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Pressure drop measurements for woven metal mesh screens used in electrical safety switchgears

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ABSTRACT

The paper deals with an experimental investigation of the pressure drops and friction factors induced by sets of metal woven screens in the case of an incompressible fluid flow, namely water flow. These woven screens are of metallic type and are used in electrical safety devices, especially at the end of exhaust duct of low voltage circuit breakers. In a first step, the whole of the set-up is used to check some approximations dedicated to pressure drops due to sphere beds around 275 µm and 375 µm as diameters. Results are discussed in terms of Darcyan and non-Darcyan permeabilities compared with published data and are analyzed in terms of the Blake-type friction factor. In the second step, the pressure drops are measured for stacks composed of eight different woven screens (of *plain dutch* type) formed with millimetric wires. Various formulations of the pressure drops and friction factors published elsewhere are tested with a special care dedicated to the choice of the geometry for the flow pattern (hydraulic diameter, spherical diameter, cylindrical diameter) and to the consideration of laminar and turbulent contribution. We then give the formulation that characterizes the fluid flowing through stacks of woven screens used in electrical safety applications.

1. Introduction

Almost all the studies dealing with woven metal screens essentially refer to topics such as high efficiency heat exchangers, energy storage units, regenerators, electronics coolers, catalytic reactors, filtering industry, gas bearing supply systems, gas-liquid two phase flow applications ((Wu et al., 2005; Belforte et al., 2009; Kolodziej et al., 2009; Mahjoob and Vafai, 2008) and references herein). But up to our knowledge, there is no published work with experimental measurements of the drag coefficients dealing with stacks of woven metal screens used for electrical safety purposes which is the aim of the present work.

Electrical safety practices are of crucial importance in electrical devices industry and have to follow the rules imposed by standards from IEC (www.schneider-electric.com 2007; IEC 2003) and specific safety guidelines for example summarized in (Schneider Electric–Square D 2003). In a recent past, filter technologies have been widely studied in order to improve existing solutions and their associated performance especially for the Medium Voltage (MV) electrical safety (Morel and Rival, 1990). We recall that among the whole of the recommendations in relation with the current study, the filter technologies have to ensure an efficient working of the electrical switchgear and to help the clearing of the very high energy level linked to the internal fault arc clearance, with a specific capacity to be proof against very high pressure and shock waves on one hand, and the brutal flow out of hot gases at the exhaust (up to around 10 kK in the center of the MV cell) on the other hand. Filters are thus designed to limit the temperature, the velocity and the pressure of the gases at the exhaust.

As a consequence innovative solutions have been carried out in order to ensure the mandatory level of electrical safety. These improvements and the general rules are depicted in various patents, among them we refer to Morel and Rival (1990), Rival et al. (1999) and Faber et al. (2003).

Whatever the voltage range considered, MV or LV (Low Voltage), the electrical safety switchgears are designed to support the clearance of the electric fault. This is done by means of the ignition of an electric arc (typically between two metallic contacts or electrodes or splitter plates) and hence of the consecutive arc plasma which has to be considered as a time dependent resistive

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Nomenclature

a	specific surface area (m $^{-1}$)
A, B	coefficients in Ergun equation (-)
A_1, A_2	coefficients in Blake-type equation (-)
C_1, C_2	coefficients in Ergun-Bird equation (-)
C_W	wall correction factor in inertial term (-)
d_1	warp wire diameter (m)
d_2	weft wire diameter (m)
d_p	particle diameter (m)
D	diameter of a single screen (m)
D_C	cylindrical diameter model (m)
D_h	hydraulic diameter (m)
D_p, D_{eq}	particle equivalent diameter (m)
D_S	spherical diameter model (m)
f, F'	friction factor (-)
k_1	viscous constant of the Darcy–Forchheimer equation (m^2) or Darcyan permeability term or permeability coefficient
k_2	inertial constant of the Darcy–Forchheimer equation (m) or non-Darcyan permeability term or inertial coefficient
L	length of the porous medium (m)
L_e	effective flow length (m)
M	wall correction factor (-)
ΔP	pressure drop (Pa)
Re, N_{Re}	Reynolds number (-)
T	water temperature (°C)
v, w_0, U, U_m	measured water velocity or superficial water velocity (m s^{-1})
w_e	effective or intersticial velocity (m s^{-1}), $w_e = w_0/\varepsilon$

Greek symbols

ε	porosity (-)
θ	angle of the fluid flow (Kolodziej and Lojewska, 2009b)
μ	water dynamic viscosity (Pa s)
ρ	water density (kg m^{-3})
τ	tortuosity (-)
ψ	drag coefficient in the *flow around* approach (Innocentini et al., 2000)

Subscripts

D	Darcy
F	Fanning
k	kinetic
Wu	for the three coefficients α, β and γ defined in the approximation of Wu et al. (2005)

component in the whole electric circuit. Due to the proximity of the arc chamber walls (typically in polymer materials) the characteristics and the properties (composition, electrical and thermal conductivities, radiation, viscosity) of the arc plasma continuously evolve due to the polymer wall ablation. They also depend on the very high gradients in temperature and pressure of the arc chamber. During the circuit breaker working some liquid (fused metal droplets) and gaseous (hot vapors resulting from ablated walls) materials are produced. Thus filters have to be designed to avoid or at least to significantly limit the flow of these fluids at the exhaust duct of the circuit breaker as it is illustrated in Rochette et al. (2015). One may easily understand that an arc plasma is a transient phenomenon whose properties variations are very important: the arc plasma chamber can have temperatures higher than 10 kK after few milliseconds, pressures up to some MPa (Rochette et al., 2015). So it is not realistic to recreate and use such media to obtain reliable measurements for Darcyan and non-Darcyan permeabilities (short duration, high gradients difficult to reproduce for systematic measurements, destructive hot power source). In a previous work (Bussière et al., 2006) we have done some measurements with air as the test fluid.

Among the possible risks that have to be taken into account, the protection against arc flash is of high interest both for the safety of the maintenance staff and for the vicinity of the electrical apparatus. In the case of MV cells, many studies have shown the significant role played by porous filters (Besnard, 2007; Rochette et al., 2007; Rochette et al., 2008; Rochette et al., 2010; Rochette et al., 2011) which are mainly of mineral kind and composed of a deformable granular medium fixed by metallic screens (whose mean granulometry and porosity are carefully checked). In these latter works, we have studied the specific influence of the porous filters on fundamental physical properties playing an important role during the MV switchgears work namely the pressure, temperature and velocity distributions in the MV cell and at the exhaust of the MV cell.

More recently the filter technologies have been adapted to the LV switchgears to take advantage of the improvements obtained in the MV range (Faber et al., 2003). The filter technology is different in so far as the dispersed granular medium is not used any more. The filter consists in one or more woven metal mesh screens defined by different wire diameters, mesh sizes and porosities which are placed on an optimal location at the gas exhaust of the switchgear. Obviously, as for the MV range, filters used in LV switchgears influence the main physical properties which characterize the gas at the exhaust, namely the pressure, the temperature and the velocity.

The aim of the current work is to assess the pressure drops and/or the friction factors of such filters in order to depict the influence of filters formed by different stacked metal screens and to provide numerical values for modeling tools. In Section 2 the features of spherical particles and of the woven metal screens are given, and the experimental set-up is described. Section 3 is dedicated to a brief review about the formulations of the Ergun approximation for spherical particles in order to validate the whole of the experimental set-up by comparison with other published data. In Section 4 we report the pressure drop measurements obtained for woven metal screens. Experimental results are analyzed by means of modified Ergun law in order to assess specific parameters such as the tortuosity, the angle between the flow inside the porous material and the flow direction induced by the porous material thickness. We give the pressure drop values and/or friction factors for the stacks of woven metal screens, these latters being analyzed by means of different equations, one of which is specifically established for the studied screens.

2. Experimental set-up and procedure

2.1. Sphere beds features

Two sets of silica spheres provided by *Sartorius* and quoted *B. Braun Glasperlen 0.25–0.30 mm* and *0.25–0.50 mm* – respectively called $d_p = 275\,\mu\mathrm{m}$ and $d_p = 375\,\mu\mathrm{m}$ in the paper – are used to check and validate the experimental set-up on the one side, and to measure the pressure drop formulations dedicated to spheres on the other side. The features of the spheres and the porosity of the sphere beds (mean values and standard deviations) are given in Table 1(a). More details about the measurement and the definition of the aspect ratio and compactness are given in Bussière et al. (2006). The relative discrepancy between the porosities obtained for the two beds is ≈ 3% and has no specific meaning in regards to experimental uncertainties. Experimental porosity values are 0.416