

ENERGY SAVING IN MINE DRAINAGE VIA OPTIMIZATION OF PUMPING OPERATING MODES

O.Beshta, O.Balakhontsev, S.Khudoliy, E.Khudy, O. Khuda
National Mining University, Dniepropetrovsk, Ukraine.

Abstract. The article is devoted to optimization of mine drainage facilities operation for reducing of energy consumption. Specific features of pumps electric drives and their operating modes are described. Basing on drainage pumps requirements the new approach for energy saving operation is developed. Experimental results proving approach adequacy are given.

Keywords: pumping installation, electric drive, operating mode, efficiency, energy saving.

Introduction

Energy saving is stated to be a key trend in Ukrainian industry. It is especially important for coal and ore mining enterprises which being the basis of GDP in Ukraine meanwhile suffer severe competition on international market. The main reason for low competitiveness of Ukrainian raw materials is high level of specific energy cost in final product.

Privatization of mining enterprises made their owners thoroughly revise management principles. Modern resource planning strategies are being applied instead of obsolete soviet approaches. The need for energy consumption assessment is realized to be the key factor for energy saving. Only “administrative” measures i.e. rational organization of equipment maintenance brought about 10% energy consumption reduction during the first decade since optimization. Now the potential for further energy saving due to only rational planning is believed to be depleted. It is time to improve technology.

The chart on Fig. 1 illustrates energy consumption distribution among main facilities of a coal mine. Obviously exact numbers depend on many factors like water content, temperature and humidity. The distribution pattern varies from mine to mine and even within a day for a certain mines. So we’ll consider average picture.

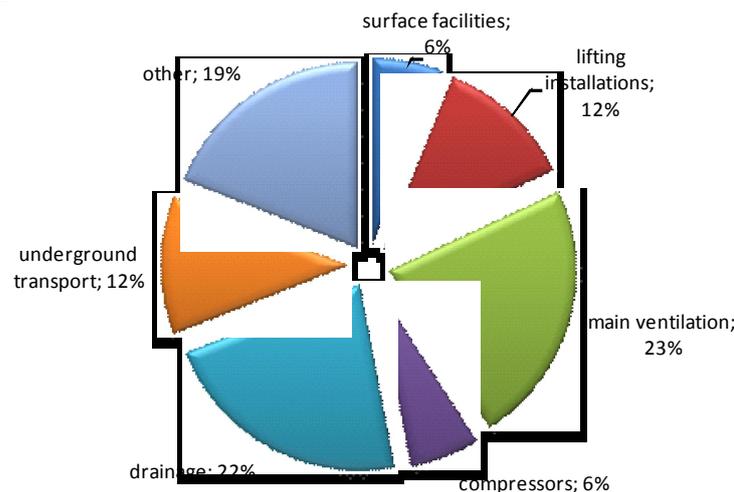


Figure 1. Typical coal mine energy consumption chart.

Amazingly, the share of “useful” energy i.e. connected with coal extraction and underground transportation and lifting it to the surface is only about 30%. The rest of total energy is consumed with “auxiliary” but nevertheless necessary loads – ventilation, drainage, compressors and other facilities.

Mine ventilation and drainage are the most important consumers at any mine. Ventilation must provide necessary oxygen content and methane rarefaction down to safe level. It mainly depend on mine structure and its energy consumption cannot be significantly decreased for safety reasons. And fault of pumping system can cause almost immediate mine flood. So these two facilities must operate stable despite on production level.

Authors had carried out a series of field research at several coal and ore mines of Dnepropetrovsk and Zaporizhya region. Preliminary results show that mine drainage systems being the key energy consumers are maintained in inefficient modes. So these systems possess the highest potential for energy saving.

Approach description

The key concept describing any pumping system is a QH-curve, it shows dependence of pump's flow rate (supply) Q from head H . The dewatering line is characterized with same values – pressure drop as a function of flow rate. The head pressure contains two components: static pressure (simply, the height you need to deliver water on) and dynamic (connected with friction between liquid and tube and other hydraulic phenomena like turbulence) [1,2].

Mine dewatering lines are featured with high static pressure and low dynamic component. Another specific feature of mine systems is parallel operation of the pumps. In order to estimate operation points of each pump under parallel operation one must build a resulting pumps' QH-curve and superimpose it to the mains curve.

Fig. 2 illustrates parallel pumps' connection scheme and typical QH-curves for mine drainage system.

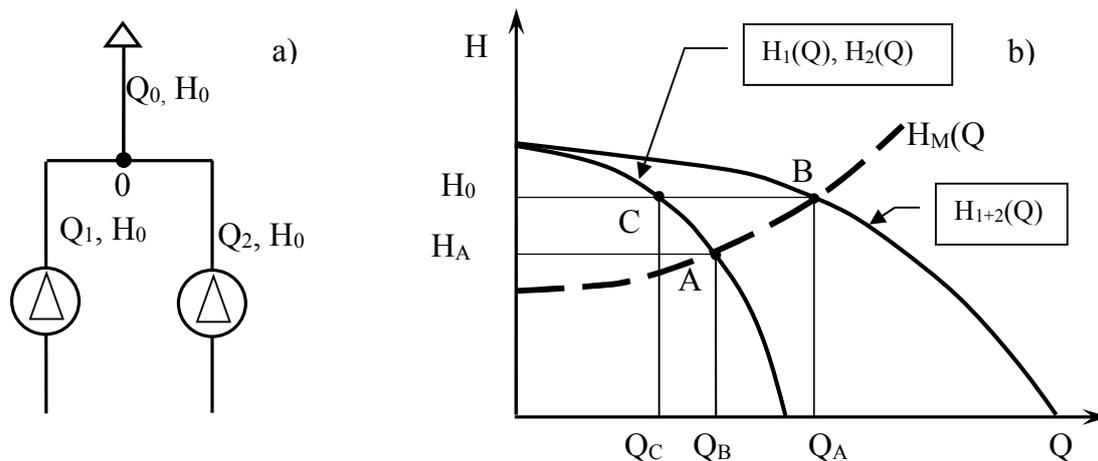


Figure 2. Parallel pumps operation in mine drainage: a) connection scheme; b) QH-curves and operation points.

$H_1(Q)$ and $H_2(Q)$ represent individual pumps' characteristics, $H_{1+2}(Q)$ – the resulting curve. $H_M(Q)$ stands for the characteristic of the water mains (the whole dewatering system).

If the pumps have absolutely coinciding characteristics, as it shown at Fig. 2, they provide equal flow rates, defined by the resulting head H_0 . The value of H_0 , in turn, depends on resulting flow rate Q_0 and hydraulic line's characteristic. The "B" point is found as intersection between the resulting pumps' $H_{1+2}(Q)$ and mains $H_M(Q)$ characteristic. Thus, point "A" shows each pump's standalone operation, point "B" represents resulting H and Q under parallel operation. This case each pump operate at its "C" point due to the rise of output head from H_A to H_0 value.

Operating at "C" point means less flow rate for each pump. The maintenance area of each pump must be wide enough to provide stable operation. It also means the increase of hydraulic drop and hence, specific energy consumption. So, the more pumps operates simultaneously the more expensive dewatering is.

The situation becomes even more strained when pumps have different QH-curves, as it is shown on Fig. 3.

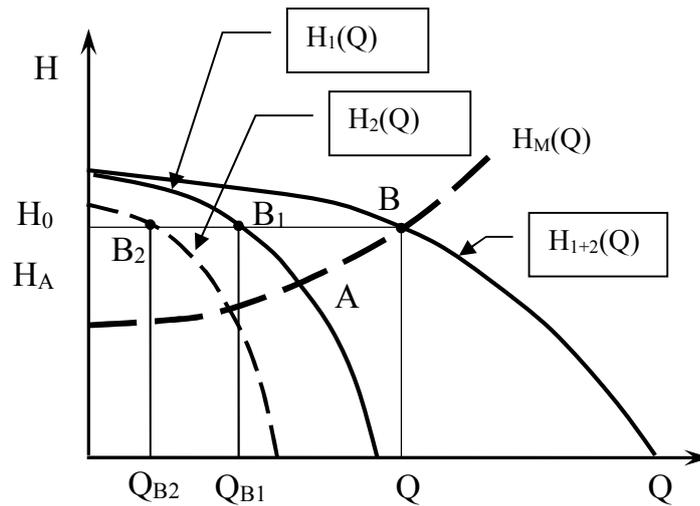


Figure 3. Parallel operation of pumps with different QH-curves.

The “2” curve is peculiar to the worn out pump – it produces less flow under the same backpressure. Simultaneous operation of pumps with different QH-curves results in shifting of operation point of the “weaker” pump down to low flow rate area Q_{B2} . In extreme case it can produce zero supply meanwhile consuming electric power. Therefore, specific energy consumption in dewatering depends not only on pumps’ general condition but also on their “matching”.

All the mentioned gives us realization of two major energy saving principles for dewatering systems:

- rational pumps’ operation time planning according to inflow rate and time-of-day tariff;
- rational pumps’ combination in case of their parallel operation for minimal specific energy consumption.

Implementation of both tasks requires introduction of mine monitoring system for constant survey of hydraulic and mechanic factors. The inflow rate, electric motors’ and pumps’ and dewatering line condition should be monitored [3].

Experimental results

To estimate energy saving potential in mine dewatering the preliminary experiments were carried out at several coal mines of Dnepropetrovsk region.

The dewatering horizon -225 m contained ten pumps of CSP 300×290 type in three sunk basins (CSP stands for “centrifugal sectional pump”, correspondent Russian abbreviation is CNS; 300 represents rated head, m, 290 – rated supply, m³/hr).

Special measuring equipment was installed, including autonomous data acquisition systems (ADA) at each pump. ADA has internal power supply and memory storage, providing continuous data collection for 48 hours. Each ADA was synchronized with the rest ones and the basic acquisition module.

Measuring of the flow rate caused certain problems. Ultrasonic flowmeter produced error up to 40% when flow rate reached 1000 m³/hr because of turbulence effect. A special approach was developed basing on water level at the inlet header on the surface. The approach is based on Bernulli equation

$$Q = \mu \cdot S_0 \cdot (2g \cdot k_0 \cdot (L - h_0))^{\alpha},$$

where μ , α – nonlinear coefficients depending on liquid’s viscosity and other parameters;

S_0 – area of the inlet;

$g=9,81$ – acceleration of gravity;

k_0 , h_0 – scale gains;

L – level of water in the inlet header.

The actual flow rate was estimated by ratio $\Delta V/\Delta t$, where ΔV is the gain of water volume in the water precipitation pool (measured rather simply) and Δt is the time period. Thus flowmeter was replaced with much cheaper hydrometric float level meter.

Figure 4 illustrates measuring scheme for each pump and dewatering mains

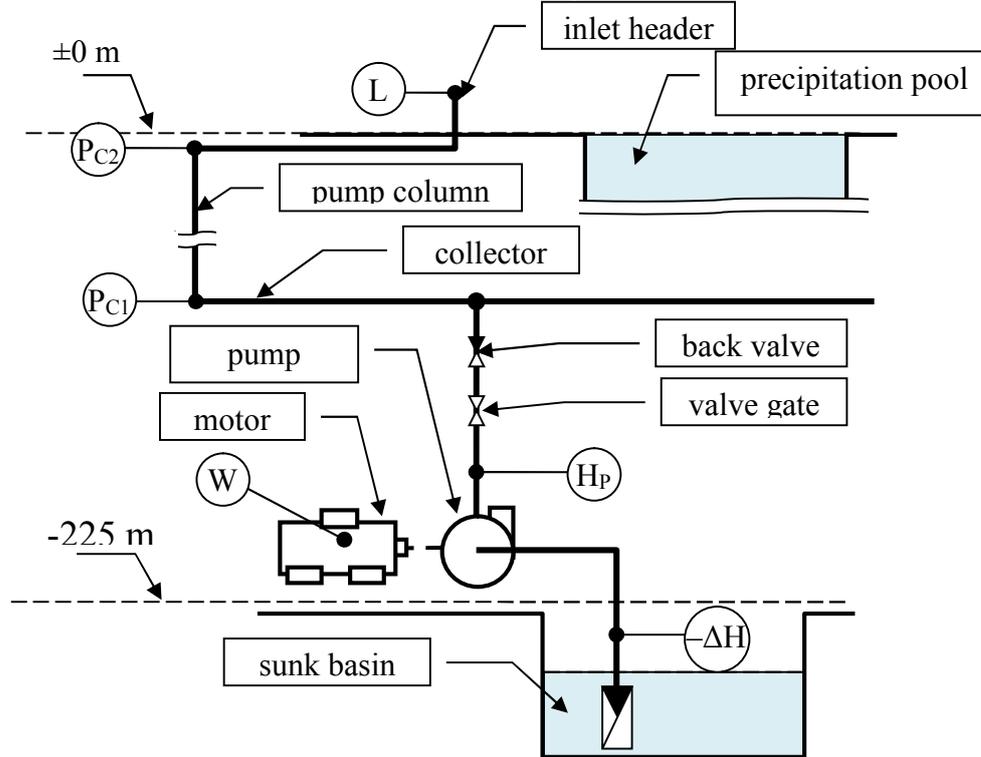


Figure 4. Measuring scheme for a pump and dewatering line.

The following parameters were measured:

- total flow rate Q (measured via water level L);
- each pump's input depression $-\Delta H$;
- each pump's head H_P ;
- pressure at the dewatering collector P_{C1} (underground);
- pressure at the pump column P_{C2} (surface);
- electric power consumption W .

During several testing sessions the individual pumps' QH-curves were obtained. Then energy consumption under each pump standalone operation and their various combinations was estimated.

As was expected, actual QH-curves and pump's efficiencies differed from each other and from rated values. Figure 5 shows rated and actual QH-curve of one pump under standalone and parallel operation.

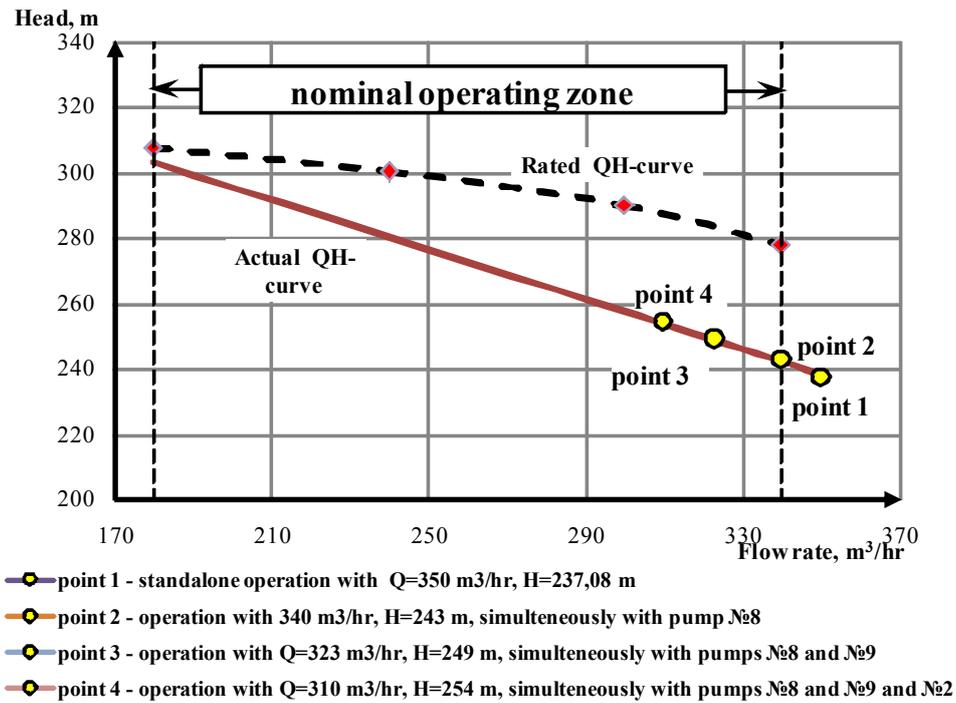


Figure 5. QH-curves and operating points under standalone and parallel operation.

The actual QH-curve lies lower than the rated one. It means that for the same backpressure the pump produce less flow rate. For example, under rated backpressure of 290 m the pump produce 210 m³/hr instead of rated value of 300 m³/hr.

Operating point #1 (standalone maintenance) lies beyond the zone of normal functioning in the area of extra supply, which is can cause cavitation effect.

Point 4 indicates simultaneous operation of four pumps – maximal number of parallel operating pumps. Even at this point the pump has a good reserve to stay in the rated operating zone.

Lower supply under required head means less pump efficiency. Figure 6 illustrates pumps' efficiencies under standalone operation. The value of "total efficiency" includes efficiencies of the pumps themselves and their drive motors.

Obviously, actual efficiency is always lower than the rated value. It depends of how worn the pump is. The pump #2, for example, posses the lowest efficiency of 29%.

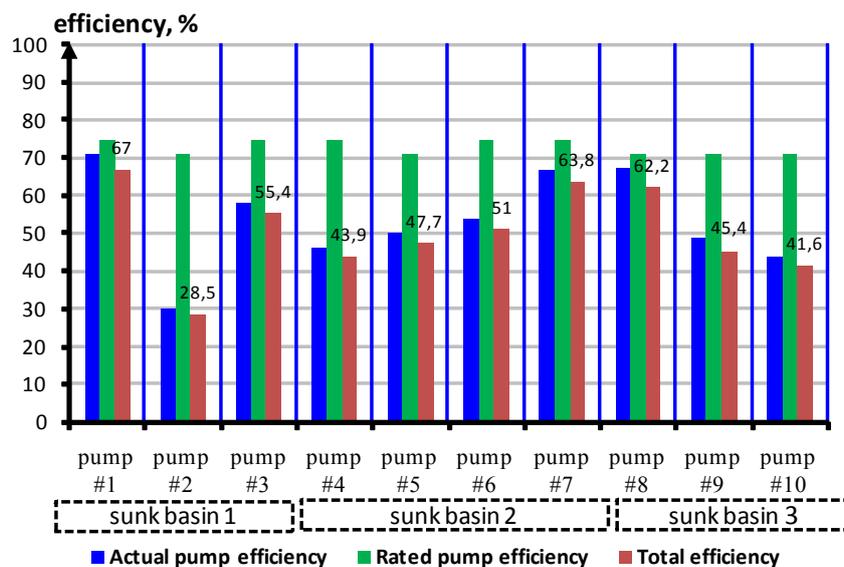


Figure 6. Estimated pumps' efficiencies.

Meanwhile, most of duty cycle pumps operate in parallel. The resulting efficiency and thus, specific energy consumption, depends not only of these parameters in standalone operation, but also on individual QH-curves.

From mathematical point of view, the number of combinations of several elements is defined by binomial coefficients, e.g. there can be 45 combinations of two pumps, 120 combinations of three, 210 possible combinations of four etc. Thus, energetic performances of dewatering system under all possible combinations of the pumps installed cannot be determined experimentally. Certain restrictions should also be considered – the allowable number of gear starting, the pumps under repair and so on. So, in order to forecast specific energy consumption under pumps' parallel operation, simulation is required.

Table 1 shows specific energy consumption (kWh/m³) under parallel operation of two of possible ten pumps.

Table 1 - Specific energy under operation of pumps in pairs.

pump #	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
#1	1,0									
#2	2,5	2,2								
#3	1,2	2,6	1,1							
#4	1,5	2,7	1,5	1,4						
#5	1,4	2,5	1,4	1,6	1,3					
#6	1,5	2,7	1,5	1,6	1,6	1,4				
#7	1,2	2,3	1,2	1,6	1,4	1,6	1,0			
#8	1,1	2,4	1,2	1,6	1,4	1,6	1,2	1,0		
#9	1,5	2,6	1,5	1,6	1,6	1,6	1,7	1,5	1,4	
#10	1,6	2,8	1,7	1,7	1,7	1,7	1,8	1,7	1,7	1,5

The diagonal of the table shows specific energy under standalone pumps operation. The cell with coordinates, for instance, 3,2 indicates specific energy consumed by dewatering system when pumps #2 and #3 are operating simultaneously and so on.

The results obtained can be presented also graphically, though, with a lack of obviousness (see Figure 7).

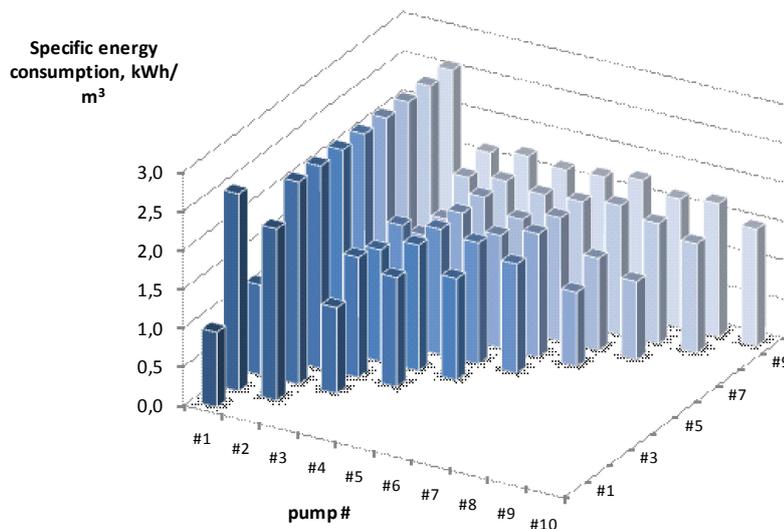


Figure 7. Graphical representation of forecasted specific energy (kWh/m³) under parallel operation of two pumps.

The pump #2, possessing the lowest efficiency in standalone operation, “spoils” the system being launched together with any of the rest of pumps. Generally, the level of specific energy demand varies within 1.1 – 2.8 kWh/m³, showing us how important is to chose correct combination of the pumps. Considering average water inflow of about 20000 m³/day gives us a huge potential for energy saving.

Forecasting of specific energy consumption for combinations of three or four pumps cannot be presented graphically. Nevertheless, the need for intelligent selection of what pump to launch is obvious.

Further research

A special system should be developed to assist dewatering dispatcher service. It should later be transformed in automated control system implementing energy saving principles.

It should be taken into account that individual QH-curves of pumps are not stable since wearing goes continuously. Faults occur, pumps and electric motors and shutoff valves are being replaced for certain technological reasons. So, the system to be developed must be adaptive to variations of industrial conditions.

Conclusions

Dewatering systems being the key consumers in mine production posses the highest potential for energy saving. Two basic principles must be implemented: rational pumps’ operation time planning according to inflow rate and time-of-day tariff and rational pumps’ combination in case of their parallel operation for minimal specific energy consumption.

References

1. G. Pivnyak, A. Beshta, A. Balakhontsev. “Efficiency of water supply regulation principles”. New Techniques and Technologies in Mining. Proceedings of the school of underground mining, © CRC Press/Balkema, 2010 Taylor & Francis Group, London.
2. United States Industrial Motor Systems Market Opportunities Assessment, report by Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998, <http://www.oit.doe.gov/bestpractices/pdfs/mtrmkt.pdf>
3. Pump Lifecycle Costs: A Guide to LCC Analysis for Pumping Systems, Europump and Hydraulic Institute, 2001t: http://www.oit.doe.gov/bestpractices/pdfs/pumplcc_1001.pdf