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EFFECT OF PARTICLES DENSITY ON HOLDUP MASS AND HEAT TRANSFER RATE IN SOLID CYCLONE HEAT EXCHANGER

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ABSTRACT

This work presents the effect of particles density on holdup mass and heat transfer rate in solid cyclone heat exchanger. Performance of cyclone heat exchanger mainly depends on operational parameters such as inlet air velocity, temperature; solid particles feed rate and density. Present work studies the effect of particles density by varying inlet air velocity and temperature. Four different solid particles (Sulfur, Dolomite, Steel and Copper) density ranges from 2050 to 8950 kg/m3 which are fed at 0.5 g/s flow rate and inlet air velocity ranging from 4.6 to 24.2 m/s at three inlet air temperatures 373, 473 and 573 K. Experimental setup was built for stairmand high efficiency cyclone. Good agreement was found between experimental and literature pressure drop. Results conclude that holdup mass and heat transfer rate increases 0.5-1.5% and 82-86% with decrease in density particles respectively. Increase in inlet air velocity, holdup mass and heat transfer rate raises 3.2-6% and 4 - 6.7% respectively for all particles at all inlet air temperatures.

Keywords: stairmand cyclone, holdup mass, heat transfer rate, cyclone heat exchanger, inlet air velocity, solid feed rate, particles density.

INTRODUCTION

Cyclone separators are most widely used for industrial gas-cleaning devices and in chemical processes .One of the reasons for the wide variety of applications of cyclones is due to the fact that they are easy to inspect and maintain .Wide-spread use of cyclones is inexpensive to purchase, they have no moving parts, and they can be constructed to withstand harsh operating conditions. Therefore it is cheap and simple equipment that can easily remove particles bigger than 5 micrometer from a gaseous phase. According to the purpose in use, the cyclone designs are generally classified into straight-through,

Uni-flow and reverse flow cyclones. Among them, it is known that the use of tangential inlet and reverse-flow is the most common way for cyclone design. Cyclone as heat exchanger has potential application in cement, fertilizer, polymer powder and other industries [8], so study of cyclone as heat exchanger deemed to be important. Use of cyclone as a heat exchanger is gaining popularity. Most of the work done in cyclone separator predicts impact of mass flow rate of air and solid with respect to pressure drop, collection efficiency and heat transfer characteristics. Use of cyclone heat exchanger is still in its early stage and holdup mass plays important role. Holdup mass is the mass of solid particles which involves in exchange of heat with hot gas stream so determination of holdup mass is deemed important.

Avici *et al.* [1] found that surface friction; vortex length and flow regimes play an important role on cyclone performance in addition to flow and geometrical parameters, in small cyclones. Many researchers studied the cyclone performance with multiple inlet valves [2-6]. The effect of cyclone on the kinetics of drying of paddy in a pneumatic dryer was studied by Kaensup *et al*. [7] who found that the dryer with the cyclone produced a relatively lower final moisture content, higher evaporation rate and at lower specific energy consumption for evaporation of water. Correlation for nusselt number experimentally by varying inlet parameters in cyclone heat exchanger was developed by A. Jain *et al*. [8]. Ramanan *et al*. [9] reported the cyclone performance at high temperature. Yen *et al*. [10] and Raju *et al*. [11] reported experimental investigations on fluid-solid heat transfer in reverse flow cyclone and proposed correlations for gas-solid heat transfer in cyclone. Nag and Singh [12] studied the heat transfer characteristics in a cyclone separator of a CFB. Shimizu *et al*. [13] developed a gas-solid direct contact heat exchanger by the use of axial flow cyclone, and they achieved a drastic improvement of the heat exchanger performance without deteriorating particle recovery efficiency. Mothilal *et al*. [14] studied the effect of mass flow rate of inlet air on holdup mass experimentally. Mothilal *et al*. [15, 16] analyzed numerically the geometries such as vortex finder diameter, inlet height and cone tip diameter of cyclone heat exchanger on flow field, Holdup mass and heat transfer rate. Hoekstra *et al.* [17] experimentally analyzed different geometric swirl numbers using laser-Doppler velocimetry. Geometry swirl number has influence on mean flow characteristics and maximum tangential velocity influences vortex size.

The effect of particles density on holdup mass in solid cyclone heat exchanger has not been studied so far. Since holdup mass plays a vital role in cyclone heat exchanger, as collection efficiency plays in cyclone separator so the aim of this study is to investigate the effect of particles density on the holdup mass and heat transfer rate of solid cyclone heat exchanger by varying inlet air flow rate and temperature for different particles.

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GEOMETRICAL DESCRIPTION OF EXPERIMENTAL SETUP

Development of different cyclones is based on stairmand and exhaustive experimental data of these cyclones are reported. Stairmand high efficiency cyclone collects more particles compared to conventional and high throughput cyclones. Therefore the design of experimental setup is performed on stairmand high efficiency model and dimension of the cyclone model is shown in Table-1 and 2D model in Figure-1.

Table-1. Dimension description of cyclone.

Cyclone description	Stairmand high efficiency ratio
Cyclone diameter (D)	**1.0**
Inlet height (H)	**0.5**
Inlet width (W)	**0.2**
Vortex finder diameter (D_v)	**0.5**
Vortex finder length (S)	**0.5**
Cone tip diameter (D_c)	**0.375**
Gas inlet (D_a)	**0.36**
Solid inlet (D_s)	**0.36**
Barrel height (L_b)	**1.5**
Cone height (L_c)	**2.5**

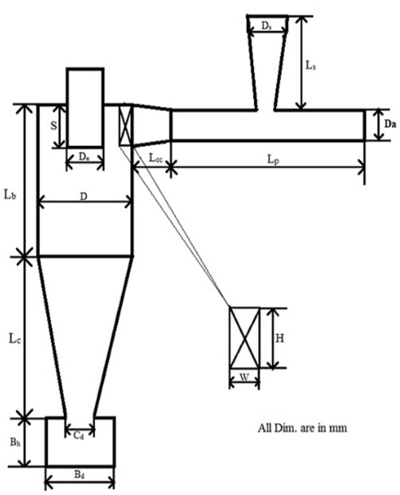

Figure-1. 2D model of stairmand high efficiency cyclone.

Experimental Description

Experimental setup consists of an air inlet duct fitted with blower, solid feeding system, cyclone separator, valve arrangements and bin shown in Figure-2. The inlet duct of cyclone heat exchanger is a hollow pipe with a hopper at its center. Circular duct is connected to cyclone body with a transition region that transforms from circular cross section to rectangular cross section. Thermocouples are placed at various distances in air entrance, bin, cylindrical and conical part of cyclone to measure temperature of air and solid particles and other geometries are similar to cyclone separator. Solid feeding system consists of small container with opening at bottom and vibratory feeder with an electromagnetic vibrator at solid discharge point. Experimental setup is fully equipped with instruments to measure airflow rate and solid feed rate and the whole experimental setup is insulated with asbestos rope to prevent the heat loss. Air and solid feed rate is controlled by varying inlet valve of blower and adjusting vibrator. Solid particles are fed into the system with the help of electromagnetic arm imparting vibrations to channel feeder. Pressure gauges are installed at inlet and outlet of cyclone to measure pressure drop.

Figure-2. Experimental setup of cyclone heat exchanger.

Experimental Procedure

Air from blower enters the heater section where it gets preheated and then it enters inlet duct. Solid particles discharged into a conical funnel, through vibrator setup at a preset value. Heat transfer takes place between air to solid particles and solid is collected in bin which is attached at the bottom of the cyclone heat exchanger. Once the desired mass flow rate of inlet gas is achieved, particles are fed into the system till desired solid feed rate is attained.

Steady solid feed rate is achieved for particular combination of gas velocity, particle size and funnel opening. Particle temperature at various position measured by thermocouples. Holdup of the particles is measured by closing both inlet and exit of cyclone airflow and solid flow simultaneously. Solid left inside the cyclone is collected in bin and weighed to determine holdup mass.

VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
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Experimental Materials

In this work material such as copper, steel, dolomite and sulfur is used for analysis and there physical properties are shown in Table-2. Experiment was done at uniform particles size and it is achieved by using sieve analysis.

Table-2. Particles properties

S. No	Materials	Density (kg/m^3)	Heat capacity (J/kgK)	Thermal conductivity (w/mK)
1	Sulfur	2046	634	0.27
2	Dolomite	2872	910	1.75
3	Steel	8030	502	16.2
4	Copper	8978	381	387

Figure-3. Experimental materials.

RESULT AND DISCUSSIONS

Heat transfer in cyclone heat exchanger takes place in two steps, transfer of heat from inlet gas to solid particles and between the particles until it attains an isothermal condition. Heat transfer rate is based on holdup mass and it is defined as the total mass of particles at any instant of time in cyclone heat exchanger which is found by measuring the particles in weighing machine by closing both gas and solid flow valves.

Heat transfer rate is defined as

$$q = m_s\, Cp_s\, (Ts_{out} - Ts_{in}) \text{ [8]} \qquad (1)$$

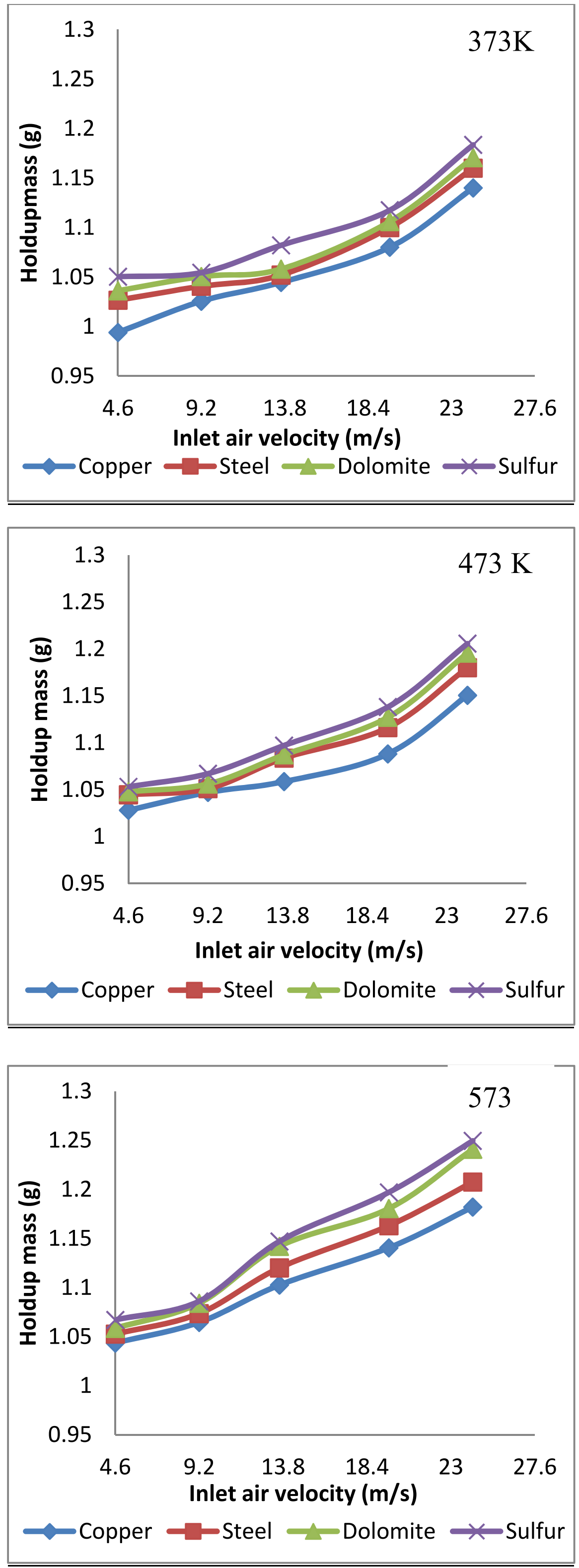

Figure-4. Effect of particles density on holdup mass for different inlet air temperatures.

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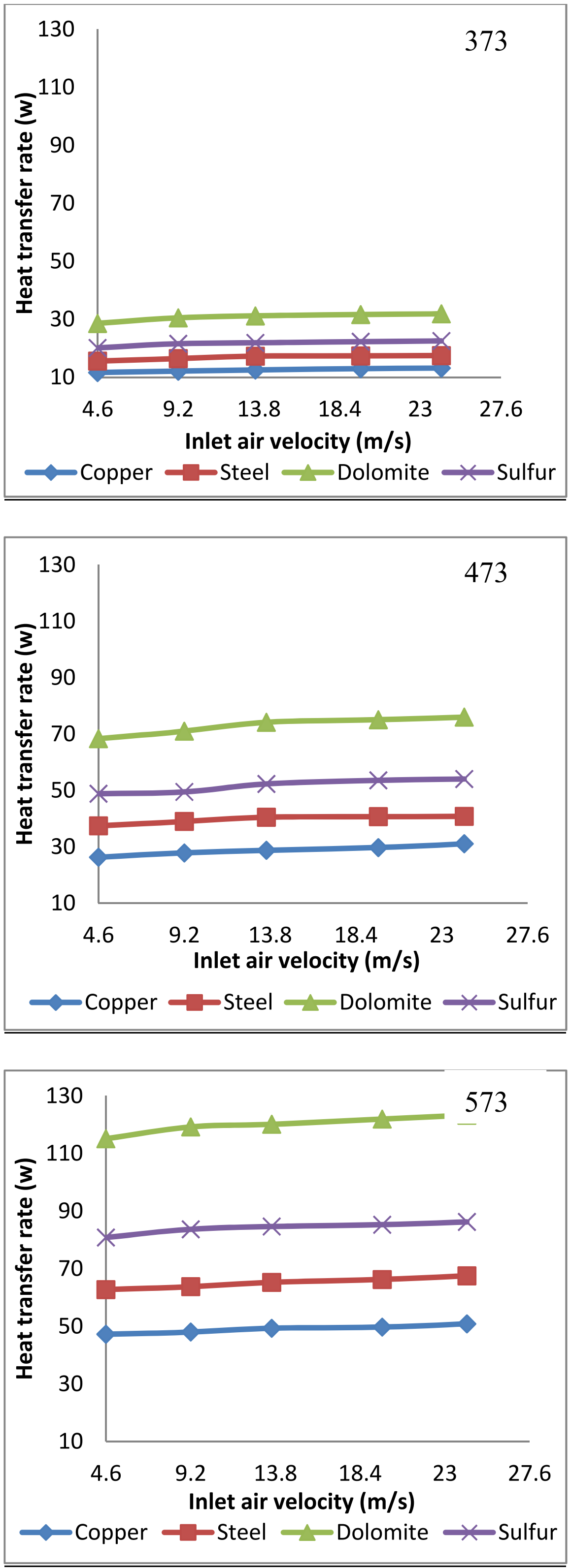

Figure-5. Effect of particles density on heat transfer rate for different inlet air temperatures.

Effect of Particles Density on Holdup Mass

To study the effect of particles density on holdup mass particles are fed at 0.5 g/s and inlet air velocity and temperature ranging from 4.6 to 24.2 m/s and 373 to 573 K. Results of the effect of particles density is displayed in Figure-4.

Holdup mass for sulfur is high compared to other particles and comparing with dolomite, increase in holdup mass of 0.5 to 1.5 % is observed for sulfur. Holdup mass rapidly increases with decrease in particle density at uniform diameter and feed rate. With decrease in particle density the drag force act on the particles decreases which increases the centrifugal force and number of swirling rotations. Therefore more amounts of particles get accumulated within the cyclone heat exchanger, thus holdup mass increases with decrease in particle density.

It is also observed that the holdup mass rises with increase in inlet air velocity at all temperature and particles. In the event of increasing inlet air velocity raises holdup mass 3.2 to 6 % due to increase in centrifugal force inside the cyclone which turn increases the swirling rotation of gas-solid phase.

Effect of Particles Density on Heat Transfer Rate

To study the effect of particles density on heat transfer rate, temperature of particles at inlet, various parts of cyclone body and outlet was measured by thermocouples. Results of heat transfer rate for varying densities of different particles materials is shown in Figure-5. It is observed that heat transfer rate is high for low density and high heat capacity particles so heat transfer rate in dolomite is higher compared to other particles. Comparing heat transfer rate of dolomite with other particles 82 to 86 % more heat transfer gained by dolomite in cyclone heat exchanger for all particles at same input parameters.

Heat transfer rate increases with increase in inlet air velocity at all temperatures. Rise in heat transfer rate of 4 to 6.7% is found with increase in inlet air velocity for all particles at all temperatures.

CONCLUSIONS

Present work studies the effect of particles density on holdup mass and heat transfer rate experimentally. Based on the result following conclusions are drawn:

1. Holdup mass raises 0.5-1.5 % with decrease in density of particles. Increasing the particle density reduces the swirling rotation and accumulation of particles inside the cyclone thus holdup mass reduces.
2. Heat transfer rate raises from 82-86% with decrease in density of particles at all inlet air temperatures. At low density the drag force acting on particles is less compared to high density particles this increases contact time between gas and solid thus the heat transfer rate more for low density particles.

3. Inlet air velocity also affects the holdup mass and heat transfer rate. Increase in inlet air velocity raises 3.2 to 5% on holdup mass and 4 to 6.2 % on heat transfer rate.
4. This work can be extended to find generalised correlation for holdup mass without compensating collection efficiency by varying cyclone geometry dimensions.

NOMENCLATURE

q	Heat transfer rate in w
m_s	Mass flow rate of solid in kg/s
T_{sout}	Outlet temperature of solid particles in K
T_{sin}	Inlet temperature of solid particles in K
Cp_s	Specific heat capacity of particles in J/kg K

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