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HITRAN MATRIX ELEMENTS AS A FLUIDIZATION PROMOTER IN SLUGGING COLUMNS

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ABSTRACT

The Hitran matrix element was investigated as a potential fluidization promoter. The standard deviation of pressure and differential pressure fluctuations measured in a cold model complemented with pilot plant tests showed that the Hitran matrix element was effective in decreasing bubble size. A negative impact on the solids circulation was observed which could potentially be solved by reducing the element diameter and matrix density.

INTRODUCTION

An existing 49 mm internal diameter pilot scale fluidized bed reactor suffered from unstable temperature control which was undesirable for catalyst activity and selectivity studies. In this reactor a Geldart (1) group A iron-oxide powder having a particle density of 5200 kg/m³ was fluidized with synthesis gas ($CO + H_2$) at a superficial gas velocity of 45 cm/s. The freeboard pressure was 19 barg and the desired bed temperature was 350°C. A typical bed temperature response under these conditions is shown in Figure 1(a). These temperature fluctuations were attributed to the suspected slugging regime in which the pilot plant was being operated.

In an attempt to optimize the pilot scale reactor, the effect of a novel internal (Hitran matrix element) on slugging abatement and bubble size reduction was studied as a function of superficial gas velocity in a transparent acrylic cold model having an internal diameter of 50 mm. The Hitran matrix element, shown in Figure 1(b), is commercially available from Cal Gavin limited and is used to improve heat transfer in shell and tube heat exchangers through turbulence enhancement (2). The Hitran element was selected because it was commercially available and it could be easily installed and removed from the reactor without having to make any modifications to the reactor. It is also a continuous matrix element which prevents bubble re-coalescence, a phenomenon common to other types of staged or baffle type internals. The results of cold model and pilot plant tests as well as operating experiences with the Hitran elements are discussed in this article.

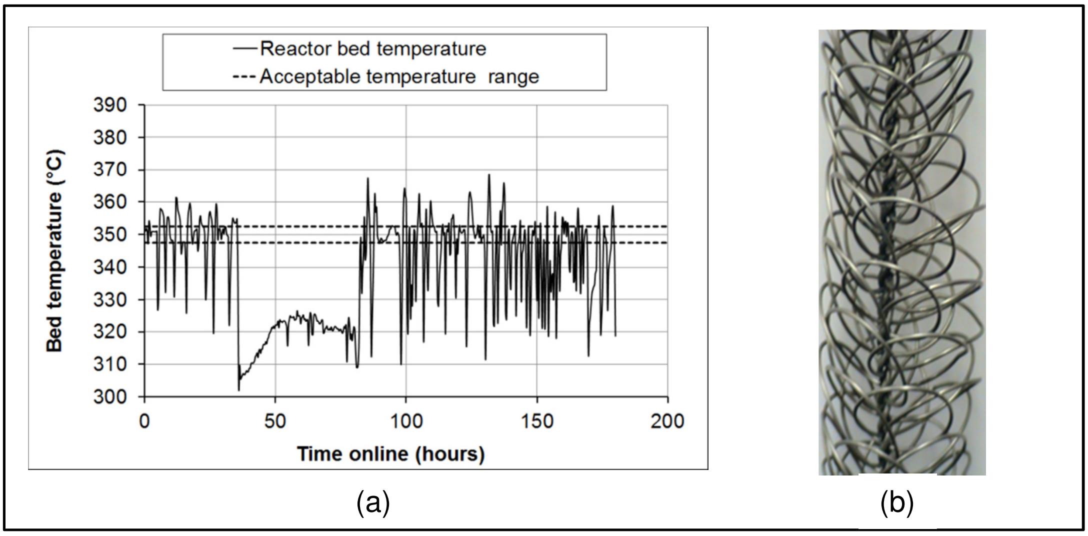

Figure 1: (a) Reactor bed temperature. (b) Hitran matrix element

LITERATURE REVIEW

Internals such as tubes and baffles are known to improve the overall fluidization quality and in commercial units often double up as heat exchangers to maintain isothermal conditions in the bed. A comprehensive review of studies which have been carried out to investigate the effect of various types of internals or promoters on fluidization is provided by Jin et al. (3). In general the internals in fluidized beds causes a reduction in bubble size and in the case of small diameter columns which are prone to slugging the onset of slugging can be delayed. Examples of internals which have been used in small diameter columns include rods, disks and blades (4, 5, 6), twisted tapes (7) and horizontal screen-like baffles (8, 9). Negative aspects associated with internals include an increase in bed pressure drop (7, 9, 10) and, more importantly, inhibition of solids mixing (3, 8, 9). The latter is due to a decrease in the stirring action caused by bubble movement through the bed due to the reduction in bubble size. The collision of bubbles with internals causes the particles in the wakes of the bubbles to be lost (9). Hence, in cases where very good particle mixing is required; internals which provide a tortuous path for bubbles may negatively affect the overall fluidization behaviour of the bed.

Slugging can also be prevented by the appropriate choice of operating conditions. For a given bed height, there exists a gas velocity below which no slugging occurs and for a given gas velocity there exists a bed height below which no slugging occurs (11). Therefore operation within these constraints of gas velocity and bed height should guarantee a stable fluidization regime. An increase in the operating pressure also delays the onset of slugging with Geldart (1) group A powders due to a decrease in bubble size with an increase in pressure (12).

In general slugging behaviour has been studied using visual observations (11, 13) and through analysis of high frequency pressure fluctuation measurements with sampling frequency and duration ranging between 100 to 1000 Hz and 1 to 20 minutes respectively (14, 15, 13, 16).

EXPERIMENTAL

The experimental set-up is shown in Figure 2.

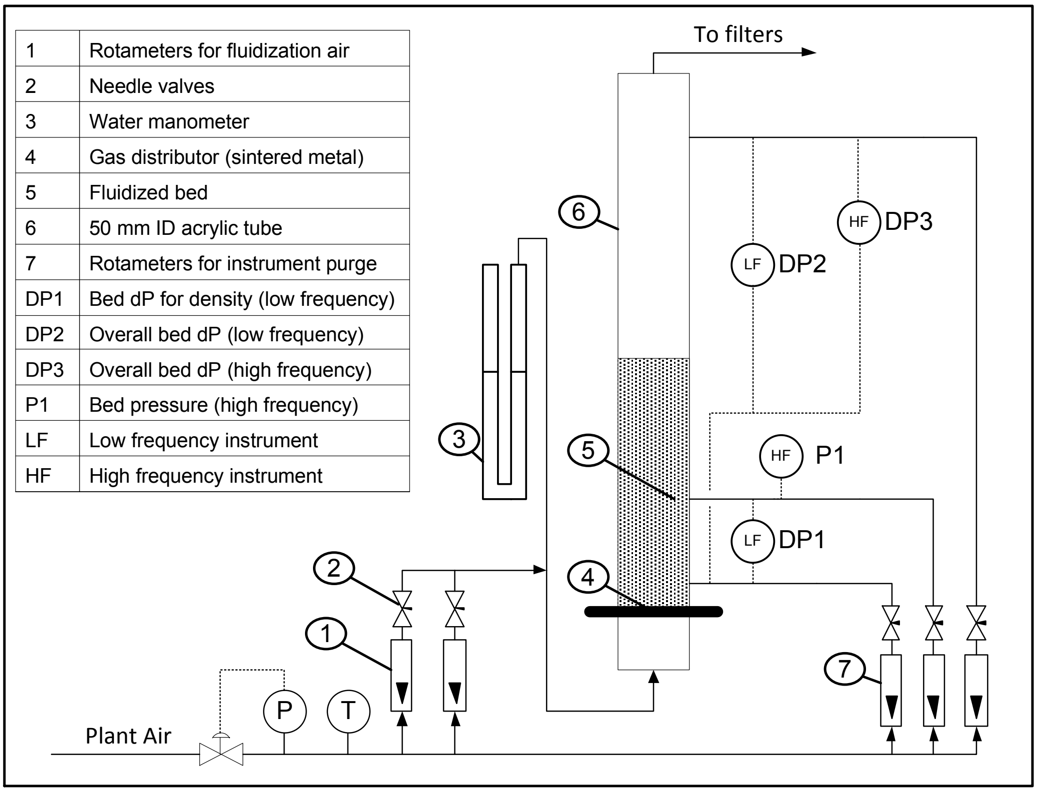

Figure 2: Experimental setup for cold model fluidization tests

The acrylic tube had an internal diameter of 50 mm and a height of 6 m. A 10 micron sintered metal plate was used as the gas distributor. Plant air was used to fluidize the 3.5 kg bed of iron oxide particles at ambient conditions (85 kPa and 25°C). The aspect ratio based on the settled bed height was 14. The air flow rate was measured and controlled using rotameters and needle valves respectively. Keller (model PD-33X) high frequency pressure and differential pressure transmitters were used to obtain bed pressure and pressure drop measurements at a frequency of 200 Hz. The data was recorded using a Beckhoff data logger (model CX9001-0001). The pressure and differential pressure instrument lines were purged with plant air at a line velocity of 3 m/s. The air leaving the acrylic tube with entrained solids was passed through a cartridge filter unit before being vented to atmosphere. A water manometer was used to protect the acrylic column from over-pressure.

Two sets of experiments were carried out: one without the Hitran insert and one with the Hitran insert. For each set of experiments the superficial gas velocity was varied in the range 10 to 60 cm/s. Each velocity setting constituted a run, which was repeated three times to test for repeatability. For each run, the fluidized bed height (minimum and maximum), bed density and high frequency bed pressure and bed pressure drop was recorded. The sampling time for the high frequency data was two minutes. For all tests iron oxide powder having a Geldart (1) group A powder classification was used for the fluidization tests.

RESULTS AND DISCUSSION

Effect of Hitran internals on bed hydrodynamics

The effect of the Hitran internals on bed hydrodynamics was obtained by analysing the standard deviation of bed pressure drop and bed pressure fluctuations as well as the overall bed voidage. These results are presented in Figures 3 and 4 respectively.

Both the standard deviation of bed pressure drop and bed pressure fluctuations showed similar trends with and without the Hitran internals. There was a significant drop in both these parameters when operating with the Hitran internals which is indicative of smaller bubbles and smoother fluidization (lower bed height fluctuation). Also, with the Hitran internals, the bubble size tends to be more stable over a wide range of gas velocities as deduced from the stable standard deviation of bed pressure drop and bed pressure fluctuations. With no internals, the standard deviation of bed pressure drop and bed pressure fluctuations both increase with superficial gas velocity indicating an increase in bubble size and slugging behaviour (from visual observations).

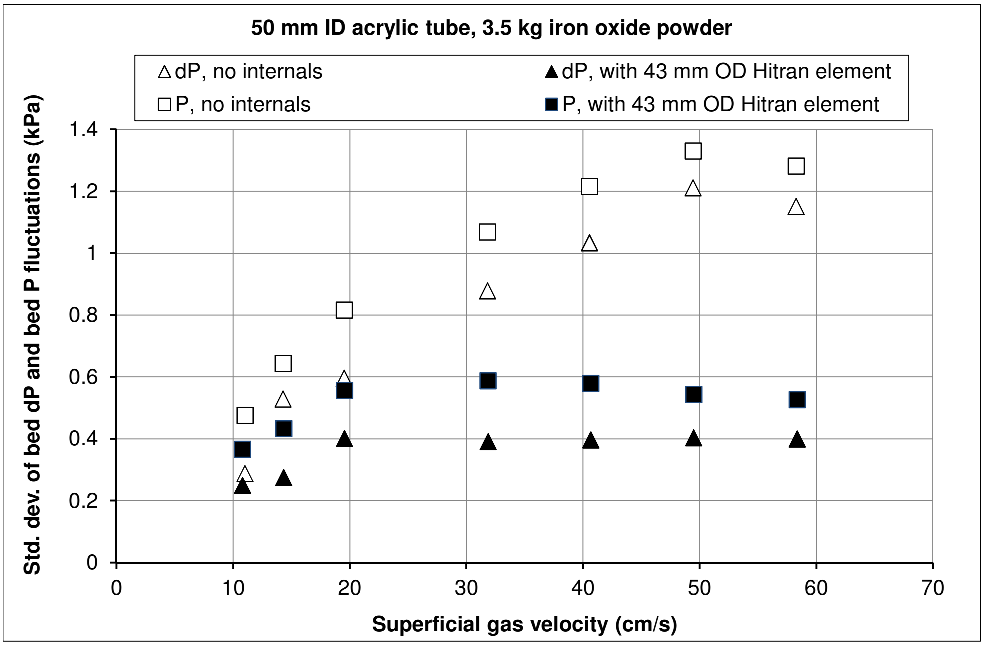

Figure 3: The effect of the Hitran element on the standard deviation of bed pressure drop and bed pressure fluctuations

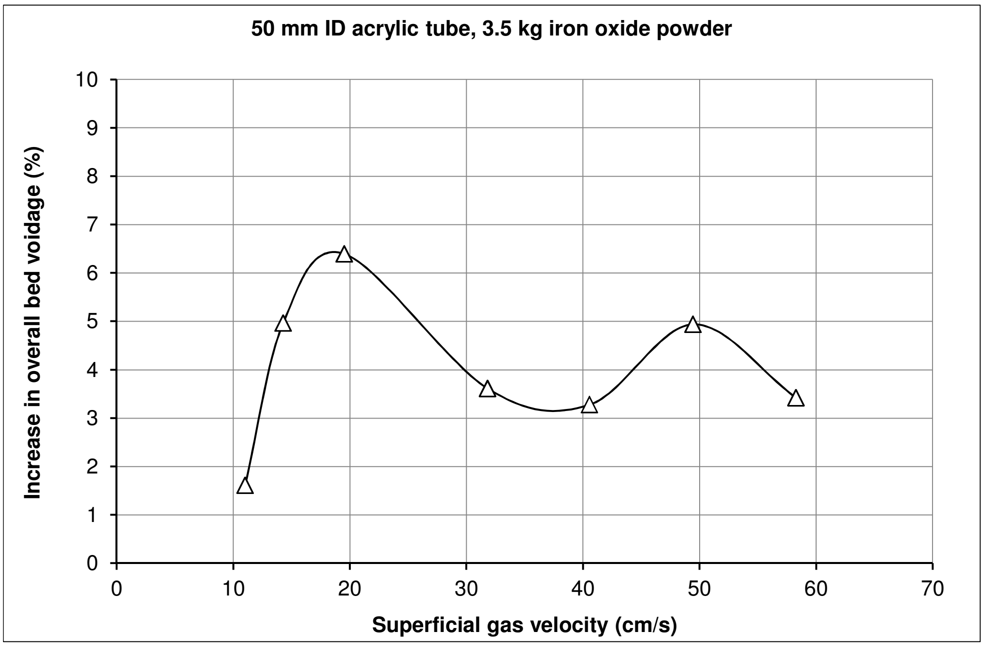

Figure 4: Percentage increase in the overall bed voidage with the Hitran element

Additional indirect evidence which shows the positive influence of the Hitrans internals as a slugging abatement device is shown in Figure 4 where it can be seen that the overall bed voidage (which was calculated from the experimental data using equations 1 to 3) is higher with the Hitran internals. The overall bed voidage is influenced by both the dense phase voidage and the bubble fraction. Previous work (10) has shown that the dense phase voidage is not a strong function of gas velocity. The dense phase voidage is dependent on the fines content of the powder which remained constant for these tests. Hence the higher overall voidage with the Hitran internals shown in Figure 4 could be attributed to a higher bubble fraction which is synonymous with smaller bubbles.

$$\rho_{bed} = {}^{DP1}/_{gh} \quad (1)$$

$$\rho_{bed} = \rho_p(1-\epsilon) \quad (2)$$

$$\epsilon = 1 - \frac{DP1}{\rho_p g h} \quad (3)$$

While the Hitran element does reduce bubble size and delays the onset of slugging, it was found from visual observations that it inhibits solids flow near the walls of the column. The effect of this on the pilot plant operation will be discussed in the next section.

Effect of Hitran internals on the pilot scale reactor operation

When compared to the initial high velocity runs, the pilot plant temperature control showed a significant improvement as shown in Figure 5.

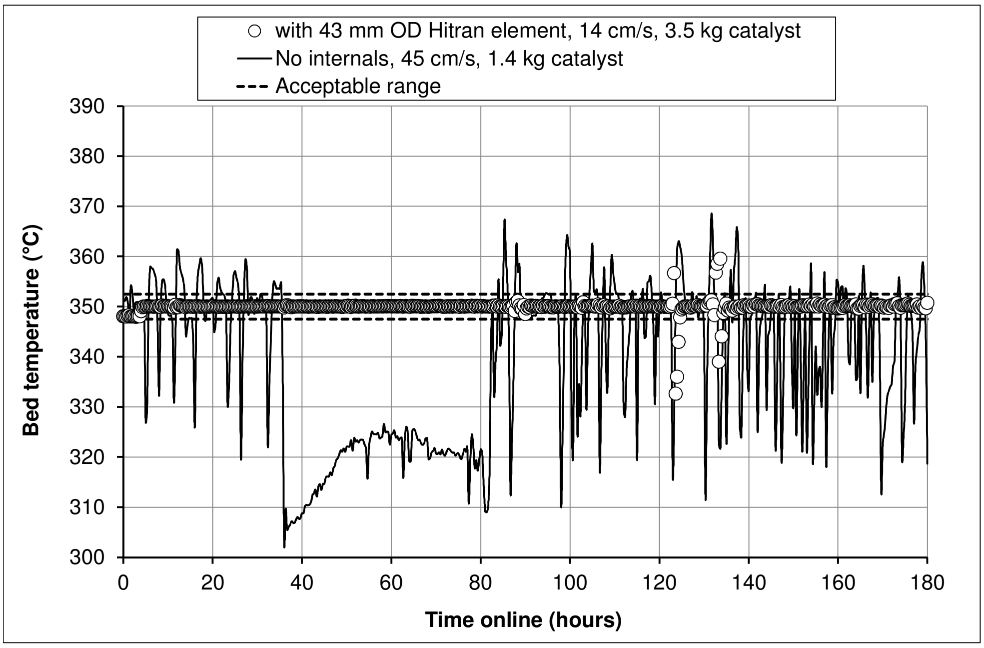

Figure 5: Reactor bed temperature with and without the Hitran element

However, the following three changes were made for this run: the gas velocity was reduced, the catalyst mass was increased and the Hitran element was installed. Hence it was not clear which change contributed the most to the improved temperature control observed. A subsequent run was therefore carried out where the Hitran element was removed and the reactor was run at the same conditions as when the Hitran element was installed. The temperature control was found to be similar. However, the run with the Hitran internal displayed a higher temperature differential in the bed compared with the run without the Hitran internal as shown in Figure 6.

These results indicate that the initial improvement in temperature control was largely due to the decrease in gas velocity and increased bed mass which reduced the heat load on the cooling system. The lower gas velocity provided a more stable fluidization regime for this application, while the increase in bed mass resulted in an increase in the heat transfer area since the reactor is oil cooled through the reactor walls. The higher temperature differential over a 600 mm section of the bed observed with the Hitran element indicates a decrease in solids mixing which was also observed during the cold model tests. In addition, on unloading the reactor it was found that large agglomerates of catalyst were stuck between the Hitran matrix which provides further evidence that solids mixing was compromised for the run with the Hitran insert.

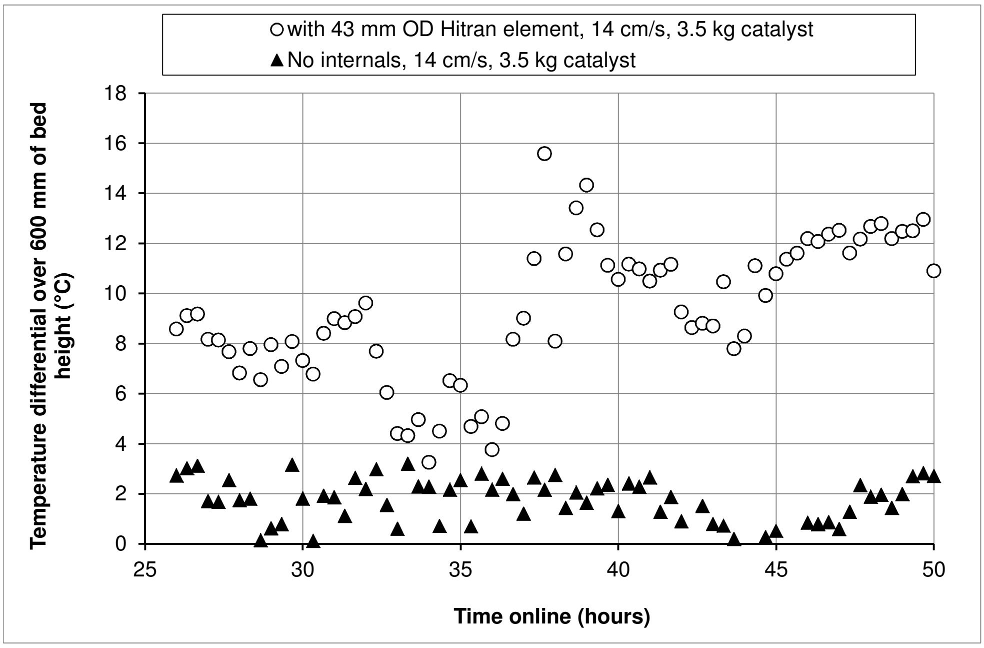

Figure 6: Bed temperature differential over a 600 mm bed height

CONCLUSION

It is concluded from this work that the Hitran matrix elements are effective in reducing bubble size and delaying the onset of slugging. However, solids mixing is inhibited with the Hitran internals when used in combination with relatively low gas velocities. The initial improvement in temperature control observed for the pilot scale reactor was due to the reduction in gas velocity and increase in catalyst mass rather than the use of the Hitran insert, indicating that the operational stability of the pilot plant is dependent on its cooling capacity. Future work will focus on testing a narrower diameter Hitran element with a less dense matrix. It is envisaged that this could prevent bridging of catalyst particles between the Hitran matrix and the reactor wall, and improve solids mixing.

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NOTATION

P	Pressure	[kPa]
T	Temperature	[°C]
dP	Differential pressure	[kPa]
ID	Internal diameter	[mm]
OD	Outside diameter	[mm]
g	gravitational acceleration	[m/s^2]

h	distance over which DP1 is measured	[m]
ρ_{bed}	bed density	[kg/m³]
ρ_p	particle density	[kg/m³]
ϵ	overall bed voidage	[-]

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