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# THE INFLUENCE OF FLUIDIZATION VELOCITY ON HEAT TRANSFER BETWEEN FLUIDIZED BED AND INCLINED HEAT TRANSFER SURFACES

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**Abstract**. *The paper presents an experimental investigation of the influence of fluidization velocity on heat transfer coefficient between fluidized bed and inclined heat transfer surfaces.*
*The investigation was conducted on laboratory scaled apparatus, of the square cross section 160×160 cm. Bed material was quartz sand, with equivalent diameter of 0,3 mm. Heat transfer surface - electrical heater is made of copper tube with inner diameter of 16 mm and 100 mm long. Investigation was conducted so that, for defined fluidization velocity, temperature measurement on front, lateral and back side of the heater, relating to the fluidization air flowing direction, was done for different angles of inclination.*
*Based on obtained heat transfer coefficient values it can be concluded that tendency of change of heat transfer coefficient with increasing fluidization velocity is similar for all heater inclination angles. With increasing angle of inclination, i.e. heater position from vertical to horizontal, heat transfer coefficient values decrease almost uniformly in the whole range of fluidization velocity.*
*The biggest change of heat transfer coefficient was obtained for fluidization rate of 1,25, slightly over the minimum fluidization velocity.*
*At fluidization rate over 2,5 heat transfer coefficient's change insignificantly depends on fluidization rate and maximum appears at the angle of inclination 10 to $15^0$.*

## 1. INTRODUCTION

Heat exchange between fluidized bed and immersed heat transfer surfaces is a function of dynamic properties of the bed, most of all bubble movement and particle mixing intensity. But it is sure that the most influencing factors are fluidization velocity and particle size.

Key factors in heat transfer between an immersed surface and fluidized bed are the

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particle motion in the vicinity of heat transfer surface, contact time with the surface and particle concentration on the wall. Gas and particle motion above, over and on the lateral side of exchange surfaces is specific, so the changes in those zones are mostly investigated.

The complexity of the problem and majority of influencing factors, which are difficult to be included into equations, cause the experimental determination of heat transfer coefficient to be accepted method.

## 2. EXPERIMENTAL APPARATUS

Experimental investigations of heat exchange between fluidized bed and inclined immersed surfaces have shown that in the wide area of fluidization velocities heat exchange between vertical surfaces and fluidized bed is more intensive than in the case of horizontal surfaces. Between those extreme positions, heat transfer coefficient depends on many factors.

Experimental investigation of heat transfer by convection between immersed tube and fluidized bed was conducted on the laboratory scaled apparatus of the square cross-section, with dimensions 160×160 mm and 600 mm in height. The sides of the apparatus are made of plexiglass 5 mm thick, that enables visual control of the process. On the bottom of the working part of the apparatus an air distributor, made of plexiglas, is built in. The holes 1 mm in diameter are evenly arranged on the surface of the distributor. For the purpose of better quality of air distribution a filter 2 mm thick is built in above the distributor. Working part of the apparatus is located after the distribution chamber for air stream equalization.

Immersed heat exchange surface - an electric heater is made of copper tube, 16 mm in outer diameter and the length of 100 mm, inside of which is scald shamotte core, with coils of resistant wire. Maximum power of the heater is 100 W. Three thermocouples are built in on the outer surface: on the front side, lateral and upper side regarding to the direction of the heater rotation, i.e. fluidization air flow. The heater is fastened on the carrier made in the shape of a frame with dimensions of 150×150 mm, which can be rotated around horizontal axis 100 mm above the distributor, enabling the change of heater inclination. It is possible to install two tubes around the heater, parallel to it, with the same dimensions as the heater, the distance of which is adjustable.

The temperature was measured by thermocouples chrommel-alumel, with the diameter of 0,2 mm. The temperature of the inlet air was measured by the thermocouple located above the distribution plate and the temperature of the fluidized bed on the height of heater's rotating axis. All thermocouples were connected to the system of data acquisition.

Quartz sand was used as the bed material with mean particle diameter of 0,3 mm. The stagnant bed height was 160 mm.

In order to get the same working conditions, the inclination of the heater was changed for every fluidization velocity. For every angle of inclination the temperature of the heater's surface and the bed was measured.

For defined fluidization velocity the inclination of the heater was changed from vertical position (angle of $0^0$) to the horizontal position (angle of $90^0$) gradually for $10^0$. For every angle of inclination the measurement were made after reaching the stationary state. The procedure was repeated for every new fluidization velocity.

Electric heater's power was varied to get as higher as possible temperature difference between heater surface and the bed, that makes better acuracy of the measurements.

After reaching the stationary state, that was determined by the control of the temperature change on the heater and in the fluidized bed, all working parameters of the process were registered. During one measurement, for the adjusted fluidization velocity and angle, of heater inclination, every single temperature was registered 500 times every 0,08 s and then averaged. In this way total time for one measurement was 40 s.

Supposing the uniform radial heat distribution through the heater (because of thin tube wall and good copper conductivity) local heat transfer coefficient was determined at three points of the heater perimeter.

$$h_{ci} = \frac{q}{S(T_{wi} - T_b)}$$

In the series of experiments fluidization air velocity was 0,1 to 0,5 m/s, heater's temperature 60 to $90^0$ and the temperature of fluidized bed 30 to $40^0$.

## 3. ANALYSIS OF EXPERIMENTAL RESULTS

Defining the mean values of heat transfer coefficients between fluidized bed and inclined heat transfer surfaces demands informations on local heat transfer coefficient, the distribution of which along the body flown around is not uniform, because of different aerodynamic conditions.

The analysis of local heat transfer coefficient measurements in three points of heat exchange tube perimeter - front, lateral and back confirmed a nonuniform aerodynamic pattern around the surface. This is why there is significant nonuniformity of the values of the heat transfer coefficient and in their dependence on fluidization velocities.

Fig 1, 2, 3 show the functions $h_{ci} = f(U)$ of the local heat transfer coefficient on the front, lateral and upper side for different inclination angles of the heater.

The change of local heat transfer coefficient with the change of angle of tube inclination and increase of the fluidization velocity are the consequence of different mode of particle circulation and their motion along the surface.

In the horizontal position of the heater, maximum values of local heat transfer coefficient at low air velocities appear in the lateral zone, where interchange of the particles, is the most intensive. Front side of the heater at greater angles of inclination, close to the horizontal position, contacts considerably long time with the gas cushion, formed above it, so the heat transfer coefficient at this zone is small. Upper zone, on the contrary is for longer time practically covered with particles, and the replacement of particle packets at low fluidization velocity is not often. That is why the heat transfer coefficients on the upper side of the heater have smaller values related to the lateral zone.

The measurements of local heat transfer coefficient's between the heater and fluidized bed were done in order to get as much as possible accurate value of mean heat transfer coefficient on the heater's perimeter.

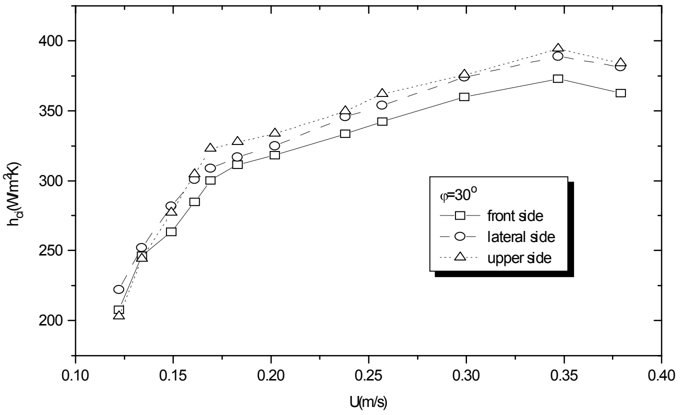

Fig. 1. Dependence of local heat transfer coefficent on fluidization velocity

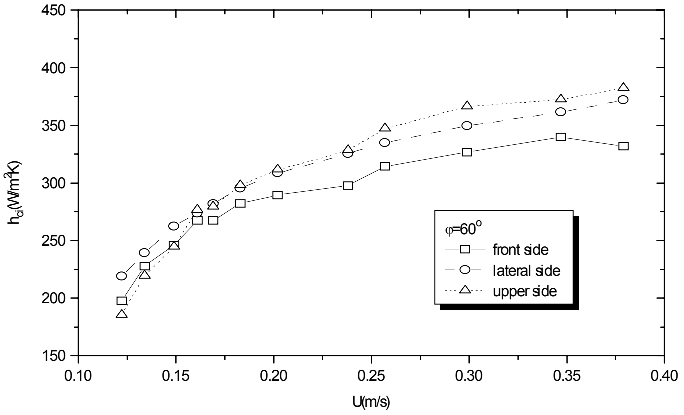

Fig. 2. Dependence of local heat transfer coefficent on fluidization velocity

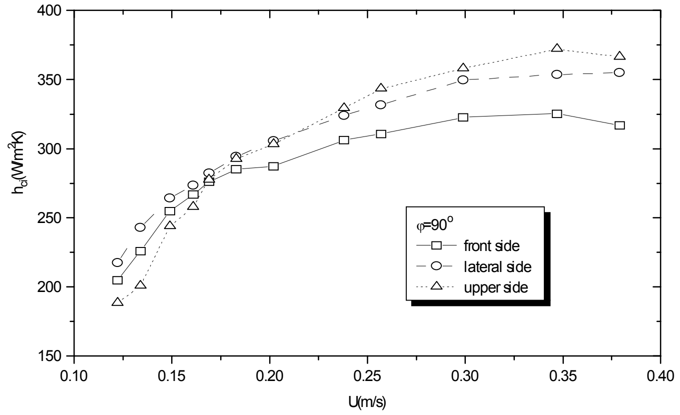

Fig. 3. Dependence of local heat transfer coefficent on fluidization velocity

Dependence of heat transfer coefficient on fluidization, i.e. fluidization rate, for different inclination angles is given of Fig. 4 and 5. It can be seen from the figures that heat transfer coefficient distribution, when fluidization velocity rises, is similar for all inclination angles of the heater. When the inclination angle rises, i.e. heater's position changes from vertical to horizontal, the values of heat transfer coefficient decrease almost equally in the whole range of fluidization velocities.

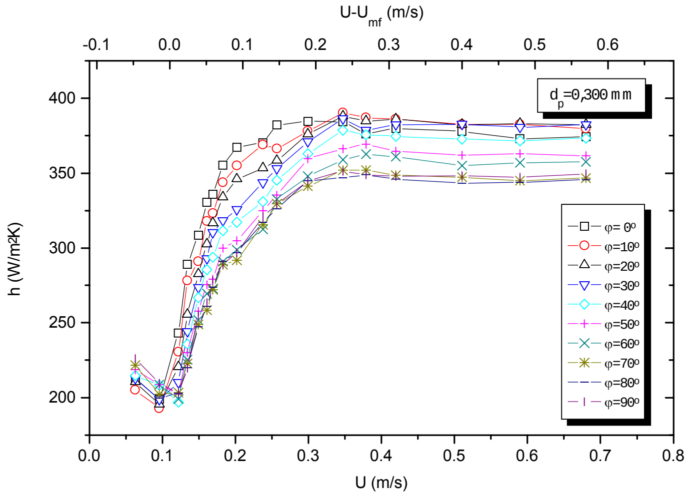

Fig. 4. Dependence of mean heat transfer coefficient on fluidization velocity for particle diameter $d_p$ = 0,3 mm and different heater's inclination angles

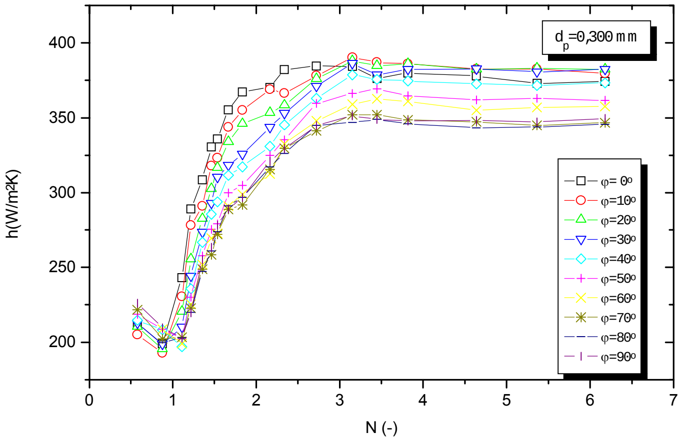

Fig. 5. Dependence of mean heat transfer coefficient on fluidization rate for particle diameter $d_p$ = 0,3 mm and different heater's inclination angles

With the increase of fluidization rate the distribution of heat transfer coefficient changes in relation with heater's inclination, which can be seen on Fig. 8, where the dependence of mean heat transfer coefficient on heater's inclination angle for fluidization rate for 1 to 3 can be seen. It can be noticed that at lower fluidization rates the change of heat transfer coefficient is more distinctive and ofter reaching some values of fluidization rates it's further increasing doesn't influence neither on distribution, nor the values of heat transfer coefficient.

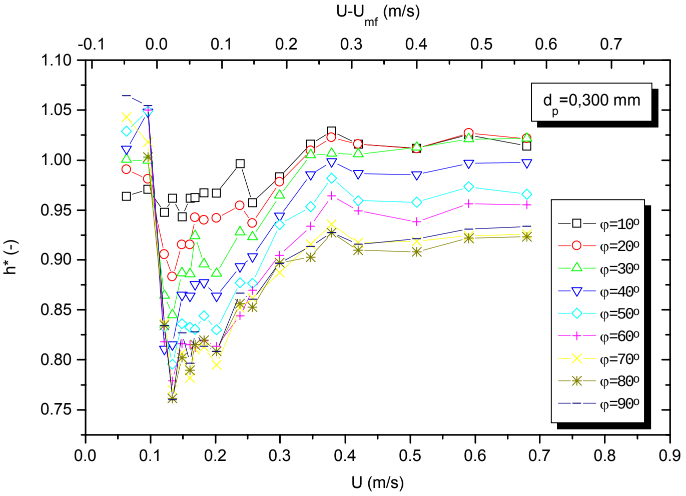

Fig. 6. Dependence of relative heat transfer coefficient on fluidization velocity for particle diameter $d_p = 0,3$ mm and different heater's inclination angles

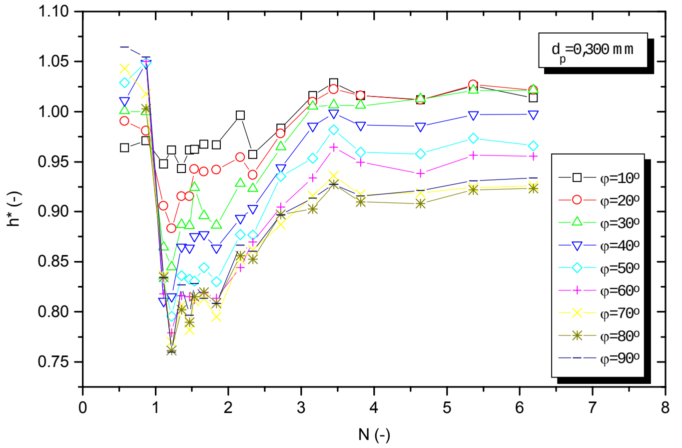

Fig. 7. Dependence of relative heat transfer coefficient on fluidization rate for particle diameter $d_p = 0,3$ mm and different heater's inclination angles

The distribution of heat transfer coefficient is better visible on Fig. 9, where the distribution of relative heat transfer coefficient depending on inclination angle for various fluidized rates is shown. At minimum fluidized velocity, N = 1, the influence of heat exchange by particle convection is small, and that's the reason why the distribution of heat transfer coefficient differs from the one at higher fluidization rates.

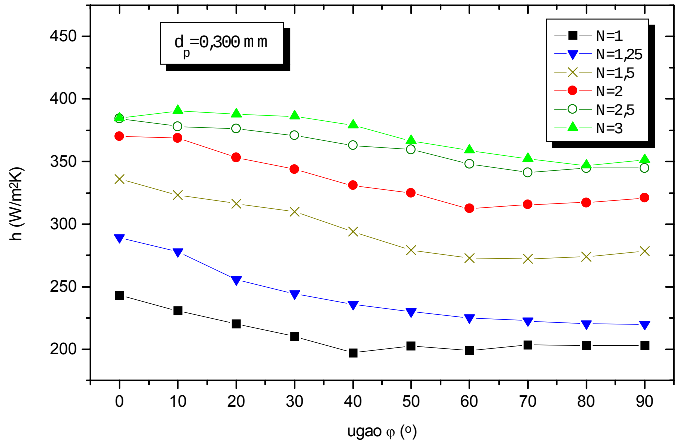

Fig. 8. Dependence of mean heat transfer coefficient on heater's inclination angles for particle diameter $d_p = 0,3$ mm and different fluidization rate

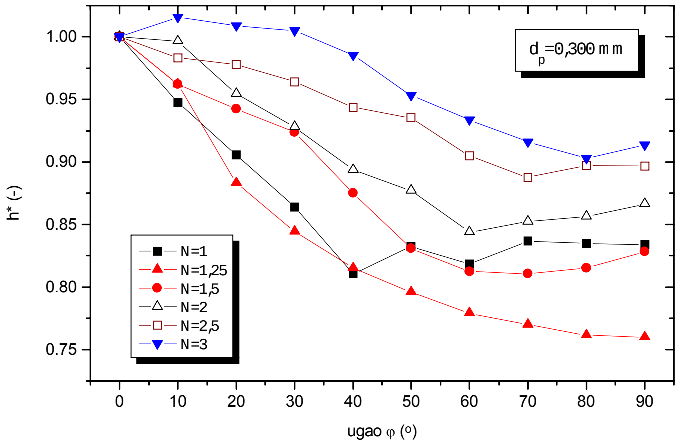

Fig. 9. Dependence of relative heat transfer coefficient on heater's inclination angles for particle diameter $d_p = 0,3$ mm and different fluidization rate

The highest change of heat transfer coefficient is at fluidization rate of N = 1,25, i.e. slighty above minimum fluidization velocity. At further increase of fluidization rate, and increase of heater's inclination angle the values of heat transfer coefficient sharply go down, and ofter reaching $60^0$ stay almost constant. i.e. slightly increase. At fluidization rates higher than 2,5 the distribution of heat transfer coefficient very little depends on fluidization rate, and the maximum is visible at $10–15^0$. With the increase of fluidization rate the change of relative heat transfer coefficient between vertical and horizontal position of the heater is less and less significant, so while at fluidization rate of N = 1 it is about 25%, at N = 3 it is only 10%.

Obtained dependence of heat transfer coefficient gives the possibility to express this dependence analytically.

## 3. CONCLUSIONS

The results of experimental investigation of intensity of heat transfer between fluidized bed and inclined surfaces confirmed it's direct dependence on local flow pattern around the surface, which, on the other hand depends on the location and inclination of heat exchange surface. Immersed heat exchange surface disturbs gas and particle flow causingnonuniform change of heat transfer coefficient raliting to the fluidization velocity for different surface angles of inclination. Optimum surface angle of inclination is between 10 and $25^0$, while angle bigger than $60^0$ doesn't influence signifacantly to the change of heat transfer exchange.

*Notation*

$h_{ci}$ – local heat transfer coefficient ($W/m^2K$)
S – electric heater outer surface ($m^2$)
$t_b$ – average bed temperature ($^0C$)
$t_{Wi}$ – surface local temperature ($^0C$)
q – power of the heater (W)

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# UTICAJ BRZINE FLUIDIZACIJE NA RAZMENU TOPLOTE IZMEĐU FLUIDIZOVANOG SLOJA I NAGNUTIH RAZMENJIVAČKIH POVRŠINA

**Branislav Stojanović, Mladen Stojiljković**

*U ovom radu je dat prikaz eksperimentalnog istraživanja uticaja brzine fluidizacije na promenu koeficijenta prelaza toplote između fluidizovanog sloja i nagnutih razmenjivačkih površina. Ispitivanje je sprovedeno na laboratorijskoj aparaturi dimenzija 160×160 mm, a kao materijal sloja korišćen je kvarcni pesak srednjeg prečnika čestica 0,3 mm. Sloj je zagrevan električnim grejačem prečnika 16 mm i dužine 100 mm. Ispitivanja su obavljena tako da je za za određenu brzinu fluidizacije izvršeno merenje temperature površine grejača na čenoj, bočnoj i gornjoj strani u odnosu na smer strujanja vazduha za fluidizaciju za različite uglove nagiba grejača.*

*Na osnovu dobijenih vrednosti koeficijenta prelaza toplote može se zaključiti da je tok promene koeficijenta prelaza toplote sa porastom brzine fluidizacije sličan za sve uglove nagiba grejača. Pri tom, sa porastom ugla nagiba, tj. pri promeni položaja grejača od vertikalnog ka horizontalnom položaju vrednosti koeficijenta prelaza toplote se smanjuju skoro podjednako u celom dijapazonu promene brzine fluidizacije. Najveća proemna koeficijenta prelaza toplote dobijena je za stepen fluidizacije 1,25. Pri stepenima fluidizacije većim od 2,5 promena koeficijenta prelaza toplote veoma malo zavisi od stepena fluidizacije i pri tom se uočava pojava maksimuma za uglove nagiba 10-15*$^0$.