2007 ECI Conference on The 12th International Conference on Fluidization - New Horizons in Fluidization Engineering
Vancouver, Canada
Editors: Franco Berruti, The University of Western Ontario, London, Canada
Xiaotao (Tony) Bi, The University of British Columbia, Vancouver, Canada
Todd Pugsley, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

Year 2007 *Paper* 31

The Measurement of Thermal Performance for a Fluidized Bed

H. R. Goshayshi*

*Azad University of Mashad

http://services.bepress.com/eci/fluidization_xii/31

The Measurement of Thermal Performance for a Fluidized Bed

Abstract

Abstract Experiments have been performed to measure the thermal performance, packed density, and velocity of a fluidized bed cooling tower of 280 mm diameter.

Hollow plastic spheres of three different sizes, with diameters of 20, 25 and 37 mm and particle densities ranging from 70 to 325 kg/m3 were investigated as packing materials, and results for static bed heights of 100 mm and 300 mm are reported. Measurements were obtained at an approximately constant inlet hot water temperature of around 42°C and cover a range of water mass flux from 0.3 to 3.6 kg/sm2. Liquid/gas ratios varied between 0.1 and 5.5. Results for thermal performance are presented showing the effects on the cooling tower characteristic, KaV/L, of the different packing elements and of varying water flow rate, air flow rate and the height of the hot water distributor above the bed. This provides a useful semi experimental relation, in the area generally lacking in design and performance data.

FLUIDIZATION XII 265

THE MEASUREMENT OF THERMAL PERFORMANCE FOR A FLUIDIZED BED

H. R. Goshayshi
Department of Mechanical Engineering
Faculty of Engineering, Azad Mashad University,
Qhasem Abad, Mashad, Iran,
Email: hamidreza97@yahoo.co.uk

J. F Missenden
School of Engineering Systems & Design
London South Bank University,
103 Borough Road. London SE1 0AA, UK

ABSTRACT

Experiments have been performed to measure the thermal performance, packed density, and velocity of a fluidized bed cooling tower of 280 mm diameter._Hollow plastic spheres of three different sizes, with diameters of 20, 25 and 37 mm and particle densities ranging from 70 to 325 kg/m^3 were investigated as packing materials, and results for static bed heights of 100 mm and 300 mm are reported. Measurements were obtained at an approximately constant inlet hot water temperature of around 42°C and cover a range of water mass flux from 0.3 to 3.6 kg/sm^2. Liquid/gas ratios varied between 0.1 and 5.5. Results for thermal performance are presented showing the effects on the cooling tower characteristic, KaV/L, of the different packing elements and of varying water flow rate, air flow rate and the height of the hot water distributor above the bed. This provides a useful semi experimental relation, in the area generally lacking in design and performance data.

INTRODUCTION

Fluidized beds posses very high heat transfer capability, therefore they are very potential to be used in heat transfer treatment industry. In general, the design of an efficient, compact mass transfer pack for gas/liquid applications is based on the optimization of the passage diameter and passage length. Also from a number of recent studies it is apparent that the choice of material plays a major role in packing design, the ideal material being highly formable in order to provide a high specific surface area. Wang (1). The present work is concerned with the thermal performance for hollow plastic spheres. A limited of researchers have addressed this subject. Teoman et al (2) measured the heat transfer coefficients between gas fluid beds and spherical calorimetric probes of different sizes. The spherical probes were of electrolytic (6.4 and 8.7 mm diameter), phosphor bronze (8.9 and 9.5 mm diameter), gold (11.1 mm diameter) and 10% phosphor bronze (31.3 mm diameter). Also Madhiyanonet al (3) recently developed a mathematical model of rapid, high heat transfer treatment grain in a fluid bed but without giving any information about mass transfer and mass transfer coefficients. The thermal performance of a cooling tower packing is often expressed by the dimensionless quantity, KaV/L, known as the tower characteristic, where the composite quantity Ka is the overall volumetric mass transfer coefficient, V is the volume of the packing per unit plan area and L is the liquid (water) mass flux. An alternative measure is the number of transfer units, NTU, which is simply related to the tower characteristic by NTU = (KaV/L) (L/G), where G is the gas (air) mass flux.

In the fluidized bed cooling tower (FBCT) hot water is sprayed downward on to the bed of spherical packing elements in counterflow to an upward flowing unsaturated air stream that fluidizes the bed, thus creating a three-phase turbulent bed contactor characterized by large interfacial area, vigorous mixing and high heat and mass transfer coefficients. Douglas (2) reported excellent performance for the cooling and humidification of a hot wet air stream in a floating bed contactor with a packing consisting of hollow polypropylene spheres of diameter 38.1 mm and a static bed height, V, of 254 mm. Over the ranges tested, NTU was found to decrease with the increasing water or air mass flow rate. Experiments for water cooling in a FBCT, by Barile et al (3), covered static bed heights up to 457 mm and spherical packing diameters of 19 mm and 38.1 mm. The tower characteristic KaV/L was found to increase, albeit at a diminishing rate, with increased static bed height, and was slightly lower for the larger spheres. The measurements exhibited values of Ka an order of magnitude higher than those for fixed packing towers. Furthermore, the data indicated that Ka decreases as V increases, and increases with increase in either G or L. Seetharamu and Swaroop (4) tested two different sizes of FBCT, with tower cross- sections 250 mm square and 1100 mm square. Extended polystyrene spheres of diameter 25.4 mm were used as the packing material and static bed heights up to 310 mm were investigated. They concluded that in comparison with conventional cooling towers, with either splash or film type fills, the FBCT requires a much lower packing height, has a comparable pressure drop and can handle higher liquid throughputs. El-Dessouky (6) experimented with a FBCT packing of 12.7mm diameter spongy rubber balls and static bed heights of 300 to 500 mm, and found that increasing the hot water inlet temperature produced a marked improvement in KaV/L. This was attributed to the increased interfacial area and gas holdup associated with the smaller air bubble mean diameter formed at higher water temperatures due to the reduction in surface tension and viscosity. This paper reports on work in progress to extend the range of experimental data available for use in the design of fluidized bed cooling towers. The FBCT tests conducted cover a larger number of spherical packing element sizes than previously considered in a single study.

EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental tower shown in Figure 1 consists of a vertical 280 mm internal diameter transparent Perspex column having working and inlet plenum sections 1500 mm and 700 mm long respectively. The bed, comprising hollow plastic spheres, is supported on a wire grid with a free flow area exceeding 80% of the tower cross-sectional area. Hot water is introduced through a single spray nozzle mounted centrally above the bed.

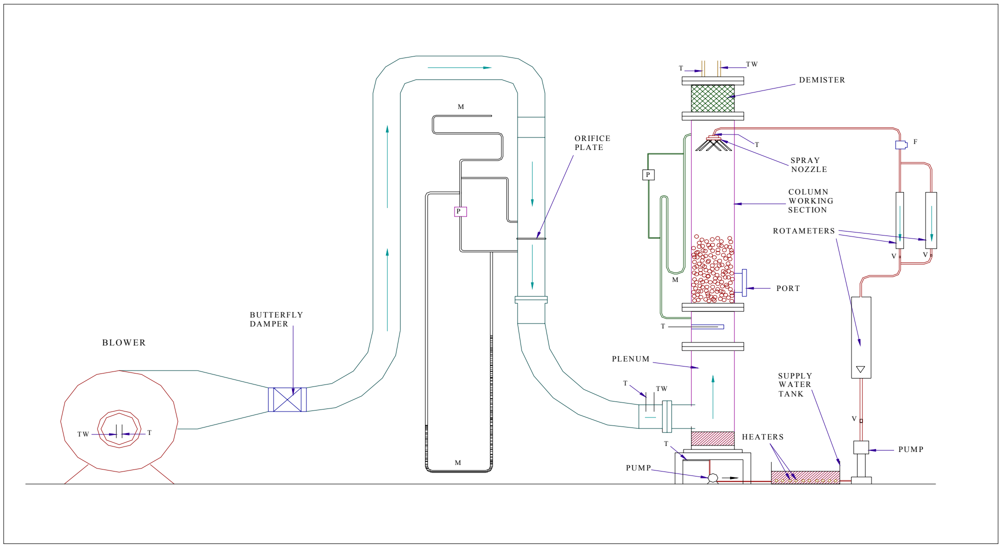

Figure 1. Schematic of the FBCT apparatus .

The nozzle height can be adjusted to vary the extent of the freeboard region. Instrumentation includes platinum resistance thermometers for measurement of the hot and cooled water temperatures, and the dry bulb and wet bulb air temperatures at inlet and outlet. The air and hot water flow rates are measured using an orifice plate and a turbine flow meter respectively. Pressure transducers are provided to measure the bed pressure drop and the orifice plate differential pressure. All measurement outputs are connected to a data-logger linked to a personal computer for rapid data acquisition and analysis. Barometric pressure and the static pressure at the orifice plate are recorded separately. A backup system of mercury-in-glass thermometers, Rota meters and U-tube manometers is also provided. The uncertainty associated with the PRT measurements is estimated to be less than ±0.5°C. Calibration data and manufacturers' specifications indicate that, apart from at the lowest end of the test ranges, the air flow rate and water flow rate measurements are accurate to ±5%. The average energy balance error for all the tests included in this paper is 11%.

Thermal performance testing of the FBCT apparatus described above has been conducted for both the fixed bed and the fluidized bed regimes. Test data have been obtained for the following approximate ranges of operating variables: water mass flux, $L = 0.3$ to $3.6\ \mathrm{kg/s\ m^2}$, water/air mass flux ratio, $L/G = 0.1$ to 5.5 and hot water inlet temperature, $T_w = 25$ to $55°\mathrm{C}$.

Three different sizes of spherical packings were employed, with diameters of 37.5, 25.4 and 20 mm and respective particle densities of 69, 326 and 239 $\mathrm{kg/m^3}$. The two smaller sizes are hollow polypropylene spheres and the largest size resembles table tennis balls. Tests were also made with the column empty. The static bed height was varied over the range 50 to 400 mm. In addition, two different commercial spray nozzles (Spraying Systems) were used; one with a 4 mm diameter single orifice that produces relatively coarse droplets of 2000 micron average median volume diameter, and a multi-orifice nozzle that produces finer droplets of 800 micron average median volume diameter. The height of the spray nozzle above the bed support grid, H, was varied from 400 to 1100 mm. A sample of results is presented in the following section.

RESULT AND DISCUSSION

The results showing the response of the FBCT performance characteristic to changes in different test variables are presented in Figures 2 to 4. In each figure, the caption shows the average values of other quantities that were held reasonably constant in the tests represented. Values of KaV/L were calculated from the test measurements using Merkel's equation (1):

$$KaV/L = dh/h_s - h_g \qquad (1)$$

Where V is taken as the static bed height, h_w is the specific enthalpy of the water stream, h_s is the specific enthalpy of saturated air at the water temperature, h_g is the specific enthalpy of the bulk air-water vapor mixture, given by $h_g = h_{g,,} + (L/G)(h_w - h_a)$, and the subscripts I and o denote inlet and outlet respectively. The integral in equation (1) was evaluated using the 4-point Tchebycheff approximation given in BS4485 (7). In Figure 2, KaV/L is plotted versus the particle diameter, d_p, of the spherical packings for seven different values of L/G.

The air flow rate, static bed height and the hot water inlet temperature are fixed. At all water/air mass flux ratios other than L/G = 0.23, KaV/L is consistently lower for the 37.5 mm spheres than for the 20 mm spheres. This appears to confirm the finding of Barile et al (3) who noted a similar tend using two spherical packing element diameters, 19.05 and 38.1 mm, approximating to the smallest and largest sizes used in this work. Figure 2 also shows that, for all but the highest value of L/G, the value of KaV/L is higher for the 25.4 mm spheres. This at first may seem to suggest an optimum diameter for the spherical packings. It should be noted, however, that the particle densities of the three sizes of spheres do not vary monotonically with sphere diameter (According to Section 2). Therefore, it is unclear if the trends seen in Figure 2 are due to variation of the sphere diameter, the particle density or a combination of both. Further work, using lower density 25.4 mm diameter spheres, is to be carried out to clarify this matter.

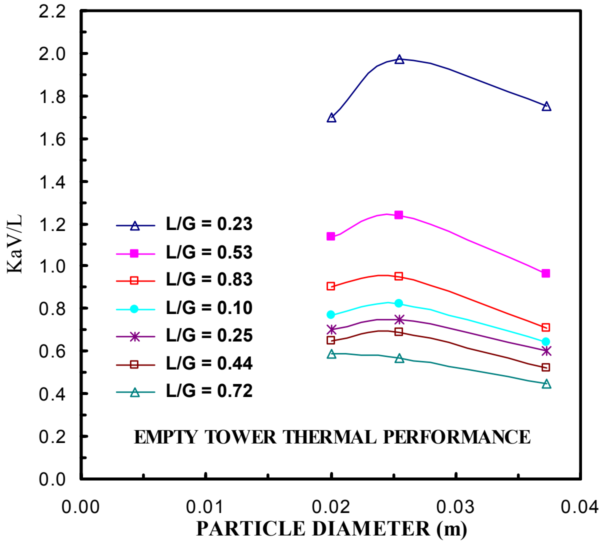

Figure 2. Effect of *L/G* and particle size on *KaV/L* (*G* = 2.5 kg/s m^2 , *V* = 300 mm , *H* = 600 mm (coarse spray) , *Tw,i* = 42.0 'C and *Twb* = 19.5 'C).

A strong dependence of KaV/L on L/G is also evident in Figure 2, and it can easily be established that this is not a simple inverse relationship as suggested by the appearance of L in the denominator of KaV/L. Factoring KaV/L by L/G, noting that F and G are fixed, reveals that the more fundamental quantity Ka, the product of the mass transfer coefficient and the interfacial area per unit volume, increases with water mass flux as found by previous workers (8, 9).

A much larger amount of test data showing the effects of water mass flux and the different size spherical packings on the tower characteristic is presented in Figure 3. With the exception of the change in the type of spray nozzle used and its height above the bed support grid, the other fixed parameters are the same as for Figure 2. Furthermore, the results confirm the relatively weak dependence of KaV/L on dp and the much stronger dependence of KaV/L (and Ka) on L. Figure 4 shows the effect of the air mass flux on KaV/L for a fixed water mass flux, and two different heights of the hot water spray nozzle. The packing used consisted of 37.5 mm diameter spheres and the static bed depth was 100 mm. As V and L are fixed, it can be deduced that the volumetric mass transfer coefficient, Ka, also increases with G in the same manner as KaV/L. Increasing the height of the spray nozzle above the packing introduces a spray zone that increases the interfacial area available for gas-liquid contact in the tower, and would be expected to lead to an increase in KaV/L for the tower. This is confirmed in Figure 4, where the lowest and highest air flow rates correspond to fixed bed operation, at a static bed height of 100mm, and full fluidization with an expanded bed height of approximately 400 mm respectively. Consequently with the nozzle set at H = 400 mm the spray zone height reduces from 300 mm to zero as the bed expands, and for H = 800 mm the corresponding reduction is from 700 mm to 400 mm. As the vertical separation of the two curves in Figure 4 remains reasonably constant, the percentage contribution to KaV/L of the additional spray zone height of 400 mm decreases as the bed expands with increasing gas flow.

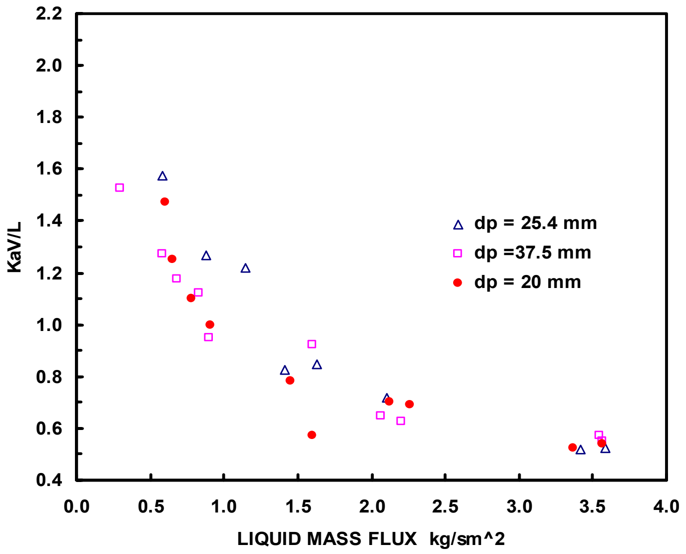

Figure 3. Effect of L and particle size on KaV/L (G = 2.5 kg/sm^2 , V = 300 mm. H = 400 mm (fine spray) , Tw,i = 41.8'C and Twb = 17.2'C).

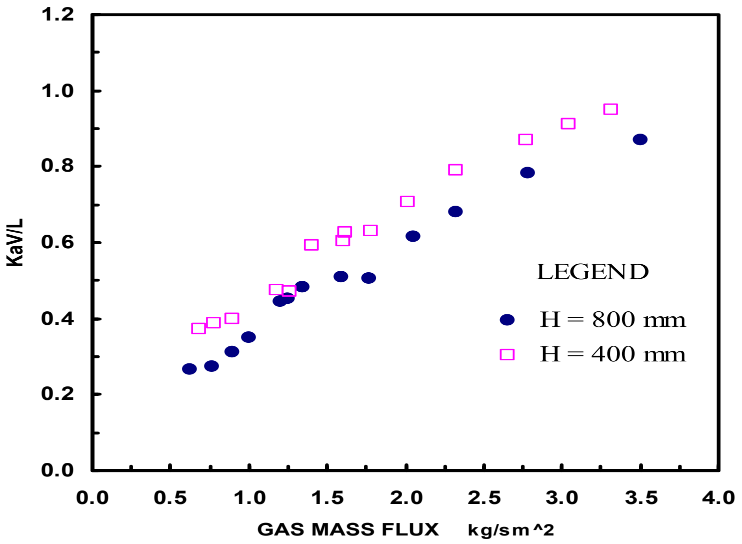

Figure 4. Effect of *G* and height of nozzle (fine spray) on *KaV/L* (L = 3.63 kg/s m^2 , *V* = 100 mm, dp = 37.5 mm, T*w,i* = 40.0 'C and T*wb* = 20.3 'C).

Also the relative velocity of the particle is an important aspect of the system performance. In particular, fluidized beds typically involve a complex mixture of solids with gases for which the relative velocity determines such aspects as fluidization velocity and mass and heat transfer. For each kind of particles, the minimum fluidizing velocity (U_{mf}) between the fluidized bed was measured and also it can be calculated. (10) See Table 1.

Table 1: Solid particle physical properties

Particle type	No	Diameter (mm)	Density (kg/m^3)	Velocity (m/s)
Hollow Sphere	1	37	325	0.62
Hollow Sphere	2	25	270	0.45
Hollow Sphere	3	20	70	0.30

CONCLUSIONS

Experiments were conducted on a fluidized bed cooling tower. The experimental results presented show the effects of the water and air mass fluxes on the tower characteristic, KaV/L, and the volumetric mass transfer coefficient, Ka, and confirm the findings of previous researchers.

To determine the effect of the diameter and the density of the spherical packing elements we plot the maximum heat transfer coefficient, h_{max} of these particles versus their parameter, d_p, as shown in Figure 5. The particles have a special character: for the same diameter, the packed density can be changed. Therefore, for mention sphere particles, particle diameter and packed density are two independent parameters.

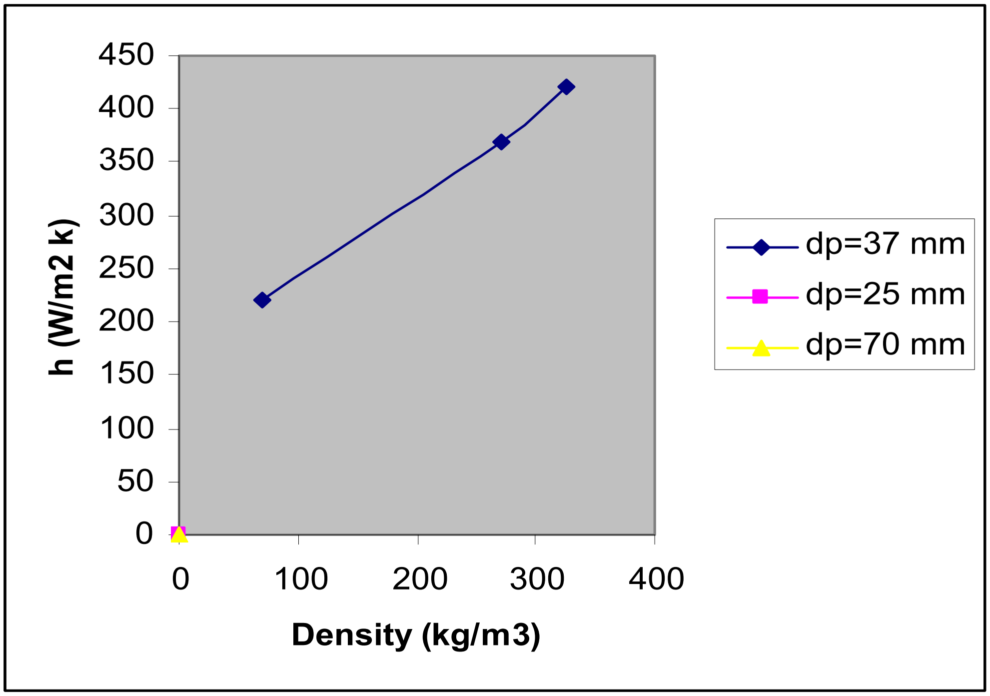

Figure 5: Influence of particle packed density on the maximum heat transfer coefficient h $_{max}$

It can see for particle with the same diameter h $_{max}$ increases as density increases. But the influence of density on h $_{max}$ is relatively small compared with density. Finally the experiment data show that with d_p, decreasing h $_{max}$ increases.

REFERENCES

(1) Wang, L., and Ping, W. (2004). "Effect of solid properties on heat transfer between high- temperature gas fluid bed and immersed surface". Applied Thermal Engineering 24(10), 2145- 2156.
(2) Teoman et al., (2001). "Factors effecting heat transfer between gas – fluidized beds and bubbling fluidized beds". Powder Technol, 101(2) , 85-91.
(3) Madhiyanan et al. (2006). "Mathematical model based on heat transfer for rapid high temperature treatment in fluidized bed". International journal of heat and mass transfer 49(1), 2277- 2290.
(4) Seetharamu, K. N and Swaroop, S. (1990). "The effect of size on the performance of a fluidized bed cooling tower". Warme – und Stoffubertragung, 26(1), 17 – 21.
(5) Barile, R.G., and Dengler, J.L., and Hertwig, T.A. (1974). "Performance and design of a turbulent bed cooling tower". AIChemE Symposium Series, I 70 (8), 154-162.
(6) El-Dessouky, H. (1993). "Thermal and hydraulic performance of a three-phase fluidized bed cooling tower". Experimental Fluid and Thermal Science, 6 (4), 31- 39.
(7) British Standard 4485. (1988). Water Cooling Towers, Part 2. Methods for Performance Testing. British Standards Institution, London
(8) Mazza, G., and Bressa F. (1997). "On the validity of the addition of independent contributions for evaluating heat transfer rates in gas fluidized beds". Powder

Technol, 90(1) , 1- 11.
(9) Molerus, O. (1999). "Resistance of particle beds at high Reynolds number , Chemical Engineering Science". 44, (5), 1071- 1079.
(10) Wu, S (1998). "Segration by size difference in gas fluidized beds". Powder technology, I 98(3), 139- 150.