Extracting Energy from Flooded Coal Mines for Heating and Air-Conditioning of Buildings: Opportunities and Challenges

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Extracting Energy From Flooded Coal Mines for Heating and Air Conditioning of Buildings: Opportunities And Challenges

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ABSTRACT: Extraction energy from flooded coal mines for heating and/or air-conditioning applications could provide a low-carbon and sustainable technology for the future. In heating applications, the implementation normally utilises heat-pump technologies to upgrade the temperature of water from a nominal value of normally about 12 to 20 ^{o}C to a level above 45 ^{o}C. For cooling applications, the water could be used directly or via a heating pump for the cooling process, depending on the temperature of the water. This paper outlines two case studies implemented in the UK at Caphouse Colliery and Markham Colliery. The paper highlights the opportunities and challenges of the technology; it compares between the two systems in terms of configuration, water quality and the need for maintenance. The paper also outlines the commercialisation aspect of the technology and the potential challenges and opportunities captured via a technical workshop and an on-line survey. The paper also discusses the geohazard prospective of coal mines when used for extracting the thermal energy. The results show that extracting energy from flooded coal mines is unlikely to create any significant geohazard risk, but has the benefits to develop and regenerate the former coal mining areas. The technology can be used to provide low-carbon, sustainable energy to homes and businesses in the UK towards zero-carbon future. However, more effort is needed to enhance public awareness and encourage future investments to allow the technology to be utilised in new and existing residential and commercial buildings.

Keywords: Coal mines; Geothermal; District Heating; Sustainability; Heat Pumps.

1. INTRODUCTION

Coal mining in the UK, and in many areas around the world, was one of the main drives for the industrial revolution and for running steam engines and heating applications. However many coal mines have since been closed in the UK and Europe. When coal mines are closed, they often continue to produce methane, usually referred to as Abandoned Mine Methane (AMM), which can be utilised to generate energy for heating or powering gas engines. Also with some quality enhancement, can be fed into the gas grid. In most cases in the UK, however, coal mines will gradually begin to fill with water and the methane will almost entirely disappear. The UK's historic coal mines have a void space of millions of cubic metres. When flooded, the water at this constant temperature could fill approximately 400 thousand Olympic swimming pools, creating another opportunity for energy utilisation which could be used for efficient heating and cooling applications and hence reducing the overall carbon emission. Figure 1 presents a tradition coal mine seam.

Several research papers have been published in relation to extracting energy from flooded coal mines in the UK and Europe. For example Al-Habaibeh et al. (2018), report on the performance of a UK-based system over the winter season and evaluate its long term benefits. The results show that the system reduces carbon emission and offers an opportunity to regenerate the former coal mining areas. Athresh et al. (2017) have reported on the integration of the coal mines with gas engines technology to reduce further the carbon emission. Banks et al. (2017) have highlighted a several configurations of heat extraction from abandoned and flooded coal mines. They also highlight the water quality issues and the response of a closed loop system. A special issue of International Journal of Coal Geology (Younger, 2016), has highlighted a wide range of applications of the technology. Among the applications, the hydro chemical characteristics of a mine water geothermal energy resource in North West of Spain at Baredo coal mine in Asturias (Loredo et al., 2017). Figure 2 presents a schematic diagram showing the concept of extracting water for heating or cooling applications, where the water is returned to the same mine shaft. This concept may be applicable to smaller schemes and results in greatly reduced capital costs.

Figure 1: A typical example of tradition coal mine seam, which over time will fill with water.

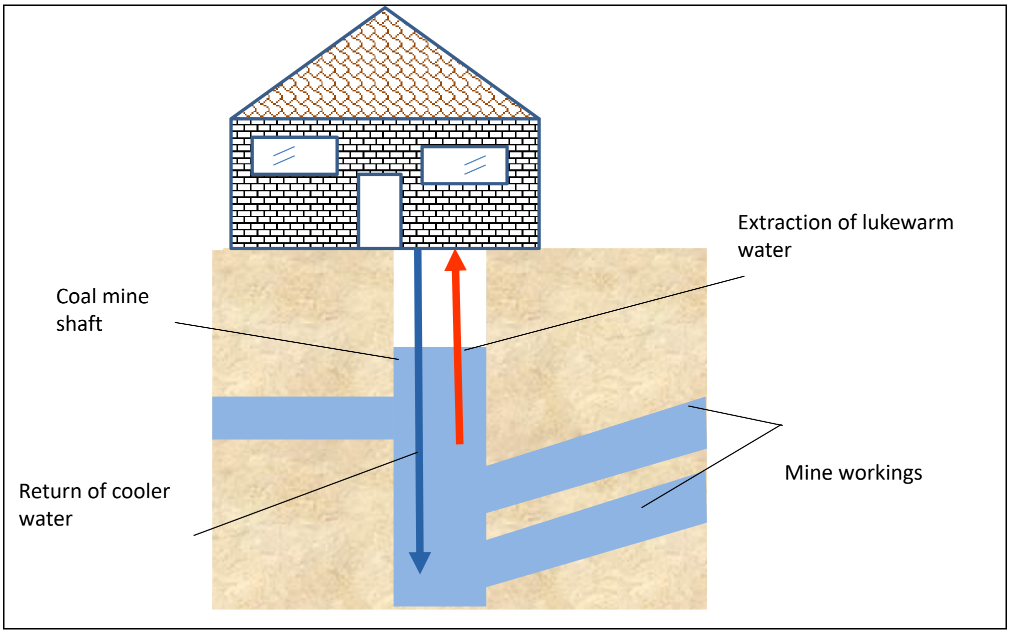

Figure 2: A schematic diagram showing the concept of extracting of water for heating or cooling applications; in this figure, the water is returned to the same mine shaft.

2. ENERGY FROM FLOODED COAL MINES – CASE STUDIES

In the UK, there are several locations that operate with this technology. At the Markham and Caphouse sites, see Figure 3, monitoring systems have been implemented to evaluate the Coefficient of Performance (COP) of the heat pumps and the complete systems. Markham site, see Figure 4-a, near Bolsover (on the M1 junction 29A), provides heating from coal mine water to two buildings. Caphouse site near Wakefield, see Figure 4-b, which is at The National Coal Mining Museum of England is utilised to heat a building as part of testing process using the water which is already being pumped to keep the museum's galleries dry for visitors. The two sites, however, have different water quality, see Figure 5. The Iron (Fe-total) concentration is found to be circa 16.5 mg/L for Caphouse and 0.72 mg/L for Markham. Figure 5-a presents a comparison between tap water and mine water from Markham. While Figure 5-b presents the water quality when pumped out of Caphouse. The pumped water from Caphouse is partially oxidised in the pumping shaft. The pumped water is ochre rich and is treated passively using several settling lagoons and reed beds to remove the ochre to acceptable levels to allow discharge into a nearby watercourse, see Figures 3-5.

Figure 3: The two locations reported in the paper, Caphouse at the National Coal mining Museum of England and Marhkam Vale (*Caphouse image is from Google Earth*).

The basic configurations of the two systems are shown in Figure 6. For Markham, see Figure 6-a, the water is pumped via a heat exchanger before returning to the same mine shaft at different water level. Then a heat pump loop consumes electricity to upgrade the water temperature to a higher level. The third loop is the building heating system where hot water is pumped via a buffer tank (thermal storage). At Caphouse, Figure 6-b, a small proportion of the pumped water is diverted via the heat exchanger and returned to the treatment lagoon. The rest of the process is similar to Markham site. The key difference between the two systems is that in Markham the water is returned to the coal mine and limited oxidation process occurs. In Caphouse, the water is pumped to keep the galleries of the museum dry for visitors. The extracted water is treated in different lagoons to allow the iron to settle for removal.

(a) (b)

Figure 4: photos of the system in Markham (a) and Caphouse (b).

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Figure 5: The difference in water quality, Markham (a) and Caphouse (b).

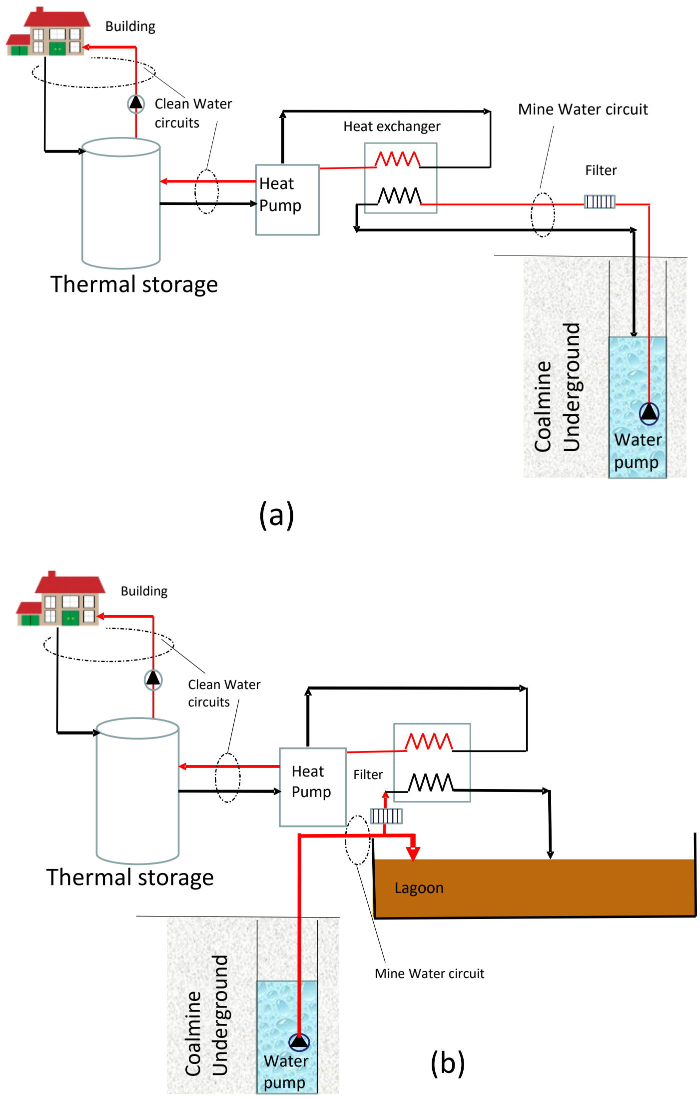

Figure 6: The basic configuration of both systems in the UK, Markham (a) and Caphouse (b).

The difference in filters and heat exchangers conditions are shown in Figure 7. In Markham the mine water quality has low and dissolved iron content. The filters, pipelines and heat

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exchangers were examined for any ochre deposition and very little deposition was found, see Figure 7-a. However, at Caphouse, the water quality is poorer and this can be seen from the ochre accretion on the filter, Figure 7-b after a limited operational time. Figure 8 presents an infrared image of the water leaving the coal mine (top pipe) and the returning water.

(a) (b)

Figure 7: Filters and system quality after a considerable running period of more than one year in Markham system (a); and after short time of operation of the Caphouse system (b).

(a) (b)

Figure 8: Heat patterns in Markham (the arrows show the direction of water flow from and to the coal mine); the visual image (a) and the corresponding infrared image (b).

3. COMMERCIALISATION AND CHALLENGES

A Workshop for pathway to commercialisation of challenges and opportunities of using water from flooded coal mines for Heating and Cooling applications was organised at Nottingham Trent University, chaired by Prof. Amin Al-Habaibeh. The workshop has included participants from a wide range of sectors including Nottingham City Council, Alkane Energy Ltd, The Coal Authority, Clean Rivers Trust, Gannet Ltd, UK Community Works CIC (Community Works) and energy researchers, see Figure 9.

Figure 9: Panel discussion and the way forward for commercialisation at Nottingham Trent University, UK.

From the discussion it has been found that energy from flooded coal mines is an opportunity to develop a better peak demand efficiency. The technology also is efficient when compared with standard air heat pumps, due to lack of fluctuation in temperature and the integration of heating and cooling processes. There is an opportunity in many European countries, including the UK, because the water is pumped in many cases for environmental and practical reasons, hence the underground risk elements have already been overcome. The technology is suitable for low temperature district heating. In the UK the Coal Authority operates over 70 mine water treatment schemes across the UK and treats around 100 billion litres of mine water per annum to protect the environment. The Authority is leading on some initiatives to expand the use of the technology. Data centres and the need for cooling makes the water from flooded coal mines a very suitable technology for use in cooling. The technology also allows for improved and localised energy control and reduces strain on national infrastructure. The technology is potentially capable of being integrated with a variety of heat sources and with stratified hot water storage. The concept is simple, being based on a combination of established technologies and offers long-term benefits in providing a resilience infrastructure. The technology is modular and adaptable to a wide range of applications. It is characterised by low noise and compact infrastructure. Water contamination with metals and chemicals is a very crucial issue in the mine technology. The ambition is to expand the deployment of this technology to provide heat to residential, commercial and industrial users. Many mine water projects in Europe are being operated that aim to demonstrate how the geothermal energy stored by mine water can be used as a safe and ecological way to heat buildings.

Nevertheless, securing investment is one of the main challenges to support the infrastructure of the technology. It is still not a well-known or understood technology for many consumers (see the following section); and more effort is needed in this part. There are cultural issues as far as the technology is concerned, particularly with the dependence on gas boilers in most buildings for heating, particularly in the UK. However, the ban on new gas boilers from 2025 should change the dynamics of the market. There is a lack of clear model to follow on all stages and on the long term; this is due to the variation in infrastructure and running costs and the breakeven models. Community acceptance of a new and relatively untried technology may be a barrier to deployment. Lack of assurance regarding the stability of government policies in the EU or a clear subsidiary of the system in most EU countries. Operating cost, particularly maintenance, could be high in some situations. The technology is only possible for areas underlain by flooded coal workings. Fortunately this includes 25% of the UK populated areas although deployment is still very much dependent on site specific circumstances where water depth is not too great. Cost of pumping is dependent on the depth of water, which is one of the significant variables in the system. Selling the product is complex, because it is most effectively done via local district heating systems. Many planning hurdles exist and simplicity is still needed. Effective use of 'Heat networks delivery funding' in the UK or similar schemes in EU countries is required. HNDU (Heat Network Delivery Unit) has been established as part of BEIS (UK Department for Business, Energy & Industrial Strategy) to provide support for those looking to develop district heating schemes. There is also a need to improve public awareness to increase the demand for the technology.

During the technical workshop discussion, it has been agreed that the pathway to commercialisation could be considered for long term and short term aspects.

3.1 Short term: the technology could be feasible commercially for the short term if some conditions are available:

- Infrastructure borehole is available; as this will reduce the cost of drilling which could be significant investment. Also the availability of the borehole remove the uncertainty of water characteristics such as volume and temperature.
- Water already pumped (for other reasons); this reduces the cost of electricity and at the same time the cost of water treatment ; hence shorter payback period on investment.
- Government organisations can absorb or support the cost of infrastructure; this would encourage the investment from the private sector.
- One main user of energy (e.g. hospital, university, shopping mole), where discussion and decisions can be simplified. This will help in terms of modelling the system, the legal agreements and long term stability of energy demand.
- Water level is high (low energy for water pumping). This will increase the COP of the system and hence the return on investment.

The above conditions will allow shorter payback period and enhance the commercialisation process.

3.2 Long Term: On the long term, the following measures should be taken:

- Integrate the technology with education and public media. This is to enhance the understanding of the technology and appreciate its advantages.
- More public engagement programmes are needed. If there is a demand from the public or enthusiasm about the technology, this will increase the interest from the commercial sector and investors.
- Educate energy installers companies and provide training courses on how the technology works and its costing process.
- Some legal issues should be resolved regarding the technology, particularly in relation to district heating contractual arrangements including the ability to switch energy suppliers and ensuring competitive pricing of energy.

4. AWARNSS OF THE TECHNOLOGY

An short online survey was carried out. The survey had 4 different questionnaires targeting 4 different types of audience (energy companies, local councils, consumers and students/academics). In total 28 companies responded, 16 local councils, 85 students/academics and 40 from the general public. The objectives is to see if further and wider improvement of the awareness of the technology is needed to enhance the pathway to commercialisation on the long term. The results, see Figure 10, show that 14% of companies did not hear about the technology and 25% of local councils. The general public and students/academics are 88% and 81% aware of the concept respectively. This results indicate that more effort is needed to make people aware of the concept of using coal mine water for district heating.

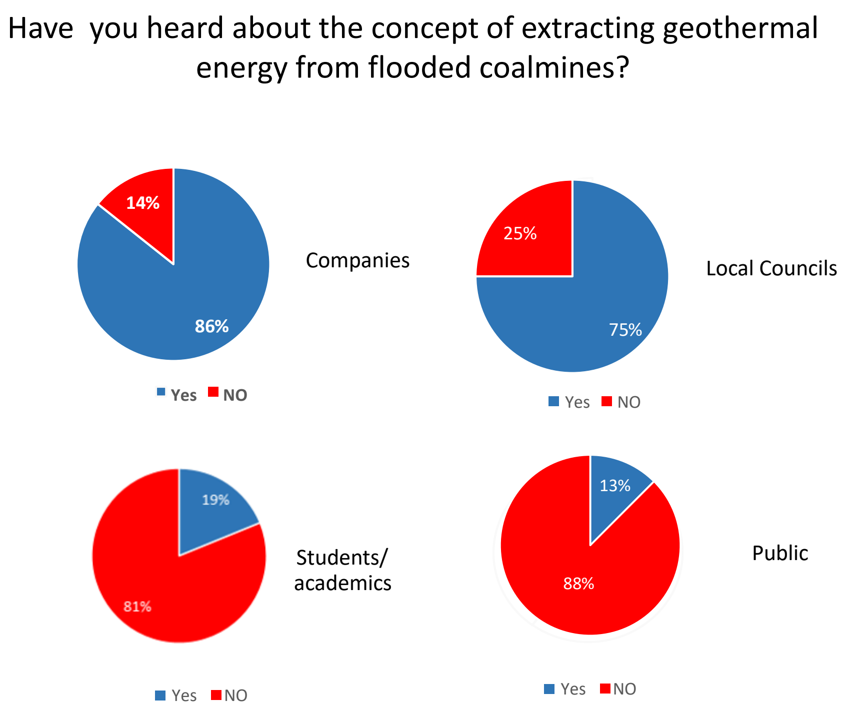

Figure 10: Familiarity of the concept of extracting geothermal energy from flooded coal mines.

When the people who are aware of the concept are asked about the technology involved, companies had 100% knowledge and local councils had 92% technical knowledge. For the general public and students/academics the their knowledge of the technology was 60% and 50% respectively.

From the survey (see Figures 10 and 11) it is clear that the majority of the energy-related companies are aware of the possibility of using mine water as an energy resource. Majority of the local councils who influence the general decision making were also aware of the technology of using mine water as an energy resource. However, the survey showed that the general public which includes customers and general researchers/students were not aware of the technology of using mine water as a thermal energy resource. This is a cause for potential concern, as without the awareness about the technology, it would be difficult for companies to convince their customers to go for this technology without a clear long term strategy. The results show that efforts are needed to educate students/academics and the public about the technology to enhance the commercialisation on the long term. However, the results show that most of local councils and energy companies are aware of the technology.

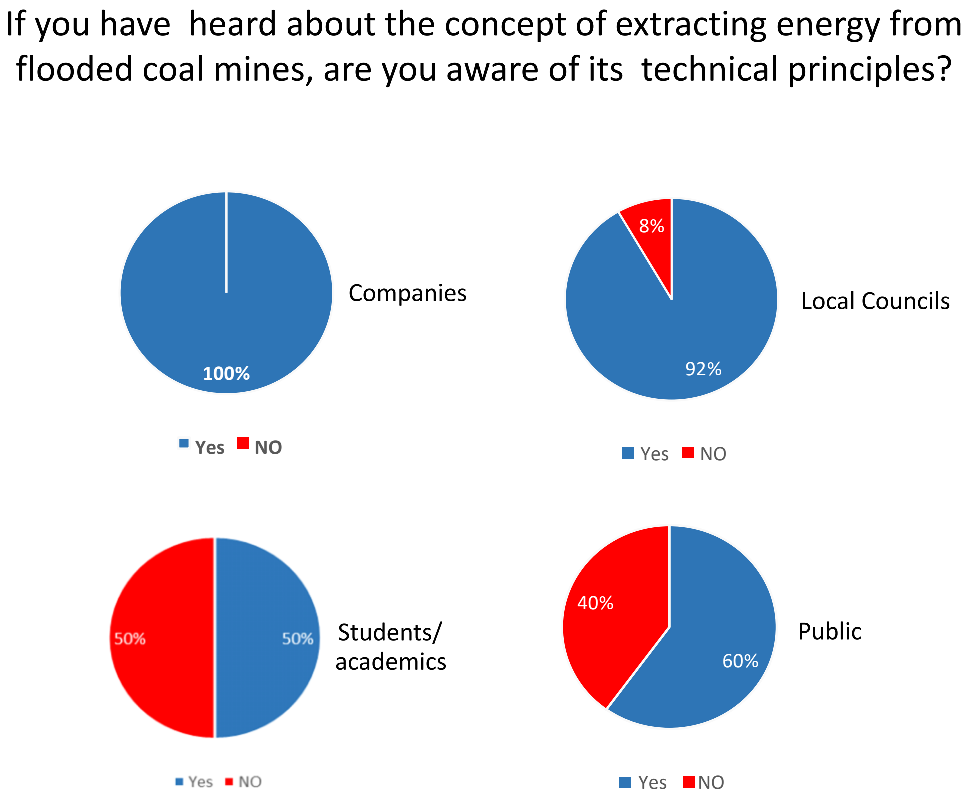

Figure 11: Awareness of the technology among the respondents who have heard about the concept of extracting energy from flooded coal mines.

5. GROUND MOVEMENT HAZARD ASSOCIATED WITH FLOODED MINES

The geohazard risk of the technology is expected to be very limited in comparison to the original existance of the coal mines themselves. Large-scale monitoring of surface deformation has shown some changing patterns of ground motion over time (Banton et al., 2013) in relation to geological conditions and mining history. Subsidence events in most cases take place at the time of active mining but can also occur a long period of time after mining has ceased (Vervoort and Declercq, 2017). However, in some cases, regional patterns of uplift following coal colliery closure have been observed over several regions in the UK (Culshaw et al., 2006) and Europe (Caro Cuenc et al., 2013) particularly in flooded coal mines where water pumping has been stopped (Devleeschouwer at al., 2008). The uplift has been attributed to several factors including submerging the previously dry mined area. Submerging of the mined area can reduce the effective vertical pressure and cause decompression of the rock mass but the main factor for inducing uplift is believed to be the swelling of clay minerals of argillaceous rocks as the water finds its way through open roadways, permeable faults, and volumes of loose blocks (Herrero et al., 2012). Clay minerals are prone to large volume changes (swelling and shrinking) that are directly related to changes in water content.

6. CONCLUSION

This paper has presented two systems implemented in the UK to extract energy from flooded coal mines. The constant feed water temperature could provide a stable source of energy for heating and cooling applications directly or via heat pumps. The geohazard of the technology is considered negligible in comparison to the original mining operations. The commercial success of the technology depends on many factors such as the location, quality of water, depth of water, existing pumping schemes and the availability of consumers. It is expected that the technology will be adopted in many areas in the UK and Europe in the coming years since it provides a sustainable and low-carbon energy opportunity. However, more public awareness is needed about the technology and its benefits. Also, further integration of the technology in teaching and learning processes in further and higher education is critical. However funding sources compatible with risk appetite for a new technology will be key for success. The general move towards district heating in the UK, as well as the ban of gas and oil boilers in new homes from 2025 are expected to create positive drivers for the technology roll out.

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