NIKODEM SZLĄZAK*, DARIUSZ OBRACAJ*, JUSTYNA SWOLKIEŃ*,
KAZIMIERZ PIERGIES*

CONTROLLING THE DISTRIBUTION OF COLD WATER IN AIR COOLING SYSTEMS OF UNDERGROUND MINES

REGULACJA I STEROWANIE PARAMETRAMI WODY LODOWEJ W INSTALACJACH KLIMATYZACYJNYCH KOPALŃ PODZIEMNYCH

In Polish underground mines in which excavations are subjected to high heat load, central and group cooling systems based on indirect cooling units are implemented. Chilled water, referred to as cold water and produced in chillers, is distributed through a pipeline network to air coolers located in mining and development districts. The coolers are often moved to other locations and the pipeline network undergoes constant modification. In such a system, parameters of cold water in different branches of the pipeline network need to be controlled.

The article presents the principles for controlling the cooling capacity of air coolers installed in an underground mine. Also, the authors propose automatic control of water flow rate in underground pipeline network and in particular coolers, depending on the temporary cooling load in the system. The principles of such a system, controlling cold water distribution, and the functions of its individual components are described. Finally, an example of an automatic control of water flow rate in a central cooling system currently implemented in a mine is presented.

Keywords: underground mines, air cooling systems, water reticulation system, automatic control

W polskich kopalniach podziemnych o dużym obciążeniu cieplnym wyrobisk stosuje się systemy klimatyzacji grupowej i centralnej, projektowane w oparciu o urządzenia chłodnicze pośredniego działania. Wytwarzana w agregatach chłodniczych woda lodowa rozprowadzana jest siecią rurociągów do chłodnic powietrza w rejonach eksploatacyjnych i przygotowawczych. Chłodnice są często przebudowywane, a sieć rurociągów ulega ciągłej zmianie. Obieg wody w sieci rurociągów wymaga ciągłej regulacji w zakresie wymaganego natężenia przepływu wody lodowej w poszczególnych odgałęzieniach sieci rurociągów.

W artykule przedstawiono zasady regulacji wydajności chłodnic powietrza. Zaproponowano układ automatycznego sterowania rozpływem wody lodowej w sieci, jaką tworzą rurociągi i chłodnice po-

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*   AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF MINING AND GEOENGINEERING, AL. A. MICKIEWICZA 30, 30-059 KRAKÓW, POLAND

wietrza, w zależności od chwilowego zapotrzebowania mocy w chłodnicach. Omówiono zasady takiej regulacji oraz funkcje, jakie muszą spełniać poszczególne elementy układu sterowania rozpływem wody lodowej. Przedstawiono przykład wdrażanego aktualnie sterowania rozpływem wody lodowej w klimatyzacji centralnej.

Słowa kluczowe: klimatyzacja kopalń podziemnych, regulacja, sterowanie, woda lodowa chłodnice powietrza

1. Introduction

In order to lower the temperature of air in underground mines, cooling devices based on the principles of direct or indirect cooling are used. They are integrated in local, group or central cooling systems. Central cooling involves installing refrigerators on the surface, underground, or both, and releasing the heat of condensation into the atmosphere. In central cooling installations, it is distinguished between the primary and the secondary circuit of cold water. The two closed circuits are separated by a high-pressure heat exchanger and a pressure regulator and thus the primary circuit is referred to as the high-pressure circuit whilst the secondary circuit is referred to as the low-pressure circuit (Łuska et al., 2009; Szlązak et al., 2001, 2005, 2009).

In a group system, cooling units are installed in underground excavations and the heat of condensation is released into the ventilation air or into independent water circulation systems, such as the dewatering system of the mine. In a group system with underground cooling units, the circulation of the evaporator is referred to as cold water circulation (Łuska et al., 2009; Szlązak et al., 2002, 2005, 2007).

Having been cooled down in the cooling units, the water, from that moment on referred to as cold water, is distributed via a network of pipelines to air coolers in mining and development districts. The network of pipelines makes a water reticulation system. The total combined length of the pipelines can reach several dozen kilometres, given the vast district of the underground excavations. Air coolers are placed at different levels and thus can be located below or above level of circulation pumps distributing water. The cold water pressure in such circuits can reach 4 MPa (Łuska et al., 2009; Rawlins, 2007; Szlązak et al., 2005, 2007).

There is a changing cooling load in excavations with air coolers and it is necessary to modify the arrangement of air coolers as existing excavations are shortened or drivaged new ones (Szlązak et al., 2007; Knechtel, 2011; Zapletal et al., 2012). Central or group cooling systems are hindered from obtaining the necessary cooling power, mainly because of the wrong positioning of air coolers. Frequently, air coolers are placed where the inlet air temperature is lower than 26°C. According to the design documentation, as well as operation and maintenance documentation of particular air coolers, they should be installed in places where the inlet temperature is at least 28°C (Łuska et al., 2009; Szlązak et al., 2002, 2005, 2007). Air temperature behind the cooler fan will then remain at the level of ca. 29-30°C (resulting from the increase caused by the fan). Air coolers should be relocated as the heading face or the longwall face moves forward. If the inlet air temperature fails to reach 28°C, the air cooler should be relocated. Should this be impossible, the amount of water supplied to the cooler has to be reduced. The water flow rate should be determined by a control system regulating the cooling power of the cooler.

The water reticulation system changes over time as new pipes are constructed, branching off from the main pipeline, while pipes leading to areas where mining has been discontinued are liquidated (Fig. 1).
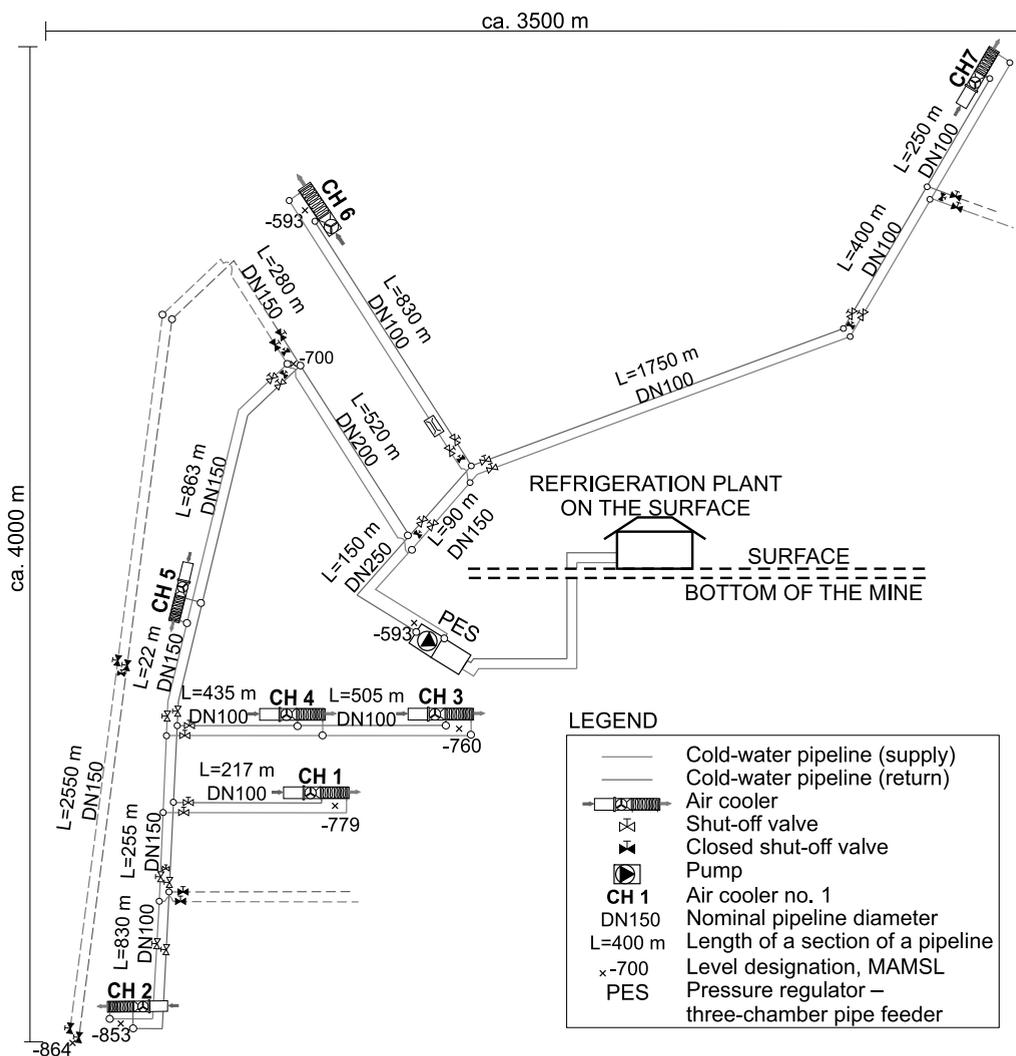
Fig. 1. Layout of a secondary circuit of a exemplary central cooling system

Along with the modifications of the pipeline network and the placement of air coolers, the values of system resistance (Atkinson's resistance) also change. Frequently it becomes necessary to connect a larger number of coolers in a given district and at the same time disconnect coolers in another district. A central cooling system is designed for the maximum possible water system resistance or system head expected to occur during planned exploitation in a mine. At the same time, the principles for the regulation of water distribution are defined. If water distribution is not regulated again after the pipeline network and the placement of the coolers have been changed, the flow rate of water passing through the coolers can fail to reach the required value. As a result, the capacity of air coolers often drops and the temperature of water returning to the

cooling units (water chillers) is lower than designed. Therefore, it is necessary to direct water into particular districts depending on the heat load and to guarantee on-going control of water distribution (Szlązak et al., 2002, 2006).

At present, in Polish underground mines there are five central cooling systems in operation and another two are under construction. Besides, a dozen or so group cooling systems are in operation. The newly constructed cooling systems are characterized by an increasing use of control systems. The major focus of the current paper is to outline the principles for the regulation and construction of a system controlling the parameters of cold water.

2. Principles for regulating the distribution of cold water in the cooling systems

In mining and development districts it is required to install air coolers with a total nominal power exceeding the forecasted cooling power in the area while maintaining the water flow rate at the level corresponding to the predicted power. This rule not only follows from the fact that air coolers installed underground seldom reach the cooling performance defined by the manufacturer, but also reflects the accepted principle for the control of a cooling system.

Control is based on the principle of being able to guarantee – in hydraulic terms – changeable cold water flow rate in particular districts in which mining is in progress.

The necessary level of cooling power in a given districts is forecasted for the least favourable conditions, i.e. for the longest lengths of longwall panels, or the target length of the drivaged heading in the period in which the temperature and humidity of the intake air are at their highest level. The required level of cooling power changes during the advance of mining works, so the coolers should be relocated accordingly to places with the highest heat load.

A central cooling system is designed in such a way as to be able to withstand the highest possible system resistance values that can occur during the planned advance of mining works in an underground hard coal mine. However, the total combined length of the pipeline network is either shortened (as a result of mining) or lengthened (as a result of development works) and it is necessary for air coolers to control and maintain the required cold water flow rate. The flow rate of water passing through a cooler is the key parametre for regulating its cooling power.

The existing pipeline network of a central or group cooling system consists of many mining districts, in which air coolers are installed. During mining, a need may arise to reduce the power of coolers in n district, combined with an increase of required cooling power in another district. The control system should leave the user a possibility to reduce or increase the flow rate of water in a given district. To make it possible, a certain throughput of the pipeline network must be ensured, resulting from the values of water flow resistance. For this reason, it is recommended that pipelines installed in excavations (such as gateroads) where the needed cooling power is between 300 kW and 1200 kW should consist of pipes with a minimum diameter of 150 mm.

Also, a greater number of air coolers is needed to ensure smooth regulation of water distribution among particular coolers. The total combined power of the coolers should remain within the range of 120÷130 percent of the required cooling power. Table 1 lists examples of the needed number of air coolers with nominal cooling power of 200 kW and 300 kW according to the required cooling power.

TABLE 1

Recommended number of air coolers with a specified nominal cooling power
in an excavation with a specified heat load

No.	Forecasted level of necessary cooling power		Required cold water flow rate		Required number of air coolers with 300 kW and/or 200 kW of nominal cooling power	
	minimal	maximal	minimal	maximal	minimal	maximal
	kW	kW	kg/s	kg/s	—	—
1.	300	500	6.0	9.9	1×300 kW + 1×200 kW	2×300 kW + 1×200 kW
2.	500	800	9.9	15.9	2×300 kW + 1×200 kW	3×300 kW + 1×200 kW
3.	800	1100	15.9	21.9	3×300 kW + 1×200 kW	4×300 kW + 1×200 kW
4.	1100	1400	21.9	27.8	4×300 kW + 1×200 kW	5×300 kW + 1×200 kW
5.	1400	1500	27.8	29.8	5×300 kW + 1×200 kW	6×300 kW

Adhering to the principle of connecting a greater number of air coolers to the DN 150 pipeline in the excavation will ensure:
- the flexibility of water flow control by the coolers,
- possibility of increasing the water flow rate in a district where a temporary need arises, combined with a simultaneous drop in flow rate in another district.

The system should be equipped with a control system for controlling the distribution of water proportionally to the temporary need for cooling power at points where air coolers are installed. The distribution of water is possible within the range of the working parameters of circulation pumps.

Also, the system should be equipped with a monitoring device to monitor the parameters of the flowing water. Its indications will be the basis for adjusting the cold water flow rate to the required level in particular branches of the pipeline network and in the particular coolers.

If the cooling load of the entire system (including all the installed air coolers) is below the value assumed at the designing stage, it is necessary to reduce the cold water flow rate and the temporary value of refrigerating capacity of the cooling units. A reduction of flow rate in the circuits should be achieved by changing the rotational speed of the circulation pumps (Fig. 2).

Chillers have to be adjusted to the fluctuations of temporary load on the side of the evaporator. The change of the flow rate of water flowing through the evaporator of a cooling unit on the surface is not a problem for most control systems of compressor or absorption-type units. Similarly, most chillers currently in use underground allow for a smooth regulation of flow rate by the evaporator. In central cooling systems, three-chamber pipe feeder, also called PES (Pressure Exchange System), enables changing water flow rate in the primary and secondary circuits.

It is most typical, however, there are cooling load fluctuations in particular sections of the system. The value of the cooling load in one district can be greater than in another, which makes it necessary to modify the arrangement of the coolers. The coolers should be relocated to places where air temperature exceeds 28°C; otherwise, the flow rate of water passing through the coolers should be authomatically reduced by a regulator installed at the cooler. An additional cooler in the district and adequate throughput of the pipeline (DN150) enable the user to increase the flow rate temporarily in a given district in exchange for reducing its value elsewhere.

The flow rate should be controlled by directing the required amount of water to selected districts using local throttles installed at points where pipes leading to each mining district branch
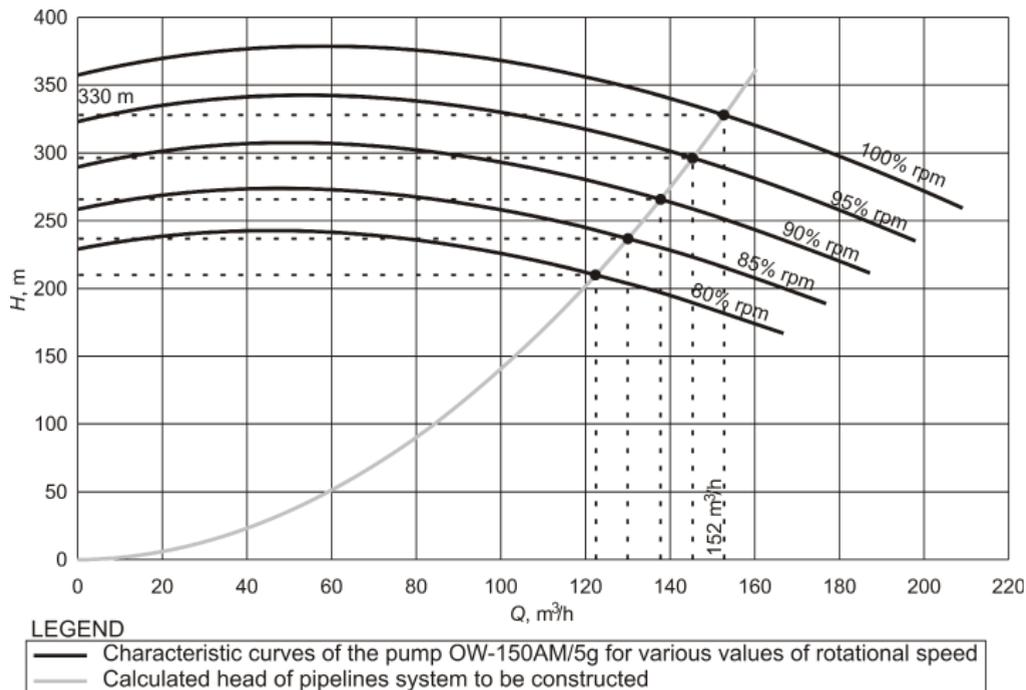
Fig. 2. Modifying the working parameters of a pump with the designation OW-150AM/5g by adjusting the rotational speed of the rotor in a sample central cooling system

off from the main pipeline. Power-operated throttles of cold water should be installed on the local pipe supplying cold water to the coolers (Fig. 3).

The water throttles should be activated by a local controller that receives information from the devices monitoring the parameters of air and cold water in the district and adjusts the water flow rate in accordance with the require instantaneous cooling power.

Based on the data received from the controllers of particular air coolers, the local controller determines the throttle response and the required flow rate (in relation to the flow rate at maximum throttle opening) in a pipeline supplying a given district with cold water. The entire control system of the cooling system has to be integrated.

3. Regulating the cooling power of air coolers

A classic control system for regulating the working parameters of an air cooler is a two-level cascade control system, consisting of a self-operated and a relay-operated control subsystems.

The regulated device is an air cooler lowering the temperature in an excavation at some distance behind the cooler. The regulation of temperature consists in adjusting the cooling capacity of the cooler by modifying the flow rate of cold water passing through the cooler. The system aims to maintain the desired temperature in an excavation by controlling and adjusting the outlet air temperature (Fig. 4a). In such cases, in order to take maximum advantage of the
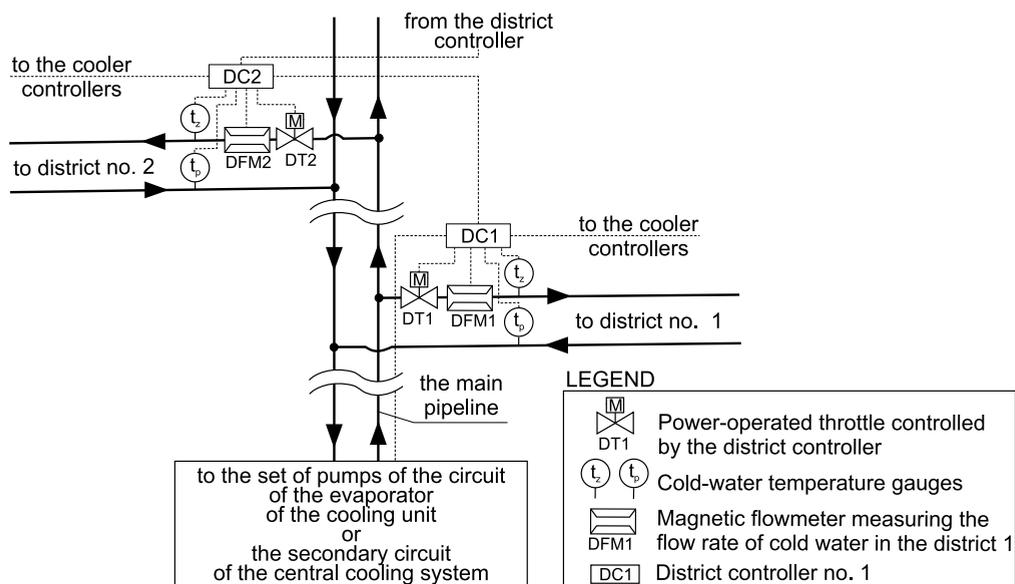
Fig. 3. A control system for regulating the flow of cold water into districts of a cooling system
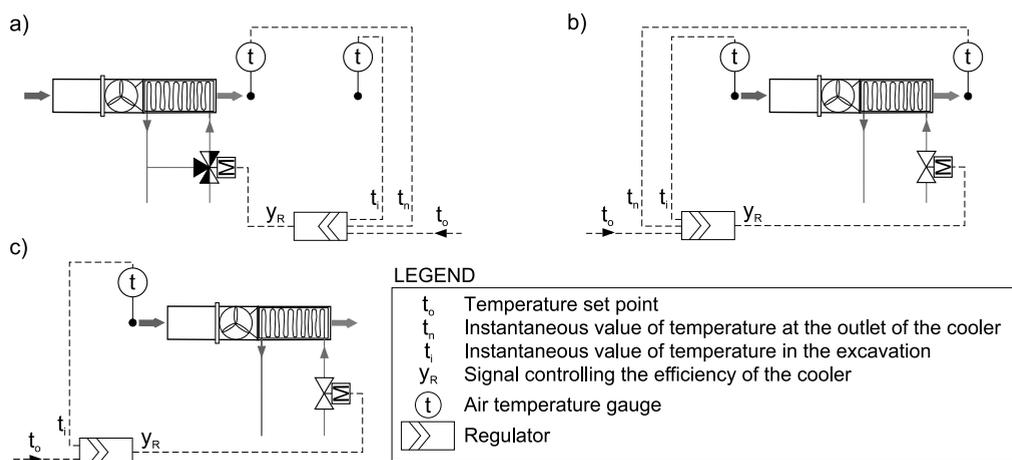

Fig. 4. Regulating the cooling capacity of an air cooler, a) a cascade control system (self- and relay-operated regulators) with regulators in one package, b) a cascade control system with a packed regulators and air temperature measured in the excavation in front of the cooler, c) a self-operated control system for regulating air temperature in the excavation in front of the cooler

available cooling power it is necessary to reduce the flow of cold water through a three-way valve, activated by a signal from the regulator determined by momentary temperature values (t_n, t_i) and the target temperature (t_o). The cooling capacity of a cooler can also be regulated by adjusting the amount of airflow through the cooler, but it is difficult to modify the capacity of

fans in the conditions of an underground mine. In fact, it is impossible to implement this type of control system in mining excavations because of the large amount of air flowing around coolers and large fluctuations of heat flux.

Employing a three-way valve in front of the cooler in underground cooling systems is not effective either, because cold water mixes with the water flowing from the cooler. As a result, water returning to cooling units may be too cold, preventing the units from normal functioning (Szlązak et al., 2002; Wojciechowski, 2013).

In case when the cooling power needed in the place where the air cooler is installed is smaller, the flow of cold water through the cooler can be reduced by throttling. A group or central cooling system includes a dozen or several dozen air coolers installed in various parts of a mine, in excavations where the need for cooling power can temporarily rise. This arrangement allows for directing surplus water to other air coolers. Thus the regulation system for regulating the working parameters of an air cooler should be based on a two-way valve that limits the flow of water through the cooler if the temperature of air in front of the cooler drops in relation to the target temperature. A master controller regulating the outlet air temperature is presented in Fig. 4b. The master mode of packed controller uses the current value of target inlet air temperature ($t_o = 28°C$) and the actual measured value of temperature (t_i) to determine the target value for the slave mode with reference to the target outlet air temperature (t_n). In a simplified version, this cascade control system can be replaced with a one-line control system, with a temperature sensor installed only at the inlet of the cooler (Fig. 4c).

4. Requirements concerning control systems

4.1. System for controlling the flow of cold water through the cooler

The cooling system should be equipped with a monitoring system to monitor the parameters of the flowing water, which will be the basis for controlling the cold water flow rate in particular branches of the pipeline network and in the individual coolers. The monitoring system should rely on intrinsically safe temperature and pressure gauges and flow meters. It is recommended that systems with a frequency output signal of 5÷15 Hz be used. In order to regulate the flow rate, it is possible to employ electric-powered throttles and an external controller (serial RS232 communication). All measuring and regulatory devices should conform with the requirements of the ATEX directive 94/9/EC (a new ATEX directive 2014/34/EU will be mandatory for manufacturer on 20 April 2016), which defines the fundamental requirements for products intended for use in potentially explosive atmospheres.

The control system for controlling the flow of cold water through the cooler consists of a cooler controller (CC), a flow meter (CFM) measuring the flow rate of water flowing into the cooler, and gauges of water temperature (t_z), (t_p), air temperature (t) and water pressure (p). The function of the controller is to adjust the flow rate of water passing through the cooler and to turn off the cooler fan automatically when the need for cooling power drops considerably. In accordance with the outline presented in Fig. 4c, the controller adjusts the flow of water through the cooler depending on the air temperature (t_i) by regulating the opening of the throttle installed in the pipe supplying cold water to the cooler. Using the defined proportionality coefficient, the controller installed at the cooler will modify the opening of the throttle at the inlet of the cooler

(Fig. 5). The water pressure gauge at the inlet of the cooler prevents pressure increase which could damage the cooler. When the pressure has reached 4 MPa, the controller shuts off the flow of water into the cooler. When air temperature falls below 23°C, the controller transmits a signal to a multi-contact switching device to switch off the drive of the cooler fan and shuts the throttle. It is possible to implement a cascade regulation system in the cooler, using an additional air temperature gauge at the outlet of the cooler in accordance with Fig. 4b.

The air cooler controller (Fig. 5) should be able to perform the following functions:
- measuring air temperature in front of the cooler (t)
- measuring the flow rate of cold water passing through the cooler (CFMx)
- shutting and opening the water throttle (CTx) in accordance with the defined algorithm
- measuring the temperature of cold water (t_z) at the inlet of the cooler
- measuring the temperature of cold water (t_p) at the outlet of the cooler
- measuring water pressure (p) at the inlet of the cooler
- activating the multi-contact transwitch of the cooler fan drive
- calculating the actual value of the cooling capacity of the cooler
- transmitting information about the required flow rate to the local controller (DCx)
- transmitting data about all measured parameters and the position of the throttle to the main controller (MC)
- displaying current measurement values and the calculated value of cooling efficiency in the place where the controller is installed.
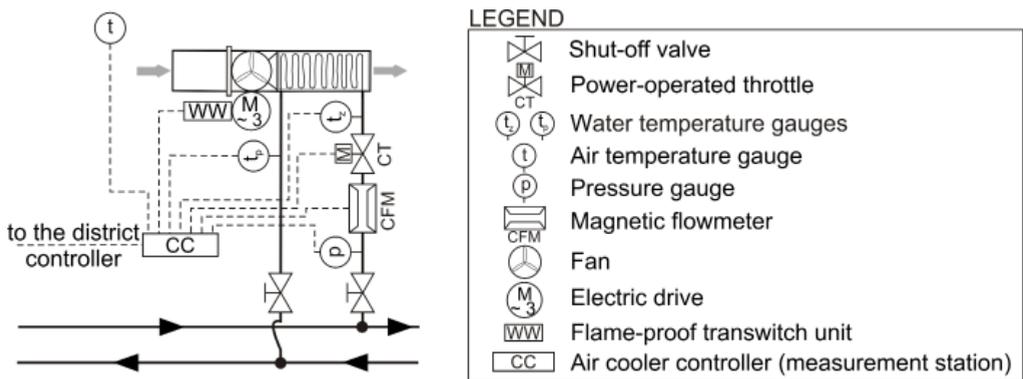

Fig. 5. Conection diagram of an air cooler controller with measuring devices and actuators

Thus the controller is required to function as both a data concentrator and a regulator actuating the throttle and the fan drive switch. In addition, the controller is supposed to function as an amplifier (repeater) of data transmission signals sent to the next element of the control system. Reading the values indicated by the measurement sensors and data transmission can take place via RS 485 communication using the MODBUS RTU standard for analog controllers. Also, the controller must enable the user to switch the air cooler off in an emergency situation (by shutting the throttle and switching off the fan drive). All local controllers installed at air coolers in the same excavation are supposed to inform the master distric controller about the required flow of water into the district.

4.2. System for controlling water parameters at the inlet of the district

If the cooling load of the entire system (including all the installed air coolers) is below the value assumed at the designing stage, it is necessary to reduce the cold water flow rate and the temporary value of cooling performance of the cooling units. A reduction of flow rate in the circuits should be achieved by changing the rotational speed of the circulation pumps (Fig. 2).

It is most typical, however, for the cooling load to fluctuate in particular sections of the system. For this reason, it is necessary to reduce the flow rate of water supplied to one district and at the same time increase the flow rate in another.

The control system for controlling water parameters at the inlet of the district should consists of the following elements: the district controller (DCx), the district flow meter (DFMx), gauges of water temperature (t_z), (t_p) and the district throttle (DTx).

Based on the information from the district flow meter (DFMx), the district controller (DCx) adjusts the flow rate of water supplied to the district by actuating the area throttle (DTx). The controller should be capable of receiving data using the same transmission format as the air cooler controller (CCx), e.g. RS 485 communication using the MODBUS RTU or ASCII standard. Also, it should be capable of receiving information from all coolers in the district and sending them to the next element of the control system.

Given the vast district covered by the pipeline network, the control range of the water flow rate in pipes supplying the district is defined with due precision. Fig. 6 presents a schematic diagram of the system with the devices controlling the parameters of cold water, whereas Fig. 7 presents a block diagramme of the monitoring and control systems.
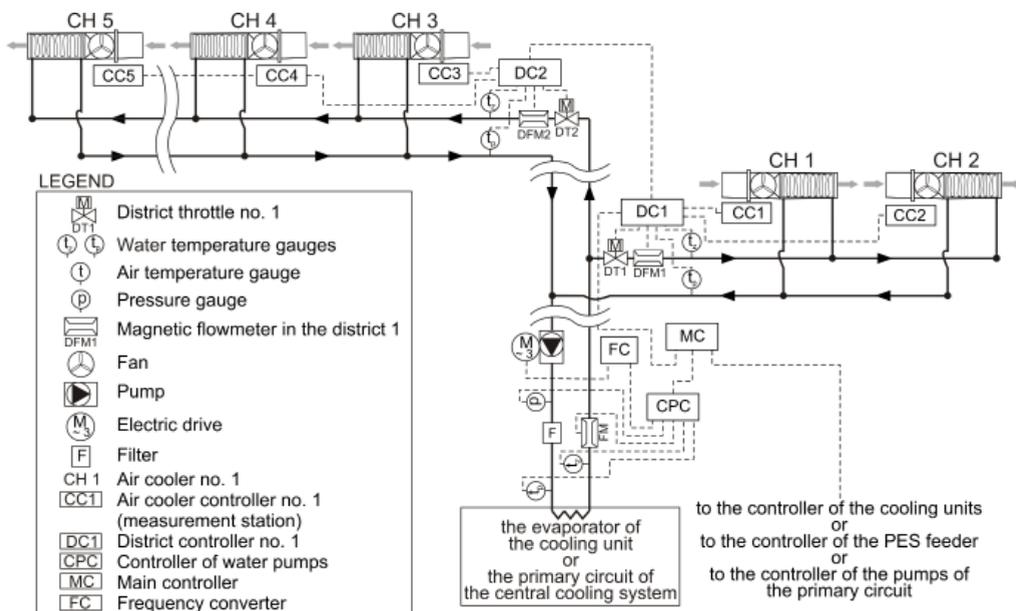

Fig. 6. Schematic diagram of the systems for the monitoring and control of the parameters of cold water in a central cooling system
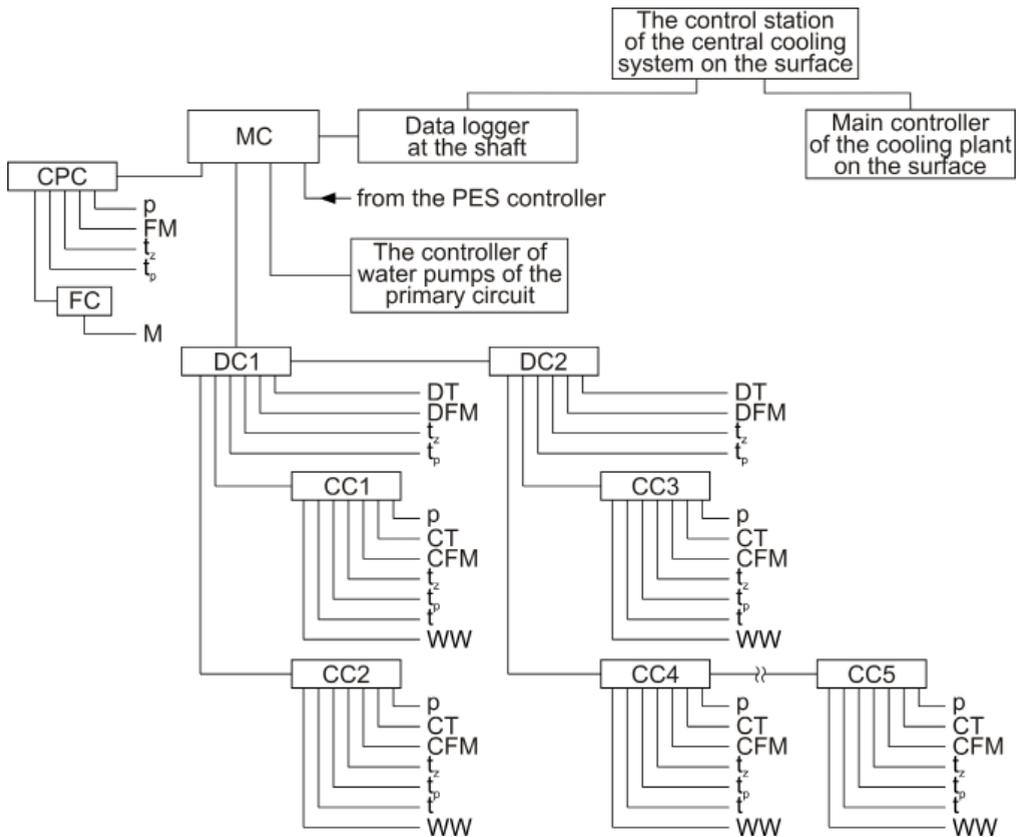
Fig. 7. Structure flowchart of the systems for the monitoring and control of the parameters of cold water in a central cooling system

The district controller (DCx) should be able to perform the following functions:
– regulating the cold water flow rate at the inlet of the district by adjusting the opening of the district throttle (DTx),
– measuring the temperature of cold water (t_z) in the pipe at the inlet of the district,
– measuring the temperature of warm water (t_p) in the pipe at the outlet of the district,
– measuring the cold water flow rate (DFMx),
– calculating the cooling power assumed for the district,
– displaying the measured and calculated values,
– transmitting data about all measured parameters, calculated values and the position of the district throttle.

The functions listed above should be performed by the following functional blocks of the controller:
– processor control block,
– data transmission block – a data concentrator module with the functions of gathering and transmitting data to the master controller and a module for controlling the district throttle,

– input module – a binary and frequency input module for binary input from controls installed in the cover of the controller (enabling the user to perform the settings manually) and for processing the data received from the measuring devices,
– information display block – an LCD display module.

Controlling the flow rate of water (by opening or shutting the throttle using the manual control function) can take place by activating either the buttons installed on the electric drive of the throttle or the controls installed in the front cover of the district controller (DCx).

All the district controllers within a system should transmit information about the required flow rate of water to the main controller (MC).

4.3. Master control system for controlling the parameters of water in a cooling system

The main controller (MC) receives information about the required water flow rate in the entire system (in relation to the maximum value of flow rate) from the district controllers (DCx). The main controller is connected with the controller of the rotational speed of the circulation pumps (CPC), to which it transmits information about the required ice water flow rate. In turn, this controller (CPC) actuates the frequency converter to adjust the rotational speed of the circulation pumps and the opening of the main throttle. Simultaneously, the main controller (MC) sends a signal to the controller of the cooling units (the underground chillers of a group system or the surface chillers of a central system).

The main controller (MC) manages information sent from the control and measurement devices, district controllers and additional controllers (e.g. the controller of the three-chamber pipe feeder in case of a central cooling system). Based on the received data, the controller manages the functioning of the circulation pumps and other parts of the system (e.g. the solenoid valve for water replenishment or the cooling of frequency converters and the controlled throttle with an electric drive – see Fig. 6).

The main controller (MC) should be equipped with the following functional blocks:
– processor control block for controlling all slave controllers,
– input module for processing binary data about the activation status of all controlled devices and for processing the analog data received from the measuring devices,
– input module for processing binary input from controls installed in the cover of the controller (enabling the user to perform the settings manually),
– data transmission block (controlling the main throttle with an electric drive and the rotational speed of the circulation pumps by actuating the frequency converter, sending information to the controller on the surface, communicating with other controllers in the mining districts and at air coolers),
– information display block – an LCD display module.

At the same time, the main controller (MC) should collect all data from local controllers (DCx, CCx), prepare pooled data and send it to the data concentrator on the surface in order to make measurement data accessible to the monitoring system of the cooling system.

The system for monitoring the distribution and parameters of cold water, combined with the telemetric system of the mine, should enable the specifically named, competent services of the mine to adjust the cold water flow rate manually to the required level from a control station

on the surface. In addition, the control system should allow for disconnecting pipelines in an district where air coolers need to be relocated, while maintaining the supply of water to coolers in other districts.

5. Example of monitoring and controlling the parameters of cold water in a cooling system

The example involves a central cooling system with an refrigeration plant on the surface, with a cooling power of 6000 kW and 16 air coolers remove of 4400 kW from the passing air. The system should include more coolers than implied by the heat balance of the excavations to allow for increasing the flow rate of water supplied to districts with greater temporary demand and at the same time reducing the flow rate or shutting off coolers in another district. Fig. 8 presents a simplified layout of a cooling system with the devices that constitute the monitoring and controlling systems.

In this case, controlling activity is limited to the automatic control of water distribution to districts by means of district controllers (DC1-DC7) and the main controller (MC). The main controller affects the rotational speed of circulation pumps located underground and on the surface. The air cooler controllers (CC1-CC16) perform the function of data concentrators not equipped with a control output. They transmit measurement data to the district controller and the main controllers. Also, they control the flow rate and temperature of water and air temperature in the places where coolers are installed. The fan drive is switched on and off only using the manual control function. The flow rate of water passing through individual coolers is regulated manually using ball valves, which should be done after every relocation of the cooler.

The controlling activity is thus reduced to regulating the distribution of water among particular coolers. The monitoring system supervises the basic parameters of cold water in particular districts and in particular air coolers.

Controlling the water flow rate in individual districts (by opening or shutting a throttle) is also performed by activating the buttons installed on the electric drive of the throttle, using the controls installed in the front cover of the district controller (DCx), or remotely by means of main controller (MC) or the control station of the refrigeration plant, located on the surface.

6. Conclusions

The cooling systems installed in underground excavations face the challenge connected with the fluctuations of the instantaneous value of heat load, caused by the advance of exploitation or development and the changing parameters of intake air. As a result, the pipelines of the cooling system need to be rebuilt frequently and air coolers need to be installed in places where the maximum air temperature permitted by the relevant regulations is exceeded. Changes in the structure of the system make on-going regulation of the distribution of cold water necessary.

Automatic control of the distribution of cold water in a central/group cooling system makes it possible to take better advantage of the available cooling power and improves thermal conditions. The proposed control system, based on air cooler controllers, district controllers and the main controller, allows for the automatic adjustment of the required flow rate of cold water passing through particular coolers and the entire cooling system.

Fig. 8. Layout of control and monitoring systems in a developed central cooling system with 16 air coolers

The control system makes it possible to increase the flow rate of water supplied to districts with greater temporary heat load and at the same time to reduce the flow rate in districts where the need for cooling power is lower. The distribution of water is possible within the range of the working parameters of circulation pumps. In order to implement such a control system in an exploitation or development district, the number of air coolers should be greater than suggested by the forecasts of cooling power requirement (in most cases, one extra cooler in a mine district is needed). Besides, in order to enable smooth regulation of the distribution of cold water among districts, the pipelines supplying water to particular districts, to which air coolers are connected, should consist of pipes with a minimum diameter of 150 mm.

The principles presented in this paper, concerning the control and monitoring of the parameters of cold water used in the cooling systems implemented in underground mines, should be adopted as guidelines for the design and construction of such cooling systems.

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