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Wellhead anti-frost technology using deep mine geothermal energy

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ABSTRACT

The auxiliary shaft is an important location for coal mine heating in the winter, where the main purpose of heating is to prevent icing of the shaft. Wellhead heating requires characteristics of openness, no-noise and big heat loads. The original coal-fired boiler heating mode causes significant waste of energy and environmental pollution due to the low efficiency of the heat exchange. Therefore, to solve these problems, we will use deep mine geothermal energy to heat the wellhead by making full use of its negative pressure field and design a low-temperature water and fan-free heating system. Through numerical calculations we will simulate temperature fields, pressure fields and velocity fields under different air supply temperatures, as well as different air supply outlet locations and varying number of radiators in the wellhead room of a new auxiliary shaft to find the proper layout and number of radiators that meet wellhead anti-frost requirements from our simulation results, in order to provide guidelines for a practical engineering design. Tests on the Zhangshuanglou auxiliary shaft wellhead shows good, look promising and appear to resolve successfully the problem of high energy consumption and high pollution of wellhead heating by a coal-fired boiler.

1. Introduction

Given China's economic and social development, her demand for energy is ever growing, with the demand for, coal as the main source of our primary energy consumption, particularly large [1,2]. In 2009, China consumed 3.05 billion tons of raw coal, accounting for 68% of one-off energy. Therefore, coal mine safety is always awarded top priority in our national security system. As the major entry for personnel and material, the auxiliary delivery shaft is crucial in coal mine safety. Most mines in northern China in the winter form ice burls in their wellheads due to the cold, which constitute serious threats to the life of the workers at the bottom of mines. Hence, most auxiliary shafts in northern, central and western China take anti-frost measures in the winter to prevent icing in the shaft. The "Mine Design Norms in Coal Mining Industry" (GB50215-94) provides that: "in case of the vertical air inlet shaft in areas when the temperature outside the heating room is lower than −4 °C, the inclined air inlet shaft in the area with temperatures not more than −5 °C, and the air inlet adit in the area with temperatures not more than −6 °C and in case of heavy side-wall water, drainage pipes, drainage ditches and air heating equipment should put in place".

On the other hand, shallow coal resources in China are nearly exhausted and an increasing number of mines face mining at greater depths. With deep mining, the mines face the problem of thermal hazards and cooling measures must be taken [3–6]. The original heat damage control technology treats heat damage as a disaster to be remedied, causing great waste of energy [7–9]. In this study, we take wellhead anti-frost and heat damage control into account and investigate the possibility of transferring the heat damage to a heat source and delivering this heat source to the wellhead to prevent the wellhead from freezing. The "Coal Mine Safety Regulations" state the following: "the air temperature below the air inlet wellhead must be above 2 °C. The air temperature at the production and mining surface must exceed 26 °C and the air temperature of the mechanical and electrical equipment chamber must not exceed 30 °C. When the air temperature of the mining surface exceeds 30 °C and the air temperature of the mechanical and electrical equipment chamber exceeds 34 °C, operations must cease".

For deep mine geothermal energy, our predecessors have carried out some investigations into using circulating water bodies and geothermal energy from abandoned mines [10–14]. We aim at solving the problems of energy waste and environmental pollution by providing heat to the auxiliary shaft from coal-fired boilers. In combination with underground thermal hazard treatment, we provide technical ideas for applying deep mine geothermal energy to conduct anti-frost and heating trials in a coal mine wellhead and conduct field test analyses.

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2. Wellhead heating characteristics

The main functions of the auxiliary shaft in coal mines are for manpower movements, lifting of waste rock and transmission of materials for production in the well. Its other function is to serve as the main air inlet channel. Functions of auxiliary shafts determine that the wellhead of the auxiliary shaft must be open with plenty of fresh cold air coming inside every minute. The auxiliary shaft is run by its operators by means of a considerable amount of ringing, hence the requirements for noise control are extremely high. The conditions imposed on the auxiliary shaft wellhead determine that the requirements for the wellhead for special heating have the following characteristics.

(1) As a heating place, the wellhead is an open system. Since the auxiliary shaft is the main channel for transportation and manpower access, so the wellhead housing should be always open, which means it is an open heating space.
(2) Its heat load is large and as the main inlet channel for mines, the auxiliary shaft has a large air intake volume, such as the air inlet amount of the Zhangshuanglou auxiliary shaft, which is 5410 m^3/min and the heat load is even larger.
(3) The auxiliary shaft wellhead has high and demanding noise prevention requirements on noise control and the use of fan forced heat transfer is likely to cause accidents.

3. Wellhead anti-frost heating by using fired boilers

3.1. Original heating design

The amount of air inlet at the Zhangshuanglou auxiliary shaft wellhead in the winter is 5410 m^3/min and the lowest outdoor air temperature −10 °C. The original mine uses steam heating, with two sets of steam radiators arranged on opposite sides, inside the wellhead housing, with the wind flow in the wellhead only heated through radiation.

It can be seen from Fig. 1 that in the original heating system, the wellhead isotherms and air flow lines have the same direction, so that an effective convection cannot be formed, implying that the heat transfer coefficient is very small, the system is inefficient and wastes large amounts of energy.

3.2. Original heating analysis

Given the actual on-site size of the original heating system and the temperature of the steam supply, which is shown in Table 1. We used Fluent (a computer program) to establish the module shown in Fig. 2 and conducted an analysis of the original heating system.

In the original heating system, 0.3 MPa steam is used as the heat medium, the temperature is 130 °C and the main mode of heating is radiation. From Fig. 2 it can be seen that the contours of the temperature field are unevenly distributed. Fig. 3 shows that locations near the radiator have higher temperatures than the central part with its considerable amount of ventilation. Fig. 4 shows that the wellhead temperature can be kept higher than 2 °C, but the overall effect of the heating supply is poor, as is the heat transfer capacity, resulting in a waste of energy. For the Zhangshuanglou coal mine alone, keeping the auxiliary wellhead frost free will require 4000 t of coal per year.

Table 1
Auxiliary shaft wellhead housing parameters.

No.	Item	Parameter
1	Outdoor temperature for heating in winter (°C)	−5
2	Outdoor temperature for air-conditioning in winter (°C)	−8
3	Atmospheric pressure (kPa)	100.26
4	New auxiliary shaft inlet wind (m^3/min)	5410
5	Wellhead space dimensions (m × m × m)	42 × 14.1 × 4.5
6	Number of layers	2
7	Layer height (m)	4.5
8	Inlet wind amount (m^3/min)	5410
9	Simulated calculation outdoor temperature (°C)	−10
10	Inlet wind velocity at door (m/s)	1
11	Inlet wind velocity at window (m/s)	0.5 m/s
12	Maintenance structural properties	Insulation surface
13	Number of steam heat exchangers	22
14	Steam pressure (MPa)	0.3

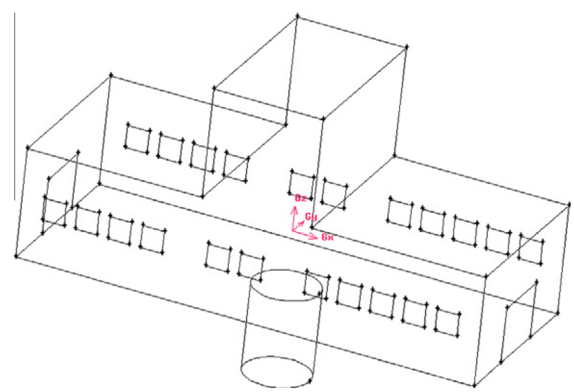

Fig. 2. Original heating model.

4. Geothermal energy for heating and frost free wellhead

4.1. Wellhead anti-frost design

The Zhangshuanglou Coal Mine is exceptionally rich in coal mine water inflow and we should use this feature to conduct a study of an integrated design for an above ground heating and

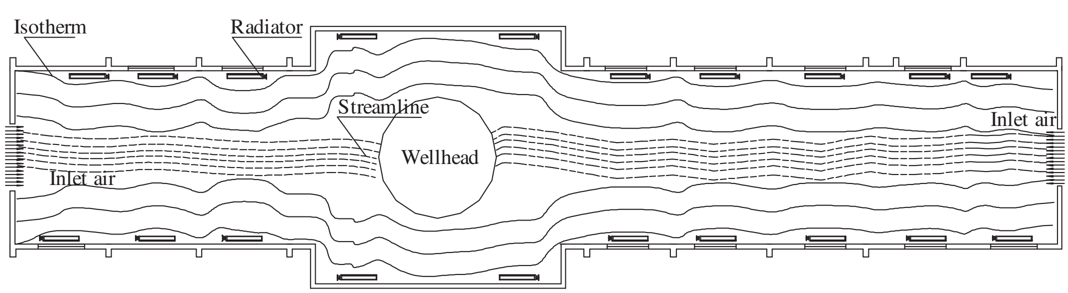

Fig. 1. Original heating system isotherms and streamlines.