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NUMERICAL STUDY OF MINE WATER HEAT RECOVERY SYSTEM USING COUPLED HEAT EXCHANGER UNITS

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ABSTRACT

This paper conducts a numerical study to investigate the Mine Water Heat Recovery (MWHR) system using a code developed in MATLAB. The system comprises two heat exchanger units, one located in mine water discharge region (Heat capturing unit) and another in mine intake air region (Heat delivery unit). Former captures heat energy from hot water at mine water outlet using a glycol closed-loop circuit and latter exchanges this captured heat with mine intake cold air. Thermal coupling between these two mentioned units is taken into account in the code. A typical underground mine in Canada is investigated as a case study to evaluate the feasibility of the system. In addition, to have a wider overview, a parametric study is conducted to investigate the impact of various parameters including mine intake air heating demand and mine intake air flow rate on energy savings.

Keywords: mine water heat recovery system, underground mining, energy recovery, mine ventilation system

1. INTRODUCTION

Heating costs associated with underground ventilation air are a significant portion of mine operating costs especially in colder countries such as Canada, Sweden and Finland [1,2]. In order to prevent the intake air shaft from freezing, mine intake air needs to be heated up to a minimum temperature of 3°C [3]. Fossil fuels such as natural gas, propane and diesel are the conventional energy sources being used to heat up the intake air [4]. As heating costs are elevating, the number of mines taking advantage of alternative heat sources for heat recovery purposes, such as mine exhaust air, mine water and compressor cooler are increasing. The heat recovery systems were utilized for decades by various underground mines, some of them were profitable while some could not meet the expectations. Depending upon the source of heat available at the mine site, ambient air condition, intake air flow rate and several other parameters, a heat recovery system could be feasible or infeasible to incorporate in mine heating system. Consequently, a detailed feasibility investigation is required before installation of any heat recovery system in an underground mine.

One of the successful examples of waste heat recovery system implementation is Williams mine, located in Northwestern Ontario, Canada, uses a combined heat recovery system of mine exhaust air, mine water discharge and compressor cooling circuits. The financial analysis of the installed system is carried out by Smith and Arthur [5] showing that $0.5 M CAD (Canadian Dollars) can be saved annually using installed heat recovery system with capital cost of $1.7 M CAD. The Macassa mine [6] is another Canadian mine located in Ontario which uses combined heat recovery system of mine water and air compressor cooler. The Pyhäsalmi zinc-copper mine [7] located in Finland is another example which uses mine water heat recovery system in order to heat up the intake air in cold season. The air flow rate at the intake shaft is $150\left(\frac{m^3}{s}\right)$.

Despite the promising applicability of MWHR system, no numerical study is reported yet in literature review. Accordingly, this paper aims to conduct a study on sustainable energy recovery from mine water discharge using coupled heat exchanger units. To investigate the feasibility of the project, paper offers a dynamic model developed in MATLAB with considering the thermal coupling effect between two heat exchanger units, namely, heat capturing unit and heat delivery unit.

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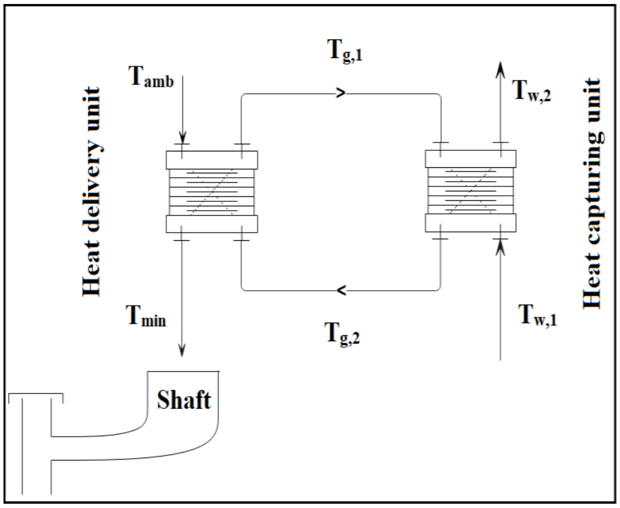


Fig 1. Design schematic

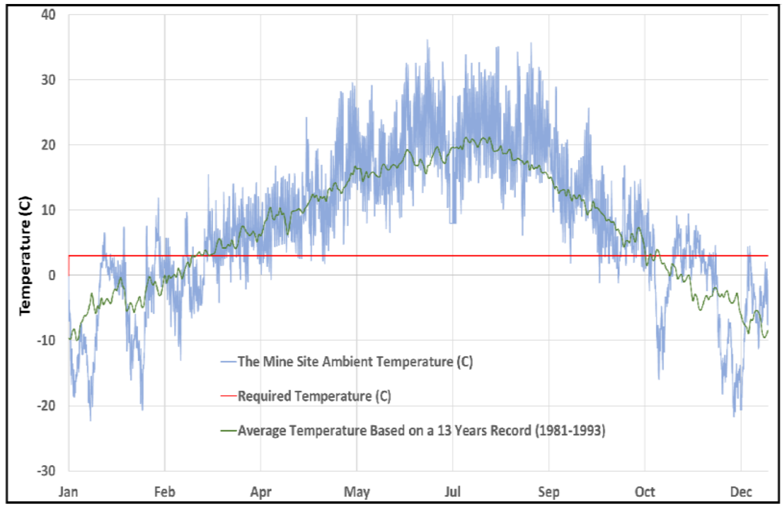


Fig 2. Ambient air temperature at the mine site

2. METHODOLOGY

Figure 1 shows the schematic of a Mine Water Heat Recovery system. This proposed system includes closed-loop glycol circuit, heat capturing unit and heat delivery unit. The closed-loop glycol circuit captures heat energy from mine water discharge and delivers it to the intake air at intake shaft region.

The captured heat from mine water can be calculated as follows:

$$\dot{q}_{cap} = \varepsilon_{l-l} C_{min,1}\left(T_{w,1} - T_{g,1}\right) \tag{1}$$

, where ε_{l-l} is the effectiveness of heat capturing unit, which is a liquid-liquid heat exchanger and $C_{min}\left(\frac{kW}{°C}\right)$ is the smaller heat capacity rate between glycol and water.

The down-stream conditions for the heat capturing units (i.e. $T_{w,2}$ and $T_{g,2}$) can be calculated using the captured heat ($\dot{q}_{cap}$):

$$T_{g,2} = T_{g,1} + \frac{\dot{q}_{cap}}{C_g} \tag{2}$$

$$T_{w,2} = T_{w,1} - \frac{\dot{q}_{cap}}{C_w} \tag{3}$$

Using the down-stream conditions, heat capturing unit's wall temperature can be calculated as follows [8]:

$$T_{wall} = \frac{T_{g,m} + \left(\frac{R_g}{R_w}\right) T_{w,m}}{1 + \left(\frac{R_g}{R_w}\right)} \tag{4}$$

, where $R_g\left(\frac{°C}{W}\right)$ and $R_w\left(\frac{°C}{W}\right)$ are the glycol and water side thermal resistances respectively and can be calculated using the heat exchanger surface area (A) and heat transfer coefficient (h) as follows:

$$R_g = \left(\frac{1}{(hA)_g}\right) \tag{5}$$

$$R_w = \left(\frac{1}{(hA)_w}\right) \tag{6}$$

Also, $T_{g,m}$ and $T_{w,m}$ in equation 4, are the glycol and water side average temperatures, which for simplification purpose, are assumed to be the arithmetic average of upstream and downstream temperature values.

$$T_{g,m} = \frac{T_{g,1} + T_{g,2}}{2} \tag{7}$$

$$T_{w,m} = \frac{T_{w,1} + T_{w,2}}{2} \tag{8}$$

In the heat delivery unit, the required heat in order to heat up the intake air to the minimum required temperature ($T_{min} = 3°C$) can be calculated as follows:

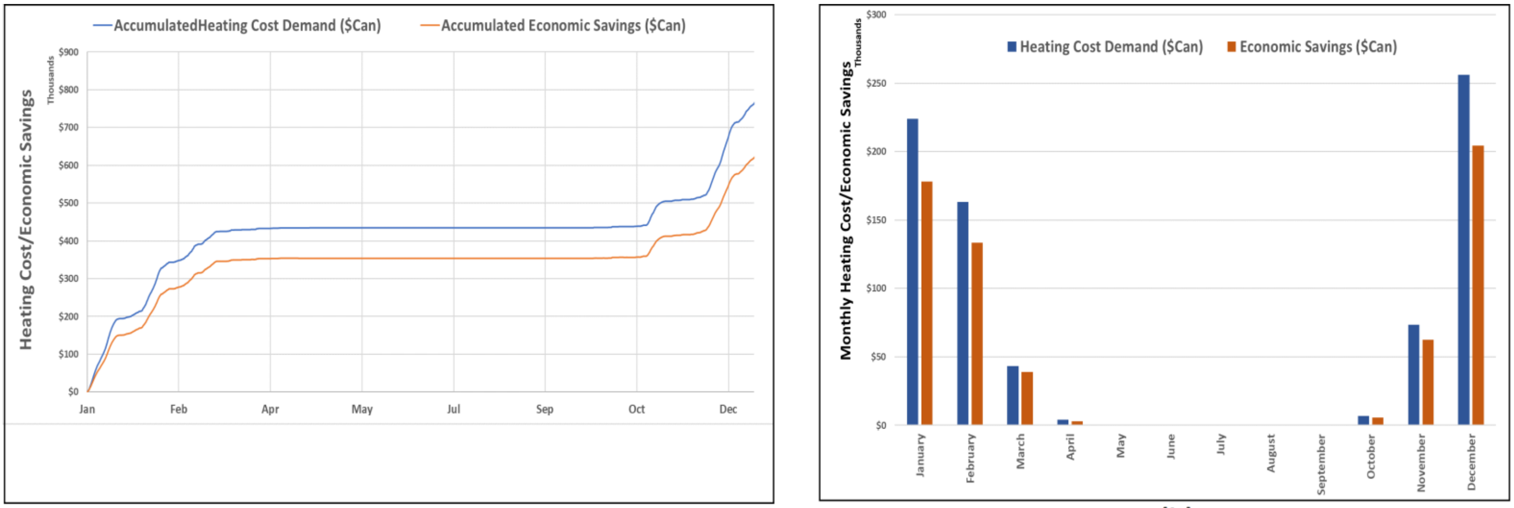
$$\dot{q}_{req} = C_{air}\left(T_{min} - T_{amb}\right) \tag{9}$$

Also, the available heat which closed-loop glycol circuit is providing can be written as follow:

$$\dot{q}_{ava} = \varepsilon_{l-g} C_{min,2}\left(T_{g,2} - T_{amb}\right) \tag{10}$$

The MATLAB code is developed based on two coupled iteration process. The down-stream conditions of the heat capturing unit are calculated by first iteration using the initial guess for glycol temperature ($T_{g,1}$) as 1°C. Then the results of the first iteration are fused as an input to the second iteration in the heat delivery unit and vice versa.

For all the cases that ambient temperature is smaller than the minimum required temperature, there are two possibilities. First case is when the available heat is greater than the required heat. In this case, the heat recovery system can cover all the required heat at intake



(a) **(b)**

Fig 3. Heating cost /Economic savings (a). Accumulated; (b). Monthly basis

shaft; and as a result, the delivered heat ($\dot{q}_{del}$) is equal to the required heat.

$$If\ T_{amb} < T_{min} \&\ \dot{q}_{ava} \geq \dot{q}_{req} \xrightarrow{1} \dot{q}_{del} = \dot{q}_{req} \quad (11)$$

The second case is, when the available heat is smaller than the required heat. In this case, heat recovery system can cover a portion of the required heat at intake shaft and the rest needs to be provided by other energy source.

$$If\ T_{amb} < T_{min} \&\ \dot{q}_{ava} < \dot{q}_{req} \xrightarrow{2} \dot{q}_{del} = \dot{q}_{ava} \quad (12)$$

The glycol down-stream temperature for heat delivery unit ($T_{g,1}$) can be calculated using the delivered heat as follows:

$$T_{g,1} = T_{g,2} - \frac{\dot{q}_{del}}{C_g} \quad (13)$$

In order to prevent the glycol stream from freezing at heat delivery unit in cold days, a bypass valve has been included in the system to keep the minimum glycol down-stream temperature ($T_{g,1}$) at 1℃, meaning that whenever the glycol temperature goes below 1℃, the bypass valve operates to mix the hot and cold glycol to maintain the minimum temperature of 1℃.

The pressure drop due to the installation of heat delivery unit at the intake shaft has been taken into the account. This pressure drop adds up to the operating cost of the mine. The pressure drops and corresponding power can be calculated as follows:

$$\Delta P_i = Res_i {Q^2}_{air,i} \quad (14)$$

$$Pow_{fan} = Q_{air,i} \Delta P_i \quad (15)$$

Assuming the motor efficiency and fan efficiency to be η_{mot} and η_{fan}, respectively, the actual power induced by heat delivery unit installed at the intake shaft area can be calculated as follows:

$$Pow_{act} = \frac{Pow_{fan}}{\eta_{mot} . \eta_{fan}} \quad (16)$$

2.1 Economic Analysis

Intake air heating cost ($Cost_{heating}$) and the total economic savings by the mine water heat recovery system by taking into account the induced fan power cost ($Cost_{sav}$) can be calculated using the price of fossil fuel at the mine site location (Pr_f), the system operation time (t_{op}) and the burner's efficiency (η_b) as:

$$Cost_{heating} = (\dot{q}_{req} . t_{op} . Pri_{fuel}) / \eta_b \quad (17)$$

$$Cost_{sav} = \frac{(\dot{q}_{req} . t_{op} . Pr_f)}{\eta_b} - Pow_{act} . t_{op} . Pr_{el} \quad (18)$$

Table1. Operating parameters used in MATLAB code

Parameters	**Value**	**Unit**
Air flow rate ($Q_{air,i}$)	438.9	$m^3.s^{-1}$
Price of Fuel (Pr_f)	13	$\$/GJ$
Price of Electricity (Pr_{el})	0.080	$\$/kWh$
Fan efficiency (η_{fan})	0.75	-
Electric motor for fan efficiency (η_{mot})	0.95	-
Burner efficiency (η_b)	0.95	-
Heat capturing unit efficiency (ε_{l-g})	0.68	-
Heat delivery unit efficiency (ε_{l-l})	0.75	-
Mine discharge water temperature ($T_{w,1}$)	16	℃
Mine discharge water flow rate	20	Lit/s

3. RESULTS AND DISCUSSION

A feasibility case study of the Mine Water Heat Recovery system is investigated for one of the real-life Canadian mines operation who asked to remain anonymous. Figure 2 shows the ambient air temperature reported by the mine site over a year (the green line), the Canadian Government temperature database [9] averaged over 13 years (the blue line) and the minimum required temperature at the intake shaft (the red line). Note that, the intake air heating system operates from January to April and October to January for the mentioned mine as the ambient temperature is below 3°C. The operating parameters used in the MATLAB code are listed in Table 1.

Economic savings with the mine water heat recovery system is compared to the intake air heating cost in figure 3. Fig. 3(a) shows the accumulated heating cost and savings by MWHR system within an operating year. As the figure shows, installing the MWHR system for the studied mine can save $0.43 M CAD out of $0.53 M CAD of annual air heating cost. In addition, Fig. 3(b) shows the monthly bases comparison of heating cost and savings by MWHR system. As seen in Fig. 3(b), there is no intake air heat demands between May to September; as a result, MWHR system can be shut down and removed during this time period in order to avoid induced fan power costs.

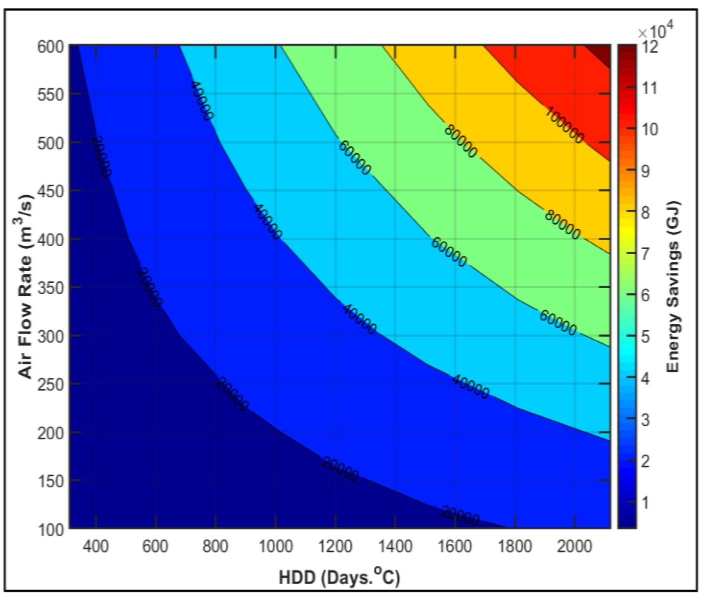


Fig 4 Energy savings contour map for HDD and air flow rate

In order to have a wider overview of the feasibility of MWHR system for different mines, the energy savings (in GJ) by the MWHR system are provided with contour map in figure 4 based on the two main parameters of mine intake air volume flow rate and Heating Degree Days (HDD). As can be seen from figure 4, depends on the intake air heating demands and mine air flow rate at intake shaft, for some cases with lower intake air flow rate and HDD, the energy savings by MWHR system is not significant compare to the size of investment which makes the system infeasible for such cases, and as the two mentioned parameters increase, the more savings can be achieved and MWHR system is more feasible to install in the mine site.

4. CONCLUSION

In this paper, a numerical model is developed using a MATLAB code to investigate the Mine Water Heat Recovery system. The model is applied to a real-life Canadian mine which shows almost 80% savings on heating cost with use of the proposed system. Throughout the study, it is shown that the feasibility of the system is highly dependent of the intake air flow rate and HDD of the mine.

REFERENCE

[1] Amiri L, Ghoreishi-Madiseh SA, Sasmito AP, Hassani FP. Performance evaluation of large scale rock-pit seasonal thermal energy storage for application in underground mine ventilation. Applied Energy 2017;185:174–11.

[2] Chatterjee A, Zhang L, Zhi X. Optimization of mine ventilation fan speeds according to ventilation on demand and time of use tariff. Applied Energy 2015;146:65–8.

[3] Hartman HL, Mustmansky JM, Ramani RV. Mine Ventilation and Air Conditioning, 2nd ed.Wiley, 1997

[4] Ghoreishi-Madiseh SA, Sasmito AP, Hassani FP, Amiri L. "Effect of buoyancy-driven natural convection in a rock-pit mine air preconditioning system acting as a large-scale thermal energy storage mass. Applied Energy 2018;221:268–11.

[5] Smith HL, Arthur DC. Mine ventilation: Waste heat recovery. CIM Bulletin 1996;89:126–5.

[6] Ruiter HD. Energy savings in mine. Mining Magazine 1992:240–5.

[7] Pyhäsalmi. Pioneering underground innovation. International Mining 2010:12–6.

[8] Shah RK, Sekulić DP. Fundamentals of Heat Exchanger Design. 2003.

[9] Canadian weather, climate and hazards, Retrieved March 10, 2019, from https://www.canada.ca/en/services/environment/weather.html.