Mining Science and Technology (China) 21 (2011) 637–640

Contents lists available at SciVerse ScienceDirect

Mining Science and Technology (China)

journal homepage: www.elsevier.com/locate/mstc

Abandoned coal mine tunnels: Future heating/power supply centers

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ARTICLE INFO

Article history:
Received 12 January 2011
Received in revised form 10 February 2011
Accepted 9 March 2011
Available online 4 November 2011

Keywords:
Mining reclamation
Energy storage
HVAC
CAES

ABSTRACT

We have studied three plans for re-use of the abandoned mine roadway tunnels as an energy center. These are the thermostat plan, the thermal accumulator plan, and the CAES plan. Calculations show that the thermostat plan can provide over 15,000 m^2 of building air-conditioning/heating load for each kilometer of roadway, but electric power is needed to run the system. Numerical research proved that the accumulation of hot water in the roadway for seasonal heating purposes (a temperature swing from 90 to 54 °C) is a viable possibility. The CAES plan proposes using the discarded coal mine tunnel as a peaking power station with an energy storage density over 7000 kJ/m^3. It can be concluded that presently abandoned coal mines could be reformed into future energy centers for a city.

1. Introduction

There is a periodic evolution of mining cities around the World. After periods of preparation, growth, and maturity most of these cities will face a recession or transformation period. This is an universal commonality of mining cities.

Taking China as an example, the statistics of the China Mining Association show over 390 mining-resource based cities currently exist in China. Among these, about 20% are in the growth period, 67.2% are in the mature period, and 12.8% are in recession. This means there are 50 cities facing resource failure and about 440 mines are being closed. It is reported that over the coming 20 years another one-third of the existing mining-resource based cities will move into a state of resource exhaustion [1].

Most the mining cities are coal-mine based in China because of the special energy structure in this country. Almost 70% of the primary energy supply is from coal. The depletion of those coal mines inevitably causes many urban environmental, social, and economic problems [2,3]. It has been estimated that about 3 million workers now associated with these mines will lose their jobs and 10 million family members will be influenced by these changes [4]. Four million km^2 of mining land has been abandoned because of mine depletion or collapse [5]. This land resource is difficult to reuse as agricultural land, or for urban business, for a certain period, which seriously restricts the economic development of the local cities. In fact, as a concomitant to the development of industrialization, abandoned mining land has become the characterization of an inner crisis of mining cities.

The reuse of discarded coal mine land is of significant import in China where cities expand so quickly but land resources are so limited. In the past decades reuse of mining lands has been intensively studied and many successful trials have been carried out around the world [6]. For example, the regional-integration redevelopment of the Ruhr in Germany, the reclamation of mining lands in the US, and the reformation of mining lands in the UK may be noted as successful. It has been proved that discarded mining land can be turned to various uses after reasonable efforts at ecological restoration. Uses include such things as retail business districts, residential areas, office districts, pollution-free industrial zones, parks, squares, or exhibition centers.

However, in addition to the land resource on the surface a huge roadway network exists underground that is a geothermal resource. The authors have the idea that during reclamation of discarded coal mines these underground roadway networks should be considered during the utilization of all the resources. This is also an international trend in the reclamation of mining land [7].

The quick urbanization of China provides two possible uses for the underground resource of a discarded coal mine: (1) a heating and air-conditioning center; or, (2) an energy storage peaking power station. In this sense a presently discarded coal mine could become a future energy center for a city.

2. A heating and air-conditioning center

The expansion of Chinese cities has resulted in many coal mines being located under cities now. During the reclamation of the surface lands of a discarded coal mine the underground tunnels can be reused as "thermostats" or "heat accumulators". An energy saving heating and air conditioning center can be built on the

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1674-5264/$ - see front matter © 2011 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
doi:10.1016/j.mstc.2011.10.011

surface and residents in the reclamation area can benefit from this use of the old tunnels.

Not every part of the coal mine tunnel is suitable for heating and air-conditioning. The authors believe the main roadway of the coal mine is a better choice because of its larger, more stable space and the existence of a water-proof cement layer on its inside walls. There are two proposals herein to fulfill this purpose: a thermostat plan and a thermal accumulator plan.

2.1. Thermostat plan

The main roadway is normally about 300–400 m underground in the thermostatic layer of the soil where the temperature is over 20 °C all year round. If the roadway is filled with water the water temperature will also be about 20 °C because of heat exchange with the surrounding rock.

Pumping water from the tunnel to heat pumps on the surface provides low cost heating or air-conditioning that will serve the residential or business area on the reclaimed coal mine land. The layout of the thermostat plan is shown in Fig. 1.

In normal situations the mining tunnel has a slope. When water filled, a warmer and a colder side will exist in the tunnel because of density differences. In winter the water is pumped from the warmer side at a temperature of 18 °C to distributed heat pumps in the reclamation district and used for heating [8]. Compared to central heat pump heating this distributed heat pump heating could be more efficient because at the same insulation level a lower water temperature has a lower heat loss to the surrounding. After passing through the heat pumps the return water temperature is reduced to 8 °C. After being pumped back into the cold side of the tunnel and exchanging heat with the ground the water warms again. In the summer the cycle can be reversed. The temperature of the water pumped from the cold side is around 20 °C and the return water is at 30 °C.

Heat exchange between the water and the rock is a key point in this cycle. Experimental data from ground source heat pumps show that a stable heat flux between underground water and the surrounding soil/rock is around 210 W/m^2 [9–11]. A 1 km coal mine tunnel (3 m in diameter) has an inside surface area of 9424.8 m^2 so the predicted heating rate is 1983.5 kW. Assuming both the COP_{HP} and the COP_R are 4.5 the heating and refrigeration capacity are calculated as:

$$Q_{hp} = \frac{1983.5 \times COP_{HP}}{COP_{HP} - 1} = 2550 \text{ kW/km} \quad (1)$$

$$Q_R = \frac{1983.5 \times COP_R}{COP_R + 1} = 1622.8 \text{ kW/km} \quad (2)$$

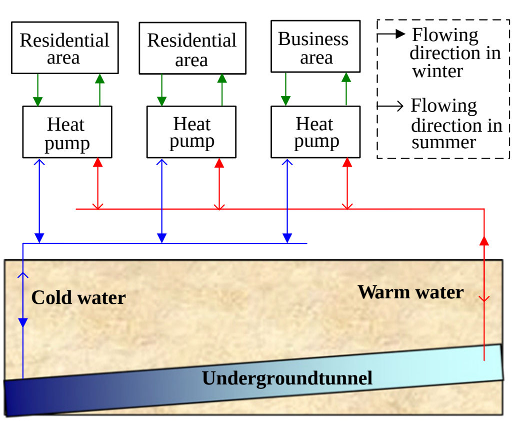

Fig. 1. Thermostat plan for use of an abandoned coal mine tunnel.

where Q_{hp} and Q_R are the available heating or cooling power for 1 km of tunnel.

This calculation shows that a heat pump and 1 km of tunnel can supply an air conditioning load of a 16,228 m^2 building (this assumes an air conditioning demand of 100 W/m^2) or a heating load of 42,503 m^2 (for a heating demand of 60 W/m^2).

Assuming there are 120 heating days with 20 heating hours every day within a district it can be calculated that in one winter the geothermal energy from a 1 km coal mine tunnel can save 4,760,331 kW h of power. It should be pointed out this *saving* is not the net income for one winter because the operation of the heat pump will consume electric power produced from coal. Compared to heating by boiler the net coal saving, G_{save}, of the thermostat plan is calculated by:

$$\begin{aligned} G_{save} &= \frac{Q_{hp} \times h_h \times D_h \times 3600}{q_{sc} \times 1000 \times \eta_b} - \frac{Q_{hp}/COP_{HP} \times h_h \times D_h \times 3600 \times \lambda}{1000000} \\ &= \frac{2550 \times 20 \times 120 \times 3600}{29271 \times 1000 \times 0.9} - \frac{567 \times 20 \times 120 \times 3600 \times 342}{1000000} \\ &= 362 \text{ ton/km} \end{aligned} \quad (3)$$

where h_h is the heating hours everyday (20 h/day); D_h the heating days in a winter (120 days/winter); q_{sc} the low calorific value of standard coal (29,271 kJ/kg); η_b the thermal efficiency of central boiler (90%); λ the average standard coal consumption rate (342 g/(kW h), 2009 in China).

These calculations show that the savings per kilometer of tunnel in the winter is 362 tons of standard coal. This equals an emission reduction of 940 tons of CO_2.

In summer, the *COP* of a water source refrigerator is much higher than that of an air source refrigerator. The energy saving will be roughly 20–30%.

The length of the roadway might be several hundred kilometers in a coal mine. If all this is reused as a thermostat then there will be an amazing amount of energy savings.

In addition, there is still the possibility to save more coal with the thermostat plan. Eq. (3) shows the consumed electric power has a negative effect on coal saving and emission reduction. If this part was to be replaced by a renewable energy such as wind or photovoltaic power a heating/air-conditioning system with zero coal consumption and zero emissions would be provided.

2.2. Thermal accumulator plan

The thermal accumulator plan is an upgrade to the thermostat plan. The consumption of electric power in the thermostat plan is needed since the water temperature from the ground is neither high enough for heating nor low enough for air-conditioning. This problem can be solved by the thermal accumulator plan.

The underground tunnel network of a coal mine is not only a thermostat but also a good thermal accumulator for seasonal heat storage [12]. If heat in the summer can be stored for later use in winter heating, or cold in the winter stored for later summer air conditioning, then a large amount of fossil energy can be saved and the emissions of CO_2, NO_x, and SO_2 will be decreased greatly.

The scheme of the thermal accumulator plan is shown in Fig. 2. This plan employs two kinds of tunnel: a hot tunnel and a cold tunnel.

In summer water is heated by the solar collectors on the surface to a temperature of 90 °C and then sent underground to the hot tunnel for seasonal heat storage. Water from the cold tunnel is pumped to the surface for use in air conditioning. A low cost flat plate collector or solar pool can be employed for solar energy collecting since the solar radiation intensity is relatively high in summer.