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A high-precision method for calculating the pressure drop across wire mesh filters

Haiou Sun, Shi Bu, Yigang Luan*

College of Power and Energy Engineering, Harbin Engineering University, 145 Nantong Street, Harbin 150001, Heilongjiang Province, China

HIGHLIGHTS

- Experiments are accomplished with wire mesh parameters precisely controlled.
- A creative numerical method for wire mesh is proposed.
- A new mathematical correlation is derived for wire mesh pressure drop.

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ABSTRACT

Three structural parameters were defined based on the characteristics of wire mesh filters: wire diameter, layer spacing and mesh size. The pressure drops across two different mesh pads were measured under different superficial air velocities in a wind tunnel. A new geometrical simplification method for numerical simulations was proposed. Using the large amount of calculated pressure drop data, a new expression was derived for predicting pressure drops across mesh pads. Good agreement was achieved among the experimental data, simulated data and expression data which demonstrated that the derived expression can accurately predict pressure drops.

1. Introduction

Wire mesh filters have many applications in industrial and dynamic systems, such as gas processing facilities (Al-Dughaither et al., 2010), multi-stage flash desalination plants (Janajreh et al., 2013), nuclear electric plants and offshore intake-air filtration systems (Brekke et al., 2009, 2010). These filters are generally installed in the form of multi-layers for steam purification and for the removal of liquid droplets or aerosols from airflows. Compared with other separation devices, such as wave-plate separators or cyclones, wire mesh filters provide better separation efficiencies down to sizes of 2 μm to 10 μm; therefore, they can also be used as coalescers or pre-filters positioned upstream of other separation devices (Setekleiv and Hallvard, 2012).

Wire meshes can be shaped as either cylinders or as multi-layer pads with certain thicknesses to suit the actual spatial pattern of the installation site. In addition to stainless steel, wire meshes can be composed of glass and plastic fibers, such as polypropylene, Dacron and Teflon. The wire mesh material primarily depends on the operating environment, including the gas temperature, causticity and liquid loading (Brunazzi and Paglianti, 1998, 2000). Despite these factors, the knit forms of wire meshes are approximately the same, which makes it possible to adopt some analogous approaches during investigations.

The three main separation mechanisms are inertial capture, direct interception and droplet diffusion; among these, inertial capture is the prominent separation mechanism (Holmes and Chen, 1984). When a gas stream that contains droplets moves through wires, the inertia of the droplets causes their directions to change from the streamline and impact the target wire (Brunazzi and Paglianti, 2001). Therefore, it can easily be deduced that the separation efficiency has a strong relationship with the structural features of the mesh pads, the droplet size distribution, the gas velocity and the liquid loading (Setekleiv and Hallvard, 2012; Setekleiv et al., 2010). In practice, when designing a wire mesh filter, a good balance must be achieved between the pressure drop and the removal efficiency. Knowing the effects of various factors on the mesh pad performance will be helpful in the design

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* Corresponding author. Mobile.: +86 18646306466.
E-mail address: shandong-313@163.com (Y. Luan).

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process. This study attempts to explore the structural and aerodynamic parameters that affect the pressure drop across wire-mesh filters and to develop a method for predicting pressure drops.

Because numerical simulations have shortcomings and difficulties, experimental and theoretical analyses are generally used to investigate the removal efficiencies and pressure drops of wire mesh filters. Some methods for predicting the separation efficiencies of mesh pads were derived based on the droplet collection efficiency of a single wire, which was related to the Stokes number, *Stk*. However, in most cases, certain assumptions must be made (Brunazzi and Paglianti, 2000, 2001; Feord et al., 1993; Langmuir and Blodgett, 1944–1945; Carpenter and Othmer, 1955; Bradie and Dickson, 1969). With the advancements in measurement technologies, researchers have been able to experimentally investigate the relationship between separation efficiency and some macro-structural parameters (pad thicknesses, densities, specific surface areas, porosities, etc.). Some empirical and semi-empirical formulas were obtained based on large amounts of measured data (Al-Dughaither et al., 2010; El-Dessouky, 2000). One typical theoretical tool for studying pressure drops across mesh pads is the famous Darcy equation, which has long been used as a basic method in the field of porous media. For example, when conducting numerical simulations of flow fields inside devices that contain wire meshes, regions of the mesh pads are typically treated as porous media with permeabilities and drag coefficients that are determined using experimental data (Janajreh et al., 2013; Rahimi and Abbaspour, 2008). The Darcy equation contains linear and quadratic terms for velocity, which are also known as the viscous and inertia terms. However, this binomial derived from regression analysis has limitations because it is only applicable to a specific porous media structure (Helsør and Svendsen, 2007). Based on a literature review, most experimental studies provide macroscopic parameters of wire mesh such as thickness, density, specific surface area and porosity. The only microscope parameter of wire mesh included in these studies is wire diameter. In this study, the relationships between the pressure drop across the wire mesh and the following three microscope parameters are established: wire diameter, layer spacing and mesh size.

According to the majority of previous investigations, when the liquid loading is low, the effect of droplets on the continuous gas phase can be neglected because neither flooding nor re-entrainment will occur. Therefore, the pressure drops of a single-phase flow and diluted gas–liquid flow should be equal. For the wire mesh studied here, the maximum volume fraction of the liquid phase is less than $3.67e-6\%$ (30 ppm); thus, experiments and simulations were performed based on single-phase airflow.

2. Experimental apparatus

The experimental setup was designed and constructed at the Department of Power and Energy Engineering of Harbin Engineering University. The horizontal wind tunnel contains two round tubes and a square tube connected using a transition section, which changes their shape gradually from the round end to the square end to avoid flow distortion and to minimize measurement error. A lemniscate flow tube was installed at the inlet part of the tunnel to indirectly measure the gas velocity. The tested wire meshes were installed inside the square tube of the tunnel, and adhesive tapes were used to seal the tube to prevent gas leakage. Each part of the wind tunnel was connected and fixed using bolts. The tunnel wall was composed of organic glass. The gas flow was driven by a centrifugal fan connected to an electric motor positioned at the end of the tunnel. The superficial gas velocity was maintained within a range of 2–8 m/s and was adjusted by changing the output power of the centrifugal fan (Fig. 1). The square tubes were used for the wire mesh test section instead of circular tubes because the investigated wire mesh filters were installed in square ducts. For actual applications, this type of wire mesh filter usually works at a velocity of nearly 10 m/s; thus, a slightly wider velocity range was chosen in this study.

2.1. Wire mesh section

Three structural parameters of wire mesh filters were defined: wire diameter (d), layer spacing (σ) and the mesh size, including the length (h) and width (w), as shown in Fig. 2.

To perform the experiment as accurately as possible, the above structural parameters must be precisely adjusted. The wire mesh used for the experiment had a wire diameter of 0.08 mm. Because wire mesh pads are easily deformed, the other two parameters were controlled using a statistical method. The cross-sectional area of the tested wire mesh section was 200 mm × 200 mm. The required mesh length h and width w can be obtained by controlling the mesh number in both the vertical and horizontal directions. Although there must be shape and size nuances among individual meshes, the through capacities of each layer are approximately identical because they have the same tensity. Plastic plates with fixed thicknesses were placed between successive layers; therefore, the average layer spacing could be adjusted by changing the number of plates and the total thickness of the mesh pad. Fig. 3 shows the tested wire mesh pad, which was pressed with stainless steel plates and bolted. Twelve sticks were welded perpendicular to one of the plates, with each stick passing through a specific mesh to obtain the requested mesh tension. The geometric parameters of the tested wire mesh are listed in Table 1.

2.2. Measurement principle

The experiments were performed at room temperature, which was measured using an anemometer. The anemometer was also

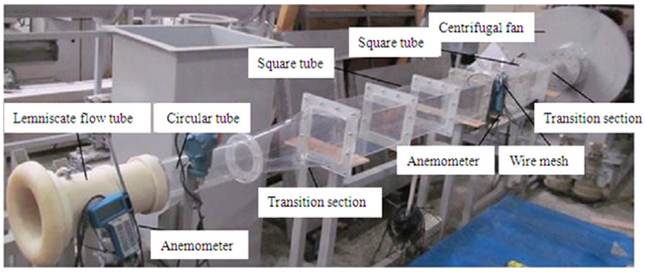

Fig. 1. Layout of the experimental apparatus.

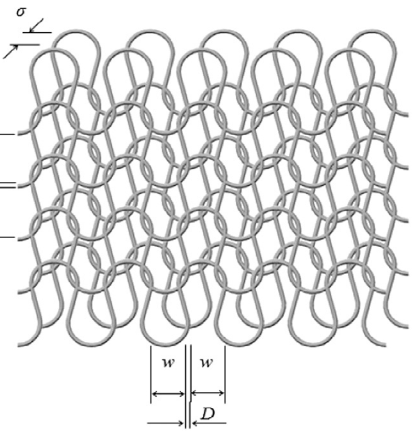

Fig. 2. Definition of the structural parameters.