Thermal Performance Analysis of Biskra's Earth-to-Air Heat Exchanger (EAHE)

Charaf-eddine MEHDID[a], Adel Benchabane[b], Noureddine MOUMMI[a], Sadam Houcine SELLAM[a], Abdelhafid MOUMMI[a], Mohammed Amin MELHEGUEG[b] and Amar ROUAG[c]

[a]*Université Mohamed Khider Biskra, Laboratoire de Génie Mécanique (LGM), Faculté des Sciences et de la Technologie, BP 145 Biskra 07000, Algeria*

[b]*Université Mohamed Khider Biskra, Laboratoire de Génie Energétique et Matériaux (LGEM), Faculté des Sciences et de la Technologie, BP 145 Biskra 07000, Algeria*

[c]*Universite Kasdi Merbah Ouargla, Laboratoire de developpement des Energies Nouvelles et Renouvelables dans les Zones Arides et Sahariennes (LENREZA), BP 511 Ouargla 30000, Algeria*

…………………………

sh.sellam@univ-biskra.dz

***Abstract*— This paper deals with the experimental effect of air mass flow and operating time on the thermal performance of horizontal earth-to-air heat exchanger (EAHE). The set up is installed in Biskra region (34°47'N - 005°43'E) characterized by semi-arid and hot climate. The results showed that the first twenty meters, the quantity of heat transferred is about seventy percent (70%) of the total heat exchange. Moreover, the energy efficiency and performance coefficient decreased by 30 % and 43% respectively when the air mass flow ranged between 0.038 and 0.054 kg/s. Likewise, a reduction of 22% in efficiency for six hours of continuous functioning for air mass flow equal to 0.038 kg/s.**

Keywords*— *thermal performance, experimental study, energy efficiency, performance coefficient, earth to air heat exchanger

I. Introduction

EAHE is one of the most renewable systems to provide both heating and cooling by using the gradient temperature between the earth subsurface temperature at certain depth and ambient air temperature over the year.

There are several experimental and numerical studies analyzed the effect of operating parameters on the EAHE's thermal performance **(1-7)**.

Bansal et al. studied experimentally the effect of the operating time in continuous mode for different lengths pipes **(1)**. The authors found that the performances of the EAHE depend mainly of the duration of operation..

Recently, Belloufi et al. studied experimentally the thermal performance of EAHE as a function of the duration operation of EAHE in Biskra region **(2)**. Measurements were taken in continuous operation for 71 hours in summer season. Results showed that the continuous operation mode have no remarkable effect on the outlet air temperature, in the case of long length of pipes (53m), and thus on the EAHE performances during all test duration.

On the hand of analytical modeling, Rouag et al proposed a new transient semi-analytical model, called RBM model, to estimate the soil radius surrounding the EAHE pipe, taking into account operation duration, soil thermal diffusivity and inlet conditions **(3)**.

Currently, experimental results have been published where the work has been focused on the experimental validation of the generalization of RBM model. This generalization has given rise to a new model, named GRBM model, to predict the transient temperature fields of the air flowing through the EAHE pipe in continuous cooling mode **(4)**.

As numerical study, Benhammou and Draoui have confirmed that the EAHE thermal performance is more influenced by the variation of duration of operation, pipe diameter and air velocity **(5)**.

In this paper, the authors are interested in the experimental evaluation of the thermal performance of the Biskra's installation using the experimental results published by Mehdid et al **(4)**.

II. Experimental method

The experimental set up (EAHE) is installed at the University of Biskra, Algeria (34°47'N - 005°43'E). As described by Moummi et al.[6], the experimental setup consists of a horizontal serpentine shape of cylindrical PVC pipe of 110 mm inner diameter and 47m of length. The whole is buried at a depth of 3m. The horizontal serpentine sections of the pipe are spaced apart by a distance of about 2m as shown in" Fig. 1& 2".

Experiments were performed in period from April 22 th to May 2nd 2013 for an interval of air mass flow [0.038-0.054 kg/s]. The Experiments were performed from 09:00 a.m. to 17:00 p.m. for each air mass flow the temperatures are measured each fifteen minutes (15 min).

Fig.1. Experimental EAHE setup: (a) hole with a serpentine shape; (b) buried horizontal PVC pipe with thermocouples **(4)**.

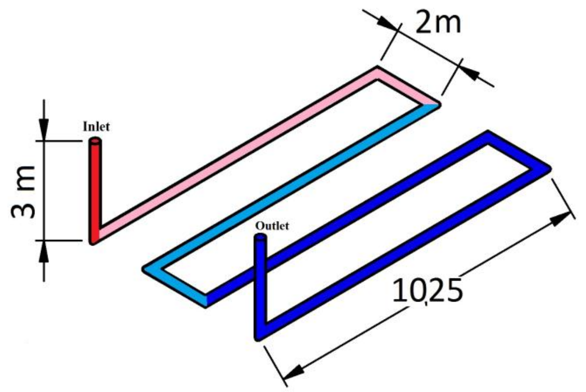

Fig. 2. Scheme shows the sizing of the Biskra's EAHE.

III. EAHE THERMAL PERFORMANCE

In order to evaluate the performance of the EAHE, we often use certain concepts as energy efficiency and coefficient of performance, expressed by the following relations:

The experimental heat exchange rate is calculated by the following equation:

$$Q_e = \dot{m}Cp_a(T_a^{(i)} - T_a^{(o)}) \quad (1)$$

The energy efficiency concept is defined by the ratio of the really heat exchange rate $Q_e$exp and the theoretically possible of maximum heat exchange rate Qmax, it is expressed by:

$$\eta_{\exp} = \frac{Qe_{\exp}}{Q_{\max}} \quad (2)$$

where:

$$Q_{\max} = \dot{m}Cp_a(T_a^{(i)} - T_s) \quad (3)$$

As we can evaluate the mean efficiency of earth-to-air heat exchanger for a period τ is calculated by the following equation:

$$\eta_{mean} = \frac{\int_0^{\tau}(T_a^{(i)} - T_a^{(o)})\,dt}{\int_0^{\tau}(T_a^{(i)} - T_w)\,dt} \quad (4)$$

In the same way, the mean coefficient of performance for a period τ is given as follows:

$$COP = \frac{\dot{m}Cp\int_0^{\tau}(T_a^{(i)} - T_a^{(o)})dt}{\Delta p\dot{V}\,\tau / \eta_{Fan}} \quad (5)$$

IV. RESULTS AND DISCUSSION

"Fig. 3" showed the evolution of air temperature inside the buried pipe as function of air mass flow. It is found that the air outlet temperature decreased with pipe length. The quantity of heat transferred, Qe, is about seventy percent (70%) of the total heat exchange in the first twenty meters, the remaining thirty percent (30%) of the total energy is dissipated with the rest of the length. This can be explained by the fact that the air inside the EAHE is cooled down along the length, reducing the heat transferred and consequently loosing lesser thermal energy to the surrounding soil **(7)**.

Furthermore, there is a rise of 1.55°C at the section 17.07m for a mass flow rate ranged between 0.038 and 0.053 Kg/s, while such a rise of 3°C for the same change in the air mass flow rate. This is due to the fact that an increasing of air velocity induced an increasing of air thermal inertia and therefore, the heat transferred by the air to the fresh soil reduced **(5)**.

The effect of air mass flow on the energy efficiency and COP of EAHE is represented in "Fig. 4". It is noticed from this figure that the daily mean efficiency and the coefficient of performance drop with the increase of air mass flow. It is found that the energy efficiency decreases by 30% when the air velocity ranged from 0.038 and 0.054 kg/s. Indeed, the increasing of mass flow rate reduces the residence time of the air inside the EAHE and the total heat transferred to the refresh soil vicinity. Hence, this latter induces the decreasing of the gradient between inlet and outlet temperature (Tinlet-Toutlet) which in turn influenced on the energy efficiency and COP.

"Fig. 5" shows the evolution of mean efficiency with operating time for 0.038 kg/s. It is observed a reduction of 22% in efficiency for six hours of continuous functioning. This is due that the reduction of heat transfer between the air inside the EAHE and the soil surrounding the pipe vicinity involves a decreasing of the gradient between inlet and outlet temperature (Tinlet-Toutlet) indeed equation (4). Consequently, the performance of EAHE deteriorates.

The evolution of air temperature along the pipe is presented in "Fig. 6" under conditions of 6 hours of continuous running and air mass flow equal to 0.038kg/s. It clear from this figure that the gradient temperature is important in the beginning of functioning then it diminishes. This decrease is due to the reduction of the heat transfer between the air inside the EAHE and the soil in the pipe vicinity.

To analyze the impact of operating time on the heat exchange rate recovered from ground, it is shown in "Fig.7" that the temperature of soil surrounding the pipe increased with operating time. As can be seen in this figure, the soil temperature gets heat with time, nevertheless the heat accumulated is more important in the first twenty meters of EAHE due the important gradient between inlet and soil temperature. It can be noticed that the air temperature tend toward initial soil temperature zero after 30 meters of length from inlet EAHE during (06)six hours of continuous functioning which involves no energy transmitted to the soil.

In other words, the performance of EAHE was better in the beginning and then the outlet air temperature starts increasing which begets the decline of EAHE performance. The subsoil saturation "Fig.7" highlights the effect of operating time on EAHE behavior and explains the main causes of performance deterioration along the pipe "Fig. 5".

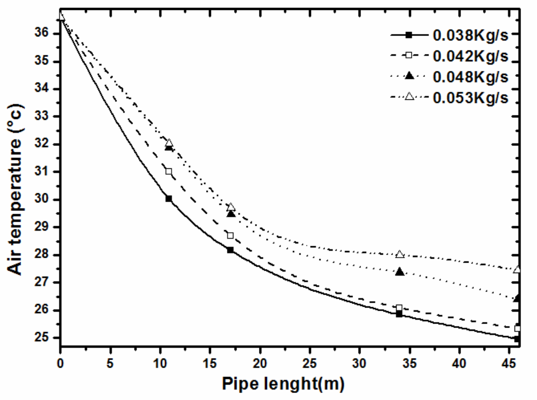

Fig. 3. Effect of air mass flow rate on the outlet air temperature along the EAHE.

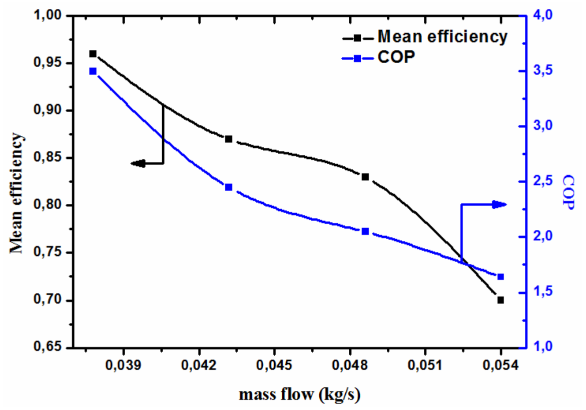

Fig. 4. Evolution of mean efficiency and COP versus air mass flow.

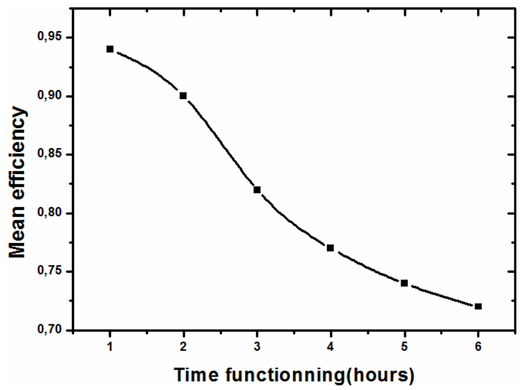

Fig. 5. Evolution of efficiency as function of time functioning (0.038kg/s).

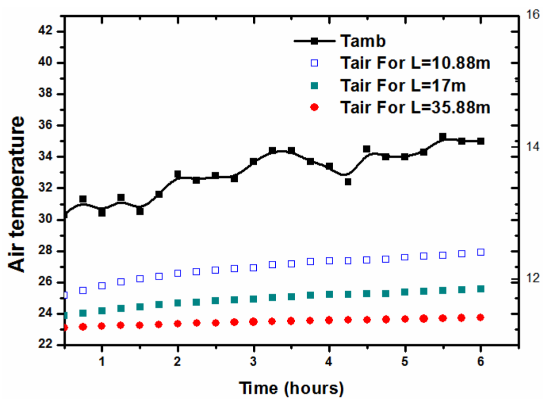

Fig. 6. Air temperature evolution versus operating time at different EAHE lengths.

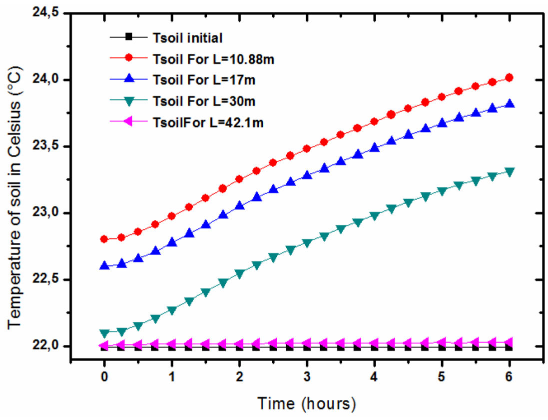

Fig. 7. Soil temperature surrounding EAHE as function of operating time.

V. Conclusions

The main considerations of this investigation is to predict at the same time the deterioration in EAHE's thermal performance as function of the air mass flow and duration operation.

The experimental results showed that the seventy percent of the total heat exchange happened in the first twenty meters, the remaining thirty percent (30%) of heat exchange is dissipated with the rest of the length. This latter involved that the forepart of pipe is more affected by deterioration than that of the end.

After various tests, it has been shown that the air mass flow is a key factor for heat transfer performance of EAHE. Increasing air mass flow reduced the residence time of the air inside the EAHE which involved the decrease of the total heat transferred to the refresh soil vicinity. So, the outlet air temperature increased and mean efficiency decreased by 30% when air mass flow ranged from 0.038 to 0.054 kg/s. In addition, the air mass flow increasing engendered the pressure losses in EAHE system which in turn reduced the coefficient of performance.

Moreover, the effect of time functioning reveals that the heat recovered from soil decreased and the outlet air temperature increased with time due to saturation of adjacent soil. For instance, where the air mass flow equal to 0.038 kg/s, the performance of EAHE system gets deteriorated with a reduction of 22% in mean efficiency for six hours of continuous functioning.

Through this experimental study, there is close relationship between operating parameters (air mass flow-time functioning) and EAHE’s thermal performance.

Acknowledgment

This study was supported by the Algerian Ministry of Higher Education and Scientific Research as a part of CNEPRU project.

References

[1] V. Bansal, R. Misra, G. D. Agarwal, and J. Mathur, "Derating Factor new concept for evaluating thermal performance of earth air tunnel heat exchanger: A transient CFD analysis," Applied Energy Special Issue on Advances in sustainable biofuel production and use - XIX International Symposium on Alcohol Fuels - ISAF, vol. 102, pp. 418-426, 2013.

[2] Y. Belloufi, A. Brima, S. Zerouali, R. Atmani, F. Aissaoui, A. Rouag, and N. Moummi, "Numerical and experimental investigation on the

transient behavior of an earth air heat exchanger in continuous operation mode," International Journal of Heat and Technology, vol. 35, pp. 279-288, 2017.

[3] A. Rouag, A. Benchabane, and C.-E. Mehdid, "Thermal design of Earth-to-Air Heat Exchanger. Part I a new transient semi-analytical model for determining soil temperature," Journal of Cleaner Production, vol. 182, pp. 538-544, 2018.

[4] C.-E. Mehdid, A. Benchabane, A. Rouag, N. Moummi, M.-A. Melhegueg, A. Moummi, M.-L. Benabdi, and A. Brima, "Thermal design of Earth-to-air heat exchanger. Part II a new transient semi-analytical model and experimental validation for estimating air temperature," Journal of Cleaner Production, vol. 198, pp. 1536-1544, 2018.

[5] M. Benhammou and B. Draoui, "Parametric study on thermal performance of earth-to-air heat exchanger used for cooling of buildings," in Renewable and Sustainable Energy Reviews, vol. 44, 2015, pp. 348-355.

[6] N. Moummi, H. Benfatah, N. Hatraf, A. Moummi, and S. Y. Ali, "Le rafraîchissement par la géothermie: étude théorique et expérimentale dans le site de Biskra," Revue des Energies Renouvelables, vol. 13, pp. 399-406, 2010.

[7] A. Mathur, A. K. Surana, P. Verma, S. Mathur, G. Agrawal, and J. Mathur, "Investigation of soil thermal saturation and recovery under intermittent and continuous operation of EATHE," Energy and Buildings, vol. 109, pp. 291-303, 2015.

Nomenclature

Cp	Specific heat	J/(kg . K)
$\dot{m}$	mass flow rate of air through the buried pipe	kg/s
T	Temperature	°C
t	Time	s

Abbreviations

EAHE	Earth-to-air heat exchanger

Subscripts

a	Air
amb	Ambient
i	Inlet
o	Outlet
p	Pipe
s	Soil
max	maximum