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Evaluation of Heat Transfer Performance between Rock and Air in Seasonal Thermal Energy Storage Unit

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Abstract

Ventilation is one of the most energy demanding parts of deep underground mining operations due to the extensive amounts of energy needed to cool (or heat) the substantial amount of air flow in underground workings. This considerable amount of energy demand can be partially satisfied by extracting renewable energies or using alternative energy solutions available at mine sites. In Canada, some mining operations have the opportunity to create a Seasonal Thermal Energy Storage (STES) unit by blowing mine intake air through large volumes of rock mass dumped in a decommissioned pit. This technique allows for creation of the so-called “Natural Heat Exchanger (NHE)” which moderates seasonal air temperature oscillations. This paper signifies a novel heat transfer model for performance assessment of a NHE system. It investigates the potential for energy savings by implementation of variable number and position of ventilation trenches in underground mines. In this regard, a 3-D heat transfer model is developed to evaluate the thermal storage and the heat transfer between broken rock mass and ventilated air flow and also to specify how design parameters such as position and number of ventilation trenches will affect the heat transfer performance as well as the total energy savings. The results of this study show that NHE can be applied in thermal management of underground mines with the aim of decreasing energy consumption for heating, cooling and ventilation purposes.

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Keywords: Seasonal thermal energy storage (STES); Natural Heat Exchanger (NHE); Mine ventilation; Porous medium; Energy efficiency

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Nomenclature			
Abbreviations:		*Symbols:*	
TES	Thermal Energy Storage	f	fluid phase
STES	Seasonal Thermal Energy Storage	s	solid phase
LTNE	Local Thermal Non-Equilibrium	ρ	density
UDF	user-defined functions	u	fluid velocity
NHE	Natural Heat Exchanger	p	pressure
		ε	porosity
		μ	dynamic viscosity of the fluid
		cp	specific heat
		k	thermal conductivity
		T	temperature

1. Introduction

The industrial sector consumes about 37% of the world's total delivered energy and among them, mining industry contributes about 9% [1]. Within mining activities, ventilation is one of the most energy demanding parts of deep underground mining operations. This energy demand can be partially fulfilled by deploying the renewable energies or using alternative energy solutions available at mine sites. Thermal energy storage (TES) systems are one these solutions which fall will within three main categories including sensible heat storage systems, latent heat storage systems and thermochemical storage systems. The selection of the TES systems mostly depends on the storage period required (i.e. short-term vs. long-term), availability of the medium, operating conditions, purpose of projects, etc. In recent years, TES systems come out to be one of the most attractive thermal applications [2]. Sensible heat storage generally utilizes rock beds or water tanks or aquifers as a storage medium and is available for short-term and long-term storage. In these systems heat/cold energy mostly is stored by increasing/decreasing the storage medium temperature [3, 4]. Some mining operations (e.g. Creighton and Kidd Creek mines in Canada) have the great opportunity to make use of the enormous mass of their fragmented waste rock as an immense seasonal thermal energy storage (STES) unit with the purpose of creating a unique type of heat exchanger; namely "Natural Heat Exchanger". In this type of heat exchanger, fresh air is passed through the huge body of broken rocks dumped in to an open pit. The heat exchange between the waste rocks and the fresh air will lead to considerable decrease in ventilation costs in these mines [4-6]. Very limited studies [2, 4] have focused on the 3D analysis of heat transfer and fluid flow in the rockpit STES. Numerous computer programs have been developed to investigate the flow of compressible and incompressible fluids through strata [7, 8]. Most of these programs are based upon the porous media concept in which it is assumed that any one stratum contains evenly distributed interconnected pores [8-10]. An extensive study of fluid flow and heat transfer in porous media was undertaken by Whitaker [11], Vafai and Tien [12] and Ghoreishi-Madiseh et al. [2, 4, 13]. Limited number of research work, most important of them [5, 9], have been dedicated to the study of heat transfer in large scale thermal energy storage systems for mine ventilation purposes. The empirical approach suggested by Sylvester [9] can be used to estimate the heat storage capacity of Creighton mine rock-pit. Afterward, Schafrik [14] developed a numerical simulation model for Creighton mine and aimed to validate its results in laboratory scale. To overcome such limitations, researchers have proposed using 3D models capable of simulating heat transfer and fluid flow in the large scale Se-TES units [2, 9, 14].

To conclude, there is a fundamental need for a generally applicable engineering design method based on which the thermal energy storage capacity of rock mass of any mine can be assessed. The main aims of this paper are (i) developed a 3D transient mathematical model of fluid flow and heat transfer of STES; (ii) quantitatively compared the effect of position and number of ventilation trenches on outlet air temperature as well as total energy savings.

2. Model description

Here, a 3D model of the rockpit - a large mass of fragmented rock - for STES system of Creighton mine in Canada is proposed. This rockpit model is assumed to be placed over a cone-shaped mine pit which is 697 (m) in diameter and 330 (m) deep. Filling the pit with waste rocks has created a porous rockpit mass. The thickness of the rockpit mass at its very bottom is 133 (m). This porous medium is accessed from the underground through trenches. These trenches are connected to mine ventilation shaft(s) where ventilation fans will continuously move fresh air