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TECHNO-ECONOMIC ASSESSMENT OF INTEGRATING THERMAL ENERGY STORAGE WITH DIESEL EXHAUST WASTE HEAT RECOVERY SYSTEM FOR REMOTE MINES IN COLD CLIMATES

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ABSTRACT

Detachment from the national gridline makes the remote mines in the cold climate regions of Canada solely dependent on diesel generators for power generation purposes. Notwithstanding, more than 30% of the consumed diesel by these generators is frittered away as heat through the exhaust. To endure the long harsh winters, these mines also require substantial amounts of heating which is usually provided by burning diesel or propane. In such a scenario, the installation of a diesel exhaust heat recovery system in these remote mines has been considered as a sustainable strategy to preheat the mine intake air. However, this combined heat and power generation strategy cannot provide all the necessary heating due to the daily misbalance between the heating demand and the available heat in the exhaust of the diesel generator. Coupling seasonal thermal energy storage with the waste heat recovery system is a possibility that seeks to resolve such issue. This study investigates the integration of a seasonal thermal energy storage with a diesel exhaust heat recovery system in a remote mine in northern Canada by analyzing several possible alternatives regarding capacity and rates of energy loss. The financial impact of these parameters has been added to show the viability of the proposed strategy.

Keywords: remote mine, diesel exhaust heat recovery, thermal energy storage, green energy, carbon emission reduction

NOMENCLATURE

Abbreviations	
CAPEX	Capital expenditure
DEHR	Diesel exhaust heat recovery
ekW	Electrical kilowatts
HEx	Heat exchanger
MWe	Electric output in megawatts
NWT	Northwest Territories
OPEX	Operational expenditure
PBP	Payback period
STES	Seasonal thermal energy storage
WHRS	Waste heat recovery system
Symbols	
e	Equivalent

1. INTRODUCTION

When a long-term establishment (communities with at least ten dwellings, commercial operation, etc.) is neither connected to the electrical grid nor to a natural gas network through pipelines, it is considered “off-grid” or “remote” in North America [1]. This remote loci makes the diesel generator the most reliable power generation option for these remote mines [2]. However, even the best available technology can only ensure the conversion of about 33% of the energy content stored in the diesel fuel into electricity. The rest is discarded as heat through various streams (e.g., friction radiation, intercooler, aftercooler, radiation, exhaust, etc.) due to the incomplete combustion mainly [3]. Studies show that all the diesel generators working at ideal operating conditions (60%~90% load factor), discard almost the same amount of heat through the exhaust as their electrical output [4].

These remote mines (specifically the underground operations) have an extensive heating demand to withstand the extreme climatic conditions. During

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winter, the ambient temperature can go below -40°C and ambient air needs to be preheated up to set-point temperatures (generally 4~7°C) to prevent freezing in underground equipment and workings [5]. A great amount of fossil fuel (diesel/propane) is being burnt to provide this heating which costs the mine a lot both financially and environmentally [6]. Studies [4] proved the viability of reducing the amount of fossil fuel burning by preheating the mine intake air through the recovered heat from the exhaust of the diesel generators. It has been shown that this diesel exhaust heat recovery (DEHR) system is able to provide about 50-70% of the heating demand of an underground operation for preheating the mine intake air.

However, this DEHR system cannot serve the entire heating demand of the mine due to the mismatch between the daily heating demand (which depends on a fluctuating ambient temperature) and the available heat in the exhaust of the diesel power plant (that depends on the power demand of the mine). This requires the mine to burn fossil fuel to provide the supplementary necessary heat when the energy available in the DEHR system is lower than the instant heating demand. Similarly, the DEHR system discards some of the recovered heat when the demand is lower than the available heat in the exhaust stream of such generators.

Coupling geothermal heat storage with intermittent power generation sources (e.g., concentrated solar plants, wind farms, etc.) has been proved a viable strategy to reduce the power plant cost and mitigate misbalance between demand and supply, as well as helping establish a source of green heat during wintertime [7–9]. A number of studies exist suggesting seasonal thermal energy storage (STES) designs (e.g., borehole, rockpile, etc.) for diesel-based power generation strategies for possible application remote communities [10,11]. However, they do not do an integrated analysis of the whole system for remote mining operations rather focus on small civil communities.

The present study aims at reducing the amount of fossil fuel burnt in underground mining operations for heating purposes to zero by proposing a novel concept of integrated thermal energy storage (TES) with a DEHR system in remotes mines located in the cold climates in Canada and possibly in other arctic environments. To do so, the outcomes of such system were evaluated and the impact of several parameters of the TES system has been

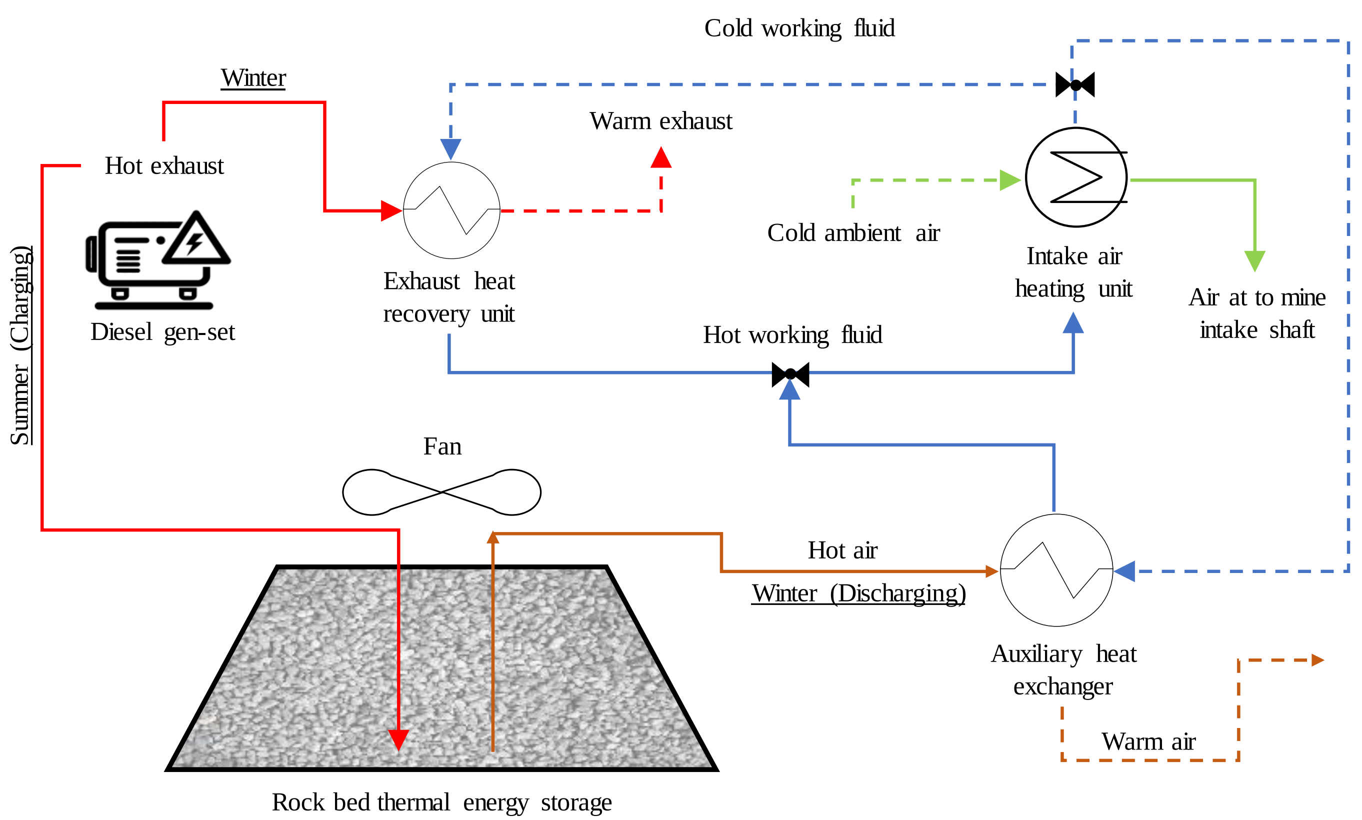

Figure 1. Schematic of the proposed system (Fluid flows have been distinguished by colors; solid and dashed lines are showing

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evaluated, culminating in an evaluation of its techno-economic feasibility.

2. METHODOLOGY

The scope of the paper was set in conceiving a suitable STES system to be integrated with a waste heat recovery system (WHRS) for a remote underground mine operating in the cold climate of Northwest Territories, Canada. The analysis was based on the WHRS system presented in a previous study [4] from this group. In that particular study, an underground mine which has an average annual power demand of 18 MWe and a maximum airflow demand of 708 m^3/s, is found to be able to achieve, through the installation of a DEHR system (heat exchanger effectiveness~61.5%), diesel savings on the order of 10^5GJ, which represents about 55-60% of the total heat demand of such mine for preheating the mine intake air during winter (when heating is needed). However, during summer (when heating is not necessary), the waste heat recoverable by the DEHR system continues to be discarded ignoring its energy potential. This paper intends to comprehend a waste heat thermal energy storage system that would allow the mine to completely meet its intake air heating demands through waste heat from diesel generators only. Using such system, the heat discarded during the summer would supply the necessary supplementary heating needed during winter (currently provided by burning fossil fuel), raising the current 55-60% fraction of the heat provided from waste up to 100%.

A rockpile or rock bed based sensible thermal energy storage has been considered for this scenario because of its practicality and ease of application previously demonstrated for such DEHR systems [11,12] and due to the readiness and availability of waste rock in mining operation sites. Also, since the system needs to be much larger than conventional STES designs commonly employed in industry, a rockpile STES seems to be one of the few options of technology that might be viable in this case due to its low-cost storage media and heat transfer fluid (air/exhaust). Figure 1 shows the schematic of the proposed integrated DEHR-STES system. Three heat exchangers can be seen in the diagram. The first one recovers the heat from the exhaust of the diesel generators during winter and delivers it to the working fluid in the cycle (glycol-water mixture was chosen because of its anti-freezing property) which transports it to the intake air heating unit (second heat exchanger) that will transfer the heat to the cold ambient air seeking to raise the temperature of the intake air of the mine to the set-point temperature (here assumed 4°C). During summer, the exhaust of the diesel generator is intended to directly feed (charge) the rockpile STES storing the previously discarded heat and during winter whenever the DEHR is not able to provide all the heating required, the stored heat from the rockpile will be transferred (discharge) to the working fluid by using a third heat exchanger. Both charging and discharging cycles are performed by the attached fan (push system for charging and pull system for discharging). Bypass valves allow the working fluid to correspondingly flow to the part of the cycle currently active.

Using the thermodynamic model for the system developed in our previous work [4][13], the thermodynamic equations for the DEHR system are solved in a daily basis resulting in values for heat needed, heat saved and heat discarded. Then, based on those results also in a daily basis, the calculations for heat delivery (during summer) and heat recovery (during winter) from the STES system are performed. The heat is fully stored on the rockpile when available and fully recovered when necessary. The losses are modeled and compiled in a seasonal heat loss term, here considered 10% over six months for the base scenario as suggested in [13]. The duration of the charging and the discharging period are functions of heating degree-days (~2034), set-point temperature (4 °C), airflow (708 m^3/s) and the annual power generation (18 MW) of the mine. All the resulting energy values are obtained through well-known thermodynamic relations for heat exchangers according to literature, as well as costs (with corresponding inflation over time) [4,14]. Heat losses are assumed negligible on the pipes as due to the very large amount of energy present [15].

The size of the rockpile has been estimated based on available scholarly articles [11] to store the all the estimated supplementary heat needed by the mine. As insulation of such system plays a vital role in the overall performance and the cost of the system, various insulation schemes and their corresponding seasonal heat losses were considered. The latter assumed in a reasonable range (10%~40%). Following these, different sizes of STES systems have been considered and their associated cost were estimated. The cost (CAPEX and OPEX) of existing the DEHR system and the proposed STES system were taken into consideration. Two types of savings were considered; one consequence of the decrease in fossil fuel burning and the second one from the carbon tax saved accordingly. Based on the cost and savings, the payback period of the proposed DEHR-STES system was added.

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3. RESULTS AND DISCUSSION

A rockpile based STES system was conceived to be integrated with an existing DEHR system for a remote, underground mine to serve the heating demand which cannot be fulfilled by the DEHR system standalone. Table 1 contains some parameters of the proposed system and its designed insulation layer. Heat loss from the rockpile was considered one of the most important parameters for the system from the operational perspective and the initial value assigned for it was 10% over the season (six months). Glass wool was selected as the insulation material due to its economic advantage over other types [16] and concrete was selected as the material for the protective dome against weather conditions. The insulation thickness was considered is around 95 cm.

Table 1 Details of the storage system

Property	Value	Property	Value
Protective dome material	Concrete	Insulation material	Glass wool
Protective dome thickness (cm)	10.0	Insulation thickness (cm)	95
Thermal conductivity of dome (W/m-K)	0.8	Thermal conductivity of insulation (W/m-K)	0.038

The discharge mass flow rate of air is variable and would be controlled by the fan coupled to the system. Limestone was chosen as the storage material due to its availability and based on the thermal characteristics of the rock, the required tonnage was calculated. Because of the substantial amount of the heat required to be stored and supply, the tonnage cost of the system was the most expensive portion of the capital expenditure of the proposed system. 2000 tpd was considered as rock piling rate that would complete the piling work in approximately 6 months. However, if a readily available waste rock pile from the mine operation was employed,

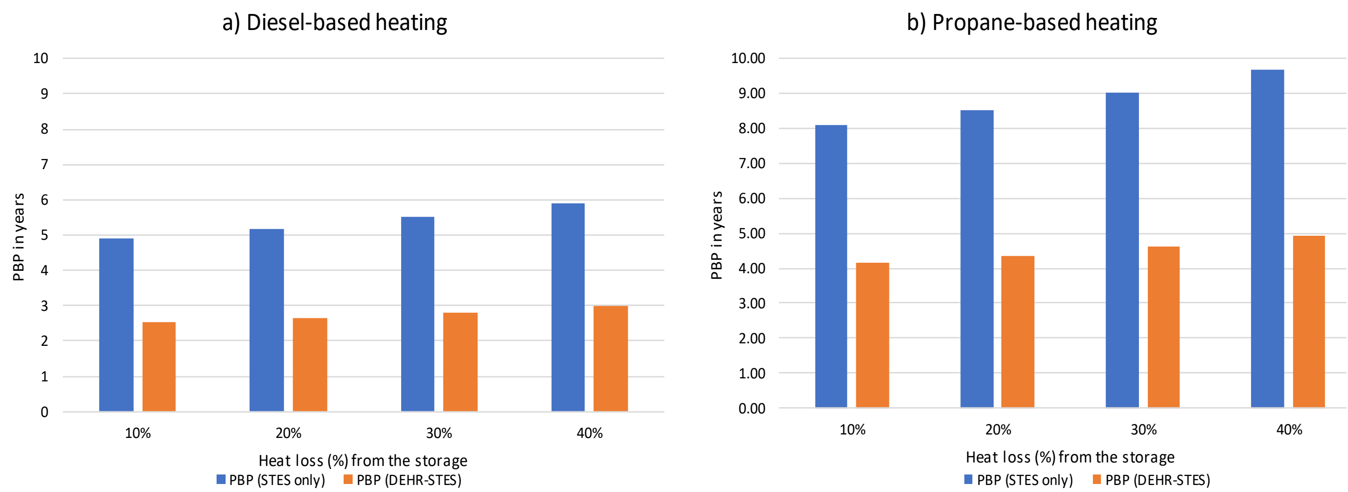


Figure 2 Payback period of the STES sytem and the DEHR-STES system at various heat losses from the storage while replacing diesel (a) and propane (b) based heating sytem in a remote mine

Table 2 Economic evaluation of the system

	Property	Value	Property	Value
Seasonal thermal energy storage (STES)	Rock Piling (tpd)	2000	Total CAPEX (MC$)	18.49
	Supplies and Labor (C$/tonne)	47.03	Total OPEX (MC$)	0.34
	Fan Owning and Installation (with backup) (MC$)	0.37	Diesel Equivalent Savings (MLiter/year)	2.69
	Days Needed for Piling (days)	183.25	Diesel Cost (C$/liter)	1.39
	Total cost of piling (MC$)	18.03	Annual Diesel Savings (MC$)	3.75
	Pile Tonnage (Million tonne)	0.05	eCO2 (Million tonnes/year)	0.01
	Fan Operating Cost (MC$)	0.32	Carbon Tax (C$/tonne)	35.00
	Storage maintenance cost (MC$)	0.02	Carbon Tax Savings (MC$)	0.35
	Dome and insulation cost (MC$)	0.20	Overall Annual Savings	4.10
	Aux. heat exchanger and piping cost (MC$)	0.21	Energy Savings (MWh/year)	65.27
	Simple Payback (years)		4.92	
DEHR	Total CAPEX (MC$)	1.83	Annual Diesel Savings (MC$)	5.93
	Total OPEX (MC$)	1.71	Carbon Tax Savings (MC$)	0.21
	Simple Payback (years)		0.41	
Simple payback for integrated DEHR-STES system (years)			**2.48**	

possibly the substantial cost for piling could be partially levied.

The insulation cost represents about 2% of the total cost of the system. This is a considerably small fraction due to the very large scale of the storage. The cost of the fan with the backup unit was added to the CAPEX and the operating cost (based on the parasitic power) was added to the OPEX of the system.

Like the existing DEHR system, this STES will also bring savings to the mining operations in two major ways. The first type of saving will come from not burning fossil fuel for heating purpose and the second type of saving will be the associated carbon tax. All these costs and savings were gathered in **Error! Reference source not found.** and the payback period for the storage only was found ~4.92 years. However, as this STES will be integrated with the existing DEHR system, it was more viable to consider the payback period for DEHR-STES system altogether. It was found that in 2.53 years this integrated system will start paying back.

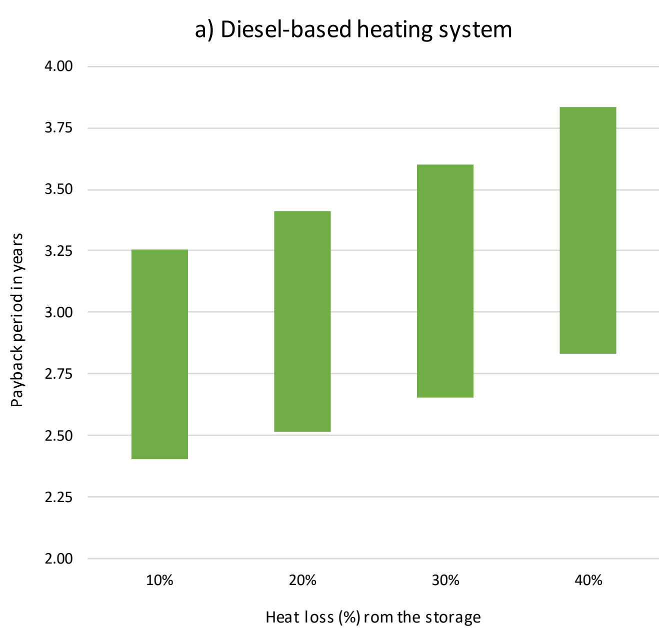
As earlier mentioned, a remote mine generally preheats the mine intake air by burning either propane or diesel. So, the next step was to evaluate the economic feasibility of the system while replacing a propane-based heating system. Figure 2 shows the payback periods for the rockpile thermal energy storage as well as the integrated DEHR-STES while replacing diesel and propane-based heating system. The various percentages of heat losses over the season (10-40%) were also taken into consideration. It was found that in the case of propane-based heating system the payback period stays below 5 years in all cases and for diesel-based heating, it stays below 3 years.

All these results showed the importance of the fossil fuel price on the economical viability of the proposed system. The next step was to evaluate the flexibility of the system in terms of vulnerability of the price of fossil fuel. To do so, the maximum and minimum price of both propane (0.44~1.25 C$/liter) and diesel (0.89~1.41 C$/liter) in Canada for the last 4 years [17] were considered. After that, all the costs shown in **Error! Reference source not found.** were calculated to evaluate the range of payback periods of the system at variable heat losses from the storage.

Figure 2 shows that the payback period for the DEHRS-STES system while replacing a diesel based heating system in a remote Canadian mine can range between 2.40~3.84 years. On the other hand, for propane-based heating the payback period ranges between 2.22~6.27 years. All these results hold the evidence that this proposed system has the potential to be applied in mines to reduce its fossil fuel consumption to zero for heating purpose during long, harsh winters faced in the Arctic. Thus, consequently reducing the carbon emission of the mine substantially.

4. CONCLUSION

This present study proposed a novel concept to reduce the fossil fuel dependence of remote mining operations to zero for heating purpose by an integrated STES-DEHR system. The integration of the proposed STES system has been studied vividly and it has been shown



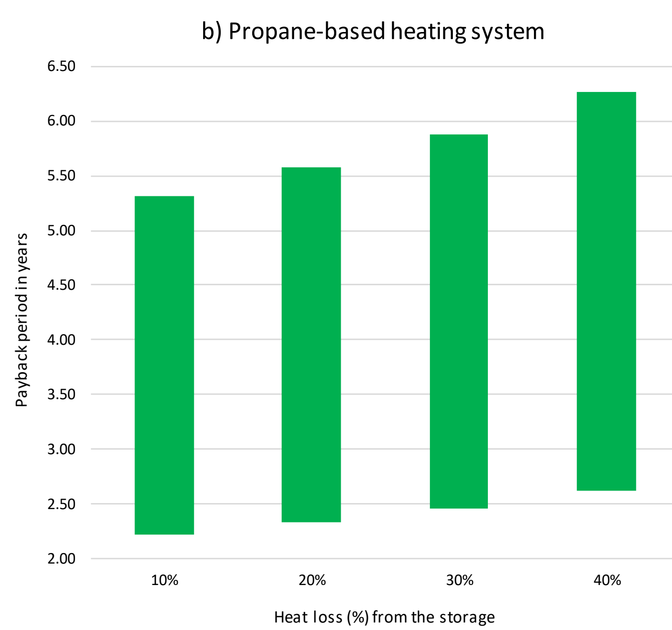


Figure 3 Range of payback periods of the DEHR-STES in a remote mine dependeing on the fossil fuel price

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that it might be a viable, sustainable heating solution for the remote mines located in cold climate regions of Canada and the other Arctic regions of the world. Techno-economic analysis has added justification to the system by providing a reasonable payback period for a mining operation in cold climate regions of Canada. Further studies should focus on developing and investigating the effect of more parameters on the STES system operation, including the effect of different storage materials.

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REFERENCE

[1] Royer J. Status of Remote/Off-Grid Communities in Canada | Natural Resources Canada. Ottawa: 2013.

[2] U.S. Energy Information Agency. International Energy Outlook 2013. Outlook 2013 2013:312. doi:EIA-0484(2013).

[3] Rehman S, El-Amin IM, Ahmad F, Shaahid SM, Al-Shehri AM, Bakhashwain JM, et al. Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant. Renew Sustain Energy Rev 2007;11:635–53. doi:10.1016/j.rser.2005.05.003.

[4] Baidya D, de Brito MAR, Sasmito AP, Scoble M, Ghoreishi-Madiseh SA. Recovering waste heat from diesel generator exhaust; an opportunity for combined heat and power generation in remote Canadian mines. J Clean Prod 2019. doi:10.1016/j.jclepro.2019.03.340.

[5] McPherson MJ. Subsurface Ventilation and Environmental Engineering. Dordrecht: Springer Science & Business Media; 1993. doi:10.1007/978-94-011-1550-6.

[6] Hall AE, Mchaina DM, Hardcastle S. Controlled recirculation in Canadian underground potash mines. Min Sci Technol 1990;10:305–14.

[7] Hasnain SM. Review on sustainable thermal energy storage technologies , Part i : heat storage materials and techniques 1998;39.

[8] Forsberg CW. Gigawatt-year geothermal energy storage coupled to nuclear reactors and large concentrated solar thermal systems 2012.

[9] Dincer I, Dost S, Li X. Performance analyses of sensible heat storage 1997;21:1157–71.

[10] Ghoreishi-Madiseh S, Fahrettin Kuyuk A, Rodrigues de Brito M, Baidya D, Torabigoodarzi Z, Safari A, et al. Application of Borehole Thermal Energy Storage in Waste Heat Recovery from Diesel Generators in Remote Cold Climate Locations. Energies 2019;12:656. doi:10.3390/en12040656.

[11] Ghoreishi-Madiseh SA, Safari A, Amiri L, Baidya D, Brito MAR, Kuyuk AF. Investigation of viability of seasonal waste heat storage in rock piles for remote communities in cold climates. Energy Procedia 2019:6.

[12] Ghoreishi-madiseh SA, Sasmito AP, Hassani FP, Amiri L. Heat transfer analysis of large scale seasonal thermal energy storage for underground mine ventilation. Energy Procedia 2015;75:2093–8. doi:10.1016/j.egypro.2015.07.324.

[13] Amiri L, Rodrigues de Brito MA, Baidya D, Kuyuk AF, Ghoreishi-Madiseh SA, Sasmito AP, et al. Numerical investigation of rock-pile based waste heat storage for remote communities in cold climates. Appl Energy (Forthcoming).

[14] Shah RK, Sekulic DP. Fundamentals of heat exchanger design. John Wiley & Sons; 2003.

[15] Rodrigues de Brito MA, Baidya D, Ghoreishi-Madiseh SA. Investigation of the techno-economic feasibility of recovering waste heat of diesel generator exhaust for heating mine intake air. 17th Noth Am. Mine Vent. Symp., Montreal, QC: 2019.

[16] Villasmil W, Fischer LJ, Worlitschek J. A review and evaluation of thermal insulation materials and methods for thermal energy storage systems. Renew Sustain Energy Rev 2019;103:71–84. doi:10.1016/j.rser.2018.12.040.

[17] Canada NR. Retail Fuel Prices by Province- Energy Sources 2017. http://www2.nrcan.gc.ca/eneene/sources/pripri/price_map_e.cfm#chartList (accessed January 24, 2019).

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