Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 10 (21): 2673-2677, 2010
ISSN 1812-5654

Temperature Profile Data in the Zone of Flow Establishment above a Model Air-cooled Heat Exchanger with 0.56 m^2 Face Area Operating under Natural Convection

Md. Mizanur Rahman, Sivakumar Kumaresan and Chu Chi Ming
Chemical Engineering Program, School of Engineering and Information Technology,
Universiti Malaysia Sabah (UMS), 88999, Kota Kinabalu, Sabah, Malaysia

Abstract: The aim of this study was to analyze the temperature profile in the Zone of Flow Establishment (ZFE) above a 0.56 m^2 hot screen placed at different height above an electrically heated model air-cooled heat exchanger operating under natural convection. Installation of screens increased the temperature difference from 30 to 140 K with respect to ambient that resulted in the air velocity increased at the inlet of the special duct from 0.67 m sec^{-1} to more than 2.0 m sec^{-1} under different heat loads ranging from 1 to 2.5 kW. The investigation of temperature profile was done above the hot screens placed at 0.35, 0.65, 0.95 and 1.25 m height over the electrically heated model air-cooled heat exchanger. The results show that the exit air temperature near to the electric heater and above the hot screens did not differ significantly but at heights of 0.09 m and upward the temperature difference differed by 2 to 6 K depending on the height of the hot screens. Maximum temperature difference was observed for hot screen placed at 0.65 and 0.95 m. Although, the temperatures at the beginning of the zone of flow establishment were almost the same for every heat load, the radial profile of temperature turned from parabolic in shape to uniformly flat for the configuration without screen and with screen respectively. This indicates turbulence increase above the hot screens.

Key words: Cooling tower, heat exchanger, natural draft, natural convection, plume

INTRODUCTION

A device that is used in the chemical industries, refineries, power generation industries, waste incineration plants, petrochemical industries, automobile industries and timber treatment industries for extracting thermal energy from hot flue gases, chemicals, petroleum products or water, flow through pipes or tube bundles and transfer heat into ambient air is known as cooling system. It is noted; in the geothermal power plant about 20 to 35% of the total plant cost goes to construct an air cooler heat exchanger (Sohal and Brien, 2001). The improved design will decrease the installation cost as well as increase the plant performance. To improve the design of the cooling system, it is important to survey the aerodynamics behavior of different types of cooling system existing in the world. Between natural draft and forced draft cooling system, the natural draft air cooled heat exchanger has a better reputation for its energy efficiency and water saving capability that enable it to be widely used in regions where, useable water is scare but coal and oil are abundantly available like South Africa, Middle East and North China (Hagens *et al*., 2007; Zhai and Fu, 2006). The basic principle of a natural draft cooling system is very easy to describe: due to the density difference the buoyancy force causes air flow in upward direction but heat and mass transfer inside a cooling system can be complex therefore until now different numerical models are used to describe this phenomena for example Smrekar *et al.* (2006) used NTU method to discuss the constant characteristic of the cooling tower, Hotchkiss *et al.* (2006) applied commercial CFD solver FLUENT™ to solve the equation for an incompressible fluid; Dirkse *et al.* (2006) used k-ω turbulence model to analyze the flow characteristic and to design a natural convection shell and tube heat exchanger, where, k is time average turbulence kinetic energy per unit mass and ω is the specific dissipation of turbulent kinetic energy Schreuder and Plessis (1989) also used k-ω turbulence model to predict turbulence level inside the air-cooled heat exchanger. These methods are broadly effective in describing the natural draft cooling system that is large in scale but the crosswinds flow, recirculation of hot air and cold air in down draft are not easily modelled. As part of the process of investigating plume rising above a finite heat source representing forced draft air cooled heat exchanger, a model forced draft air-cooled heat exchanger was designed at Universiti Malaysia Sabah to determine

Corresponding Author: Md. Mizanur Rahman, Chemical Engineering Program, School of Engineering and Information Technology, Universiti Malaysia Sabah (UMS), 88999, Kota Kinabalu, Sabah, Malaysia Tel: +60146594093

the temperature and average velocity above the hot surface under different condition such as placement of hot screens above electric heater, face dimensions and different heat load. The different face areas with hot screens are used under different heat load to determine the rate of heat removal. During the experiments the exit temperature had to be measured as accurately as possible in order to determine the heat removal rate by the upward flowing air and perform the heat balance. To minimize the radiation effect the thermocouple were separated from heaters by using screen wire meshes just above the electric heaters and also covered above from entraining cold air. The space between upper and lower was varied to optimize the readings. The present study to be described here is relevant to natural draft cooling tower because the height between the lower and upper hot screens makes up a solid chimney. In the earlier study, the measured average air velocity is compared with calculated velocity from different methods and found remarkable improvement in the average velocity in the system (Rahman *et al*., 2008).

MATERIALS AND METHODS

Numerical methods are plentiful to describe temperature and velocity profile in natural draft cooling tower but experimental methods such as Lorenzini (2006) technique are noted to be very rare in the literature. The size of the electric heater and face dimension are important factors to represent the actual situation and carry out this investigation. Chu *et al*. (1988) observed that the electrically heated air cooled heat exchanger of small face dimension of 457×457 mm did not have a significant effective plume-chimney height although this conclusion was apparently supported by the data obtained from industrial size heat exchanger face dimension of 2×3.1 m. Later on the effective plume chimney height was found to be significant with data from another industrial size heat exchanger 2.4×6.0 m with the size at face dimensions (Chu, 2002).

Meyer and Kroger (1998) conducted series of experiments to determine the performance characteristics mainly exit airflow profile and pressure drop of a particular axial flow fan affects the plenum chamber aerodynamic behavior of a forced draught air-cooled heat exchanger by using 1.6×1.9 m, 1.64×1.9 m and 1.9×1.9 m of face dimensions. Where, the tube was 1.6 m long to represent actual situations of the industrial forced draft air cooled heat exchanger that is widely used in the chemical and processes industry. The present experimental facilities were already described and explained in Rahman *et al*. (2008). To perform investigation on heat exchanger dimensions of similar order of magnitude as Meyer and Kroger (1998) and others, initially 0.75×0.75 m model

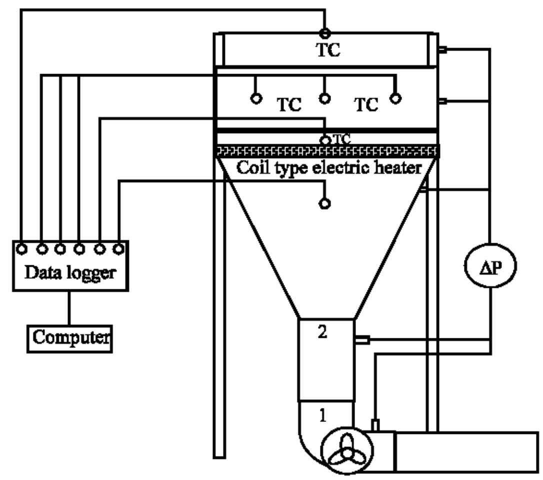

Fig. 1: Experimental setup

heat source was used to represent a model air cooled heat exchanger to conduct the experiment. To obtain the temperature difference at 80 to 120 K between exit air of electric heater and ambient, the heat load was varied from 1 to 2.5 kW. Two layers of hot screens were used above the electric heater in different height to increase the exit air temperature from electric heater.

To measure the magnitude of the temperature at above the hot screens, seven K-type thermocouple were placed in a line of different locations at the same height. The heights also varied from 0.03 to 0.27 m because from it is estimated using Chu (2002) correlation that for temperature difference of 80 to 120 K the effective plume chimney height would be around 0.2 m. To determine the temperature profile at the Zone of Flow Establishment (ZFE) above the hot screens, the equal distance were maintained between the adjacent thermocouple and connected with computer through data logger. The data were recorded in 30 sec interval for 3 times and 5 min between each height to ensure accuracy of the temperature Fig. 1.

RESULTS AND DISCUSSION

A total of seven K-type thermocouples were used in the ZFE to determine the profile of temperature at the same height above hot screens but different location. The heights changed up to 0.27 m with 0.03 m increment to determine the profile of temperature inside the establishment zone of flow over hot screens. The experimental results were recorded automatically and average results presented below in graphical format to analyze the profile of temperature over hot screens with face area of 0.56 m^2. The average exit air temperature in the

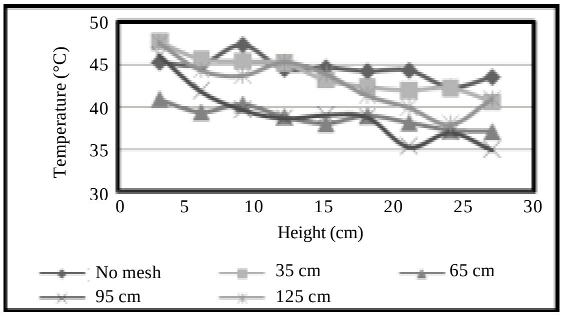

Fig. 2: Radial profile of average temperature in the zone of flow establishment at different heights above hot screen for heat load 2.33 kW

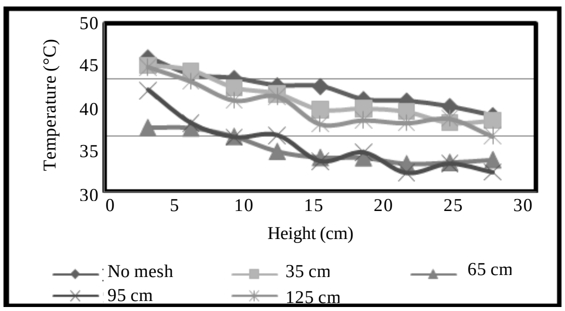

Fig. 3: Radial profile of average temperature in the zone of flow establishment at different heights above hot screen for heat load 1.00 kW

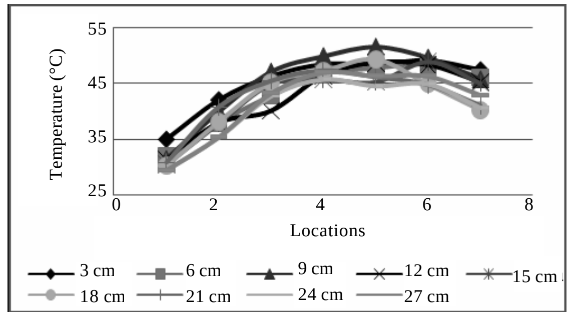

Fig. 4: Radial profile of temperature in the zone of flow establishment at different heights above electric heater

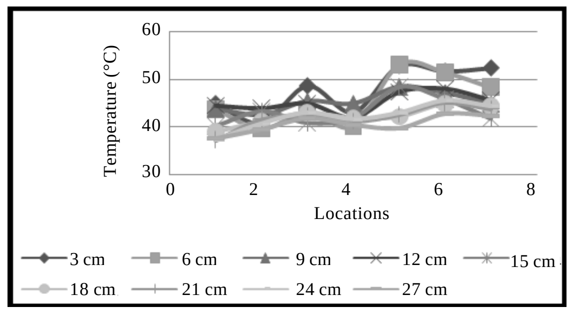

Fig. 5: Radial profile of temperature in the zone of flow establishment at different heights above hot screen placed at 0.35 m and fixed heat load 2.32 kW

zone of flow was found higher at 0.03 m height in all cases (Fig. 2) because this point was very near to the hot screen. It is also observed the temperature in the ZFE decreased with height significantly in all cases but the reduction rate was found faster when hot screens were placed above electric heater, probably because the hot screens increased the turbulence of flow and hot air mixed up with surrounding cold air faster than without hot screens.

The temperature in the ZFE reduced faster when hot screens were placed at 0.95 m. Figure 2 and 3 indicate that the exit air temperature and its standard deviation in the establishment zone of flow is lower when hot screens were placed at 0.65 m compared to other heights for both 1 and 2.33 kW heat loads.

Although, the trend of the average exit air temperature in Fig. 2 and 3 show a decrease with height after installing hot screens. The turbulence of flow and high rate of mixing of cold air from surrounding with hot air in the establishment zone of flow causes significant drop of temperature. The temperature in the central axis (Location 4) of the establishment zone of flow reached higher value than at other locations (1-3, 5-8) when there was no screen at the top of the electric heater. The radial temperatures become parabolic in shape as shown in Fig. 4.

After setting up hot screens in the model electrically heated model air cooled heat exchanger, the temperature was recorded and plotted. The radial temperature in the ZFE changes from parabolic into more or less flat in shape (Fig. 4-8). The distribution of temperature was believed to be more uniform from heights 12 to 27 cm. The change in the pattern of temperature in the ZFE occurs due to the screens. The screens are believed to increase the turbulence of the air flow over it more than without screens therefore hot air mixed up quickly in the ZFE and decreased the temperature.

The investigation also showed that the temperature at different heights above 12 cm from hot screens are having almost 50% less fluctuation compared to 3 to 9 cm. Further investigation is going on determine the

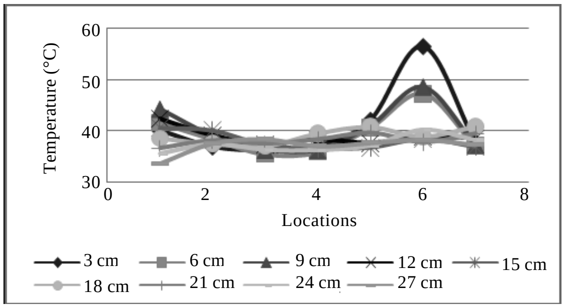

Fig. 6: Radial profile of temperature in the zone of flow establishment at different heights above hot screen placed at 0.65 m and fixed heat load 2.30 kW

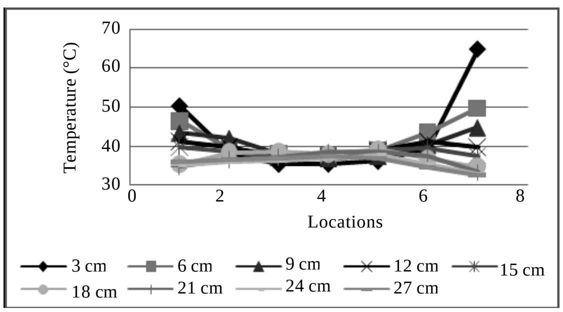

Fig. 7: Radial profile of temperature in the zone of flow establishment at different heights above hot screen placed at 1.25 m and fixed heat load 2.46 kW

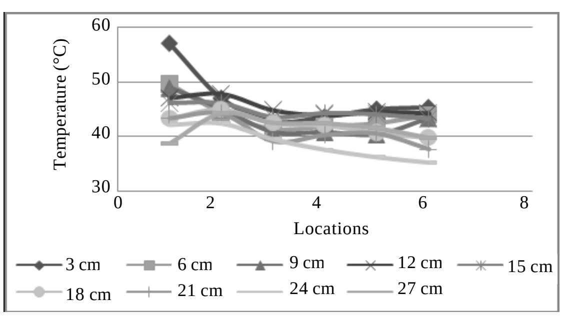

Fig. 8: Temperature in the zone of flow establishment at different heights above hot screen placed at 1.25 m and fixed heat load 2.34 kW

relationship between the temperature in the ZFE and the temperature in the gap between electric heater and hot screens. It will be extended to determine the relation ship between exit air velocity and temperature in the establishment zone of flow. Primary investigation showed that more than 50% air velocity increased when the hot screens were present in the 0.56 m^2 face dimension electrically heated model air cooled heat exchanger. Although the average temperature in the establishment zone of flow depends on the heat load but for the same heat load at different heights the variation of temperature was very little at not more than 10%.

CONCLUSION

The average temperature in the zone of flow establishment at above hot screens decreased with heights faster then without hot screens because of high turbulence and mixture of surrounding cold air hot air because the hot screens likely increased the turbulence above it allow hot air to mix with cold air faster compare than without screens.

The radial profiles of temperature in the establishment zone of flow when operating without screen was found parabolic in shape but after installing screens the shape became more or less flat. This is attributed to the turbulence in the establishment zone of flow above hot screens.

Preliminary results show that the hot screens do not have any significant impact on average temperature in the establishment zone of flow but it raised the temperature between electric heater and hot screens; simultaneously it enhanced the average air velocity at the inlet of the model from 1.05 to 1.64 m sec^{-1} and more. The velocity enhancement and temperature rise depend on the number of hot screens, electric heat load, face dimensions and the gap between electric heater and hot screens.

ACKNOWLEDGMENT

The author would like to give thanks to the Ministry of Higher Education in providing the financial support under grant No. FRG0022 to complete this experiment in the School of Engineering and Information Technology, University Malaysia, Sabah, Malaysia.

REFERENCES

Chu, C.M., P.E. Farrant and T.R. Bott, 1988. Natural convection in air cooled heat exchanger. Nat. Conf. Heat Transfer, 2: 1675-1688.

Chu, C.M., 2002. A preliminary method for estimating the effective plume chimney height above a forced draft air cooled heat exchanger operating under natural convection. Heat Transfer Eng., 23: 3-12.

Dirkse, M.H., K.P.W. van Loona, T. van der Wallea, S.L. Speetjensa and G.P.A. Bot, 2006. A computational fluid dynamics model for designing heat exchangers based on natural convection. J. Biosyst. Eng., 94: 443-452.

Hagens, H., F.L.A. Ganzevles, C.W.M. van der Geld and M.H.M. Grooten, 2007. Air heat exchanger with long heat pipes: Experiments and predictions. Applied Thermal Eng., 27: 2426-2434.

Hotchkiss, P.J., C.J. Meyer and T.W. von Backstrom, 2006. Numerical investigation into the effect of cross-flow on the performance of axial flow fans in forced draught air-cooled heat exchangers. J. Applied Thermal Eng., 26: 200-208.

Lorenzini, G., 2006. Experimental analysis of the air flow field over a hot flat plate. Int. J. Thermal Sci., 45: 774-781.

Meyer, C.J. and D.G. Kroger, 1998. Plenum chamber flow losses in the forced draft air cooled heat exchanger. Applied Thermal Eng., 18: 875-893.

Rahman, M.M., C.C. Ming and S. Kumaresan, 2008. Design rationale of the facility for the study of plumes above forced draft air cooled heat exchanger operating under natural convection. Proceedings of the 1st Seminar of Engineering and Information Technology, April 14-15, Sabah, Kota Kinabalu, Malaysia.

Schreuder, M.J. and J. Plessis, 1989. Simulation of air flow about air cooled heat exchanger. J. Build. Environ., 24: 23-32.

Smrekar, J., J. Oman and B. Sirok, 2006. Improving the efficiency of natural draft cooling towers. J. Energy Convers. Manage., 47: 1086-1100.

Sohal, M.S. and J.E. O'Brien, 2001. Improving air cooled condenser performance using winglets and oval tubes in a geothermal power plant. Proceedings of the Geothermal Resources Council Transactions, Aug. 26-29, Idaho National Engineering and Environmental Laboratory, Idaho Falls, USA., pp: 607-610.

Zhai, Z. and S. Fu, 2006. Improving cooling efficiency of dry-cooling towers under cross-wind conditions by using wind-break methods. J. Applied Thermal Eng., 26: 1008-1017.