Powder Technology 291 (2016) 284–298

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Numerical and experimental study of pulse-jet cleaning in fabric filters

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ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 25 November 2015
Accepted 21 December 2015
Available online 30 December 2015

Keywords:
Computational fluid dynamics
Fabric filter
Baghouse
Pulse-jet cleaning
Low-pressure cleaning
Design optimisation

ABSTRACT

Pulse-jet cleaning and understanding of the complex physics are essential when designing fabric filters used for air pollution control. Today, low-pressure cleaning is of particular interest due to demand for reduced compressed air consumption. Pulse-jet cleaned fabric filters have been studied for many years by experimental investigation and to a limited extent by Computational Fluid Dynamics (CFD). The majority of the studies have focused on high-pressure cleaning systems, and the CFD models presented are so far two-dimensional (2D). In the work presented here, pulse-jet cleaning of low-pressure fabric filters (2 bar) is studied using a full three-dimensional (3D) CFD model. Experimental results obtained in a pilot-scale test filter with 28 bags, in length of 10 m and in general full-scale dimensions of the cleaning system are used to verify the reliability of the present CFD model. The validated CFD model reveals the strong compressible effects, a highly transient behaviour, the formation of compressible vortex rings and the shock cell phenomenon within the overexpanded supersonic jet. The cleaning nozzles and venturi design aid or oppose the pulse-pressure within the bags, and this plays an important role in the resulting efficiency of removing the dust layer from the bags. The CFD simulation shows that the traditional straight-bore nozzles provide substantial misalignment of the jet, and the add-on nozzle design offers only limited improvement. Further, the need for venturis in low-pressure filters and the importance of optimising the venturi design are demonstrated. The working principle of the venturi is to restrict backflow which is detrimental to the pressure rise in the bags. Reducing the venturi throat diameter is shown to reduce backflow and improve the pulse-pressure.

1. Introduction

Pulse-jet cleaned fabric filters are commonly used for air pollution control in many industries, e.g. power production and mining. Dust transported by the flue gas is collected on the external surface of the fabric bag, thereby forming a so-called ‘dust cake’. Periodic removal of the dust cake is required due to the continuous build-up of dust. Pulse-jet cleaning is widely used for this purpose as it enables frequent cleaning whilst the filter is operating.

In pulse-jet cleaning, a short pulse (50–150 ms) of compressed air is released by a valve and distributed in a purge tube to multiple nozzles (Fig. 1). Each nozzle is directed towards a venturi placed above the open end of a single bag. The compressed air expands through the nozzle, thereby forming a pulse-jet of primary air. In the near-field region around the pulse-jet, secondary air entrains the pulse-jet as it travels towards the venturi (Fig. 2). The pulse-jet acts in countercurrent direction to the flow of flue gas during normal filter operation (Fig. 3). In cleaning mode, the pulse-jet travels through the venturi and into the bag where the flow reversal and high resistance in the fabric cause an internal pressure increase called the pulse pressure. As a result, the bag is briefly inflated and the dust cake is removed (Fig. 3 right).

In recent years, interest in low-pressure pulse-jet cleaning has increased in the search for reduced energy consumption. Low-pressure filters operate at a tank pressure of 2–3 bar gauge, whereas traditional high-pressure filters operate at much higher pressure, typically 4–7 bar gauge. This relatively new technology is expected to introduce challenges not found in traditional high-pressure systems. Of particular interest is the potential axial misalignment between pulse-jet and venturi/bag.

In low-pressure filters, the lower density of the compressed air is expected to cause higher axial velocity in the purge tube and therefore increased jet misalignment.

Understanding the jet behaviour and the interaction with the venturi and bag is crucial to design effective pulse-jet cleaned fabric filters. The introduction of low-pressure filters poses an even greater challenge to engineers, requiring a detailed insight into the highly dynamic fluid flow. Obtaining this valuable information is difficult through conventional methods relying on physical measurements, which often fall short in terms of spatial as well as temporal resolution. Computational Fluid Dynamics (CFD) is highly suited for this purpose as it offers the

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http://dx.doi.org/10.1016/j.powtec.2015.12.028
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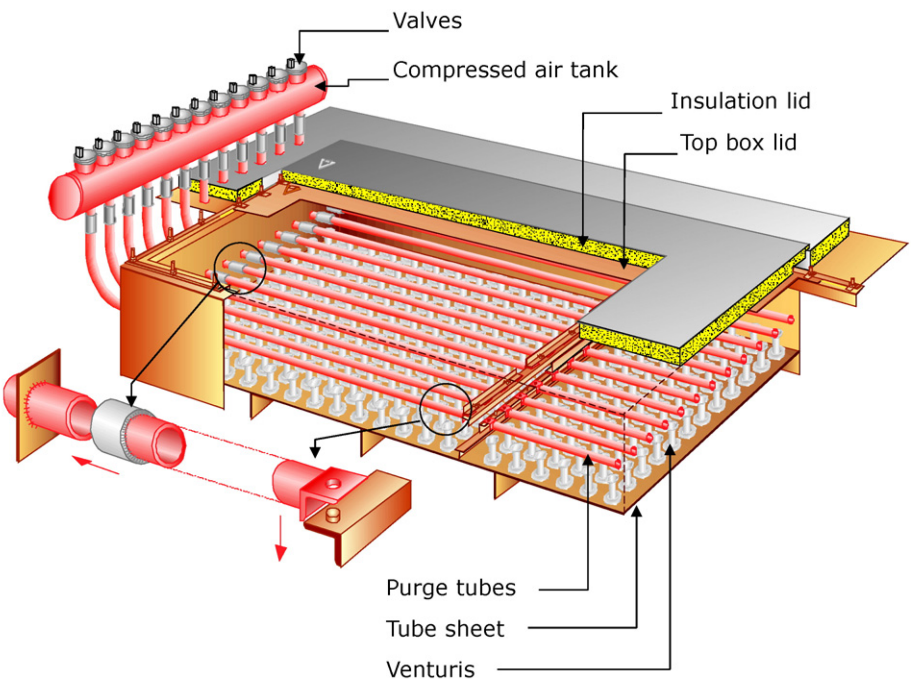

Fig. 1. Schematic view of the pulse-jet cleaning system.

level of detail needed at a fraction of the cost compared to physical experiments.

There are a number of studies in the literature on pulse-jet cleaning, although the majority of the work has focused on high-pressure filters. Previous research has found that several parameters affect pulse-jet cleaning, the most important being: nozzle diameter, distance between nozzle and bag opening, pulse duration, initial tank pressure and volume [1–7]. Bakke [1] identified the jet and venturi concept as essentially a jet pump and found that the pulse pressure developed in the bag is inversely proportional to the flow rate entering the bag. Lu and Tsai [2–4] found that increasing the bag resistance leads to an increase in pulse pressure. Increasing the nozzle diameter was found to increase the pulse pressure until a certain limit, after which a larger diameter will be detrimental; hence an optimum nozzle diameter exists. Similarly, an optimal distance between nozzle exit and bag opening exists. A longer distance allows for more entrainment of secondary air, but if the distance is too long, the jet width will exceed the diameter of the bag or venturi opening. A mathematical model for optimising this distance was later developed by Qian et al. [8], who studied high-pressure filters (6 bar) without venturis.

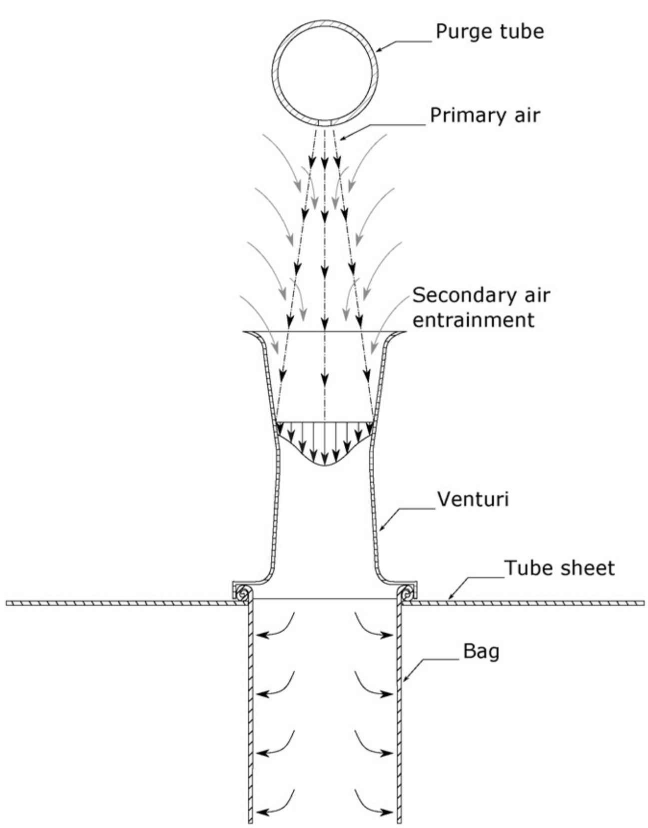

Fig. 2. Illustration of the jet pump principle showing primary air from the nozzle and secondary air entraining the jet from the surroundings.

The role of the venturi is not fully covered in the literature and is a subject of debate. According to Morris et al. [9], the role of the venturi is to allow the pulse to travel easily into the bag, while restricting its escape and thereby increasing the pressure within the bag. The provision of a high pulse pressure was found to be incompatible with a low pressure loss through the venturi during filtration. Removal of the venturi caused significant reduction of the pulse pressure. Lanois and Wiktorsson [10] compared the performance of 'advanced' filters at 1–2 bar tank pressure without venturis to 'traditional' filters at 4.8–6.2 bar with venturis and found that advanced filters require lower energy for the equivalent cleaning efficiency. In the study by Lu and Tsai [4], two venturis were tested against a venturi-less design. The necessity of the venturi was found to depend on the combined resistance of the bag and dust cake. For high resistance bags, maximum pulse pressure was obtained with venturi and vice versa. The venturi role was also studied by Hájek [11], who found a three-fold increase in the mass flow rate entering the bag when installing a venturi, claiming increased entrainment of secondary air to be the reason. Further, a two-fold increase in pulse pressure was found, demonstrating the unambiguous advantage of the venturi. Whether the venturi is beneficial is indeed a subject of debate and is perhaps best summarised by Lu and Tsai [3]: "There are situations where venturis are required to increase pressure pulse inside the bag, and there are also situations where venturis are not necessary."