IOP Conference Series: Materials Science and Engineering

Computational Analysis on Performance of Thermal Energy Storage (TES) Diffuser

To cite this article: M A H M Adib *et al* 2012 *IOP Conf. Ser.: Mater. Sci. Eng.* **36** 012015

IOP Conf. Series: Materials Science and Engineering **36** (2012) 012015 doi:10.1088/1757-899X/36/1/012015

Computational Analysis on Performance of Thermal Energy Storage (TES) Diffuser

M.A.H.M. Adib[1], F. Adnan[2], A.R. Ismail[1], K. Kardigama[1], H.A. Salaam[1], Z. Ahmad[1], N.H. Johari[1], Z.Anuar[1] and N.S.N.Azmi[1]

[1]Sport and Human Engineering Group (SHEG), Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 UMP, Pekan, Pahang, Malaysia.

[2]Department of Applied Science and Technology, Universiti Kuala Lumpur, 32200 Lumut, Perak, Malaysia.

E-mail[1]: azrul@ump.edu.my

Abstract. Application of thermal energy storage (TES) system reduces cost and energy consumption. The performance of the overall operation is affected by diffuser design. In this study, computational analysis is used to determine the thermocline thickness. Three dimensional simulations with different tank height-to-diameter ratio (HD), diffuser opening and the effect of difference number of diffuser holes are investigated. Medium HD tanks simulations with double ring octagonal diffuser show good thermocline behavior and clear distinction between warm and cold water. The result show, the best performance of thermocline thickness during 50% time charging occur in medium tank with height-to-diameter ratio of 4.0 and double ring octagonal diffuser with 48 holes (9mm opening ~ 60%) acceptable compared to diffuser with 6mm ~ 40% and 12mm ~ 80% opening. The conclusion is computational analysis method are very useful in the study on performance of thermal energy storage (TES).

1. Introduction

Air conditioning system is essential for residential, commercial and also the industrial sector especially for countries with high ambient temperature such as Malaysia. The usage of conventional air conditioning system as what most household and building have, are generally being used more often during the day time especially during the afternoon when it is at the “peak-time”. Peak time is when demand for electricity energy is high and to cater to this demand, utility company will have to generate more energy and this comes with a price hence contributes a big portion to the customers’ monthly utility bill. The solution for this is to shift the energy or load needs during peak time to off peak. Off peak is when the electric energy demand is low and the tariff per kilowatt hour is less than that of the peak time. Thermal energy storage or TES for short is a storage system that can be use to shift the peak load demand to off peak load demand. TES is a concept where the ice or chilled water is produced and stored in storage during at night. The stored cooling medium is later used to meet a cooling load of the total integrated complexes during the day when the electricity rate is higher. The concept behind TES is simple. Storage medium is cooled by chillers during off-peak hours and stored in an insulation tank. Electrical costs peak during the day is very high, and are less during evening hours, because demand decreases. TES in naturally stratified tanks is used to reduce the operating costs and refrigeration plant capacity of many large cooling systems. TES takes advantage of natural properties of water which cause it to naturally stratify at different temperatures. For this TES system was controlled with an inlet and outlet diffuser. By properly designing an inlet and outlet diffuser system, a tank can be used to store cold and warm water separated by a boundary layer knows as a thermo cline. In this study, the diffuser must be designed to minimize the effect of mixing (optimum diffuser design), so that the density differences of the cold and warm water will result in stratification.

2. Method
Selection design of diffuser will have to consider many criteria such as performance, efficiency and the design itself since different diffuser have different system setup for example radial and octagonal diffuser is more suitable for cylindrical tank and H-diffuser is suitable for rectangular tank. However, this study objective is to obtain the optimum diffuser design. With using CFD-Fluent will be carried out to fulfill the objective. The ratio of inertia force to kinematics force calls Reynolds number. This dimensionless number is use to contribute the inlet flow through the cylindrical storage tank. (Dorgan *et al*., 1993) suggested using 200 Reynolds number. For the 5 meter length and above, 400 to 850 Reynolds number is suggested to use. Even though, the Reynolds number must less than 2000.

$$\mathrm{Re} = \frac{\rho v d}{\mu} \quad (1)$$

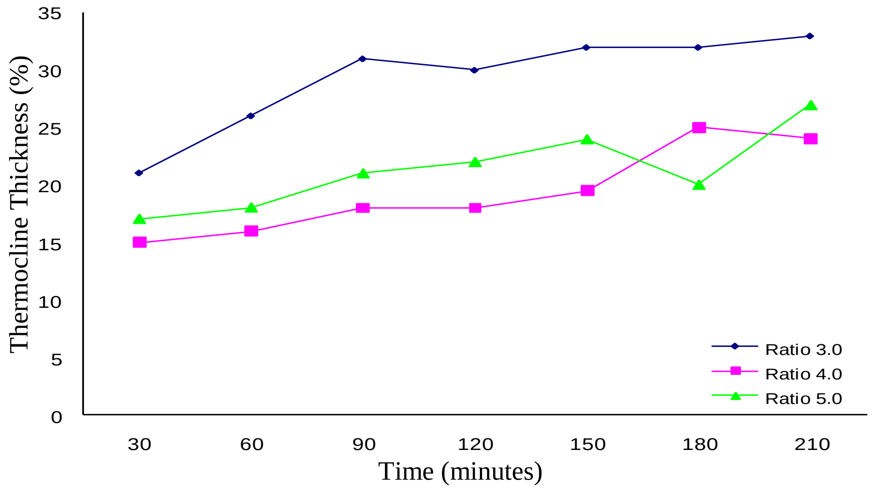
3. Parameters and Equation
From this project, all the parameters are considered from two sources of investigator, (J.E.B. Nelson *et al*.,1999; Mohd Shamsurie Anuar,1996; B.J. Sliwinski *et al*.,1978; C.R. Truman *et al*.,1989; Wildin, M. *et al*.,1990) experiment that have been done from their research of parametric studies on thermally stratified chilled water storage system.

Table 1. Parameter setting

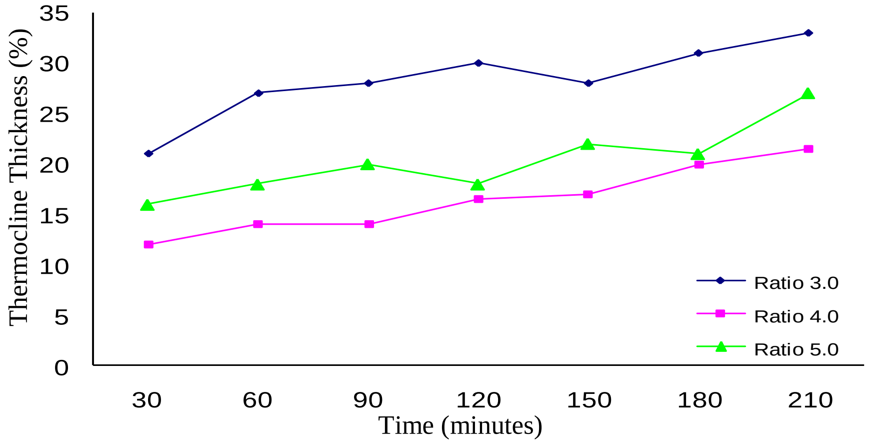
Characteristic	Value
Warm water temperature	290 K
Chilled water temperature	277 K
Aspect Ratio (Ar)	3.0, 4.0, 5.0
Number of Diffuser	24 holes, 48 holes
Types of Diffuser (Octagonal)	Single Ring, Double Ring
Diffuser Size (Diameter)	6 mm, 9 mm, 12 mm
Flow rate	123 Liters / Hours
Reynolds Numbers	Re 200
Initial temperature different	277 K to 290 K

4. Result and Discussion
Comparison was made for thermocline thickness produced and good agreement was observed. Figure 1 and 2 below shows comparison made for charging process with the same inlet *Re* of 200. Study on shallow tank with HD 3.0, 4.0 and 5.0.

(a).



(b).



(c).

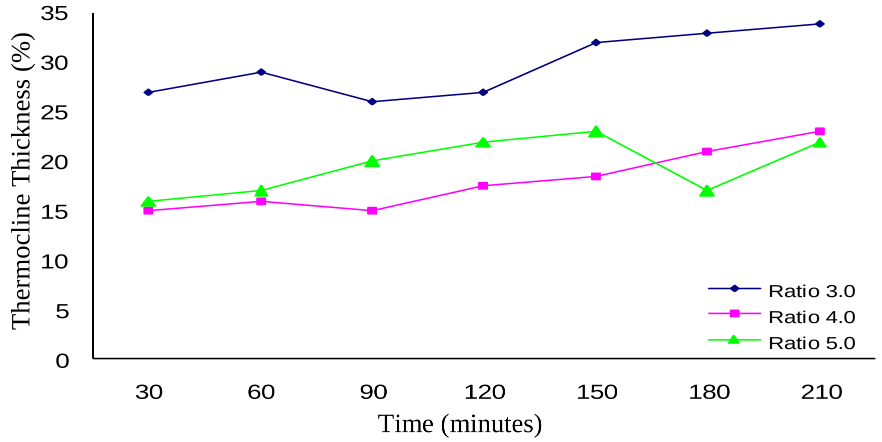


Figure 1. Thermocline thickness with Double Ring type for different diffuser size; a) 40% (6mm) ; b). 60% (9mm) ; c). 80% (12mm)

Chilled water at various Reynolds (*Re*) was charged into the tank and observations on the development of the thermocline were made and all the result with compare between diffuser size of Double Ring and Single Ring are shown in Figure 2 below.

(a).
(b).
(c).

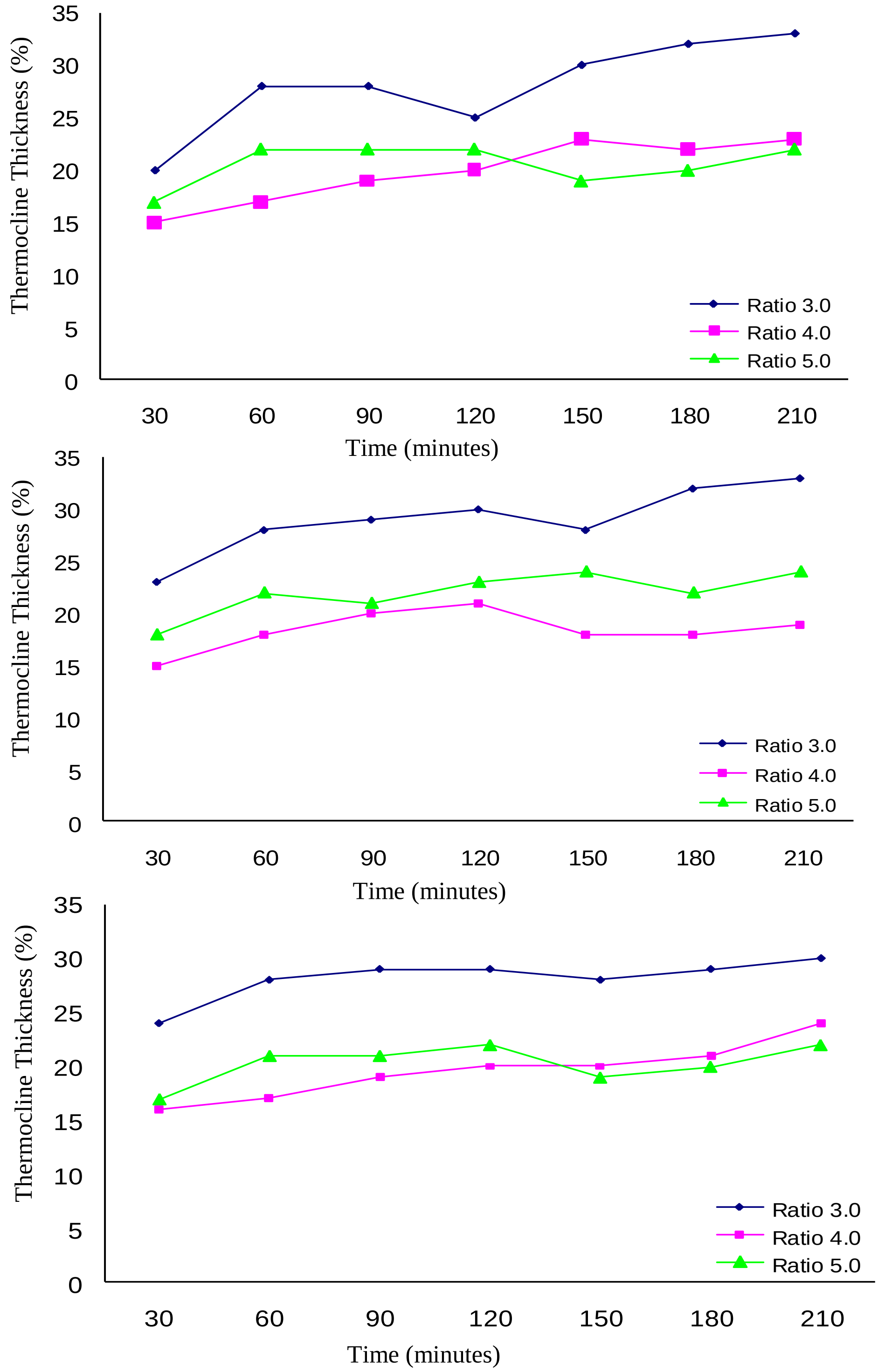
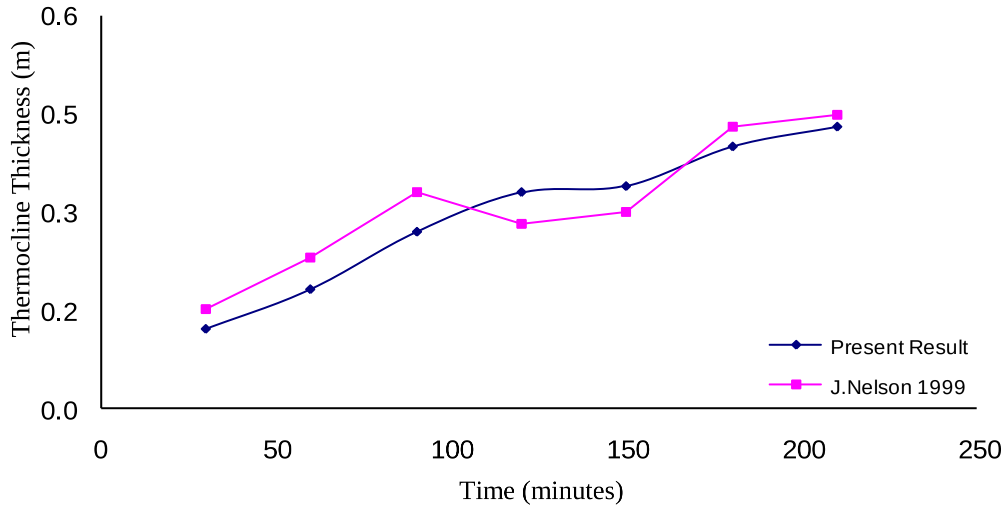


Figure 2. Thermocline thickness with Single Ring type for different diffuser size; a). 40% (6mm) ; b). 60% (9mm) ; c). 80% (12mm)

Results reveal that the thermocline degradation is more pronounced at low flow rates. Thermal diffusion, axial wall conduction and heat exchange with the ambient are rate process. The energy degradation due to these is directly proportional to the charging time. Hence the degradation of energy due to heat conduction across the thermocline and long the storage tank (axial wall conduction) increase with the increase in charging time. Stratification improves with increasing flow rate up to a certain value and there after remains constant. The rates of warming up due to energy transfer from the ambient decreases with decrease in the aspect ratio and also with the diffuser size (opening holes). The thickness of the thermocline is increased by heat conduction through the thermocline during the charging and discharging portions of cycle and this may obscure the initial thickness produced by mixing and heat transfer during thermocline formation. It has been found that mixing near the inlet diffuser may be minimized by introducing fluid through that diffuser so that it initially forms gravity current. Gravity current is a thin layer, composed almost entirely of incoming fluid that travels across the tank due to a density difference rather than inertia of the incoming flow. Such a current gently pushes the fluid previously in the tank out of the way so the mixing occurs only at the front of the current during the first pass of the current across the tank.

(a).



(b).

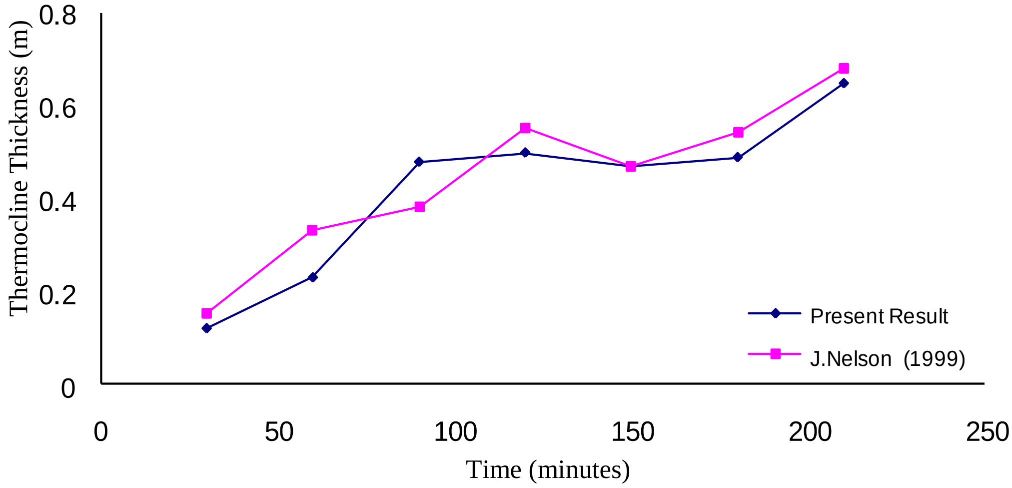


Figure 3. Verification Result for 3D model for thermocline thickness between; a). Double Ring with 48 holes ; b). Single Ring with 24 holes

Figure 3 shown verification result between double ring and single ring. For double ring result with 48 holes, the accuracy of the thermoclines thickness compare between present result and J.Nelson (1999) result achieved 86.3% and for single ring result with 24 holes, the accuracy of thermoclines thickness achieved 73.4%**.** Based on both 3D comparison result shown, it seen that the thermocline thickness can be predictable with a different diffuser size (hole size).

5. Conclusion

The need for ease and comfort when indoor have lead to building nowadays either it residential, commercial or industrial equipped with air conditioning system. Air conditioning systems have considerably contributed a big portion to monthly utilities bill hence, the need for a more efficient and reliable system is essential. Thermal energy storage, chilled water system to be more precise is undeniable a great solution to be used as air conditioning system considering it benefits and the finding on this study had shown that the best performance of thermocline thickness during 50% time charging occur at double ring type diffuser with holes diameter of 9 mm (60% opening) in range 16% and the good initial state of thermocline thickness range is between 15%~21%. Medium height-diameter (HD) ratio 4.0 simulation also shows the good thermocline behavior and clear distinction between warm and cold water regions.

Acknowledgement

The support of the Universiti Malaysia Pahang, under SHEG group is gratefully acknowledged. The authors of this paper also would like to express their gratitude to Universiti Kuala Lumpur (UniKL) for supporting these research activities.

References

[1] B.J. Sliwinski, A.R.Mech and T.S.Shih. 1978. Stratification in thermal storage during charging, Proc.Sixth Int. Cof. Heat Tranfer, American Society of Mechanical Engineers, Vol. 4, pp. 149-154.
[2] C.R. Truman, M.W. Wildin. 1989. Finite Difference Model for Heat Transfer in a Stratified Thermal Storage Tank with Through Flow, Numerical Heat Transfer with Personal Cumputers and Super Computer, ASME/Ache National Heat Transfer Conference.
[3] Dorgan and J.S. Elleson. 1993. Design Guide for Cool Thermal Storage, Atlanta, Atlanta Ga, America Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE.
[4] J.E.B. Nelson A.R. Balakrisnan, S. Srinivasa Murthy. 1999. Experiments on Stratified Chilled Water Tanks, Int. Journal of Refrigeration.
[5] Mohd. Shamsurie Anuar. 1996. Penyimpanan Tenaga Terma Air Dingin: Proses Simulasi Tangki Penyimpanan Silinder Menegak, Universiti Teknologi Malaysia.
[6] Wildin, M. 1990. Diffuser Design for Naturally Stratified Thermal Storage. ASHRAE Transactions 96(1)1094-1102.
[7] Wildin, Yoo, and C.R.Truman.1986. Initial formation of a thermocline in stratified thermal storage tanks. ASHRAE Transactions 92(2): 280-92.