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Optimization of bubble column performance for nanoparticle collection

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HIGHLIGHTS

- Collection efficiency improvement for high liquid height.
- Nanoparticles collection efficiency is improved by presence of small beads of high density.
- Bubbles size is the most influential parameter on nanoparticles collection efficiency.
- Good agreement between modelling and experimental collection efficiencies in the diffusional regime.

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ABSTRACT

Fibrous media embody the most effective and widely used method of separating ultrafine particles from a carrier fluid. The main problem associated with them is filter clogging, which induces an increasingly marked pressure drop with time and thus imposes regular media cleaning or replacement. This context has prompted the idea of investigating bubble columns, which operate at constant pressure drop, as alternatives to fibrous filters. This study examines the influence of different operating conditions, such as liquid height, air flow rate, bubble size and presence of granular beds on ultrafine particle collection. Experimental results show that bubble columns are characterised by high collection efficiency, when they feature a large liquid height and small diameter bubbling orifices, while their efficiencies remain lower than those of fibrous filters. Gas velocity does not greatly influence collection efficiency, but the inclusion of a granular bed, composed of beads, increases the bubble residence time in the column, thereby increasing the column collection efficiency.

1. Introduction

The origin of nanoparticles likely to be found in workplace air and in the environment is essentially two-fold: manufactured (nano) particles found in a growing number of industrial applications and ultrafine particles generated in certain manufacturing processes: surface processing and coating (thermal spraying, . . .), machining (drilling, grinding, . . .), combustion (fire, boilers, blast furnaces, . . .), fragmentation of raw materials (crushing, sieving, demolition, . . .), and so on.

In industry, metal coating processes involving thermal spraying are used for protecting the surface of machined parts against various forms of attack (abrasion, dry or wet corrosion) or for insulating them thermally or electrically [1]. This process is based on spraying, onto the part to be coated, fine metal particles melted by a heat source (flame or electrical arc) using a carrier gas (usually compressed air). This technique is a very major source of ultrafine metal particles (zinc, aluminium, tin and alloys). While their toxicity remains unknown, exposure to these particles must be strictly controlled. Various studies have effectively revealed that, for a given chemical composition and mass, the nanostructured particles could present a higher toxicity than micronic particles of the same type [2]. Implementation of suitable protection systems therefore appears necessary for protecting persons and the environment. To curtail inhalation of these particles, the operator performing this operation must wear personal protective equipment (PPE) – a supplied air hood – and work in a cabin fitted with a system for filtering the air before it is discharged to the exterior. The most efficient and widely used de-dusting methods for separating the particles from the carrier fluid are currently fibrous media (often in the form of folded cartridges) comprising roughly micrometre size fibres. The main problem with industrial dust filtration involves rapid clogging of the filters, requiring regular unclogging operations, generally

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by injecting a reverse flow of compressed air. Experience shows that, for nanostructured particles, fibrous media regeneration is far less efficient than for other types of particles. Moreover, unclogging may cause particles previously collected by the media to be put back into suspension and a deterioration of the filter structure, which may cause leaks leading to a major degradation of efficiency [3], thereby eroding the purpose of process, personal and environmental safety. Filter clogging is worse in metal coating processes because the particle concentrations are particularly high, 10^8 to $10^9\,cm^{-3}$, $100\,mg{\cdot}m^{-3}$ and the particles emitted very fine (more than 90% of particles, by number, have a diameter smaller than 100 nm). These fumes are therefore highly clogging [4].

The purpose of this study is to examine the potentialities offered by particle separation processes other than fibrous media for purifying metal coating fumes or more generally nanoparticles generated in manufacturing processes. In this connection, bubble columns could prove to be a credible alternative to fibre filters because they operate at constant pressure drop. The advantages offered by bubble columns include their minor maintenance requirement and low initial installation costs. Furthermore, the risk of operators inhaling nanoparticles during servicing and maintenance phases is limited: bubble columns do not put particles back into suspension because they collect ultrafine particles in the liquid phase. Their main drawback is the bubble coalescence phenomenon, but this can be significantly reduced by including packing material [5]. The nominal grain size of the packing material must result from a compromise between small sizes, which favour mass transfer efficiency, and larger sizes, which increase the column capacity while reducing the pressure drop [6]. The literature contains little on the subject and most studies have focused on collecting large and micronic particles in bubble columns [7,8]. Bubble column performance has been studied with the aim of optimising column sizing (diameter and height) and operating conditions such as gas velocity, which directly influences bubble size [8]. The type and height of the trapping liquid have also been studied. However, all the studies to date have focused on collecting particles with diameters of between 1 and 10 μm. They reveal that particle collection efficiency increases exponentially with the trapping liquid height and hence with the residence time [9,10]. We may also observe that addition of a surface active agent to the liquid induces a reduction in bubble size with a resulting increase in collection efficiency [11].

In the nanometric field, only Koch et al. [11] and Charvet et al. [12] have studied the separation efficiency of bubble column purification systems with respect to nanometric particles. These authors have determined the efficiency of a bubble column for a restricted particle size range (4–75 nm). They have shown that the collection mechanism is essentially diffusional within this particle size range.

The Pich and Schütz [13] model effectively reveals close agreement with experience in the diffusional area. This theoretical model integrates three collection mechanisms, namely Brownian diffusion (a_D), inertia (a_I) and sedimentation (a_S). These three mechanisms have been defined by Fuchs [9], based on assumed independence and additivity between them, enabling particle collection to be expressed in terms of a global absorption coefficient. Finally, the theoretical model for calculating particle collection

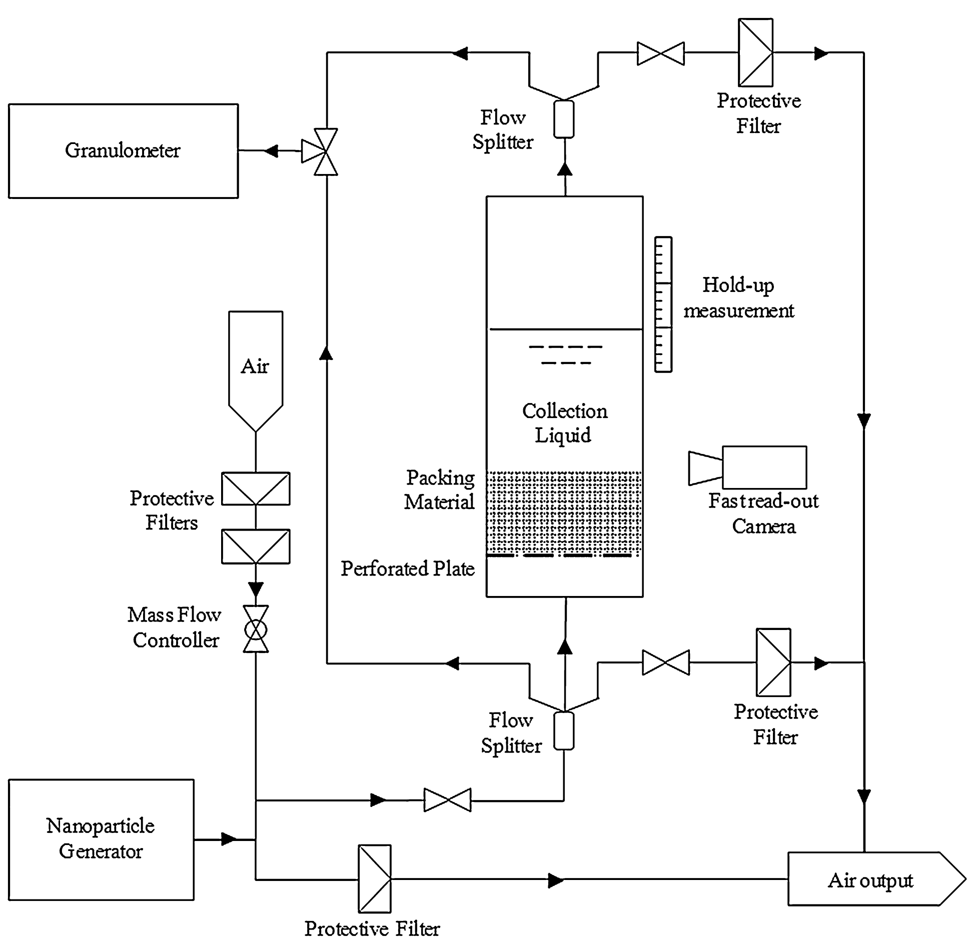

Fig. 1. Schematic view of experimental set-up.