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Performance comparison of a blast furnace gravity dust-catcher vs. tangential triple inlet gas separation cyclone using computational fluid dynamics ☆

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ABSTRACT

A gravity dust-catcher is a high tonnage device that is widely used to separate a mixture of dusts from blast furnace (BF) top gas flow. Dusts include limestone, iron ore and coke/coal. For decades, the gravity dust-catcher has been the equipment of choice to clean blast furnace top gas generated from the energy intensive iron making process. However, in recent years there has been an increase in demand for gas separation cyclones in place of the gravity dust-catcher due to the substantially higher particle separation efficiencies that can be achieved. Yet, reliability still remains an issue due to higher maintenance costs associated with regular repair of refractory lining within the cyclone.

The effect on particle separation efficiency is analysed as a result of these two different dust separation approaches. Using a modified gravity dust-catcher design, together with a new design developed by Siemens VAI for a triple inlet gas separation cyclone, computational fluid dynamics (CFD) simulations are used to predict the potential performance of the two types of equipment. It is concluded that whilst the patented gravity dust-catcher substantially increases the particle separation efficiency over existing dust-catcher designs, the gas cyclone is some 48% more efficient. The modified dust-catcher design may however provide an effective low cost alternative to a gas separation cyclone if it can be retro-fitted to existing operations.

1. Introduction

Tata Steel Strip Products UK (TSSP UK) at Port Talbot has two blast furnaces (Nos. 4 and 5) with a combined production output of approximately 86 kT of iron per week. Blast furnace operation requires high efficiency top gas cleaning equipment to cope with changes to the top gas composition, dust loading, pressure and temperature fluctuations to match the campaign life of the furnace.

The dust-catcher is the first of the major dust separation and cleaning devices, and functions to remove the majority of the incoming dust (on a mass in-flow/out-flow basis) with recorded efficiencies from on site plant data of up to 50–55%. Dust concentration in the blast furnace gas ranges between 10 and 20 g/N m^3, averaging around 15 g/N m^3. The dust collection efficiency of the wet scrubbing stage and the demister are relatively insensitive to the inlet dust loading, but the real benefits of dust removal from the top gas flow extends to the efficiency of operation of the water treatment plant.

Duty of care to the surrounding environment requires that top gas is cleaned to a reasonable level, reducing the environmental impact of the iron making process. The recycling of blast furnace top gas provides a major source of energy for heating the blast furnace stoves. The amount of dust in this recycled gas affects the chequers, leading to operational problems, while mist affects the performance of the burners. With studies being carried out by TSSP UK into the incorporation of a top gas recovery turbine on blast furnace No. 4 (BF4), the importance of clean, dust free top gas, has never been higher.

☆ *Disclaimer*: The multi-trumpet gravity dust-catcher and its designs mentioned herein are property of Tata Steel Europe and used with kind permission. The multi-trumpet gravity dust-catcher and variations on its design are covered by patent application no. EP1100716. The triple inlet gas cyclone mentioned herein is property of Siemens VAI Metals Technologies Ltd., with patents pending and used with kind permission from the manufacturer.

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In order to ascertain the preferred device for BF4 gas cleaning plant at TSSP UK, it has been necessary to assess the current status on worldwide installations from a wide range of plant operators and manufacturers. Installation data gathered from a range of sources that include equipment manufacturers and individual steel plants up until the end of 2010, shows that the gas separation cyclone appears to lead the gravity dust-catcher by nearly 2:1, but there is still some evidence that operating steel plants are unsure which technology to adopt, selecting a dust-catcher for removing the coarse particles from the blast furnace top gas, whilst choosing a smaller cyclone to remove the finer particulates from this top gas flow.

If this data is considered over that last 10 years to 2010, it is found that the installation of a gas cyclone dominates that of the dust-catcher at nearly 9:1. It is noted however, that most plants that have specified a cyclone in the last 10 years are new build projects, and generally, it is the Asian continental steel plants that have specified a cyclone over a dust-catcher.

2. Current research and objectives

There appears to be no evidence of CFD simulation work undertaken to calculate the particle separation efficiency performance of a gravity dust-catcher over an operational cycle. Where CFD simulation has been carried out its focus has mainly been on cyclone technology. Gas cyclones are widely used in industry to separate dust from gas or for product recovery, allowing a certain degree of recyclability of process waste. Due to their geometrical simplicity and relatively low power consumption and pressure drop, they may be adapted for use in extreme operating conditions such as high temperatures, high pressures and atmospheres containing corrosive gases, that are typically experienced by dust-catchers in the blast furnace environment. Due to a lack of moving parts, cyclones are relatively maintenance free, and have found increasing utility in the field of air pollution, petrochemical and minerals process industries.

Much work has been done on CFD modelling of various cyclone designs for a range of industrial applications. Syred et al. and Zhang & Ahmadi and Mazaheri et al. have looked at cyclone modelling for pollution control in a coal fired power station [1] and hot gas filter vessels [2,3], whilst others have looked at cyclone performance when varying some part of the geometry such as the inlet section angle [4], cone tip diameter [5], the incorporation of a post cyclone [6,7], changes to the dust outlet geometry [8,9], and running multiple cyclones in parallel [10]. Changes to the inlet configuration have also been assessed [11], much like the aims of this paper, but only on small scale models. Various turbulence models have been used including LES [12,13] and the less complicated RSM [14–16] in order to generate a representation of the internal flow profile in such cyclones.

This paper addresses the problem of specifying the best piece of equipment required for the primary dust separation process in order to optimise the design of a blast furnace gas cleaning plant. A case is thus presented for both the gravity dust-catcher and the gas separation cyclone, where the multi-phase fluid flow performance is assessed using CFD simulation, which includes results on two optimised designs. An outline discussion, including potential problems and benefits that may arise from their selection and operation, is included to support both configurations.

3. Gas cleaning plant layout

A typical blast furnace gas cleaning plant (see Fig. 1) contains three main pieces of equipment for the extraction and separation of dust and particulates from blast furnace top gas flows. Gas, which is injected and produced through numerous chemical reactions in the blast furnace passes out of the uptakes and into a down comer before entering the primary separation phase [17]. In the case of BF4 at TSSP UK this phase comprises a gravity dust-catcher.

At other plants throughout the world a gas separation cyclone is also specified for this phase of the operation. Gas passes out of this primary phase and into a wet scrubber where gas is mixed with injected water and passed between a male and female cone under very high pressure enabling the majority of the dust laden gas to be recovered as slurry. Finally, the remaining gas is dried in a demister before being recycled back through the system and used to heat up incoming cold blast in the hot blast stoves, which is injected into the blast furnace. The whole cycle is continuous.

3.1. Dust-catcher principles of operation

A gravity dust-catcher consists of four main parts; the inlet section, an internal trumpet, the main body and hopper, and the gas outlet pipe. The dust-catcher trumpet is the main feature which affects flow performance and the consequent particle separation efficiency. A dust-catcher relies solely on gravity to separate out dust particles from the blast furnace top gas flow. These particles, carried by the free flowing gas pass out the top of the furnace and through a down-comer section where they enter another section which reduces the incoming velocity of the top gas through its diverging expansion profile (known as a trumpet). The flow then passes into the main body of the dust-catcher. The flow is then forced to turn 180° in the bottom third of the dust-catcher causing the heavier particles to deposit themselves in the dust-catcher hopper where they are removed periodically.

The current installation on BF4 at TSSP UK has been in service since 1992, and has experienced no major problems with its operation. Problems that have been encountered have been rectified with minimal downtime. Due to its construction methods, it is cheap to manufacture and lacks moving parts which could wear out over time. A dust-catcher is a relatively cheap piece of equipment to operate due to a small, almost negligible pressure drop, reducing energy consumption over its campaign life.

A dust-catcher has a low operating efficiency, proving difficult to increase its efficiency much above 55–60%. For a given top gas flow rate, the design of the dust-catcher is rather bulky when compared to other pieces of plant equipment which function to do the same task.

3.2. Cyclone principles of operation

The principle of a cyclone (see Fig. 1) is to separate dust and particulates from a free moving gas stream without the use of filters. The shape of the cyclone generates an internal gas vortex aiding the separation of the solid particles from the gas stream. Rotational effects and gravity are used to separate mixtures of solids. The inlet to the cyclone brings in the blast furnace top gas, establishing a high speed rotating spiralled flow within the cylindrical confines of the cyclone body. The spiral begins at the cyclone's top end (widest point), and ends up in the bottom end (narrowest point), before exiting vertically upwards, in a straight stream along its central axis [19].

Higher specific gravity particles have too much inertia to follow the tightly curved profile of the gas stream, and collide with the inner wall of the cyclone. The particles within this rotational flow field (or vortex) experience a centrifugal force, which is opposed by a corresponding drag force. The centrifugal force is directly dependent on the circumferential velocity, and the knowledge of such is vital to predict cyclone performance. When particles strike the cyclone shell, the larger particles fall to the bottom where they are periodically removed. This principle is repeated from the top to