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Review

Ceramic block packing of Honeycomb type for absorption processes and direct heat transfer

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HIGHLIGHTS

- Ceramic block packing of Honeycomb type for absorption and heat transfer processes in column apparatuses is developed.
- Detailed studies of the mass transfer and fluid flow characteristics result in development of a reliable methodology for design of apparatuses with Honeycomb packings.
- An installation for gas purification in staple cellulose fiber production and systems for direct heat transfer in heat recovery from flue gases are successful applications with positive environmental impact.

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ABSTRACT

Ceramic block packing of Honeycomb type has been developed and studied for the purpose of absorption and heat transfer processes in column apparatuses. The packing design ensures high efficiency at relatively low pressure drop. The packing is easy to manufacture and the ceramic is resistant to high temperatures and chemically aggressive environments. Detailed studies on the characteristics of mass transfer and fluid flow have resulted in development of a reliable methodology for design of packed columns for absorption processes and direct heat transfer. Their successful implementations in the chemical industry, for environmental protection, and in the power production have confirmed the validity of the methodology.

The Honeycomb packing is used in an industrial system for purification of process gases from H_2S in staple cellulose fiber production, which operates with a degree of absorption greater than 99%. The packing is employed in industrial systems for heat recovery of flue gases from boilers burning natural gas, which utilize up to 13–15% extra heat and significantly reduce the harmful emissions. The heated and humidified air for combustion in one of the variants creates special conditions for fuel combustion such that the formation of nitrogen oxides is decreased by 3.5 times.

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1. Introduction

One of the ways for intensification of the heat and mass transfer in apparatuses with packing requires the geometry of the individual packing element to be fit for arrangement in a layer with identical channels throughout the column cross-section. This provides a better distribution of the liquid and the gas phase in the packing and therefore a more complete usage of the packing surface. The vertical orientation of the packing walls ensures their complete wetting. The smaller element height creates conditions for more frequent tearing of the liquid film, and greater void fraction, resulting in lower pressure drop. The studied ceramic block packing of Honeycomb type has been created in accordance with those considerations.

The first announcement for development and investigation of ceramic block packing of Honeycomb type was published by Molstad et al. (1942). Later (Ramm, 1966) this packing was presented with the opinion that it did not show enough efficiency. This statement was made on the basis of studies of a packing with a 50 mm incircle diameter of the hexahedral cell. It was concluded that the packing was inadequate for mass transfer processes, despite of the low pressure drop.

Successive studies (Elenkov et al., 1967) were motivated by the fact that the Honeycomb packing, in addition to the uniform bed channels, exhibited high strength characteristics, even when the elements were manufactured with very thin walls. Those were the prerequisites which suggested decrease in element dimensions, particularly the incircle diameter, resulting in increased efficiency. This was achieved with preserving the main advantage - low pressure drop due to a large free volume (void section), provided by reducing the wall thickness.

It is worth noting that Honeycomb packings are very easy to manufacture. The manufacturing process is the same as with production of Raschig rings, by extrusion through specially shaped dies. The material used is acid-resistant ceramic, porcelain or semiporcelain. It allows for very thin walls of the packing. The block elements are extruded and cut at a certain height, and then air-dried and kilned at appropriate temperatures.

Ceramic packings are very suitable for operation in conditions of high and low temperature and are much more resistant to all kinds of organic and inorganic acids and solutions than metal packings, except for the hydrofluoric acid. These advantages have made them widely used in refineries, acid plants, gas plants, oxygen plants, steel plants and pharmaceutical plants. They are also placed in washing, cooling, reclaiming, desulphurization, drying, and absorbing towers and in reaction vessels.

Fig. 1 shows an element of the Honeycomb packing, its main dimensions and arrangement pattern. Fig. 2 is a photograph of packing elements of various sizes. The arrangement is particularly important because it ensures the uniform structure of the apparatus cross-section. The individual packing layers are placed on top of one another, so that the upper vertical hexahedral channels are offset relative to the lower in the plane of contact. Fig. 3 illustrates an upper layer offset of half the incircle diameter (d_0) of the element opening. The offset divides each channel into three parts, promotes turbulence in the phases, causes fracturing and regeneration of the interface area and consequently favors mass transfer intensification (Hegbie, 1935; Danckwerts, 1951; Sherwood et al., 1975).

The studies to determine the main hydrodynamic and mass transfer characteristics of the packings were conducted with the element sizes presented in Table 1.

Much of the investigations were carried out years ago. Present continuation of the research and the interest in this packing is due to its successful implementation in industry. A particularly successful one is the contact economizer system for heat recovery from waste gases leading to higher energy efficiency. The high heat and acid resistance makes the Honeycomb packing especially suitable for this kind of systems.

Additionally for completeness, new data are presented for the packing holdup capacity and the liquid spreading coefficient, as well as from industrial implementation in heat recovery systems with first generation contact economizers. The aim of the paper is to present the main packing characteristics, a methodology for calculation of packed bed columns for absorption and direct heat transfer, as well as examples of application in the chemical industry, environmental protection, and energy production.

2. Basic performance characteristics

2.1. Packing pressure drop

Pressure drop investigations of the first 3 packings in Table 1 were carried out on a test column with a diameter of 500 mm at a bed height of 3.2 m. The test systems were air-water, and air - sugar solution with a viscosity of 6.2×10^{-3} Pa s. The gas velocity was varied from 0.5 to 3 m s^{-1} and the liquid superficial velocity from 1.4×10^{-3} to 1.4×10^{-2} m^3 m^{-2} s^{-1} (Elenkov et al., 1967).

The test results are shown in Fig. 4. The sharp increase of the pressure drop above a certain velocity value ($w_0 = 1.8\text{–}2.0$ m s^{-1}) corresponds to the loading regime of the liquid in the packing, due to increased friction between the phases. The velocity at which this regime starts is called the loading point. Usually the packed columns operate at velocities just below the loading point. The comparison of the experimental results with those of other types of packings shows similar influence of the liquid superficial velocity and the gas velocity on the pressure drop. Moreover the Honeycomb packing is distinguished by a relatively low pressure drop. As in reason, the smaller element sizes correspond to higher packing pressure drop.

The experimental results for Honeycomb packing No 1, Table 1, are compared to the pressure drop of metal structured packing, Mellapak 250.X (Fourati et al., 2012). It is observed that at gas velocity $w_0 = 1.7$ m s^{-1} and liquid superficial velocity $L = 8.4 \times 10^{-3}$ m^3 m^{-2} s^{-1}, the pressure drop of the ceramic packing is 23% lower.

The packing pressure drop can be calculated by the following equations (Kolev, 2006):

Equation for dry packing:

$$\psi = (37/\mathrm{Re}_G + 0.113/\mathrm{Re}_G^{0.1})(h/d_e)^{-0.51}\varepsilon^{-3.42}, \tag{1}$$

where $\psi = \frac{\Delta P_0 d_e}{2H\rho_G (w_0/\varepsilon)^2}$ is the dimensionless pressure drop and $\mathrm{Re}_G = \frac{w_0 d_e \rho_G}{\mu_G \varepsilon}$ - the Reynolds number of the gas phase.