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# Energy consumption analysis of the main dewatering pumps in underground mines

*Mine dewatering is one of the main tasks and problems in the mining sector which do not affect output directly but are necessary for correct mine operations. The main dewatering pumps are located at various levels, but the pumping head is always a few hundred metres underground. The number and operating time of the pumps depends on the water inflow and are specified in the applicable regulations. Due to the capacity and required head, the power demand may well be in excess of 1 MW. Consequently, the correct use of main dewatering pumps, at low energy consumption, is a basic condition of limiting water pumping costs. The analysed pumping station is located at level 500, is equipped with ten $Q = 500\ m^3/h\ (0.139\ m^3/s)$ OW-250/8 pumps. The operating time of most pumps exceeds 20 000 h and the energy consumption is from 2.17 to 2.67 kWh/$m^3$ of pumped water. The analysis results and the energy consumption ratios have been compared with the data for new pumps which operate at data sheet parameters (efficiency). This was the basis to evaluate the impact of exceeding the time between repairs on operating parameters and the increase in the operating costs of the main dewatering pumps.*

Key words: *dewatering pumps, energy consumption, pumping costs*

## 1. INTRODUCTION

Correct operation of underground mines requires a number of actions that, although not directly related to output, are necessary to ensure the output and safety. One of the more important and necessary auxiliary processes is mine dewatering. Mine water is the natural outflow from the rock mass as well as water supplied artificially during the extraction process [1]. The main problem is natural water, as the amount of water flowing from the rock can be from a few to a few dozen cubic metres per minute. The factors affecting the amount of inflowing water and resulting hazards have been described in numerous publications [2, 3]. The amount of inflowing water depends mainly on the hydrological and geomechanical conditions [4]. The impact of random factors on mine water was analysed by Miladinović [5] and Qazizada [6]. The inflowing mine water must be pumped up to the surface to ensure the safety of both employees and mining operations [7–9]. The mine water is removed by an underground mine dewatering system, usually consisting of face, section and main dewatering pumping stations, supported by water galleries [10]. The face and section stations pump the water to galleries and main dewatering pumping stations.

The main dewatering systems in underground mines can be divided into single-stage (from the lowest level to the surface) and cascade (with an intermediate pumping station at a smaller depth). The more widely used are single-stage systems in which the pump units located at the lowest level remove water to the surface through pressure pipelines. The head is often a few hundred metres below ground; hence the main dewatering pumps are multistage. Due to the pump head and required capacity, the power demand is in the order of megawatts. The main dewatering pumping stations are located near shafts to reduce the length of high-pressure pipelines and facilitate the transport of heavy and bulky pump units. Suggestions for the determination of methods and operating costs of main dewatering pumping stations have been given by Wojciechowski et al. [11].

The requirements for the main dewatering equipment are specified in the *Regulation of the Minister of Energy of 23 November 2016 on detailed requirements for operation of underground mines*. The requirements for the main dewatering pumping stations are given in Section VI: *Machinery, equipment and installations, and buildings of a mining plant*, Chapter 3: *Main dewatering equipment and systems* [12].

The most important requirements from the point of view of the analyses presented in this paper are that the removal of the greatest daily inflow of water must be effected within 20 h, and the minimum number of pumps in the pumping station chamber is calculated according to the formula: $i = 2n + 1$ ($n$ – number of pumps in the unit). The main dewatering system is equipped with at least two pressure pipelines with a total flow capacity which is not less than the total rated capacity of the required number of the installed pumps, at a flow rate not exceeding 3 m/s [13, 14].

## 2. UNDERGROUND MINE MAIN DEWATERING SYSTEM

The reviewed main dewatering system (Fig. 1) is located in an underground mine at the 500 m level. Multistage pumps are installed in the pumping station chamber near the shaft. The main dewatering pumping station has ten pump units comprising OW250/8 pumps and SCUd134u motors. Each pump unit is connected to two ∅500 mm pressure pipelines (Fig. 1) which transport the water to the surface. The water inflow forecast based on the hydrological conditions and the size of underground excavations is 16.83 $m^3$/min, giving the daily inflow of 24,235 $m^3$. The capacity of water galleries in which water is collected is 20,196 $m^3$. When the pumping is stopped, the water galleries take about 24 h to fill up. A diagram of the examined main dewatering system is presented in Figure 1.

At the forecast mine water inflow, the total capacity of the pumps to comply with the mining regulations is $Q = 20.20$ $m^3$/min, and the pump head is $H_u = 530$ m. The rated capacity of OW250/8 eight-stage pumps is $Q = 8.33$ $m^3$/min (500 $m^3$/h) and the head $H_u = 560$ m. The requirements specified in the mining regulations are met when two pumps working continuously and the third one working 50 percent of the time. The number of required pumps is seven and the pumping station has ten pumps, meaning that the main dewatering system is overdimensioned.

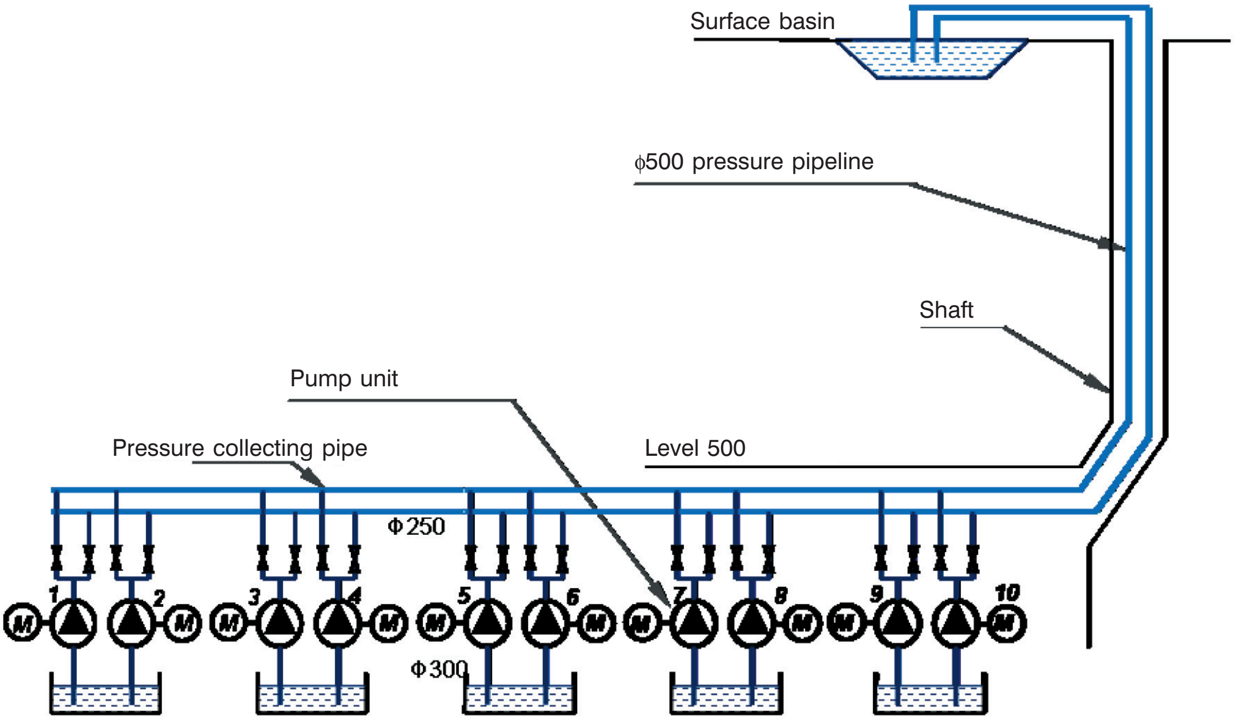

*Fig. 1. Main dewatering system diagram*

The OW250 stationary, horizontal multistage pumps are manufactured by the Powen – Wafapomp S.A. Group in Zabrze (Silesia, southern Poland). They are used for mine dewatering and the pumping of slightly mechanically polluted and saline water. They can pump water up to 800 m and are of a robust design suitable for the adverse operating conditions typical in underground mines.

The water inflowing to the pumping station is heavily mechanically polluted, hence prior to being fed to the pump wells it is purified in sedimentation tanks to remove the largest mechanical pollutants. The pumped water is very saline (conductivity from 5.35 to 9.18 mS/cm) and polluted with very fine suspensions (grain size from 9.6 to 11.9 μm).

## 3. PERFORMANCE OF THE PUMP UNITS

The measurements were made in the main dewatering pumping station at the level of 500 m to determine the pump flow performance: water stream in the main collecting pipeline, pressure in the suction port and delivery port and electric power of the motors [15]. Figure 2 shows an example of a pump unit (No. 2 – SCDdm 134u, engine, OW-250AM / 8, pump).

The stream was measured using a FlowKat 200 flowmeter, pressure using dial pressure gauges, negative pressure using a 0–(–)0.1 MPa vacuum gauge, and pressure at delivery using 0–8 MPa pressure gauges. The power consumption was measured with a SENTRON PAC3200 analyser. The pumps were choked by means of gate valves installed in the pipelines connecting the pumps with the main collecting pipe. The measurements were made after the flow had stabilised.

The effective head $H_u$ was determined using the relationship:

$$H_u = \frac{p_t - p_s}{\rho g} + \frac{c_t^2 - p_s^2}{\rho g} + \Delta h_m \tag{1}$$

where:

$p_s, p_t$ – pressure in the suction port and delivery port [Pa],
$c_s, c_t$ – water speed in the suction port and delivery port [m/s],
$\rho$ – liquid density [kg/m$^3$],
$\Delta h_m$ – height difference between the pressure gauge at the suction port and the pressure gauge at the delivery port [m].

*Fig. 2. Pomp unit no. 2*

The speeds in the suction port and delivery port were calculated using the water volumetric stream and the ports cross section area:

$$c = \frac{\dot{Q}}{A} \tag{2}$$

$c$ – average water speed in ports [m/s],
$\dot{Q}$ – water volumetric stream [m$^3$/s],
$A$ – cross section area [m$^2$].

The effective power (i.e. the power transmitted to the stream of pumped water) is determined using the relationship:

$$P_u = \rho g H_u \dot{Q} \tag{3}$$

The pump unit efficiency is in relation to the power fed to electric motors:

$$\eta_{zp} = \frac{P_u}{P_{el}} = \frac{\rho g H_u \dot{Q}}{P_{el}} \tag{4}$$

The pump shaft power was determined taking into account the motor efficiency. The constant motor efficiency was used ($\eta_{sel} = 0.93$).

Pump shaft power:

$$P_m = \eta_{sel} P_{el} \tag{5}$$

Pump efficiency:

$$\eta_p = \frac{P_u}{P_m} = \frac{\eta_{zp}}{\eta_{sel}} \tag{6}$$

Relationships (1)–(6) were used to calculate the flow performance of the pumps.

The performance of all the pumps was determined during the measurements. The pumps were choked in a small range of their capacity because the main dewatering pumps are operated at maximum capacity. The paper presents the performance of only two pumps: pump 1 – which has been recently overhauled, and pump 10 – with the highest degree of wear.

In order to evaluate the pump condition, the figures also include the pump data sheet performance in terms of the measured parameters.

Figures 3–4 present the performance of pump 1. During the measurements, pump 1 worked about 3,340 operating hours after the overhaul, so the performance deviations from the data sheet values are significantly less in comparison with the pumps that had clocked over 20,000 operating hours. The pump efficiency is lower than the data sheet value by approximately 8% at the 8 m$^3$/min capacity to 14% at the 4.5 m$^3$/min capacity.

The performance of pump 10 is presented in Figures 5–7. Pump 10 has the highest degree of wear in the examined pumping station.

The operating time of pump 10 was about 32,000 h. The long operating time particularly strongly reflects the pump performance. The pump efficiency was reduced by about 27% in comparison with the data sheet value. The energy consumption increased by the same degree.

The character of the operation of the main dewatering pumps leads to the fact that only heads which are minimally dependent on choking are effective. A decisive role is played by the geometrical head; in the pumping station it is $H_g = 489$ m. The pressure increase in the pump due to flow resistance is relatively low (2.0–9.5%, average about 5%) in relation to the geometrical head.

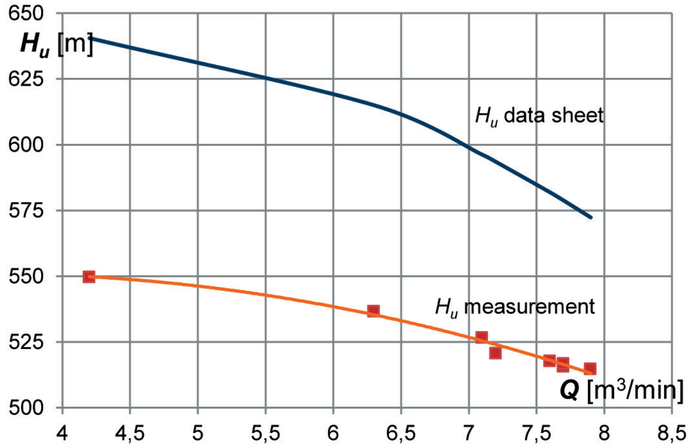

*Fig. 3. Flow performance of pump 1 OW250/8*

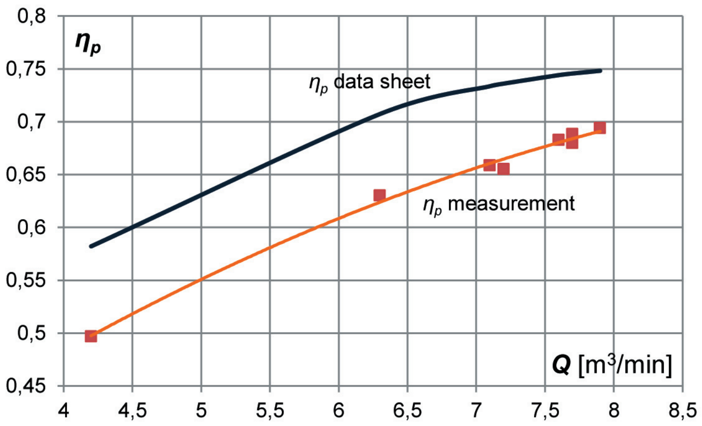

*Fig. 4. Efficiency of pump 1 OW250/8*

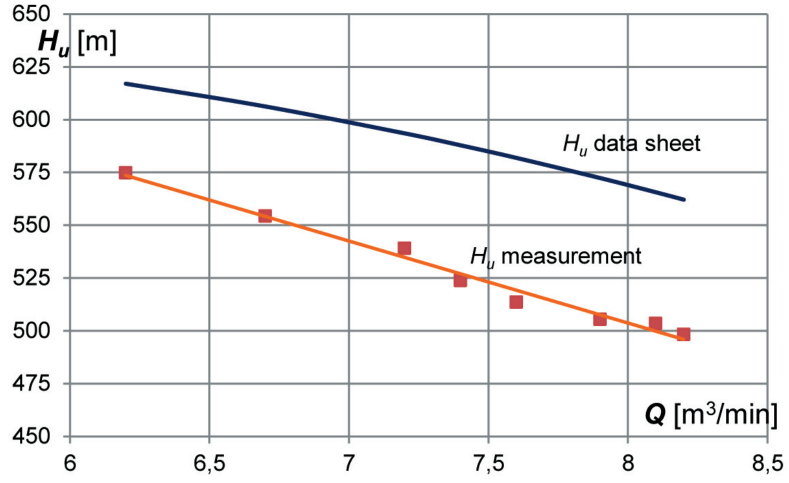

*Fig. 5. Flow performance of pump 10 OW250/8*

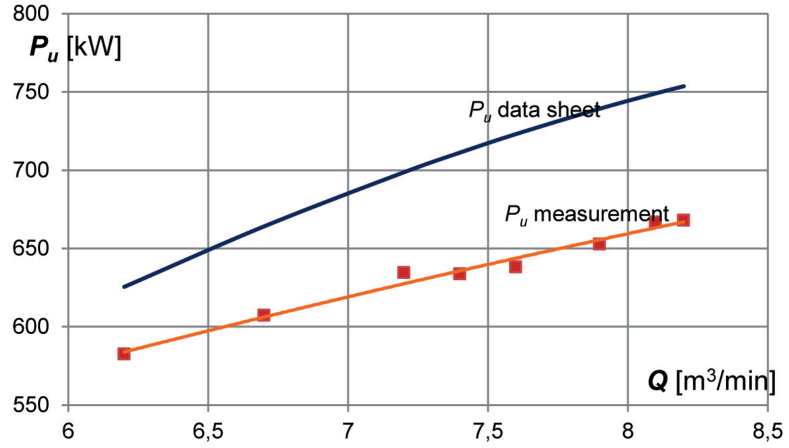

*Fig. 6. Effective power of pump 10 OW250/8*

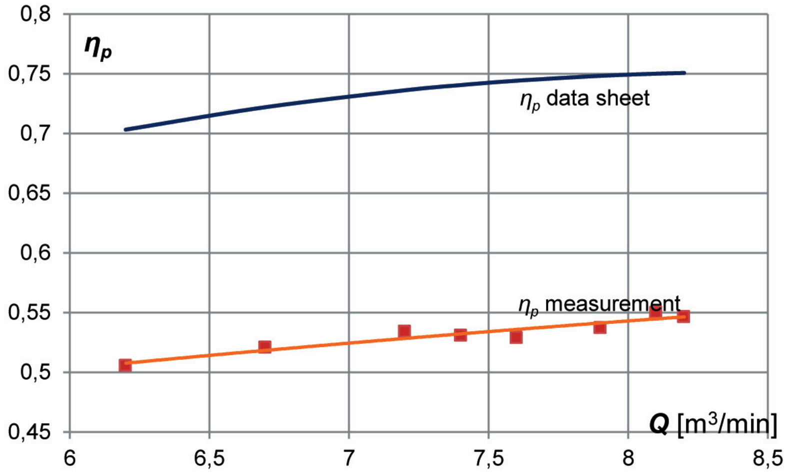

*Fig. 7. Efficiency of pump 10 OW250/8*

Such operational characteristics make pump operating parameters minimally dependent on choking. A distinct pump choking effect appears only when the gate valve is closed to a significant degree. Consequently, the pump operation measurements include narrow ranges for the pump capacity changes.

## 4. OPERATING INDICATORS OF THE MAIN DEWATERING PUMPS

The main dewatering pumps run at a maximum capacity that is achievable for the pump system, i.e. geometrical pumping head and flow resistance in pipelines.

The choking regulation is not used due to energy losses. Therefore, the evaluation and analysis of pump operation and energy consumption only requires determination of relevant indices for the maximum capacity operation.

The efficiency, energy consumption and pumping unit cost indices were determined for the examined pump units and the results are presented in Table 1.

Table 1 also includes the relative pump head expressed as a ratio of effective head at actual conditions $H_u$ to the data sheet head $H_{uk}$ at the same flow. This fraction can be interpreted as a measure of the correct selection of a pump to lift the water to the required height. The calculated $H_u/H_{uk}$ ratios allow the statement that the pumps have been selected correctly for the requirements. The $H_u/H_{uk}$ ratio of 0.92 for the examined pumping station indicates a slight overdimensioning of the pump system.

The ratio of pump efficiency $\eta_p$ to the data sheet efficiency $\eta_{pk}$ at a specified water stream can be considered a measure of the pump's condition. The lower value of this ratio indicates a poorer pump condition. In the examined pumps, the $\eta_p/\eta_{pk}$ ratio is in a wide range. For pumps 1 and 3 it is above 0.90, and for pump 10 only 0.73. The condition of the pumps with a ratio below 0.80 can be considered unsatisfactory. The average value for all pumps in the pumping station is $\eta_p/\eta_{pk} = 0.82$.

**Table 1**

**Operating parameters of the OW250/8 pumps at maximum capacity**

| | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volumetric stream $Q$ [m$^3$/min]** | 7.9 | 8.1 | 9.2 | 8.1 | 8.5 | 8.4 | 8.0 | 9.2 | 7.6 | 8.2 | 8.3 |
| **Effective head $H_u$ [m]** | 514.7 | 523.6 | 535.1 | 508.8 | 516.4 | 513.9 | 498.2 | 514.0 | 503.3 | 498.2 | 512.6 |
| **Relative head $H_u/H_{uk}$ [–]** | 0.90 | 0.93 | 1.0 | 0.90 | 0.94 | 0.93 | 0.87 | 0.98 | 0.86 | 0.87 | 0.92 |
| **Electrical power $P_{el}$ [kW]** | 1030 | 1214 | 1200 | 1195 | 1263 | 1275 | 1266 | 1399 | 1137 | 1314 | 1229 |
| **Pump efficiency $\eta_p$ [–]** | 0.694 | 0.614 | 0.721 | 0.615 | 0.613 | 0.595 | 0.553 | 0.594 | 0.591 | 0.547 | 0.614 |
| **Relative pump efficiency $\eta_p/\eta_{pk}$ [–]** | 0.93 | 0.82 | 0.97 | 0.82 | 0.81 | 0.79 | 0.74 | 0.80 | 0.79 | 0.73 | 0.82 |
| **Energy consumption $q_P$ [kWh/m$^3$]** | 2.173 | 2.498 | 2.174 | 2.459 | 2.476 | 2.530 | 2.638 | 2.534 | 2.493 | 2.671 | 2.465 |
| **Water pumping cost $q_E$ [PLN/1000 m$^3$]** | 1012 | 1163 | 1012 | 1145 | 1153 | 1178 | 1228 | 1180 | 1161 | 1244 | 1148 |
| **Pump operating time $\Delta\tau$ [h]** | 3336 | 12,032 | 757 | 21,000 | 24,000 | 29,017 | 24,015 | 6015 | 23,473 | 32,041 | 17,569 |

P1, P2,..., P10 – pump unit number

Table 1 also includes indices of pump energy consumption $q_P$ and water pumping costs $q_E$. The $q_P$ index is the amount of electrical energy in kWh necessary to pump 1 m$^3$ of water. The $q_E$ index is the pumping cost of 1,000 m$^3$ at the price of PLN 465.70/MWh (September 2021, ca. fi100/MWh).

The energy consumption of the water pumping process was $q_P = 2.173–2.671$ kWh/m$^3$, the mean value is $q_P = 2.465$ kWh/m$^3$. The cost of pumping 1000 m$^3$ of water is $q_E$ = PLN 1012–1244/1000 m$^3$, the mean value is $q_E$ = PLN 1148/1000 m$^3$. The energy consumption of the water pumping process is also shown in Figure 8, where the red line marks the average value for the main dewatering pumping station. The table includes the operating times of the individual pumps. The analysis of quality indices shows the impact of operating time on the pump condition and energy consumption.

Figure 9 shows the relationship between the operating time and energy consumption.

Obviously, the energy consumption curve is reciprocal to the efficiency curve, as shorter operating times correspond to lower energy consumption. The deterioration of the pump's technical condition caused by wear and tear causes an increased demand for the electrical energy needed to pump 1 m$^3$ of water.

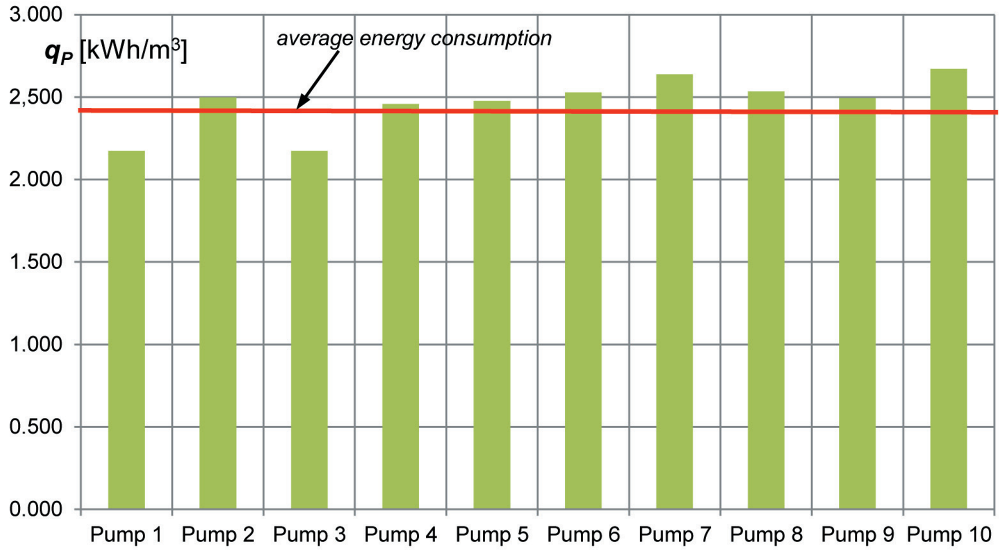

*Fig. 8. Energy consumption of the water pumping process*

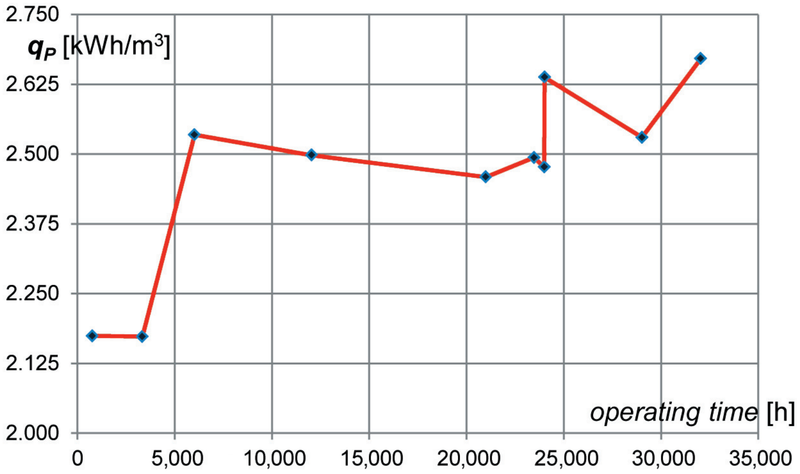

*Fig. 9. Energy consumption vs. operating time*

## 5. SUMMARY

The examined main dewatering pumping station (located at a depth of 500 m) has nine pump units. According to mining regulations, the required number of pumps to pump out the water inflow is 7.2.5 pump units – totalling 20.20 m$^3$/min in capacity – should be in continuous operation.

The measurement results and the calculated performance and quality indices indicate the unsatisfactory or poor condition of most of the pumps. This is the result of long pump operating times without overhauls (6 pumps in excess of 20,000 hours. Water with mechanical pollutants and high salinity significantly increases the erosion wear of impellers and other pump parts. Most pumps have an efficiency 20% lower than the data sheet efficiency of new pumps. Such low efficiency obviously causes an increase in energy consumption and unit water pumping costs. It can be said that the energy consumption and water pumping costs increase to the same degree as the efficiency is reduced, that is ca. 20%.

The overhauled pumps (Nos. 1 and 3) feature better performance and operating indicators, which proves the need for an adequate maintenance and repair policy.

The condition of the pumps in the main dewatering pumping station must be considered unsatisfactory. The pumping station has high indices of both energy consumption and operating costs.

### References

[1] Inung A., Adnyano A., Bagaskoro M.: *Technical study of mine dewatering system in coal mining*. PROMINE 2020, 1: 28–33.

[2] Gonet A., Stryczek S., Brudnik K.: *Causes and Consequences of Water Flux on the Example of Transverse Heading Mina in the Salt Mine "Wieliczka"*. Archives of Mining Sciences 2012, 57: 323–334.

[3] Bukowski P.: *Evaluation of Water Hazard in Hard Coal Mines in Changing Conditions of Functioning of Mining Industry in Upper Silesian Coal Basin – USCB (Poland)*. Archives of Mining Sciences 2015, 60, 2: 455–475.

[4] Rybicki Cz., Dubiel S., Blicharski J., Falkowicz S.: *Water Inflow Prognosis for the Gas Wells.* Archives of Mining Sciences 2006, 51, 2: 241–251.

[5] Miladinović B., Ristić Vakanjac V., Bukumirović D., Dragišić V., Vakanjac B.: *Simulation of Mine Water Inflow: Case Study of the Štavalj Coal Mine (Southwestern Serbia)*. Archives of Mining Sciences 2015, 60, 4: 955–969.

[6] Qazizada M.E., Pivarčiová E.: *Reliability of parallel and serial centrifugal pumps for dewatering in mining process*. Acta Montanistica Slovaca 2018; 23(2): 141–152.

[7] Chen T., Riley C., Van Hentenryck P., Guikema S.: *Optimizing inspection routes in pipeline networks*. Reliability Engineering & System Safety 2020, 195: 106700.

[8] Hancock S., Wolkersdorfer C.: *Renewed demands for mine water management*. Mine Water Environ 2012, 31(2): 147–158.

[9] Zhang C., Zhang Y.: *Common cause and load-sharing failures-based reliability analysis for parallel systems*. Eksploatacja i Niezawodność – Maintenance and Reliability 2020, 22(1): 26–34.

[10] Matysik A.: *Odwadnianie kopalń podziemnych*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2002.

[11] Wojciechowski J., Mikoś M., Ptak J.: *Zastosowanie modelowania matematycznego do komputerowych obliczeń systemu głównego odwadniania kopalni.* Pompy. Pompownie 2006, 1(120): 26–30.

[12] *Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych*. Dz.U. 2017, poz. 1118.

[13] Jędral W.: *Pompy wirowe*. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2014.

[14] Wilk S., Golec K., Wilk A.: *Wirowe pompy stacjonarne, podręcznik doboru, instalowania i eksploatacji*. Zakład Mechaniki Przemysłowej ZAMEP Sp. z o.o., Gliwice 2015.

[15] Szymański Z.: *Nowoczesne metody sterowania i badań diagnostycznych kopalnianych pomp głównego odwadniania.* Napędy i Sterowanie 2013, 2: 54–61.

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