Evaluation of two crossflow cooling tower splash fills

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ABSTRACT

A crossflow cooling tower test section has been designed and instrumented to facilitate the evaluation of various types of fill materials commonly used in crossflow cooling towers. Two types of fill material have been tested to obtain correlations for their performance in crossflow by applying the Merkel theory to the measured data.

It is concluded that the facility developed can be used to accurately determine the transfer and pressure-drop characteristics of any type of cooling tower fill in crossflow and to carry out comparative tests between different fill materials.

Nomenclature

a	Area of transfer surface per unit volume	[m²/m³]
C_p	Specific heat at constant pressure	[J/kg K]
X	Fill depth (in air flow direction)	[m]
G	Air mass flow rate per unit area	[kg/m² s]
h_D	Mass transfer coefficient	[kg/m² s]
i	Enthalpy	[J/kg]
K	Mass transfer coefficient	[kg/m² s]
KaY/L	Transfer characteristic	[–]
L	Water mass flow rate per unit fill material area	[kg/m² s]
m	Mass flow rate	[kg/s]
N_p	Resistance coefficient	[m⁻¹]
P	Pressure	[N/m²]
T	Temperature	[°C]
v	Air velocity (based on frontal area)	[m/s]
V	Fill volume	[m³]
Y	Fill height (in water flow direction)	[m]
ρ	Density	[kg/m³]

Subscripts

a	Air
asw	Saturated air at bulk water temperature
i	Inlet
o	Outlet
w	Water

Introduction

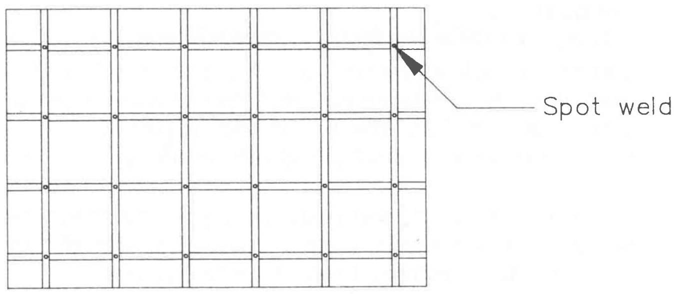
Direct contact evaporative cooling towers are used extensively in industry to remove superfluous industrial heat. For brevity, cooling towers are heat transfer devices in which water is evaporatively cooled by means of a counterflowing or crossflowing airstream, as it descends through a fill. The fill serves to increase the heat and mass transfer area between the water and the air, by either breaking the water up into numerous droplets or spreading it into a thin film, depending on the type of fill and the tower configuration.

As manufacturers of cooling towers often do not supply the transfer characteristics of their fill freely, small-scale test facilities can be used to determine these characteristics from experimental data.

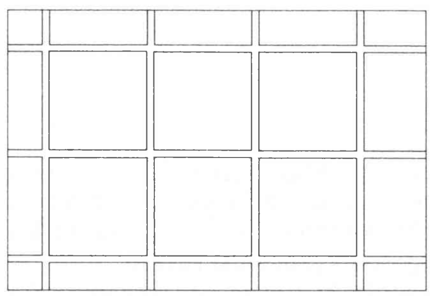
The theoretical model generally used for this purpose, is the well-known Merkel model, which uses a combined heat and mass transfer coefficient with enthalpy difference as driving force.

The Merkel model was used in conjunction with experimental measurements, to determine the performance characteristics of two crossflow cooling tower fills i.e. a stainless steel mesh and an injection moulded plastic grid shown schematically in Figure 1 (a) and (b). The performance characteristics were determined from data obtained from tests conducted in a 2 × 2 × 1.5 m³ crossflow test facility, for water temperatures ranging between 35 °C and 45 °C.

The results, used for crossflow cooling tower performance prediction, are correlated in terms of water and air flowrates.



a) Fabricated steel mesh
Thickness = 0.5 mm
Open fraction = 80%



b) Injection moulded plastic grid
Thickness = 25 mm
Open fraction = 90%

Figure 1 – Schematic representations of fills evaluated

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Available information on fill evaluation

In order to assist the engineer, the British Standard [1], Singham [2] and the Cooling Tower Institute [3] discuss the experimental aspects of fill performance evaluation and deal with subjects like test conditions, test requirements, test procedure, methods of measurement, instrumentation and computation of results using Merkel theory.

The transfer characteristics of many types of commercially available fill have not been published. However, Electric Power Research Institute [4] and Cale [5] describe the experimental test detail and the performance characteristics of a number of counterflow and crossflow fills, evaluated in their test facilities.

Theory of crossflow cooling towers evaluation

Merkel [6] derived a simplified model for counterflow cooling tower operation in terms of an enthalpy driving potential. This model, which is equally applicable to crossflow cooling towers, can be written as two differential equations

$$dT_w = -\frac{m_a di_a}{m_w C_{pw}} \tag{1}$$

$$di_a = \frac{h_D a dV}{m_a}(i_{asw}-i_a) = \frac{KadY}{L}\frac{m_w}{m_a}(i_{asw}-i_a) \tag{2}$$

where $\frac{KadY}{L}$ is termed the transfer characteristic.

With the test section inlet and outlet conditions known, these equations can be integrated numerically using an iterative procedure to determine the fill transfer characteristic (see Stoecker & Jones [7]).

Figure 2 gives a schematic representation of a crossflow differential element with regard to the Merkel equations.

The transfer characteristic of fill material is strongly dependant on fill geometry and is correlated for crossflow as a function of its operating parameters by an equation of the form

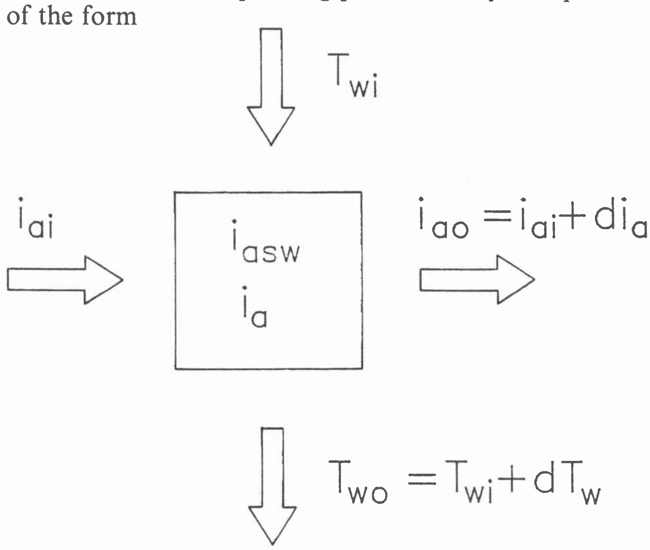

Figure 2 – Merkel Equation applied to a crossflow element

$$KaY/L = C_1(L/G)^{-n} \tag{3}$$

where C_1 and n are constants for a particular fill pack.

The similar equation for counterflow cooling towers differs from the crossflow with regard to the constants, as the air and the water flow are at right angles to each other.

Another important factor influenced by the geometry and density of fill material, is its airflow resistance. This gives an indication of the fan power required to achieve a specific air flowrate.

The airflow resistance of a fill packing is expressed in terms of a pressure coefficient

$$N_p = \frac{(\delta P/X)}{\frac{1}{2}\rho_a v^2}\ [m^{-1}] \tag{4}$$

N_p, determined from test data, is correlated as a function of the operating parameters L and G

$$N_p = a\, L^b\, G^c\ [m^{-1}] \tag{5}$$

whera a, b and c are constant for a particular fill pack.

Description of experimental apparatus

Figure 3 shows the schematic layout of the experimental apparatus.

Operation

A variable-speed centrifugal fan, downstream of the $2 \times 2 \times 1.5\ m^3$ test section, draws atmospheric air into the wind tunnel. Hot water in a 40 000 litre reservoir, is pumped to the water distribution system, which spreads the water evenly onto the fill material. The water falling through the fill, is collected in a sump from which it is returned to the reservoir.

The water distribution system, shown in Figure 4, consists of thirty 2m × 20 mm ø high pressure plastic tubes, situated inside 2m × 40 mm ø PVC pipes. Each of the outer tubes has a narrow slot cut lengthwise on the lowest point. The high pressure tubes are connected to the water inlet manifold and spray water through evenly spaced 1 mm ø holes along their length, into the larger diameter PVC pipes. The water in the PVC pipes, trickles from the slots onto the fill. The small holes in the upper side of the smaller tubes ensure an even water distribution in the PVC pipes.

The fill in the test section rests on tensioned wire, attached to galvanised angle iron runners. The angle irons are riveted to the walls on both sides of the test section, at 100 mm intervals, allowing a maximum of nineteen layers of fill.

Measurements

The air mass flow rate is determined by measuring the pressure drop over a set of four elliptical nozzles. The air density of the air passing through the nozzles is determined from wet and dry bulb temperature readings, measured just upstream of these nozzles, and atmospheric pressure.

The supply water mass flow rate is determined by

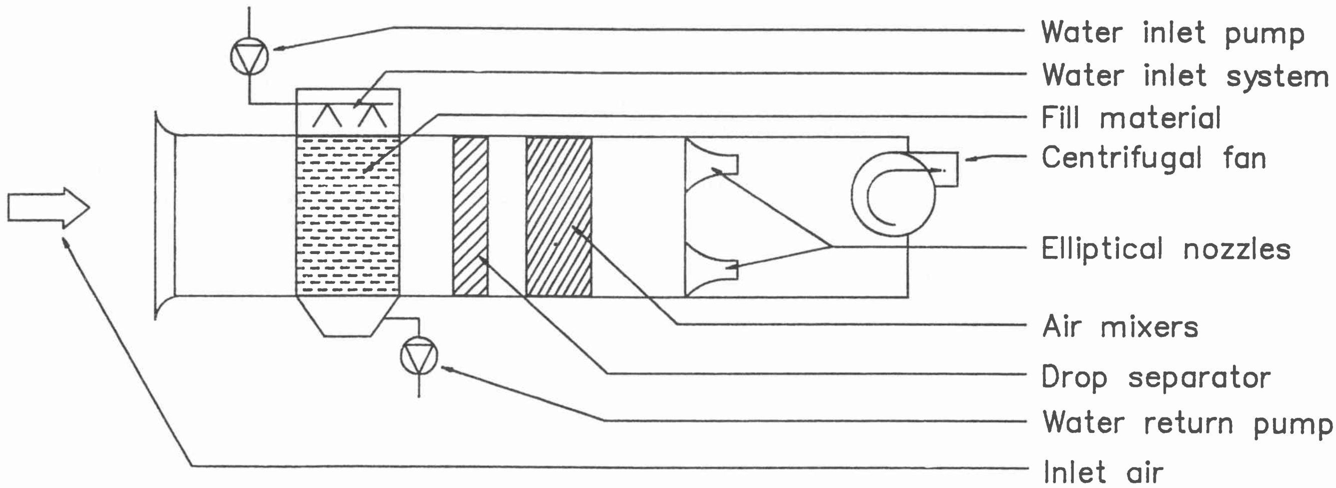

Figure 3 – Schematic representation of the test facility

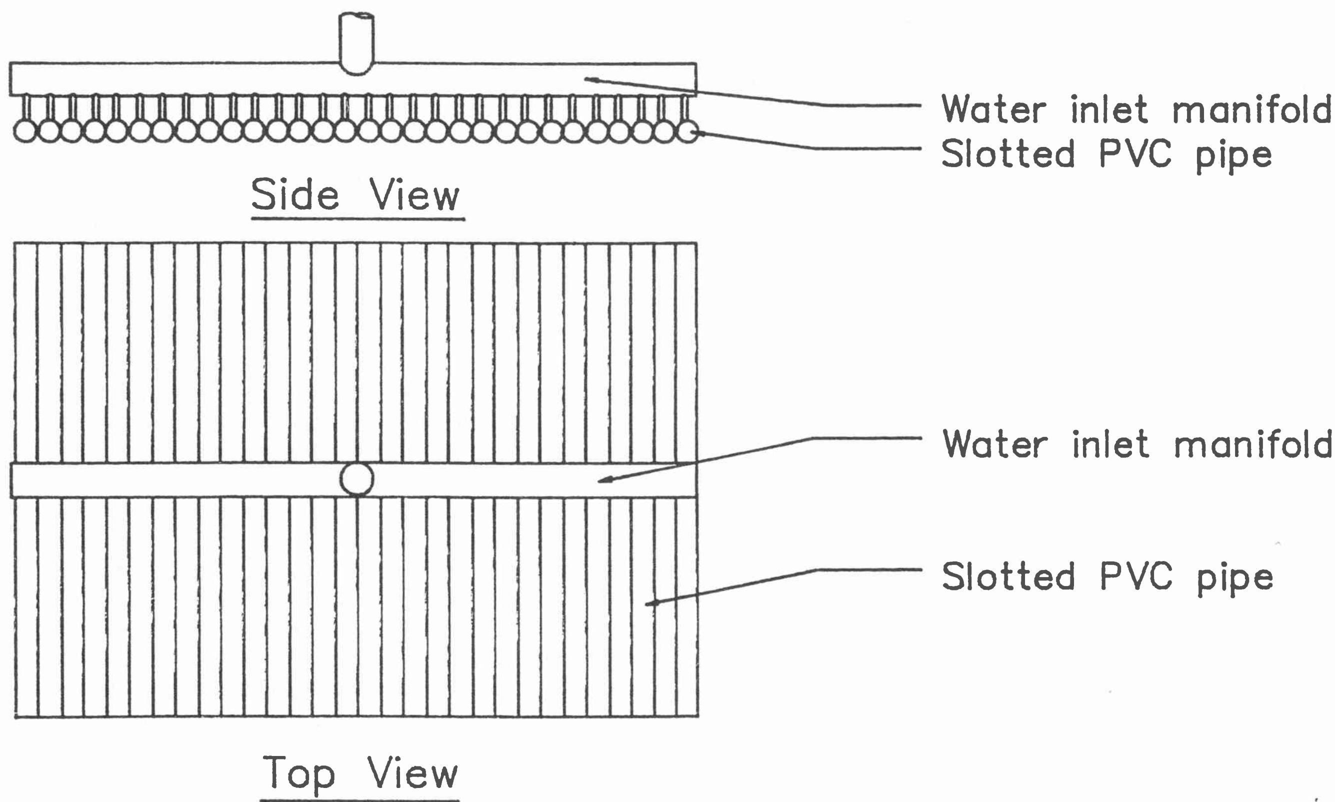

Figure 4 – Schematic representation of water distribution system

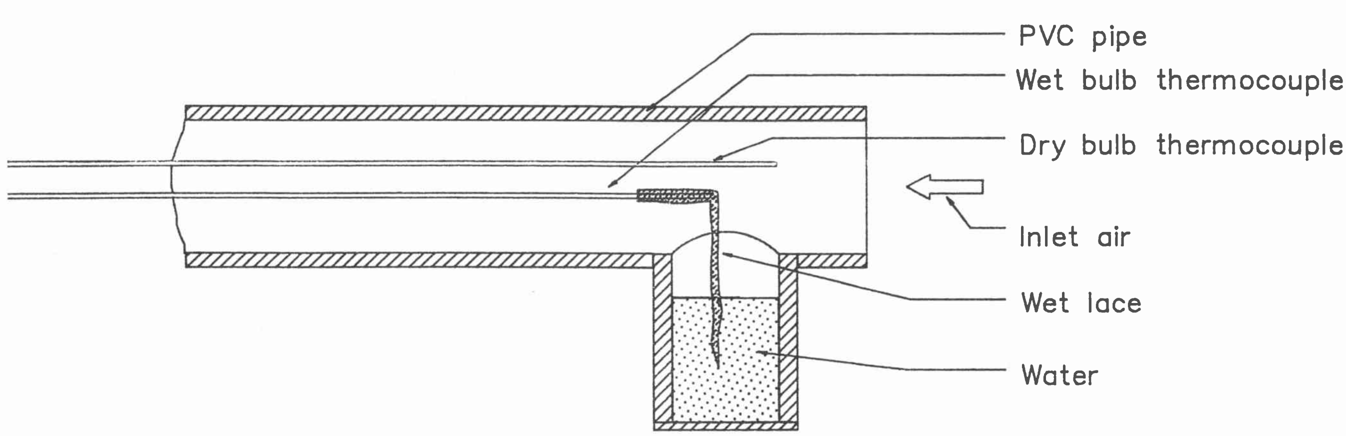

Figure 5 – Schematic representation of a wet and dry bulb measuring station

measuring the pressure drop across a standard orifice plate in the supply pipe.

Calibrated pressure transducers are used to measure the differential pressures across the nozzles and the orifice.

Air inlet and outlet conditions are measured using four sets of wet bulb and dry bulb copper-constantan thermocouples, upstream and downstream of the test section. As shown in Figure 5, each set of thermocouples is positioned in a PVC pipe connected to the suction side of a small fan. In this way air is continuously drawn across the thermocouples at approximately 3 m/s to eliminate radiation effects and ensure good wet bulb temperature readings.

For accurate average outlet air condition measurement, the outlet air measurement stations are situated behind a set of air mixing louvres.

The thermocouples and differential pressure transducers are all connected to an analogue to digital datalogger, which in turn is linked to a personal computer. The computer is programmed to process incoming data from the data-logger.

Experimental procedure

The water used for the fill evaluation tests, is heated to approximately 45 °C in a 40 000 litre reservoir, and then it is pumped to the cooling tower test facility. Measurements are taken at five different air mass flow rates at each of five water inlet flowrates, giving twenty five averaged data points for each test.

All tests were conducted for the following conditions:
(i) water inlet temperatures between 35 °C and 45 °C
(ii) water mass flow rates between 1.5 [Kg/m²/s] and 4 [kg/m²s]
(iii) air flow rates between 1 [kg/m²s] and 2.4 [kg/m²s]
(iv) air inlet wet bulb temperatures between 9 °C and 16 °C

Results

The transfer characteristic and fill resistance correlations for stainless steel mesh and a significantly thicker injection moulded plastic grid, was determined from tests done in the crossflow test facility as described above.

The stainless steel mesh was evaluated for horizontal fill spacings of 100 mm, 200 mm and 300 mm, for which the following results were obtained.

100mm fill spacing:

$$KaY/L = 0.6648 (L/G)^{-0.3381}$$

$$N_p = 2.0294 (L)^{0.6747} (G)^{-0.8381} [m^{-1}]$$

200mm fill spacing:

$$KaY/L = 0.4753 (L/G)^{-0.2938}$$

$$N_p = 3.2534 (L)^{0.4774} (G)^{-1.0891} [m^{-1}]$$

300mm fill spacing:

$$KaY/L = 0.3866 (L/G)^{-0.3383}$$

$$N_p = 1.5719 (L)^{0.5184} (G)^{-0.6354} [m^{-1}]$$

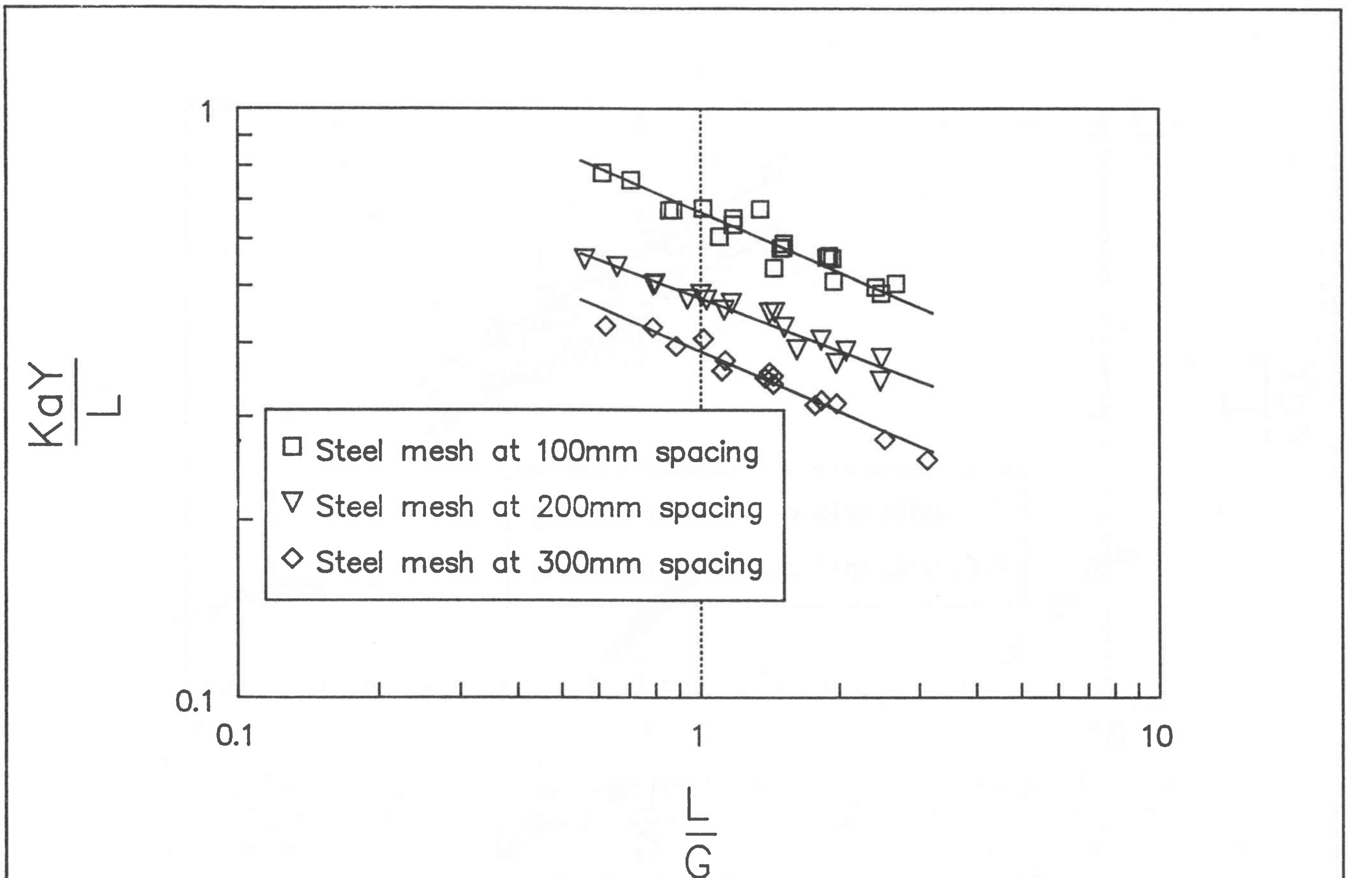

Figure 6 – Transfer characteristic correlations for steel mesh

A graphical representation of the transfer characteristic correlations is shown in Figure 6.

Due to the thickness of the plastic grid (approximately 25 mm) it was only evaluated for horizontal fill spacings of 200 mm and 300 mm, as the blockage effect would render tests for a fill spacing of 100 mm impractical. The following results were obtained.

200 mm fill spacing:

$$KaY/L = 0.5681\ (L/G)^{-0.4532}$$

$$N_p = 3.6173\ (L)^{0.4073}\ (G)^{-0.5294}\ [m^{-1}]$$

300mm fill spacing:

$$KaY/L = 0.4501\ (L/G)^{-0.4354}$$

$$N_p = 2.9993\ (L)^{0.4542}\ (G)^{-0.6944}\ [m^{-1}]$$

A graphical representation of the transfer characteristic correlations is shown in Figure 7.

As the transfer characteristic data only refers to its cooling potential, a relation $(KaY/L)/N_p$ was used to express the over-all efficiency of fill. This relation gives an indication of the fan input needed to obtain a certain cooling potential, and serves as a means of comparing fills. Figure 8 uses this relation, to compare the efficiencies of the two types of fill evaluated.

Discussion of results

From the Merkel equations (1) and (2), it can be seen that fill material having a higher transfer characteristic, (KaY/L value), has the better thermal performance than one with a low KaY/L value. This KaY/L value of a fill material, is dependant on a combination of two factors, i.e. the geometry of the fill and the fill density. These factors determine the transfer area between the water and the air, with regard to the breaking up of the water into numerous small droplets and also retarding its average velocity through the cooling tower.

From Figures 6 and 7, the effects of both the factors mentioned above can clearly be seen. The transfer characteristic of the steel mesh spaced at 100 mm is very similar to that of the plastic grid spaced at 200 mm for the higher air flow rates. This better KaY/L value of the plastic fill can be attributed to greater air turbulence in the cooling tower, due to its thickness. For higher water flow rates and low air flow rates however, the transfer characteristic of both fills are similar for corresponding fill spacing. This can be ascribed to the similar fill geometries in the water flow direction.

From Figure 8, it is however seen that the over-all efficiency of the steel mesh is better than that of the plastic grid, especially for higher air flow rates. This is ascribed mainly to the blockage factor of the plastic grid, which contributes to a higher pressure drop.

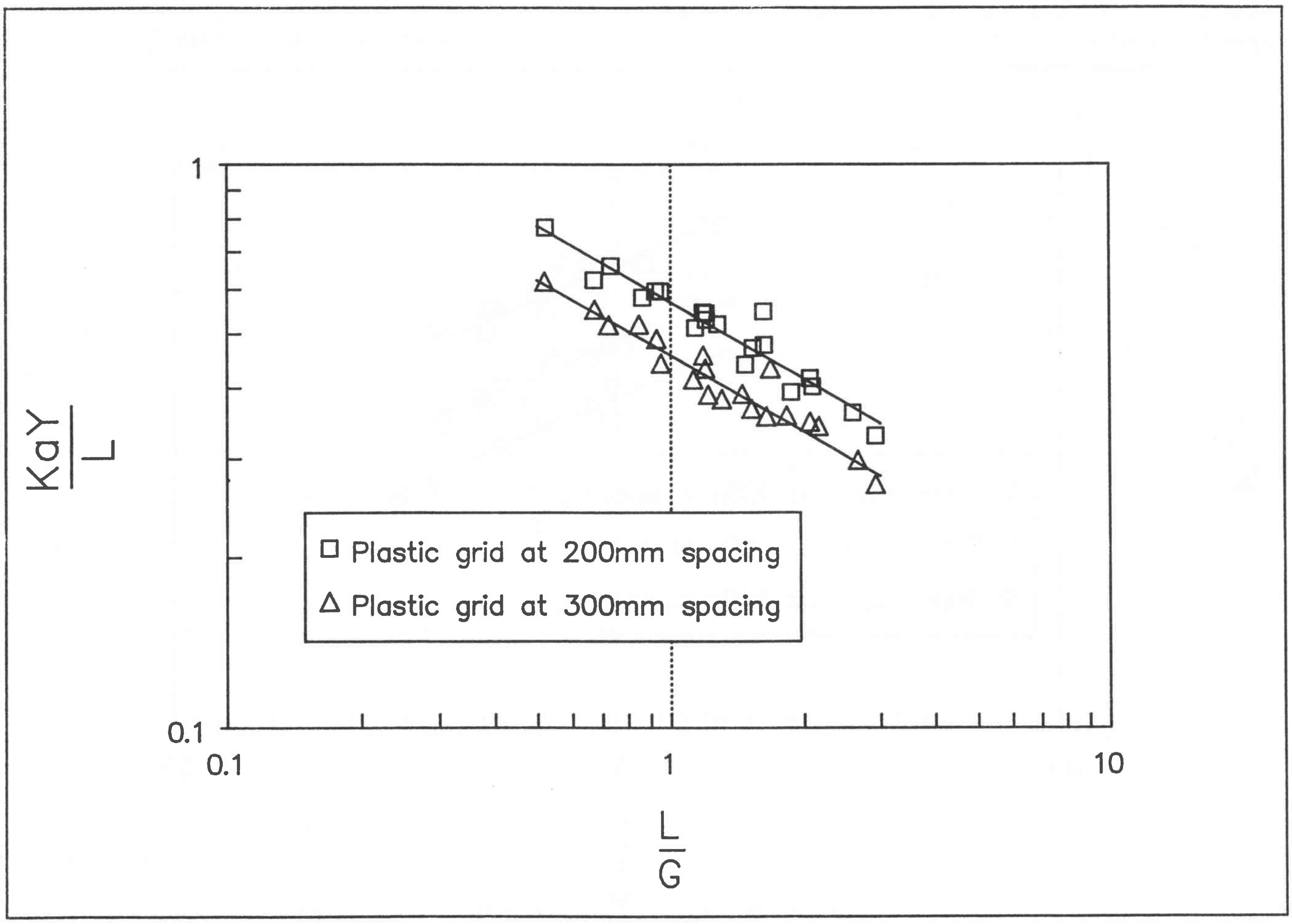

Figure 7 – Transfer characteristic correlations for plastic grid

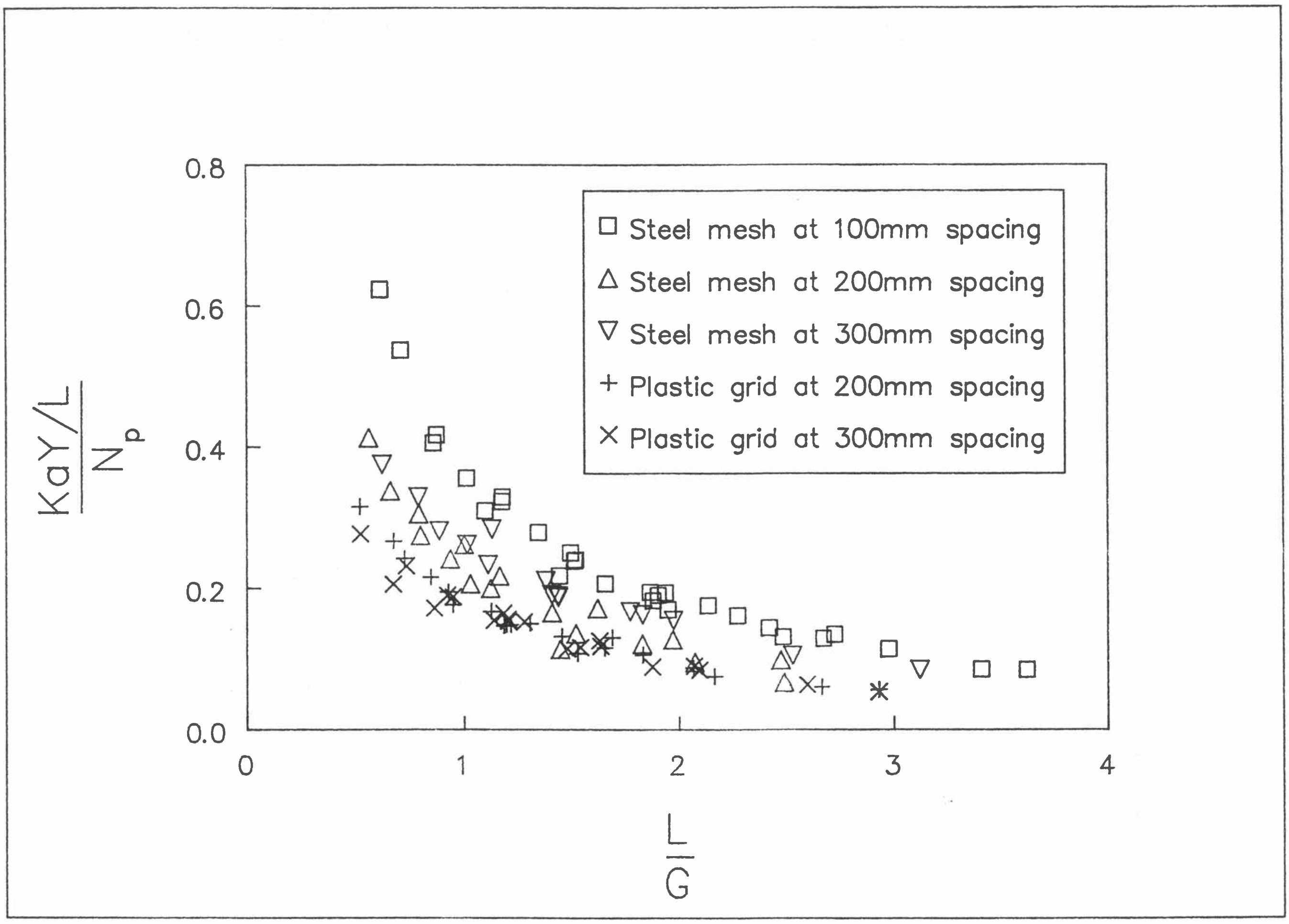

Figure 8 – Fill efficiencies

Conclusion

A useful test facility and computer program to measure the pressure drops and transfer coefficients of cooling tower fill material in crossflow have been developed.

Consistent correlations characterising two fill materials were obtained and compared.

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