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Heater Surface Coating Effect on Fluidized Bed Heat Transfer Coefficient

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ABSTRACT

The effect of different coatings painted on the heat transfer surface of the horizontal heater in a vertical fluidized bed heat transfer unit is studied. Polyurethane and polyurethane based zinc coatings are applied on the horizontal heat transfer surfaces and their effects on the heat transfer coefficient are investigated for different heater heights, different heater heat inputs and for different superficial velocities. It is found that the application of polyurethane coatings has decreased the heat transfer coefficient as compared to the heat transfer coefficient obtained with the bare uncoated heater. It is also found that by applying the polyurethane based zinc coatings the heat transfer coefficient has increased as compared to that obtained with the polyurethane coating. Procedure and the results of the experiments done to study this fluidized bed heat transfer analysis are presented in this paper.

Keywords: *Fluidisedbed heat transfer coefficient, solid-gas flow, heater surface coating, superficial velocity*

Nomenclature
H_H or HH: Height of the heater from the reference line

1. INTRODUCTION

Fluidized bed heat transfer devices such as fluidized bed boilers, dryers etc. have gained popular acceptance because they have demonstrated that they can burn a wide variety of solid fuels efficiently and in an environmentally acceptable manner. The heat transfer coefficient from the solid-gas two-phase flow to the immersed surface in the fluidized bed is an important parameter in overall equipment design and in ensuring efficient operation and control. Following information is available in the research papers [1-13] viz. the effect of fluid velocity on heat transfer, the effect of the thermal conductivity of the solid and the fluid on the heat transfer coefficient, the effect of the specific heat of the solid particles and the fluid on the heat transfer coefficient at various operating parameters, the influence of the fluid bed height, the length of the heat transfer surface, the heat transfer tube diameter, the ratio of the tube bundle spacing to the tube diameter in vertical and horizontal tube bundles on the heat transfer coefficient, the influence of the bed pressure and the temperature on the gas convective heat transfer component and the particle convective heat transfer component. In this paper, the effects of the different coatings applied on the heat transfer surface of the horizontal heater in a vertical fluidized bed chamber are studied. Different coatings are applied on the horizontal heater in the vertical fluidized bed chamber and their effects on the fluidized bed heat transfer coefficient are studied and are putforth in the present paper.

2. EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is shown in Fig. 1. Bed of fused alumina (white aluminium oxide of average particle size 250 µm and density 3770 kg / m^3), about 0.08m height, was contained in a vertical glass cylinder of 0.105 m internal diameter and 0.22 m height. At the lower end of the cylinder a distribution chamber and an air distributor were affixed to ensure uniform airflow into the bed without causing excessive pressure drop. On leaving the bed, the air was made to pass through the chamber and then the air escaped to the atmosphere through a filter. The chamber, filter and the distributor assembly were suspended from a bracket mounted on the panel. In this bracket, probes for temperature and pressure measurement, a horizontal cylindrical heating element were accommodated in such a way that they can be moved vertically to any level in the bed chamber. Air from the compressor was delivered through a filter, an air flow meter fitted with a control valve and an orifice plate to the distribution chamber.

A variable transformer was used to control the heat transfer rate from the horizontal heating elements. All the heating elements used for the experimentations were basically cylindrical copper sleeved resistance heaters of 0.0158 m diameter and 0.050 m length on which different coatings were applied. The specifications of these heaters used for the investigations are given in Table 1.

Table 1. Specifications of the heaters used for the experimentations

Heater No.	Specifications
1	Bare heater of 0.0158 m diameter × 0.050 m length, with no coating over it
2	heater of 0.0158 m diameter × 0.050 m length, with polyurethane coating of 0.000115 m thickness over the heating surface
3	heater of 0.0158 m diameter × 0.050 m length, with polyurethane coating of 0.000215 m thickness over the heating surface
4	heater of 0.0158 m diameter × 0.050 m length, with polyurethane based zinc coating of 0.00023 m thickness over the heating surface
5	heater of 0.0158 m diameter × 0.050 m length, with polyurethane based zinc coating of 0.0003 m thickness over the heating surface

Coatings for heater 4 and 5 were prepared by addition of zinc metal powder (Merck Ltd., Mumbai) of average size ~ 45 µm in polyurethane paint (Asian Paints (I) Ltd., Mumbai) and the concentration of the zinc powder in polyurethane paint was 3.94 gm of zinc powder per 1 gm of polyurethane paint. The mixture of zinc powder and polyurethane paint was thoroughly mixed and then applied on the heater surfaces. Enough care was taken to apply the coating uniformly over the whole heating surface. After applying the coatings, the coated heaters were allowed to dry completely. When the heaters were dried completely, the thickness of the coating was determined with the help of Micrometer (Mitotoyo Corporation, Tokyo). Voltmeter (0 –250 V) and Ammeter (0 – 3 A) were used to display the voltage and current taken. The surface temperature of the heating element was measured with the help of thermocouple bids pasted on the heating element surface underneath the coating as shown in Fig. 1. A digital temperature indicator with a selector was used to indicate the temperatures of the heating element, the air supplied to the distributor and the bed. The pressure of the air at any level in the bed chamber was measured with the help of a liquid filled manometer. An excess pressure relief device was used if pressure rose above 0.030 m of H_2O. Here it is to be noted that the thicknesses of the coatings were chosen very carefully to study the heat transfer phenomenon.

3. EXPERIMENTAL PROCEDURE

Air from the compressor was allowed to pass through the chamber and its superficial velocity was noted. The electric heater was powered and its heating inputs were noted in terms of Volts and Amperes readings from the Voltmeter and Ammeter. Temperatures of the heating element, bed and the air supplied were taken from the digital temperature indicator.

By varying the superficial velocity and the heater heat input following fluidized bed heat transfer analysis has been done:

1. ***Study of the heat transfer coefficient associated with the bare cylindrical heater (with no coating over it) i. e. Heater 1 only****:* effect of the heater height on the heat transfer coefficient has been studied. For different heights of the heater, the superficial velocity and the heater heat input were varied; the heat transfer coefficient values have been found out and are plotted in Fig. 2.
2. ***Study of the effect of the coatings, applied on the heaters i. e. heater 2 – 5, on the heat transfer coefficient:*** Individual heaters were affixed inside the fluidized bed chamber one by one and the analysis has been done as below:
   Study of the effect of the heater height H_H on the heat transfer coefficient for different heat inputs and for different superficial velocities has been done. For the heaters, heater 2 – heater 5, H_H was varied and the effect of heater height on the heat transfer coefficient was investigated, the heat transfer coefficient values have been found out and are shown in Fig. 3 to Fig. 6.

4. OBSERVATIONS AND DISCUSSION

Comparison of the results of the heat transfer studies has been done and is given in Table 2. Considering the Fig. 2 – Fig. 6, for all the cases i. e. the case of the bare heater (heater 1) and the cases of the heaters painted with coatings (heater 2 – heater 5), it is concluded that the heat transfer coefficient increases with the increase in the heater heat input and the superficial velocity and the heat transfer coefficient decreases by increasing the heater height H_H.

The comparison of the experimental data of the heat transfer coefficient values between the cases of the heaters painted with polyurethane coatings i. e. heater 2 and heater 3 is given in Fig. 7. From Fig. 7, it is concluded that, with the increase in the coating thickness of polyurethane, the heat transfer coefficient values have decreased. Similarly, the comparison of the experimental data of the heat transfer coefficient values between the cases of the heater painted with polyurethane based zinc coatings i. e. heater 4 and heater 5 is given in Fig. 8 – Fig. 9 and it is observed from these figures that with increase in the polyurethane based zinc coating thickness, the heart transfer coefficient values have also increased. The comparison of the experimentally found heat transfer coefficient values among the bare heater, the polyurethane painted heater with 0.00215 m thickness and the heater painted with polyurethane based zinc coating of thickness 0.0003 m is portrayed in Fig. 10 (for heater height 0.11m) and Fig. 11 (for heater height 0.13 m). From Fig. 10 and Fig. 11, it is inferred that the heat transfer coefficient

Table No. 2 Comparison of the results of the heat transfer studies

Cases studied	Attributes	Comments and Discussion
A. Study of the effect of the heater height on the heat transfer coefficient for the bare cylindrical heater alone	H_H : 0.11 m, 0.13 m and 0.15 m. Heater heat input and the superficial velocity were varied.	From the Fig. 2, it is concluded that the heat transfer coefficient has increased as the heater heat input and the superficial velocity have increased. Also it has been found that, as the heater height increases the heat transfer coefficient decreases.
B. Study of the case of the heater 2 which is painted with polyurethane coating of thickness 0.000115m.	H_H : 0.11 m, 0.13 m and 0.15 m Heater heat input and the superficial velocity were varied.	From the Fig. 3, it has been found that, by increasing the heater height the heat transfer coefficient decreases. The heat transfer coefficient has increased as the heater heat input and the superficial velocity have increased.
C. Study of the case of the heater 3 which is painted with polyurethane coating of thickness 0.000215m.	H_H : 0.11 m, 0.13 m and 0.15m Heater heat input and the superficial velocity were varied.	It has been inferred form Fig. 4, the heat transfer coefficient decreases with increase in the heater height $H_{H.}$ The increase in the heater heat input and the superficial velocity resulted in increase in the heat transfer coefficient.
D. Study of the case of the heater 4, which is painted with polyurethane, based zinc coating of thickness 0.00023 m.	H_H : 0.11 m, 0.13 m and 0.15m Heater heat input and the superficial velocity were varied.	From the Fig. 5 it has been concluded that, the increase in the H_H has resulted in decrease in the heat transfer coefficient. Increase in the superficial velocity and the heater heat input has resulted in increase in the heat transfer coefficient.
E. heater of 0.0158 m diameter × 0.050 m length, with polyurethane based zinc coating of 0.0003 m thickness over the heating surface	heater of 0.0158 m diameter × 0.050 m length, with polyurethane based zinc coating of 0.00023 m thickness over the heating surface	It is found from Fig. 6 that the heat transfer coefficient increases with the increase in the heater heat input and the superficial velocity and decreases with the increase in the H_H.

values obtained with the heater coated with the polyurethane based zinc coating are more than those obtained with the heater with only polyurethane coating. Comparison of the heat transfer coefficient values between the bare heater and the heater coated with polyurethane based zinc coating i. e. heater 5 shows that, the heat transfer coefficient values for the heater painted with the polyurethane based zinc coating are lower than those of the bare heater. But the rate of increase of heat transfer coefficient values with the superficial velocity for the heater coated with the polyurethane based zinc coating of thickness 0.0003 m is same as that of the bare heater at H_H 11 m (for 17.25 W and 22.5 W heater heat input) and at H_H 0.13 m. The heat transfer coefficient values obtained with the polyurethane coated heater are lower than those obtained with the bare heater.

It is concluded from this experimental investigation of carefully chosen coating thicknesses that, the coating of polyurethane has offered thermal resistance to the heat transfer while the inclusion of zinc in polyurethane has overcome this heat resistive effect and together with the phenomenon of boundary layer (which couldn't be studied here in detail), heater with the polyurethane based zinc coating gave the higher values of the heat transfer coefficient as compared to those obtained with the polyurethane coated heater. In the present study, effect polyurethane based zinc coating of only concentration i. e. 3.94 gm of zinc powder per 1 gm of polyurethane paint, was investigated. Effect different coating concentrations for the same coating thickness, on the heat transfer properties are to be analyzed for thorough understanding. Also more experimental data for different coatings of various thicknesses and various coating concentrations is needed for wide range of experimental variables.

5. CONCLUSION

Experimental assessment is done to find out the possibility of the application of the different coatings over the heat transfer surface of the horizontal heater to increase the vertical fluidized bed heat transfer coefficient. Different thicknesses of polyurethane coating and polyurethane based zinc coating are applied and their effect on the heat transfer coefficient with increase in the superficial velocity, heater heat input and the heater height are investigated. In order to analyse the phenomenon of heat transfer, thicknesses are chosen wisely and it is fount that, the application of polyurethane coating has rendered thermal resistance, thus decreasing the values of the heat transfer coefficient. Also by increasing the polyurethane coating thickness, the heat transfer coefficient values have decreased. In the case of heaters with polyurethane based zinc coatings, with increase in the thickness of polyurethane based zinc coating the heat transfer coefficient has increased. Heat transfer coefficient values for the heater painted with polyurethane based zinc coating are lower than those obtained with the bare heater but higher than those obtained with the polyurethane coated heater. The reason for this can be attributed to the addition of zinc, which has overcome the thermal resistance offered by polyurethane and the boundary layer phenomenon. More experimental analysis of the system along with the detail study of boundary layer phenomenon, for different coatings of various thicknesses and various coating concentrations is required.

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Legends for the figures

H_H or HH: Height of the heater from the reference line

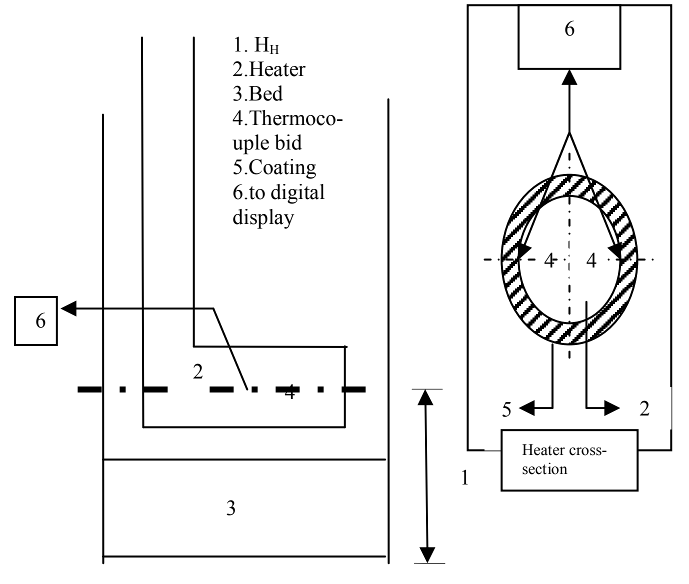

Fig. 1. Schematic of the Experimental Setup

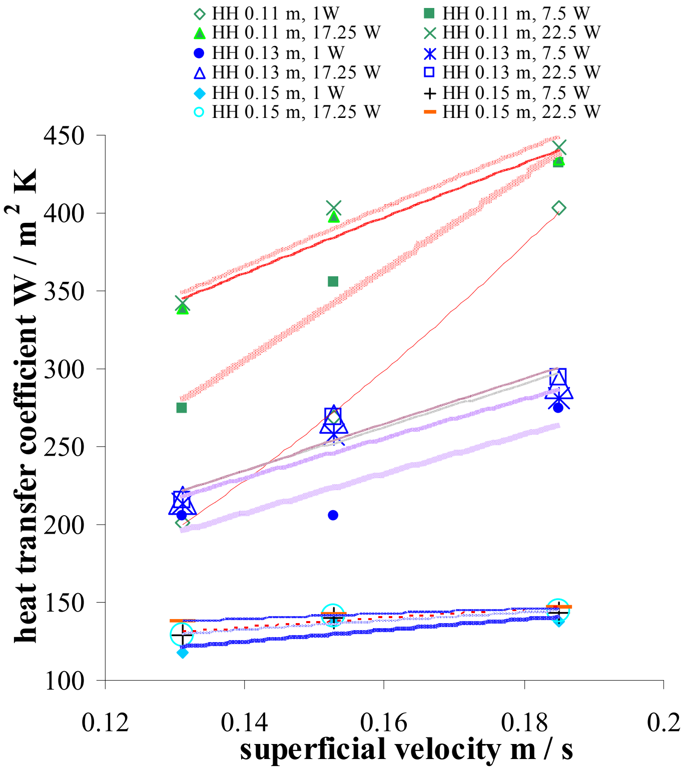

Fig. 2. Variation of heat transfer coefficient with superficial velocity for the bare cylindrical heater only

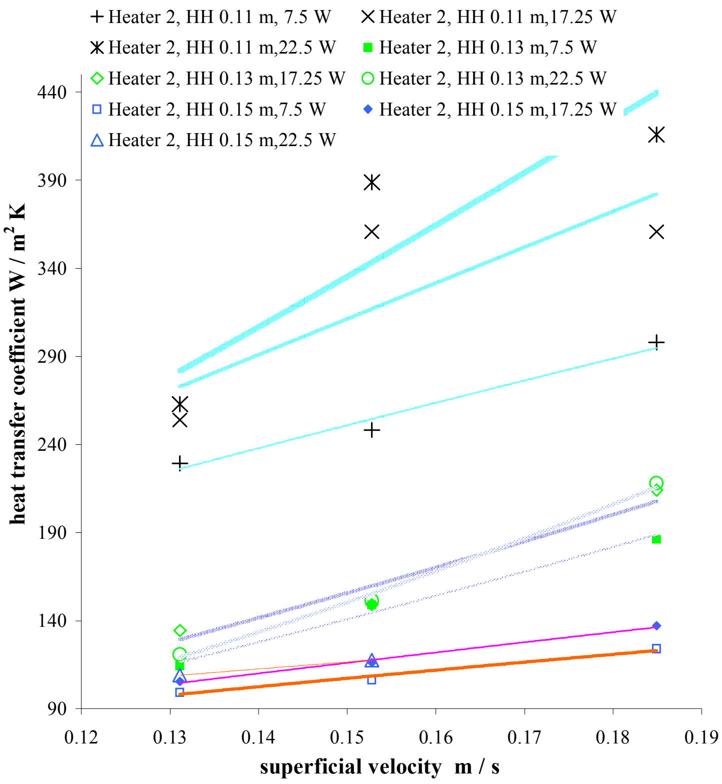

Fig. 3. Variation of heat transfer coefficient with superficial velocity for the case of heater 2 i. e. the heater painted with polyurethane coating of thickness 0.000115 m

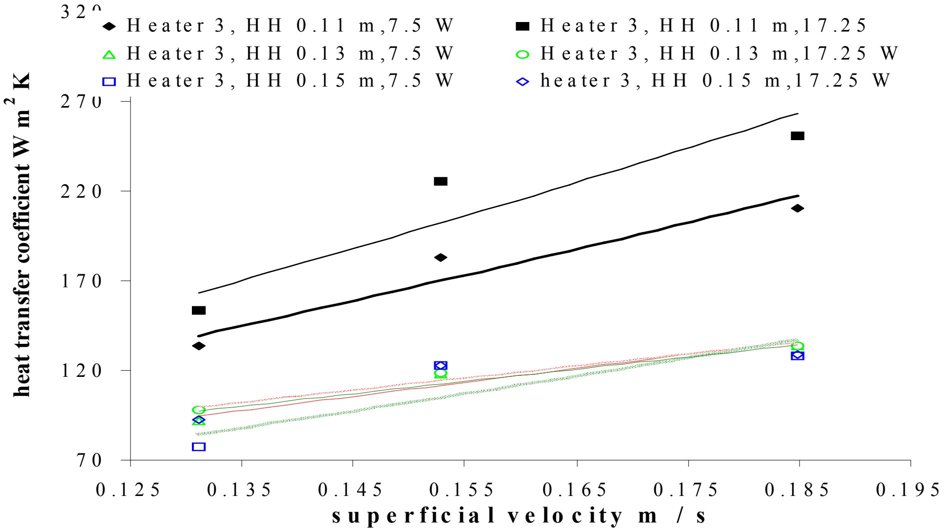

Fig. 4. Variation of heat transfer coefficient with superficial velocity for the case of the heater 3 i. e. the heater painted with polyurethane coating of thickness 0.000215 m

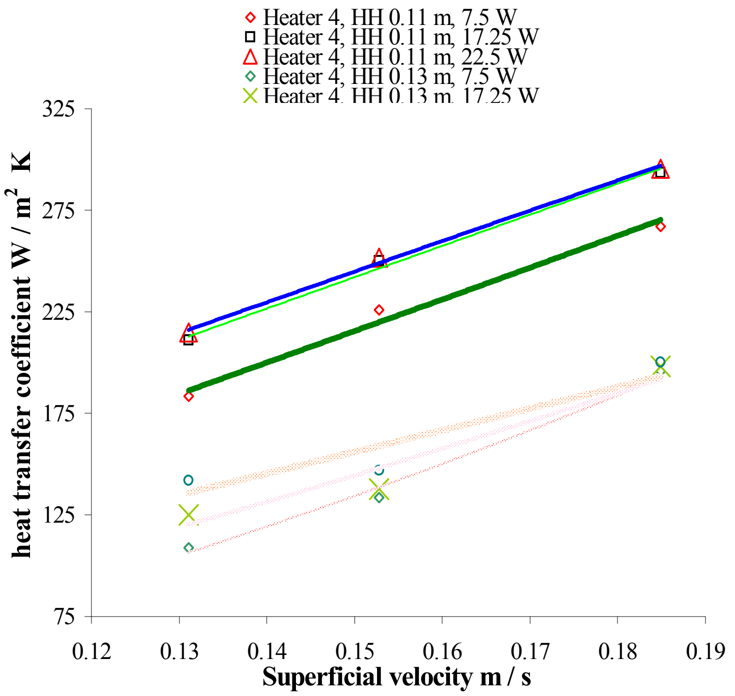

Fig. 5. Variation of heat transfer coefficient with superficial velocity for the case of the heater 4 i. e. the heater painted with polyurethane based zinc coating of thickness 0.00023 m

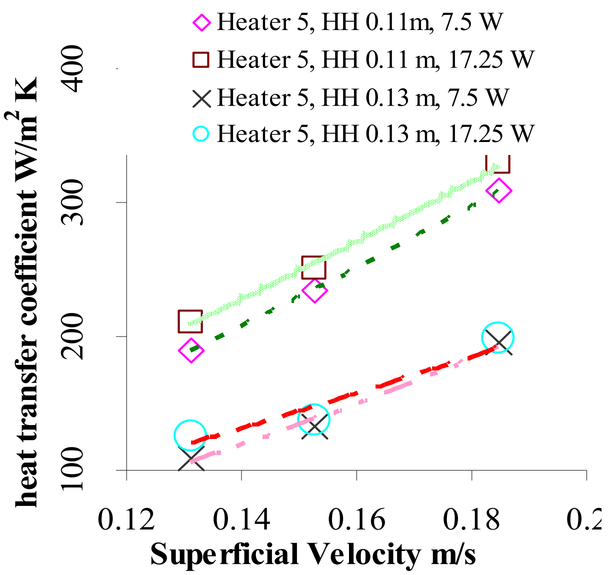

Fig. 6. Variation of heat transfer coefficient with superficial velocity for the case of the heater 5 i. e. painted with polyurethane based zinc coating of thickness 0.0003 m

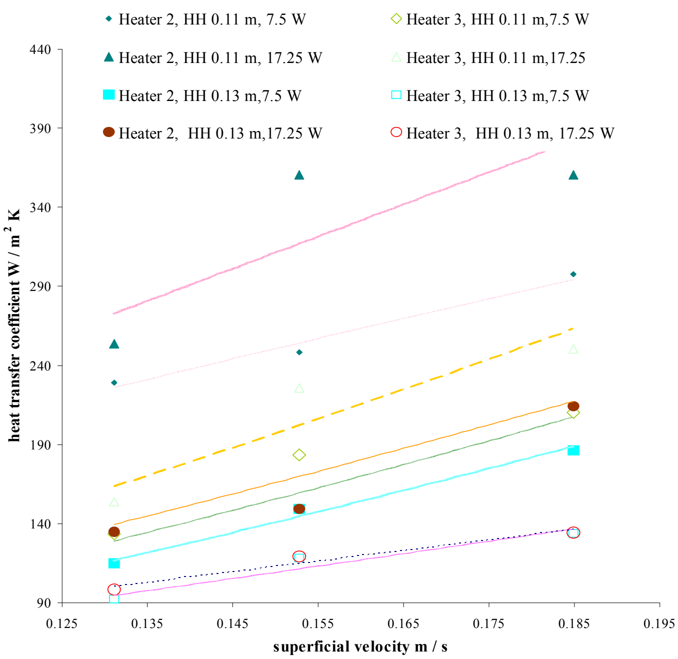

Fig. 7. Comparison of variation of heat transfer coefficient values with superficial velocity between the heater 2 and heater 3 i. e. the heaters painted with polyurethane coating with thicknesses 0.000115 m and 0.000215 m

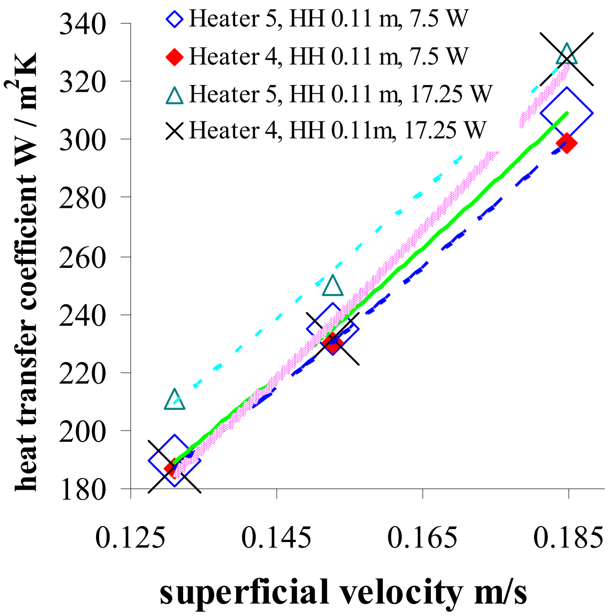

Fig. 8. Comparison of variation of the heat transfer coefficient values with superficial velocity between the heater 4 and heater 5 i. e. the heaters painted with polyurethane based zinc coating with thicknesses 0.00023 m and 0.0003 m at HH 0.11m.

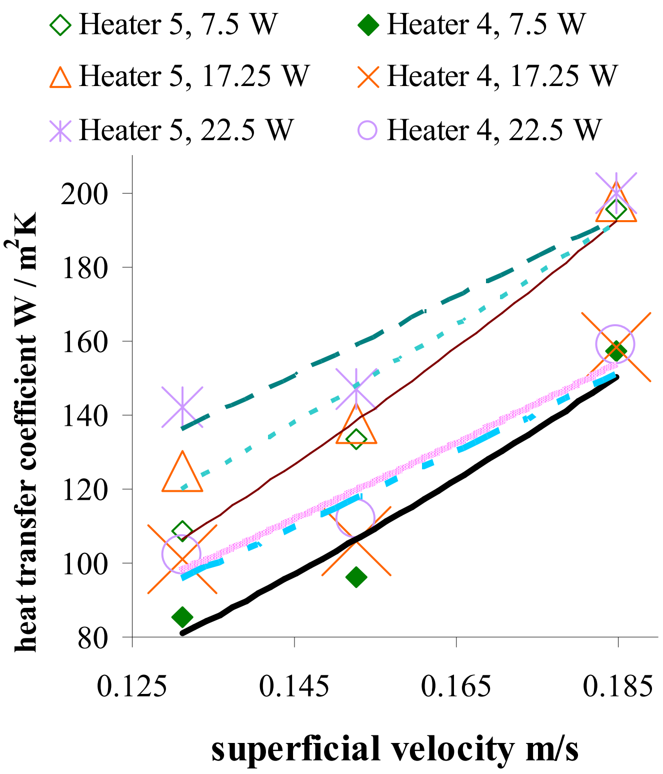

Fig. 9. Comparison of variation of the heat transfer coefficient values with superficial velocity between the heater 4 and heater 5 i. e. the heaters painted with polyurethane based zinc coating with thicknesses 0.00023 m and 0.0003 m at HH 0.13m

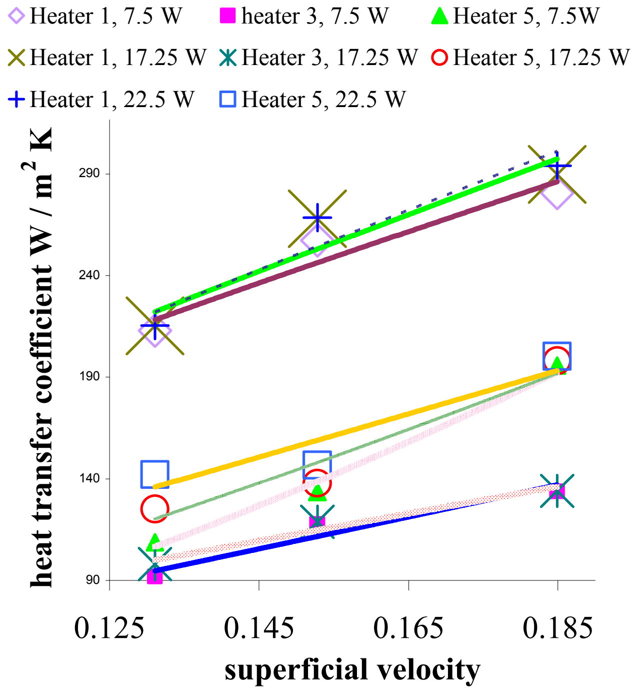

Fig. 11. Comparison of the variation of heat transfer coefficient values with superficial velocity among the heater 1 (bare heater), heater 3 (polyurethane coated heater) and heater 5 (heater painted with polyurethane based zinc coating), for HH 0.13 m

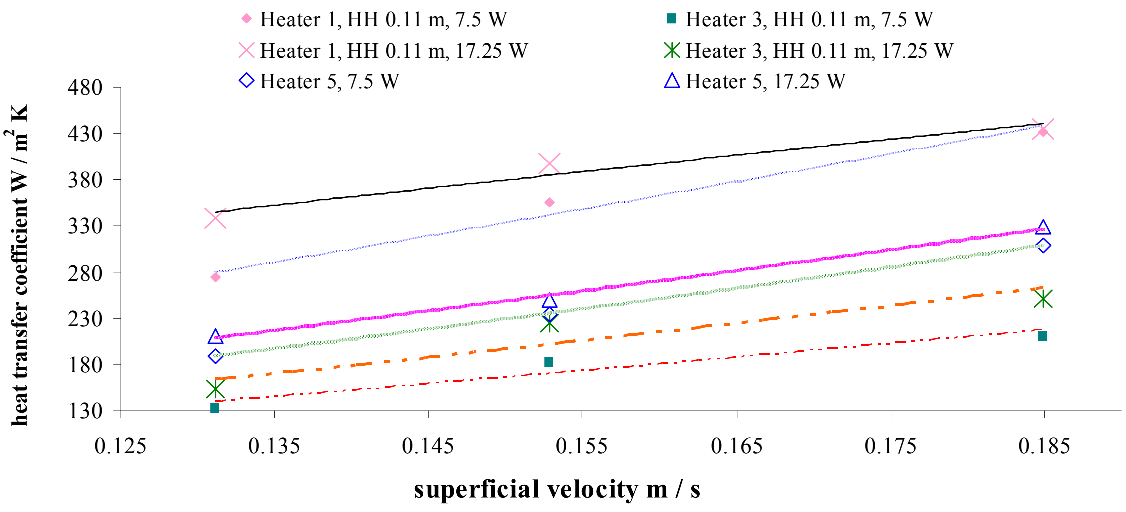

Fig. 10. Comparison of the variation of heat transfer coefficient values with superficial velocity among the heater 1 (bare heater), heater 3 (polyurethane coated heater) and heater 5 (heater painted with polyurethane based zinc coating), for HH 0.11 m.