STANDPIPE INLET FOR ENHANCING PARTICULATE SOLIDS CIRCULATION FOR PETROCHEMICAL AND OTHER PROCESSES

The invention relates to a standpipe inlet design for enhancing particle circulation and reducing gas entrainment, the design being suitable for applications in fluid catalytic cracking (FCC) units and other processes, such as fluid cokers, flexicokers, and fluidized bed combustors which circulate large quantities of particulate solids between different vessels connected with standpipes and risers.

In a typical Fluid Catalytic Cracking (FCC) process consisting of a regenerator, a riser reactor and a stripper, such as that shown in US Patent No. 5,562,818 to Hedrick, finely divided regenerated catalyst leaves a regenerator and contacts with a hydrocarbon feedstock in a lower portion of a reactor riser. Hydrocarbon feedstock and steam enter the riser through feed nozzles. The mixture of feed, steam and regenerated catalyst, which has a temperature of from about 200 °C to about 700 °C, passes up through the riser reactor, converting the feed into lighter products while a coke layer deposits on catalyst surface. The hydrocarbon vapors and catalyst from the top of the riser are then passed through cyclones to separate spent catalyst from the hydrocarbon vapor product stream. The spent catalyst enters the stripper where steam is introduced to remove hydrocarbon products from the catalyst. The spent catalyst containing coke then passes through a stripper standpipe to enter the regenerator where, in the presence of air and at a temperature of from about 620 °C to about 760 °C, combustion of the coke layer produces regenerated catalyst and flue gas. The flue gas is separated from

entrained catalyst in the upper region of the regenerator by cyclones and the regenerated catalyst is returned to the regenerator fluidized bed. The regenerated catalyst is then drawn from the regenerator fluidized bed through the regenerator standpipe and, in repetition of the previously mentioned cycle, contacts the feedstock in the reaction zone.

Catalyst circulation is critical to overall performance and reliability of FCC units. The main drive for catalyst circulation comes from stable and adequate pressure build-up in the standpipe. One critical element of the standpipe design is the inlet design because it determines the inlet condition of the catalyst which, in turn, affects the entire standpipe operation.

The prior art of standpipe inlet design, for both stripper standpipe and regenerator standpipe, is a conical hopper such as that shown in the open literature in Handbook of Petroleum Refining Process, second edition by R.A. Meyers. The key concept of the inlet hopper design of the prior art is that when catalyst particles are drawn from a fluidized bed into a standpipe, bubbles are also drawn together with the catalyst. The inlet hopper provides residence time for the bubbles to coalesce and grow into large bubbles before entering the standpipe. Since large bubbles have a higher riser velocity, they have a better chance to escape back into the fluidized bed, thus reducing gas entrainment into the standpipe.

However, the design concept of the prior art standpipe inlet has several disadvantages. If the inlet hopper is too small, many bubbles drawn into the inlet hopper do not have enough time to grow but flow directly into the standpipe, leading to high gas entrainment. If, on the other hand, when the inlet hopper is large enough to allow small bubbles to grow, large bubbles could form

and hang stationary inside the hopper for a period of time as the bubbles try to rise against the downward catalyst flow. These large hanging bubbles can temporarily restrict catalyst flow into the standpipe. When the bubbles finally grow large enough to escape into the fluidized bed, the release of the large bubbles creates a sudden surge of catalyst into the standpipe, leading to a sudden pressure swing in the standpipe. The sequence of growing and releasing of large bubbles leads to a very undesirable condition of unstable standpipe operation. The fundamental flaw of the prior art design is that, while the objective of the standpipe inlet design is supposed to reduce gas entrainment into the standpipe, the design in fact encourages many bubbles to be drawn in. This is inherently very inefficient. Furthermore, the prior art of the inlet hopper design is a bulky structure such that in many FCC units there is not enough room to place it. A common compromise is to use either a straight pipe or an asymmetric hopper for the standpipe inlet which further exacerbates the problems described above.

Standpipe inlet geometry not only affects catalyst circulation, the entrained gas can also have a negative impact on the performance of a stripper of a FCC unit. It is common practice that the stripper includes special trays, such as shown in the invention by Johnson et al in international patent PCT/US95/09335. The special trays in the main vessel enhance the efficiency of hydrocarbon vapor stripping by steam. The spent catalyst is then transported to the regenerator through a stripper standpipe with a hopper inlet as shown in the prior art. The hopper inlet for the stripper standpipe has been shown to be rather ineffective in reducing gas entrainment. The study of Nougier et al in the Second FCC Forum (May 15-17, 1996, The Woodlands, Texas) shows that,

even after intensive stripping in the main vessel, the vapor leaving the stripper still contains 20 to 25% by mole (or about 40% by weight) of hydrocarbon products. Gas entrainment from the stripper standpipe into the regenerator has two negative impacts in addition to the impact on catalyst circulation discussed above. First, the entrained gas from the stripper to the regenerator represents a loss in hydrocarbon products which could have been recovered as products. Second, the entrained hydrocarbon has to be burned in the regenerator which consumes limited air available in the regenerator and generates additional heat that has to be removed. Thus, it is essential to reduce gas entrainment into the stripper standpipe.

One objective of the instant invention is to reduce gas entrainment into standpipes by a standpipe inlet design. This will lead to increases in overall pressure build-up in the standpipe and catalyst circulation rate as well as improving standpipe stability. The reduction in gas entrainment will also reduce hydrocarbon entrainment from the stripper to the regenerator of an FCC unit, as discussed above.

These objectives are achieved with the following apparatus.

Apparatus comprising means for keeping a bed of particulate solids in a fluidized bed mode in a vessel, a conduit for transferring said particulate solids into the resulting fluidized bed and a standpipe, protruding into said fluidized bed, for transferring particulate solids out of the fluidized bed, wherein a disk surrounding the standpipe circumference is present below the upper part of the standpipe and above means for keeping a bed of particulate solids in a fluidized bed mode, said the upper part of the standpipe comprises an inlet for receiving particulate solids from the fluidized bed, said

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the disk induces, in use, a local partial de-fluidization, resulting in a local dense fluidization zone thereabove, and near the proximity of the inlet of the standpipe.

Applicants have found that with the apparatus according to the invention the solids flow smoothly into

the standpipe with less of the above described gas entrainment. More advantages will be described below.

The main drive for catalyst circulation in FCC units comes from stable and adequate pressure build-up in the standpipe. One critical element of the standpipe design is the inlet design because it determines the inlet condition of the catalyst which, in turn, affects the entire standpipe operation. It is essential to reduce gas entrainment by a properly designed standpipe inlet.

The key concept of the instant invention of the standpipe inlet design is totally different from the inlet hopper design of the prior art, which has many disadvantages as discussed previously. The design concept of the instant invention relies on partial de-fluidization, rather than bubble coalescence and growth inside the hopper, to reduce gas entrainment which is discussed in detail below.

The reason that FCC catalyst can be maintained at the fluidization state in the regenerator or the stripper is by a continuous supply of upflowing, fluidizing gas. Thus, as soon as the supply of the fluidizing gas is cut off, the fluidized catalyst starts to settle, or de-fluidize, immediately. In the initial stage of this de-fluidization process, bubbles escape very quickly from the fluidized bed, as shown by Khoe et al in Powder Technology Vol. 66 (1991) which is incorporated herein by reference. After the depletion of all bubbles, FCC catalyst can still be maintained at a dense fluidization state for a certain period of time before becoming completely de-fluidized, as also shown by Khoe et al. In Khoe et al's experiments, the de-fluidization process was triggered by shutting off fluidization gas supply, leading to de-fluidization of the entire fluidized bed. Applicants now found that, by strategically blocking off the upflowing, fluidizing gas in a selective area a local

de-fluidization process within a fluidized bed is achieved. The instant invention of standpipe inlet design utilizes this partial de-fluidization in a strategic area to eliminate the bubbles and by allowing only densely fluidized catalyst to flow into the standpipe.

The apparatus according to the invention will be further described making use of the following non-limiting Figures.

FIGURE 1 is a sectional view of the lower portion of a regenerator of a FCC unit including a regenerator standpipe.

FIGURE 2 is an enlarged sectional view of a portion of Figure 1 of the regenerator standpipe inlet.

FIGURE 3 is an alternative embodiment of Figure 2 of the regenerator standpipe inlet.

FIGURE 4 is another embodiment of the regenerator standpipe inlet when catalyst is drawn from a space near the bottom wall of the regenerator vessel of a FCC unit.

Referring now to Figure 1 which is a sectional view of the lower portion of a typical regenerator vessel 20 of a FCC unit with a regenerator standpipe 10 which includes an inlet portion 60 to draw in regenerated catalyst according to the instant invention. Spent catalyst is transported from a stripper (not shown) through a typical spent catalyst transport duct 70 and enters the regenerator 20 where coke deposition on catalyst is burned off by air which is supplied by main air grid 30. The air from grid 30 and the resulting combustion gas rise through the regenerator, thus keeping the catalyst fluidized in fluidized bed 40. The combustion gas and entrained regenerated catalyst are separated in the upper part of the regenerator by cyclones (not shown). The combustion gas exits from the upper part of the regenerator and the regenerated catalyst, separated by cyclones (not shown), is returned

to the fluidized bed 40. Typical density of the fluidized bed 40 in regenerator 20 is in the range of 0.32-0.64 g/cm^3 [20 to 40 lb/ft^3], with the presence of many rising gas bubbles. The density of the fluidized bed 40 is controlled mainly by the air flow from air grid 30 where higher fluidizing air flow leads to more gas bubbles and lower density of fluidized bed 40. The fluidized bed 40 is maintained at a certain level 50 by a slide valve (not shown), or other means, located at the bottom of the regenerator standpipe 10 to control the rate of regenerated catalyst being drawn into regenerator standpipe 10. The top of the regenerator standpipe 10, including a standpipe inlet 60 according to the instant invention, is shown as enclosed by the dotted circle, is completely submerged in the fluidized bed 40 inside regenerator 20. Although the standpipe 10 is shown in Figure 1 to be vertical and protruding into regenerator 20 from the bottom, the instant invention of the standpipe inlet 60 can be applied to other configurations where the standpipe 10 might protrude into regenerator 20 through the side wall, instead of the bottom of the vessel, and it might be inclined, instead of vertical.

Referring now to Figure 2 for the details of standpipe inlet 60 in Figure 1, the regenerator standpipe 10 is typically a cylindrical duct with a diameter in the range of about 1 to about 5 feet. Regenerated catalyst is preferably drawn into the standpipe 10 through one of two types of openings, or both. The first preferred embodiment for the opening is a top opening 11 of the standpipe. The second preferred embodiment for the opening is a plurality of openings 12 cut through the walls of the upper portion of the standpipe 10. Although slots are shown in Figure 2 for openings 12, other forms, such as circular holes, could also be used. Below the openings 11 and/or 12 is a

horizontal disk 13 surrounding the standpipe 10. In the following discussion, the element 13 will be referred to as a "disk", which is the most logical form for a cylindrically-shaped vessel. It will be appreciated, however, that the element 13 may simply be a plate of any desired shape. Since the entire standpipe inlet is submerged in the fluidized bed 40 where catalyst is fluidized by the continuous upflow of fluidizing gas from air grid 30 (see Fig. 1), disk 13 strategically blocks off the supply of the fluidizing gas coming from below and triggers the local de-fluidization process in the region directly above disk 13. As fully fluidized regenerated catalyst together with gas bubbles are being drawn toward the standpipe openings 11 and 12, the fluidizing gas is blocked off by disk 13 (except as described below) and bubbles migrating toward standpipe openings 11 and 12 run out of the continuous supply of fluidizing gas very quickly. This creates a dense fluidized zone 14, shown enclosed by the dotted line in Figure 2, with almost no bubble presence in the near proximity to the standpipe openings 11 and 12. This allows catalyst to partially de-fluidize by eliminating gas bubbles before entering standpipe 10, but not to the extent of complete de-fluidization where catalyst can no longer flow. To prevent complete de-fluidization in the dense fluidization zone 14 above the disk 13, a small gas flow is preferably supplied. The small gas flow is preferably supplied by vent holes 13c in the disk 13 and/or through a gas injection ring 15 located above the disk 13. Although a gas injection ring 15 is shown in Figure 2, other means, such as a gas injection grid, can also be used to achieve the same objective of preventing complete de-fluidization in the dense fluidization zone 14 above the disk 13.

The disk 13 suitably includes a downwardly-projecting side or lip 13a which circles the disk 13, preferably at its circumference. The void below disk 13 surrounded by lip 13a allows the disk to capture fluidizing gas coming from below. To continuously vent off the fluidizing gas, lip 13a suitably further includes a plurality of vent holes 13b which allows fluidizing gas to be vented off outside the dense fluidization zone 14. Alternatively, a vent tube 16 may be used to discharge fluidizing gas from below the disk 13 to a location above the dense fluidization zone 14. Although a horizontal disk 13 is proposed as one means to achieve local de-fluidization in the dense fluidization zone 14 in Figure 2, other means can be applied to achieve the same objective. One such alternative is shown in Figure 3.

Referring now to Figure 3, regenerated catalyst is again drawn into the standpipe 10' through the top opening 11', or a plurality of openings 12', or both. Instead of using a horizontal disk 13 as in Figure 2, Figure 3 shows that below the openings 11' and 12' is a conical disk 13' surrounding the standpipe 10'. The function of the conical disk 13' is to strategically block off the supply of the fluidizing gas coming from below and to trigger the local de-fluidization process in the region directly above disk 13'. This creates a dense fluidized zone 14', enclosed by the dotted line in Figure 3. To prevent complete de-fluidization in the dense fluidization zone 14', a small gas flow is preferably supplied, either by vent holes 13c' in the disk 13' and/or through a gas injection ring 15' located above the disk 13'. Although a gas injection ring 15' is shown in Figure 3, other means, such as a gas injection grid, can also be used to achieve the same objective of preventing complete de-fluidization in the dense fluidization zone 14' above the disk 13'. The void below

conical disk 13' allows the disk to capture fluidizing gas coming from below. To continuously vent off the accumulation of the fluidizing gas, disk 13' suitably further includes a plurality of vent holes with extension pipes 13b' which allows fluidizing gas to be vented off outside the dense fluidization zone 14'. Alternatively, a vent tube 16' may be used to discharge fluidizing gas from below the disk 13' to a location above the dense fluidization zone 14'. One advantage of the conical disk 13' over the horizontal disk 13 in Figure 2 is that catalyst is less likely to become stagnant when gas flow from the gas injection ring 15' is turned off.

Figure 4 shows another embodiment of a regenerator standpipe inlet using a design similar to the concept of Figure 1 except when the FCC process prefers to draw regenerated catalyst from a region very close to the bottom of regenerator 120. Spent catalyst is transported from a stripper (not shown) through a spent catalyst transport duct 170 and enters the regenerator vessel 120. The regenerated catalyst is separated from flue gas in the upper part of the regenerator by cyclones (not shown). The flue gas exits from the upper part of the regenerator vessel and the regenerated catalyst separated by cyclones (not shown) is returned to the lower part of the regenerator vessel 120 to form the fluidized bed 140 by the continuous upflow of fluidizing air and combustion gas from air grid 130. The fluidized bed 140 is maintained at a level 150 by a slide valve (not shown), or other means, located at the bottom of the regenerator standpipe 110 to control the rate of regenerated catalyst being drawn into the regenerator standpipe 110.

In this embodiment the disk surrounding the standpipe 110 is part of the lower end of the regenerator vessel 120. The regenerator standpipe 110 still has one of two types of inlet openings, or both, to draw catalyst

from the fluidized bed 140 of the regenerator vessel. The first opening is the top opening 111 of the standpipe 110 and the second is a plurality of openings 112 cut through the walls of the upper portion of the standpipe 110 just above the bottom vessel wall 113 of regenerator 120. Although the standpipe 110 is shown in Figure 4 to be vertical, the instant invention of the standpipe inlet can also be applied to other configurations where the standpipe 110 might be inclined. The function of the lower end wall 113 of the regenerator vessel in Figure 4 is similar to that of the disk 13 in Figure 2, i.e., to induce local de-fluidization and to create a dense fluidization zone 114 (as in zone 14 of Fig. 2) with almost no bubbles present in the near proximity to the standpipe openings 111 and 112. To prevent complete de-fluidization near the vessel wall, a small gas flow can be supplied through a gas injection ring 115. Although a gas injection ring 115 is shown in Figure 4, other means, such as a gas injection grid, can also be used to achieve the same objective of preventing complete de-fluidization in the dense fluidization zone 114 above the vessel wall 113.

A regenerator standpipe inlet according to Figure 4 was installed in one of Assignee's FCC units which originally had a hopper standpipe inlet of the prior art design. The original inlet hopper was removed and four slots measuring 6 inches wide by 40 inches long were created on the standpipe wall. After the installation of the new regenerator standpipe inlet, catalyst circulation rate of the FCC unit was increased by 30%, with an additional 3 psi pressure build-up in the regenerator standpipe. This was a clear indication that the standpipe inlet of the instant invention was very effective in reducing gas entrainment from the regenerator thus allowing the standpipe to run at higher density and to

build more pressure for increasing catalyst circulation. Furthermore, the standpipe operation became more stable even at a higher catalyst circulation rate compared to previous operation.

From the discussion above, it is demonstrated that the standpipe inlet design of the instant invention has several advantages over the inlet hopper design of the prior art when it is applied to the regenerator standpipe of a FCC unit:

More Stable Operation - The inlet design of the instant invention does not rely on the mechanism of the prior art inlet hopper to draw in lots of bubbles, letting them coalescence and grow into large bubbles. Instead, the new inlet design minimizes bubble entrainment by strategically eliminating bubbles around the standpipe inlet region with local de-fluidization. Since the new design does not require the formation and release of large bubbles in the hopper design, which leads to standpipe instability, the design of the instant invention is inherently more stable.

More effective in reducing gas entrainment - The concept of the prior art inlet hopper is to draw in lots of bubbles while trying to reduce gas entrainment. This is inherently a very inefficient design. On the other hand, the basic design of the instant invention is to strategically eliminate bubbles by local de-fluidization of the catalyst before it enters the standpipe. Thus, the design of the instant invention is inherently more efficient in reducing gas entrainment into the standpipe.

Better Control - The prior art hopper inlet has little control of gas entrainment around the inlet. As the catalyst circulation rate increases, more and more bubbles are drawn into the hopper, leading to higher and higher gas entrainment. The design of the instant invention, on the other hand, maintains complete control

of the flow condition near the inlet by eliminating all bubbles, then introducing only a small amount of gas necessary for smooth operation.

Simplicity - The design of the instant invention is simpler and more robust than the prior art hopper design.

When the standpipe inlet design of the instant invention is applied to the stripper standpipe, it provides several additional advantages over the prior art inlet hopper design for enhancing stripper and regenerator performance of a FCC unit. This is in addition to the benefits already discussed for application in the regenerator standpipe where catalyst circulation and standpipe stability are the main concerns:

Higher stripping efficiency - The standpipe inlet design of the instant invention is shown to be more effective in reducing gas entrainment into the standpipe. Since the entrained gas from the stripper standpipe may contain about 40% by weight of hydrocarbon products, the standpipe inlet design of the instant invention effectively increases hydrocarbon products by reducing hydrocarbon loss to the gas entrainment.

Lower regenerator loading - Since the stripper standpipe inlet design of the instant invention is more effective in reducing gas entrainment, less hydrocarbon will enter the regenerator. This leads to lower air requirement and less heat to be removed as less hydrocarbon is to be burned in the regenerator. More importantly, many FCC units today are limited by air supply or heat removing capacity in the regenerator. Thus, the instant invention can be used to debottleneck the unit.

Although the above discussion focuses on the applications of the instant invention in FCC units, a similar standpipe inlet design can also be applied to

improve circulation of particulate solids and reduce gas entrainment in other petrochemical processes, such as fluid cokers and flexicokers, and processes other than petrochemical, such as circulating fluidized bed combustors, where large quantities of particulate solids are circulated between different vessels connected by standpipes and risers.

C L A I M S

1. Apparatus comprising means for keeping a bed of particulate solids in a fluidized bed mode in a vessel, a conduit for transferring said particulate solids into the resulting fluidized bed and a standpipe, protruding into said fluidized bed, for transferring particulate solids out of the fluidized bed, wherein a disk surrounding the standpipe circumference is present below the upper part of the standpipe and above means for keeping a bed of particulate solids in a fluidized bed mode, said the upper part of the standpipe comprises an inlet for receiving particulate solids from the fluidized bed, said the disk induces, in use, a local partial de-fluidization, resulting in a local dense fluidization zone thereabove, and near the proximity of the inlet of the standpipe.

2. Apparatus according to claim 1, wherein the inlet in the upper part of the standpipe comprises a plurality of openings cut through the wall of the standpipe below the upper end and above the disk.

3. Apparatus according to claim 2, wherein a plurality of openings are vertical slots cut through the wall of the standpipe below the upper end and above the disk.

4. Apparatus according to any one of claims 1-3, wherein above the disk a means for injecting fluidizing gas is present for maintaining a dense fluidization zone of particulate solids located thereabove.

5. Apparatus according to any one of claims 1-4, wherein the upper end of the standpipe is open.

6. Apparatus according to any one of claims 1-5, wherein a means for venting gas from below the disk is present.

7. Apparatus according to claim 6, wherein the venting means are holes in the disk.

8. Apparatus according to claim 7, wherein the venting means is a tube connecting the region below the disk and the region above the upper end of the standpipe.

9. Apparatus according to any one of claims 1-8, wherein on the circumferential of the disk a downward projecting lip is present.

10. Apparatus according to claim 9, wherein the lip comprises a plurality of vent holes.

11. Apparatus according to any one of claims 1-10, wherein the disk has a conical shape pointing towards the upper end of the standpipe.

12. Regenerator apparatus of a fluid catalytic cracking unit comprising the apparatus according to any one of claims 1-11.

13. Stripper apparatus of a fluid catalytic cracking unit comprising the apparatus according to any one of claims 1-11.