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Steady state numerical simulation of the particle collection efficiency of a new urban sustainable gravity settler using design of experiments by FVM

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ABSTRACT

The aim of this work is to analyze the efficiency of a new sustainable urban gravity settler to avoid the solid particle transport, to improve the water waste quality and to prevent pollution problems due to rain water harvesting in areas with no drainage pavement. In order to get this objective, it is necessary to solve particle transport equations along with the turbulent fluid flow equations since there are two phases: solid phase (sand particles) and fluid phase (water). In the first place, the turbulent flow is modelled by solving the Reynolds-averaged Navier–Stokes (RANS) equations for incompressible viscous flows through the finite volume method (FVM) and then, once the flow velocity field has been determined, representative particles are tracked using the Lagrangian approach. Within the particle transport models, a particle transport model termed as Lagrangian particle tracking model is used, where particulates are tracked through the flow in a Lagrangian way. The full particulate phase is modelled by just a sample of about 2,000 individual particles. The tracking is carried out by forming a set of ordinary differential equations in time for each particle, consisting of equations for position and velocity. These equations are then integrated using a simple integration method to calculate the behaviour of the particles as they traverse the flow domain. The entire FVM model is built and the design of experiments (DOE) method was used to limit the number of simulations required, saving on the computational time significantly needed to arrive at the optimum configuration of the settler. Finally, conclusions of this work are exposed.

1. Introduction

Settling is the process by which particulates settle to the bottom of a liquid and form a sediment. Particles that experience a force, either due to gravity or due to centrifugal motion will tend to move in a uniform manner in the direction exerted by that force. For gravity settling, this means that the particles will tend to fall to the bottom of the vessel, forming a slurry at the vessel base. Settling is an important operation in many applications, such as mining, wastewater treatment, biological science and particle mechanics [1].

The events of precipitation and stormwater give place to problems into urban areas. These problems are mainly due to inadequate drainage, transport and disposal systems to adequately handle stormwater from extreme events and the ability

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to drag the surface water contaminants in the areas through which transits to natural and artificial water bodies, an effect known as diffuse pollution [2,3].

The sustainable device presented in this work is able to separate the solid from the liquid phase in urban or industrial parking areas. This feature is very important due to the main pollutant present in this kind of waters is sand and other solid particles which are dragged into the wastewater stream [4,5].

The finite volume method (FVM) is a numerical procedure than can be used to obtain solutions to a large class of engineering problems involving fluid flow, heat transfer, etc., and in our case a new type of urban sustainable gravity settler [6–8]. The main objective of this paper is to determine by the FVM, the efficiency of a new type of gravity settler in preventing the diffuse pollution and in improving the stormwater waste quality. Firstly, the FVM is used in order to obtain the velocity field of the turbulent flow in the urban sustainable gravity settler. Next, the trajectories of particles are determined from the previous flow velocity field solving the particles' motion equation inside this flow [9].

The device explained in this work consists in a prismatic volume divided into two chambers. Both spaces are connected through a rectangular slot at the bottom. The first smaller chamber corresponds with the inlet of the feed stream (wastewater) and the second bigger chamber, corresponds with the output (clean water). This configuration allows that the fluid which is carrying particles, suddenly changes its direction. Because of their inertia, particles tend to continue along their original paths. If the change in fluid direction is caused by an object located in the stream, particles with sufficient inertia will strike the object and will be captured. Despite the fact that the main design criteria in this divide is the simplicity and economy, there are some geometrical parameters that affect its behavior. In this sense, in order to achieve the maximum efficiency, it is important to analyze the behavior of the device under different work conditions.

In this sense, some collection particle systems integrated into the conventional drainage and designed as complements are [1–5]:

- Roughing baskets: corresponding to a wire o plastic mesh (usually in the form of basket) installed at inlet points of the drainage systems.
- Sedimentation tramps: are elements designed to retain sediment carried by water. Collection (or retention) is achieved through the settling of sediments inside the element.
- Hydrodynamic separators: are special types of sedimentation tramps in which their hydraulic complexity gives place to the collection of the particles. The cyclone is inside this category.

Fig. 1 shows the previous conventional urban solid retention devices in current use. However, these types of systems are complex and they do not have the capacity to be adapted to different work conditions with good results with respect to the collection efficiency. Hence, it is evident the need of the more specific collection devices to separate the solid phase from the liquid in urban or industrial parking areas. Fig. 2 shows a specific collection device in parking areas: the new urban sustainable gravity settler.

In the majority of moderate and high speed flow problems, some form of random variation of flow variables exists. In fluid dynamics, turbulence or turbulent flow is a fluid regime characterized by chaotic, stochastic property changes. This includes low momentum diffusion, high momentum convection, and rapid variation of pressure and velocity in space and time. To fix ideas, turbulent flow is defined as a flow with random variation of various flow quantities such as velocity, pressure and density. This kind of turbulent flow is present in the study of the gravity settler's efficiency. Turbulence is a property of a flow, not that of a fluid. Numerical solutions of the transient Navier–Stokes equations are sufficient to resolve the turbulent behaviour if an adequate fine mesh resolution and time increment are used. Despite significant progress in understanding turbulent behavior during the last century, the modeling of turbulence is still an unresolved problem. A turbulent flow is a [10–14]:

- Highly non-linear flow process.

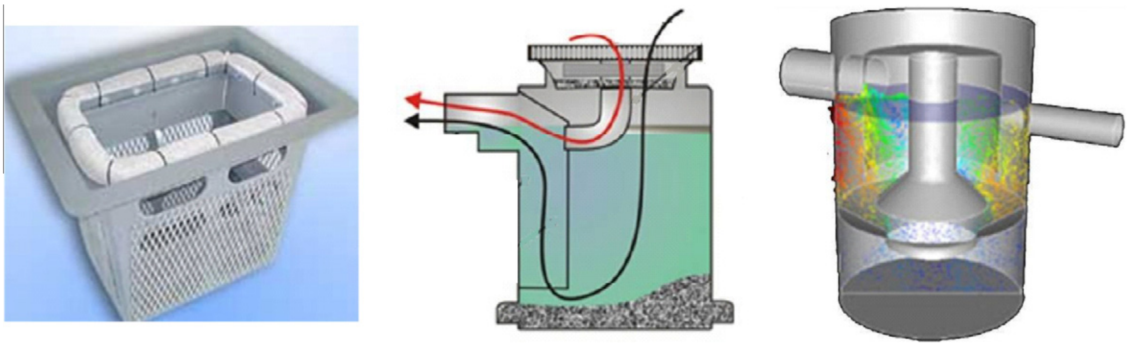

Fig. 1. Conventional urban solid collection devices: roughing baskets (left), sedimentation tramps (middle) and hydrodynamic collector (right).