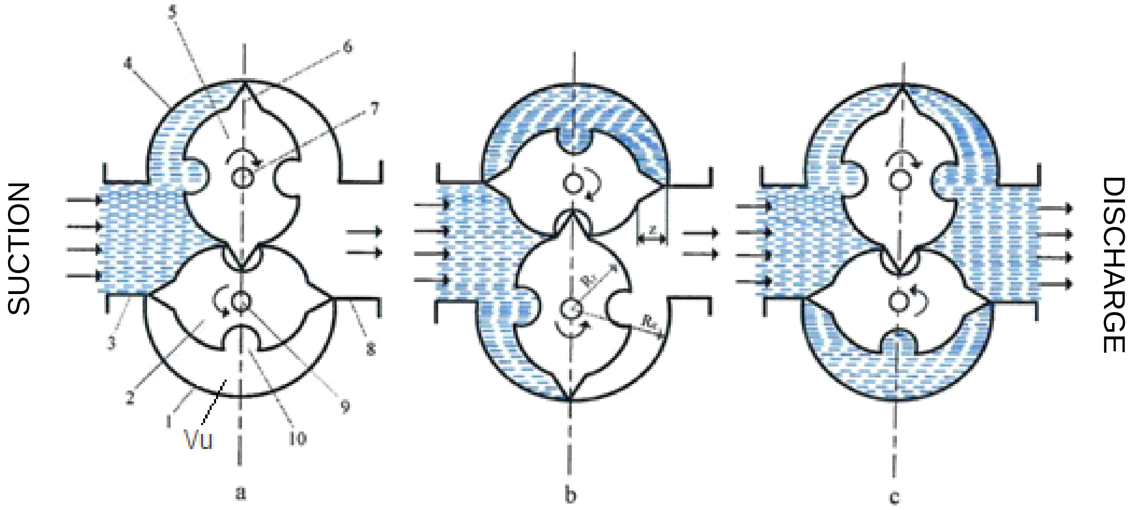

Fig. 2. Position of the rotors after a rotation of 90 °
1 - lower case; 2 - lower rotor; 3 - the suction chamber; 4 - upper case; 5 - upper rotor; 6 - rotating piston; 7 - driven shaft; 8 - discharge chamber; 9 - driving shaft; 10 - cavity in which the piston of the upper rotor enters

The useful volume is the volume between two pistons and the case (figure 2.a).

2. Calculation relations for the determination of the volumetric flow rate and the driving power of the pump

When operating as a rotating volumetric pump with profiled rotors, at a complete rotation of the shaft (9) two volumes will be transported from suction to discharge [3] [4] [5]:

$$V_u = \left(\pi R_c^2 - \pi R_r^2\right) \cdot l \left[m^3 / rot\right] \tag{1}$$

where l - the length of the rotor [m].
Case radius (R_c) is the sum of rotor radius (R_r) and piston height (z):

$$R_c = R_r + z[m] \tag{2}$$

The flow rate conveyed by a rotor is obtained:

$$\dot{V} = \pi l z\left(z + 2R_r\right) \cdot \frac{n}{30}\left[m^3 / s\right] \tag{3}$$

One can observe that the volumetric flow rate increases linearly with the length (l), with the rotor radius (R_r) and with the speed (n).
For the volumetric pump with profiled rotors the theoretical driving power is obtained with the relation [6] [7]:

$$P = \dot{V} \cdot \Delta p[W] \tag{4}$$

$$\Delta p = \rho_l \cdot g \cdot H\left[N / m^2\right] \tag{5}$$

* $\dot{V}$ – volumetric flow rate [m^3 / s];
* Δp - pressure increase [N / m^2];
* ΔH - pumping height [m];

* ρ_l - the density of the conveyed fluid [kg / m³].
Replacing the flow rate in relation (3) one can obtain:

$$P_m = \pi l z\left(z + 2R_r\right)\cdot\frac{n}{30}\cdot\rho_l\cdot g\cdot H\left[W\right] \quad (6)$$

It is observed that $P_m = f\ (l, z, R_r, n, \rho_l, \Delta H)$. (7)

3. Determination of the fluid nature influence on the driving power of a rotating volumetric pump with profiled rotors

For the experimental installation the following are specified:
- l = 0.05 m; z = 0.03 m; R_r = 0.05 m;
- machine speed n: 200, 300, 400, 500 [rot / min];
- the working fluid is water and engine oil [5] [8]:
- $\rho_{H2O} = 10^3$ [kg/m³];
- $\rho_u = 0.9 \cdot 10^3$ [kg /m³].

3.1 Calculation of the driving power of the volumetric pump for the two fluids

I. The working fluid is water

$$P_{H_2O} = \pi l z\left(z + 2R_r\right)\cdot\frac{n}{30}\cdot\rho_{H_2O}\cdot g\cdot H\left[W\right] \quad (8)$$

For the speed of 200 rpm:

$$P_{H_2O} = 3.14\cdot 0.05\cdot 0.03\cdot\left(0.03 + 2\cdot 0.05\right)\cdot 200/30\cdot 10^3\cdot 9.81\cdot 4 \ = \ 160.18\left[W\right]$$

Performing the calculations, the data from table 1 are similarly obtained.

Table 1: The values of the theoretical driving power of the pump

n [rot/min]	200	300	400	500
P_{H_2O} [W]	160.18	240.27	320.36	400.44

Based on the data in the table, the function P_{H_2O} = f (n) was graphically constructed for the conveyed liquid, the water (figure 3).

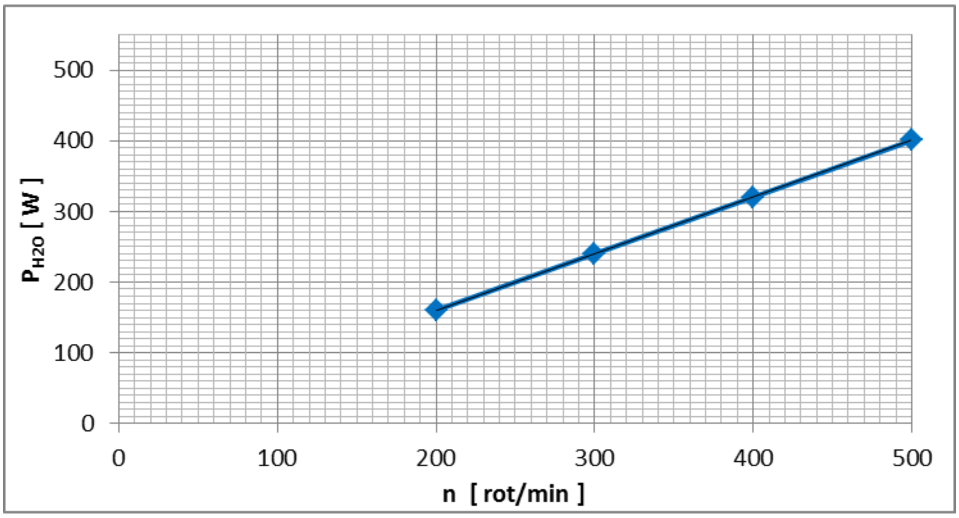

Fig. 3. The theoretical driving power of the pump function the speed of the rotating machine

From figure 3 one can observe that the dependence P_{H_2O} = f (n) is a linear function.

II. The working fluid is engine oil

The relationship (6) becomes:

$$P_u = \pi l z\left(z + 2R_r\right) \cdot \frac{n}{30} \cdot \rho_u \cdot g \cdot H\left[W\right] \tag{9}$$

For the speed of 200 rpm:

$$P_u = 3.14 \cdot 0.05 \cdot 0.03 \cdot \left(0.03 + 2 \cdot 0.05\right) \cdot 200/30 \cdot 0.9 \cdot 10^3 \cdot 9.81 \cdot 4 \;=\; 144.16\left[W\right]$$

Performing the calculations, the data in table 2 are similarly obtained.

Table 2: The values of the theoretical driving power of the pump

n [rot/min]	200	300	400	500
P_u[W]	144.16	216.24	288.32	360.40

Based on the data in the table 2, the function P_u= f (n) was graphically constructed for the conveyed liquid, the engine oil (figure 4).

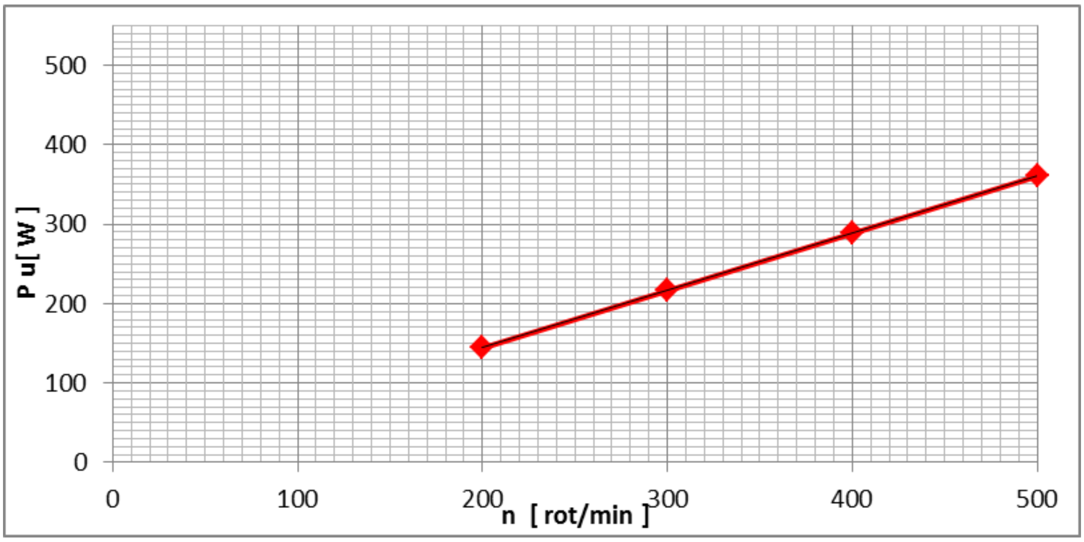

Fig. 4. The theoretical driving power of the pump function the speed of the rotating machine

The data for the theoretical driving power of the pump for the two fluids are presented in table 3.

Table 3: The values of the theoretical driving power of the pump depending on the conveyed fluid

n [rot/min]	200	300	400	500
P_{H_2O} [W]	160.18	240.27	320.36	400.44
P_u [W]	144.16	216.24	288.32	360.40

Based on the data in table 3, the graph in figure 5 was plotted.

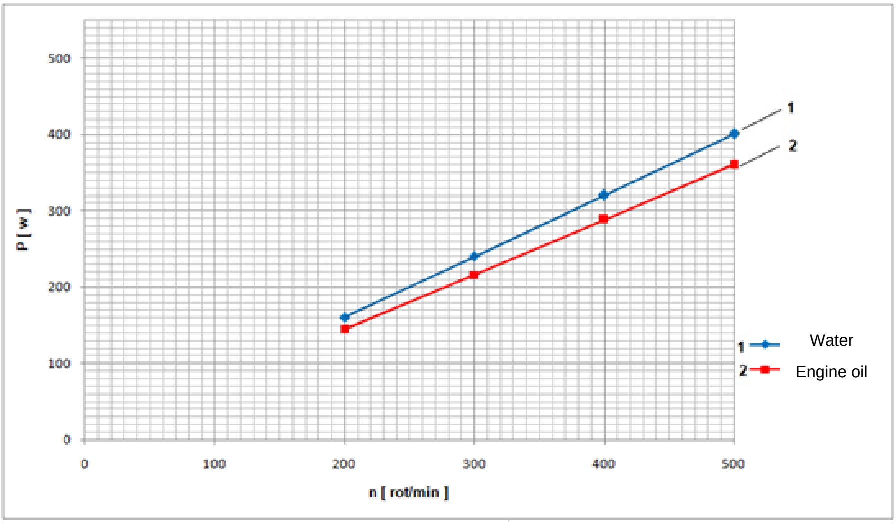

Fig. 5. Theoretical driving power depending on the speed of the rotating machine and the conveyed liquid nature

From figure 5 one can observe that the theoretical driving power of the pump has lower values in the case when the fluid conveyed is engine oil, this because the $\rho_{oil} < \rho_{water}$.

4. Experimental researches

4.1 Sketch of the experimental installation

Figure 6 shows the sketch of the experimental installation. This installation was developed, designed and built to validate the theoretical results previously presented [9] [10] [11].

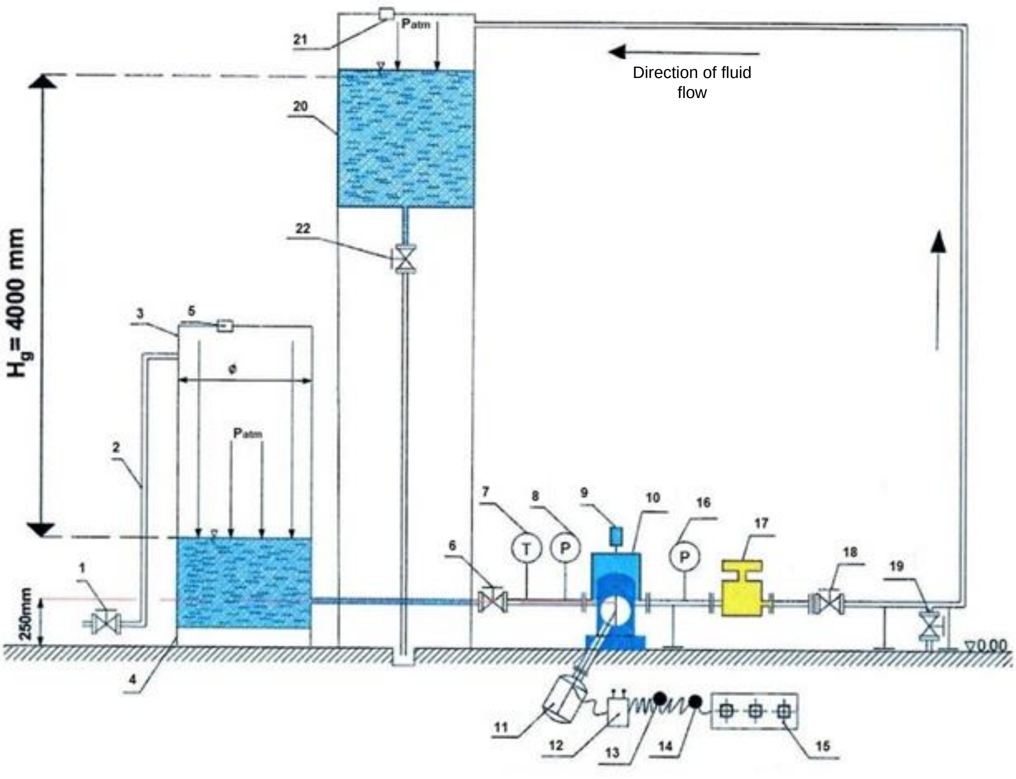

Fig. 6. The sketch of the experimental installation
1-tap; 2-pipe; 3- water tank; 4- the water tank support; 5- air vent; 6- valve Dn 60 Pn 2 bar; 7- thermometer; 8- pump suction manometer; 9- differential pressure manometer; 10-volumetric pump; 11 - electric motor; 12- frequency converter; 13-ampermeter; 14-multimeter; 15 - AC 380 V; 16- manometer at pump discharge, 17- electromagnetic flow meter, 18- adjusting valve, 19- drain valve; 20 - water tank; 21- air vent; 22 - drain tap.

The experimental installation consists of a tank (3) from which the working fluid (water, engine oil) is aspired in by a rotating volumetric pump with profiled rotors (10), driven by an electric motor (11) whose speed is controlled by a frequency converter (20).

4.2 Experimental obtained results

For the two types of fluids the voltage (U) and the intensity of the electric current (I) were measured at the rotational speed variation from 200 to 500 rot / min [12] [13].
The active power absorbed by the electric motor (P_{me}) is calculated with the relation [14]:

$$P=\sqrt{3}\,U.\ I\cos\phi[W] \tag{10}$$

Where:
U- electrical voltage [V]
I - current intensity [A]
cosφ - power factor of the electric motor
From supplier data (UMEB) cosφ = 0.71.
The power at the electric motor torque is calculated by the relation [15]:

$$P_{c,me}=P_{me}\cdot\eta_{me}\ [W] \tag{11}$$

where:
$P_{c,\,me}$ - the power at the torque of the electric motor [W];
P_{me} - the active power absorbed by the electric motor [W];
η_{me} - efficiency of the electric motor.
η_{me} = 74.7%.

I. The values of the measured quantities and the calculation obtained results when the fluid conveyed is water

For the speed of 200 rpm:

$$P=\sqrt{3}\,U.\ I\cos\phi=1.73\ \cdot 0.75\cdot 384.7\cdot 0.71=354.40[\mathrm{W}]$$

$$P_{c,me}=P_{me}\cdot\eta_{me}=345.4\cdot 0.747=264.73\ [W]$$

Performing the calculations, the data presented in tables 4 and 5 are similarly obtained.

Table 4: Values of P_{me}, $P_{c,me}$ experimentally established

n [rot/min]	**200**	**300**	**400**	**500**
U [V]	384.70	384.00	381.00	381.00
II [A]	0.75	1.1	1.45	1.8
$\mathbf{P_{me}}$ [W]	354.40	518.83	678.57	842.37
$\mathbf{P_{c,me}}$ [W]	264.73	387.57	506.90	629.25

II. The values of the measured quantities and the calculation obtained results when the conveyed fluid is engine oil

Table 5 : Values of P_{me}, $P_{c,me}$ experimentally established

n [rot/min]	**200**	**300**	**400**	**500**
U [V]	383.90	384.40	384.00	381.00
I [A]	0.70	1.00	1.30	1.60
$\mathbf{P_{me}}$ [W]	330.08	472.16	613.17	748.77
$\mathbf{P_{c,me}}$ [W]	246.57	352.70	458.04	559.33

The power from the electric motor coupler is used to drive the fluid conveyed by the pump.
Taking into account the actual efficiency of the pump (η_p) [16] [17], the actual power used to drive the fluid (P_r) results.

$$P_r = P_{c,me} \cdot \eta_p \ [W] \qquad (12)$$

η_p = 77%.
For the two fluids, at a speed of 200 rpm is obtained:

$$P_{r,H_2O} = 264.73 \cdot 0.77 = 203.84 \ [W]$$

$$P_{r,u} = 246.57 \cdot 0.77 = 189.86 \ [W]$$

Performing the calculations in a similar manner to the data in tables 4 and 5, the data in table 6 are obtained.

Table 6: The values of the power required to circulate the fluid

n [rot/min]	**200**	**300**	**400**	**500**
P_{r,H_2O} [W]	203.84	298.43	390.31	484.52
$P_{r,u}$ [W]	189.86	271.58	352.69	430.69

Based on the data in table 3 and table 6, the graph P = f (n) in figure 7 was plotted.

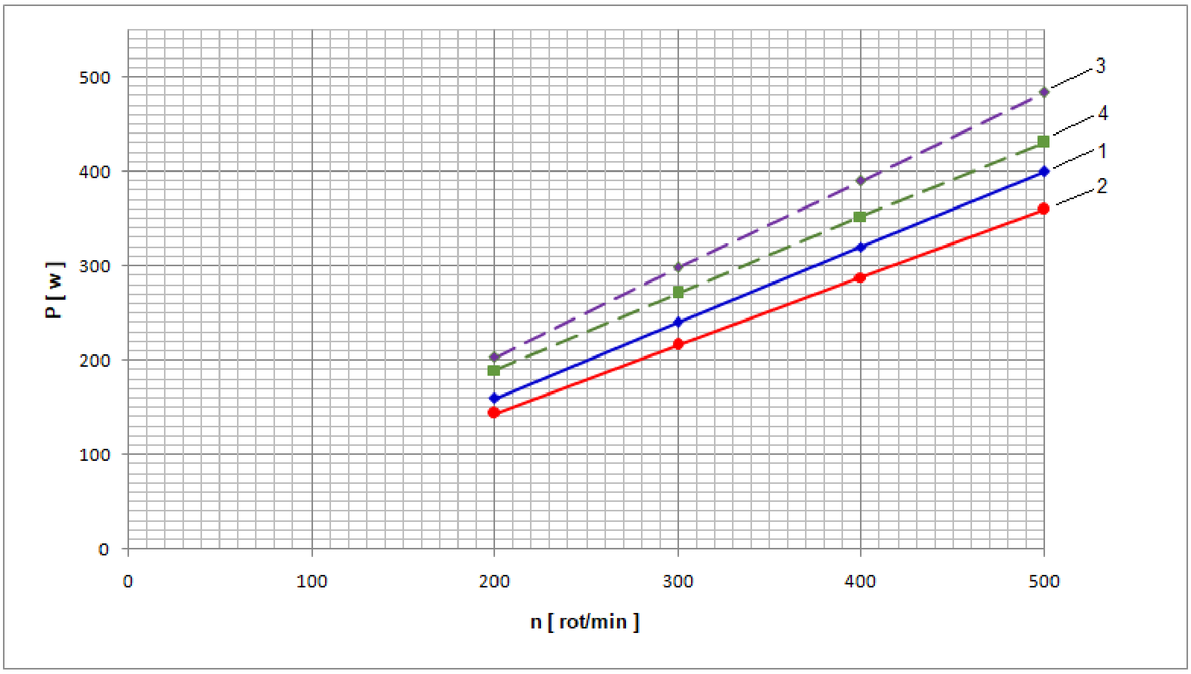

Fig. 7. Theoretical power and actual power required for fluid transport
1-2 calculation results for water, oil
3-4 experimental results for water, oil

The actual power consumed by the pump in the case of transporting engine oil is lower than in the case of transporting water, because the losses due to mechanical friction between the rotors and the case are lower in the case of transporting engine oil.

5. Conclusions

1. The constructive presented solution can transport clean or suspended liquids, as well as rheological fluids or gases.

2. The driving power of the machine is influenced by the nature of the conveyed fluid and by the density of the fluid.
3. Volumetric pumps with profiled rotors can be used in the field of land improvements, in wastewater treatment plants, in the: mining industry, energy industry, petrochemical industry.
4. From figure 7 one can observe that there is a satisfactory accordance between the theoretical and the experimental data.

References

[1] Băran, N., I. Căluşaru, and A. Detzortzis. "Research Regarding the Testing of a New Type of Rotating Machine with Profiled Rotors.˝ *Journal of Materials Science and Engineering A* 2, no. 3 (2012): 372-376.
[2] Motorga, A. "Influența parametrilor constructivi și funcționali asupra performanțelor mașinilor rotative cu rotoare profilate.˝ PhD. Thesis. Politehnica University of Bucharest, 2011.
[3] Băran, N., P. Răducanu, et. al. *Bases of Technical Thermodynamics*. Bucharest, Politehnica Press Publishing House, 2010.
[4] Băran, N., D. Despina, D. Besnea, and A. Detzotzis. "Theoretical and experimental researches regarding the performances of a new type of rotating machine with profiled rotors.˝ *Advanced Materials Research* 488-489: 1757-1761.
[5] Hawas, M. PhD Thesis, "The influence of fluid viscosity on the performance of rotating machine with profiled rotors.˝ Politehnica University of Bucharest, 2015.
[6] Băran, N., D. Ion, and Al. Motorga. "Un nou tip de mașină de lucru și de forță în domeniul fluidelor.˝ Lucrările celei de a cincea conferință a Hidroenergeticienilor din România, Universitatea POLITEHNICA din București, 2008, pp. 376-381.
[7] Băran, N., D. Ion, and Al. Motorga. "Un nou tip de mașină care poate funcționa ca pompă sau ca motor hidraulic. ˝ *Revista Hidrotehnica* 53, no. 7-8 (2008).
[8] Motorga, A. "Influence of constructive and functional parameters on the performances of rotating machines with profiled rotors." PhD Thesis. Faculty of Mechanical Engineering and Mechatronics, Politehnica University of Bucharest, 2011.
[9] Exarhu, M. "Pneumatic and hydraulic machine and installations." (in Romanian). Bucharest, S.C. ANDOR SRL, 2011.
[10] Băran, N., D. Besnea, and A. Motorga. "Elements of computing the architecture and manufacturing technology for a new type of profiled rotor.˝ Proceedings International Conference, 6th Workshop on European Scientific and Industrial Collaboration on promoting Advanced Technologies in Manufacturing, WESIC'08, Bucharest, Romania, 2008, pp. 233-241.
[11] Băran, N., A. Motorga, and D. Duminică. "Research Regarding the Building of an Experimental Setup for the Testing of a New Type of Rotating Machine with Profiles Rotors.˝ *Rev. Mecatronica*, no.1 (2011): 27-30.
[12] Detzortzis, A., N. Băran, and M. Hawas. "The influence of the rotor architecture of a rotating working machine on the driving power.˝ *U.P.B. Sci. Bull. Series D* 77, no. 1 (2015):155-166.
[13] Hawas, M., N. Băran, and A. Detzortzis. "Influence of the rotor architecture and of the speed on the volumetric efficiency of a new type of rotating volumetric machine.˝ *Advanced Materials Research* 905, (2014): 487-491.
[14] Hawas, M. "Research regarding the establishment of efficiency for a new type of rotating volumetric pump.˝ *International Research Journal of Engineering and Technology (IRJET)* 2, no. 2 (2015): 796-800.
[15] Băran, N., D. Duminică, D. Besnea, and A. Detzortzis. "Theoretical and Experimental Researches Regarding the Performances of a New Type of Rotating Machine with Profiled Rotors.˝ *Advanced Materials Research* 488-48 (2012): 1757-1761.
[16] Băran, N., Gh. Băran, D. Duminică, and D. Besnea. "Determinarea experimentală a randamentului efectiv pentru un nou tip de pompă volumică rotativă. ˝ *Revista de Chimie* 57, no. 12 (2006): 1294-1297.
[17] Băran, N., A. Detzortzis, M. Hawas, and D. Besnea. "The correlation between the rotor shape and the energetic performance of a rotating machine with profile rotors.˝ *The Romanian Review Precision Mechanics, Optics & Mechatronics*, no.45 (2014):18-26.