

## COMPLEX CLEANING OF GASES IN THE FIBROUS FILTERS

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**Abstract.** The fibrous filters-mist collectors have received wide application at mist drops' collecting in the manufactures of sulfuric and phosphoric acids, galvanic and etching manufactures, etc. Industrial tests of such devices have shown that the question of effective collecting of aerosols unequivocally is solved application of fibrous filters. However, questions of collecting of the gaseous impurities containing in cleared gases, due to an irrigation of the filter by special absorption liquids, demand additional consideration. In this connection on experimental setup which basic element was the absorber developed on the basis of a design of the fibrous filter, have been carried out researches on absorption of carbonic gas by aqueous solution of sodium.

**Keywords:** fibrous filters, mesh of knitted weave, mist drops' collecting, absorption of gaseous impurities, pressure loss, volumetric mass transfer coefficient, height of transfer unit.

## 1. Introduction

The fibrous mist collectors (fibrous filters) are widely used to mist drops' collecting in the manufactures of sulfuric and phosphoric acids, galvanic and etching manufactures, etc. (Вальдберг *et al.* 2003). However, industrial tests of fibrous filters have shown that, besides mist drops' collecting, they are effective means for absorption of gaseous impurities (in case of irrigation of the filter by special absorption liquids).

So, at industrial tests of the fibrous filter by productivity of 10 000 m<sup>3</sup>/h, used for clearing ventilating gases in the galvanic shop of ММРО «Krasnyi Ocyabr'» (Вальдберг *et al.* 2004), quite high efficiency of both catching of aerosol particles (56.5 %) and vapors (73.7 %) of hydrochloric acid (HCl) has been marked. The fibrous packing was represented of the framework with polypropylene mesh of knitted weave. The thickness of the packing layer was equal 1.0 m. Diameter of fiber was equal 0.3 mm. An aqueous solution of sodium hydroxide (NaOH) was used for irrigation. At velocity of a gas stream about 1.1÷1.2 m/s and density of the irrigation about 7150÷9295 kg/(m<sup>2</sup>·h) the volumetric mass transfer coefficient of the order of 2000÷7000 1/h has been obtained, that agrees well with published dates on absorption of well soluble gases in packings columns (Коуль *et al.* 1967; Астарита 1971; Рамм 1976).

Considering it, absorption of gases in devices with a fibrous packing represents considerable scientific interest.

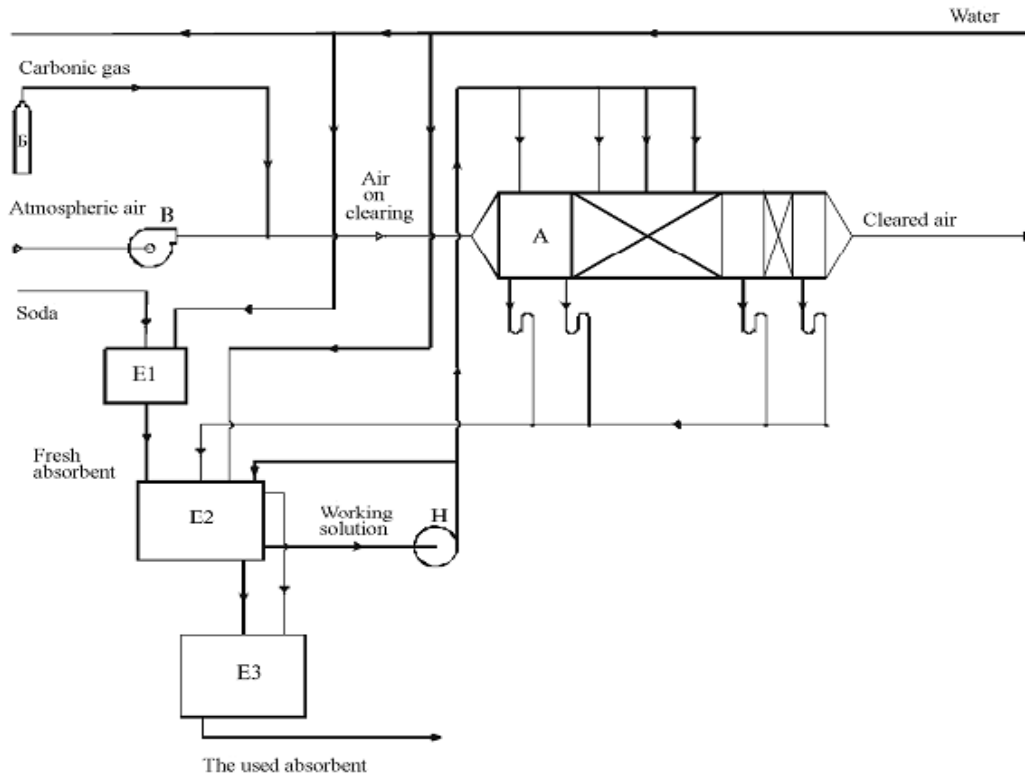
Tests, that enabled to receive of quantitative results on carbon dioxide (CO<sub>2</sub>) absorption from air by aqueous solution of sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>), were made (Valdberg *et al.* 2009; 2010).

## 2. Experimental setup

Tests were carried out on experimental setup (Fig 1) located in Moscow State University of Environmental Engineering. Device with a fibrous packing by productivity of 1000 m<sup>3</sup>/h is its main element.

Absorber with the fibrous packing represents horizontal device of square section and includes five cassettes and drops' collector at the outlet from absorber (Fig 2). It developed on the basis of a design of the fibrous filter and has three irrigation systems: horizontal, vertical and combined (complex) irrigation. Cassettes and drops' collector represent of the frameworks with metal mesh of knitted weave (Fig 3).

Work of experimental setup is carried out as follows. The gas stream (mix of air and carbonic gas) passes through absorber in a horizontal direction. Cassettes are irrigated of horizontal and vertical streams of liquid (aqueous solution of sodium carbonate) through irrigators located before and above them respectively. As a result contact of gas and liquid chemisorption of carbonic gas by aqueous solution of sodium carbonate occurs: Na<sub>2</sub>CO<sub>3</sub> + CO<sub>2</sub> + H<sub>2</sub>O ↔ 2NaHCO<sub>3</sub>.



**Fig 1.** Scheme of experimental setup: A – absorber with the fibrous packing; B – steel balloon with carbon dioxide; B – cooler; E1, E2, E3 – reservoirs with fresh absorbent, working solution and used absorbent respectively; H – pump

### 3. Investigation results

Aerohydrodynamic tests were carried out on the experimental setup, using water-air system.

Average air velocity in the relation to full section of an empty device and density of the irrigation were varied in the following ranges:  $v_g=0,14\div 1,37$  m/s,  $L=2960\div 18765$  kg/(m<sup>2</sup>·h) respectively. The thickness of the packing layer  $H$  was varied from 0.26 to 0.65 m.

The fibrous packing has following parameters: the porosity of packing layer  $\varepsilon$  is equal 0.98 m<sup>3</sup>/m<sup>3</sup>, the diameter of fiber  $d_f$  is equal 0.3 mm.

The pressure loss value of packing in the relation to the thickness of the packing layer has reached about 270 Pa/m (Fig 4) at average air velocity  $v_g=1,37$  m/s and density of the irrigation  $L=18765$  kg/(m<sup>2</sup>·h). At determination of pressure loss value of packing pressure loss at the inlet and outlet of absorber and pressure loss in the drops' collector were excluded.

Purpose of aerohydrodynamic tests was determination of the hydraulic resistance coefficient of fibrous packing. The hydraulic resistance coefficient of not irrigated (dry) fibrous packing  $\xi_{dry}$  was calculated with help of measured pressure loss value of dry packing  $\Delta p_{dry}$  from expression:

$$\Delta p_{dry} = \xi_{dry} \cdot \frac{v_g^2 \cdot \rho_g \cdot H \cdot \alpha}{\varepsilon^2 \cdot \pi \cdot d_f} \quad (1)$$

in which  $\Delta p_{dry}$  – pressure loss value of dry packing, Pa;

$\xi_{dry}$  – hydraulic resistance coefficient of dry packing;  $v_g$  – average air velocity in the relation to full section of an empty device, m/s;  $\rho_g$  – air density, kg/m<sup>3</sup>;  $H$  – high of the packing layer, m;  $\alpha=1-\varepsilon$  – density of the packing layer, m<sup>3</sup>/m<sup>3</sup>;  $\varepsilon$  – porosity of packing layer, m<sup>3</sup>/m<sup>3</sup>;  $d_f$  – diameter of fiber, m.

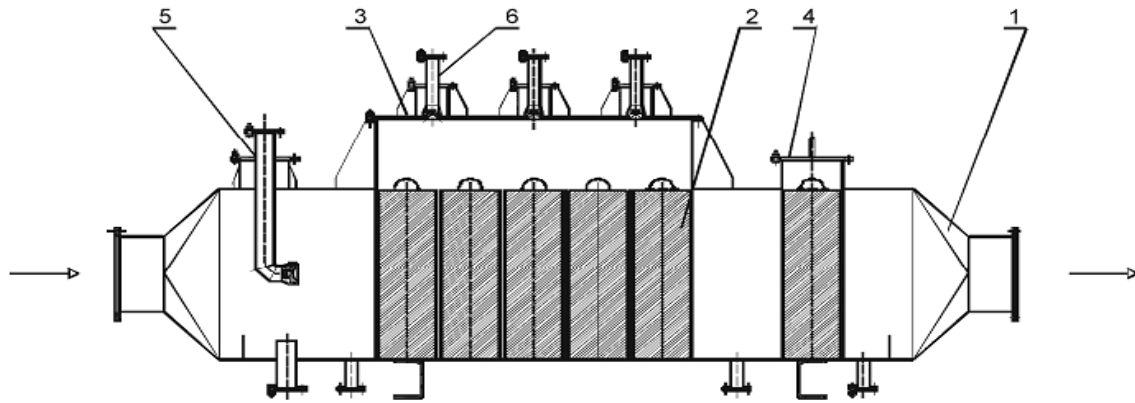
As a result of treatment of experiments there was received dependence of the hydraulic resistance coefficient of dry packing  $\xi_{dry}$  from the Reynolds' criteria for gas phase  $Re_g$ :

$$\xi_{dry} = f(Re_g) \quad (2)$$

$$\text{in which } Re_g = \frac{v_g \cdot d_f \cdot \rho_g}{\varepsilon \cdot \mu_g} \text{ – the Reynolds' criteria for gas phase; } \mu_g \text{ – dynamic viscosity of gas, Pa}\cdot\text{s.}$$

The critical value of the Reynolds' criteria for gas phase for the fibrous packing corresponding to the beginning of aerodynamic regime in absorber at which the hydraulic resistance coefficient of not irrigated packing keeps constant value was established. It is 15.

Moreover, comparison of received values of the hydraulic resistance coefficient of not irrigated fibrous packing with values of the hydraulic resistance coefficient of other fibrous packings was made. It has shown that the critical value of the Reynolds' criteria for gas phase for fibrous packings is varied from 10 to 15.

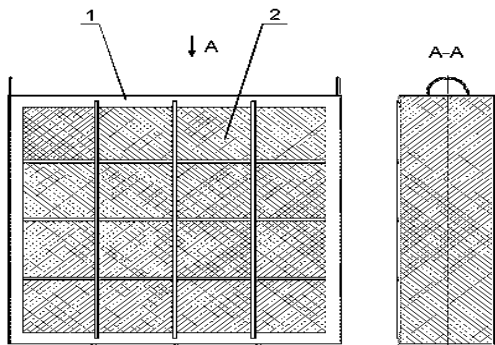


**Fig 2.** Absorber with fibrous packing (general view): 1 – corpus; 2 – cassette; 3, 4 – cover; 5 – horizontal irrigator; 6 – vertical irrigator

The hydraulic resistance coefficient taking into account of presence liquid phase in the packing  $\xi_L$  was calculated with help of measured pressure loss value of irrigated (wet) packing  $\Delta p_{wet}$  from expression:

$$\Delta p_L = \xi_L \cdot \frac{v_g^2 \cdot \rho_g}{2 \cdot \varphi^2 \cdot \varepsilon^2} \quad (3)$$

in which  $\Delta p_L = \Delta p_{wet} - \Delta p_{dry}$  – pressure loss value of liquid phase in the packing, Pa;  $\Delta p_{wet}$  – pressure loss value of wet packing, Pa;  $\xi_L$  – hydraulic resistance coefficient taking into account of presence liquid phase in the packing;  $\varphi$  – part of packing filled with gas,  $m^3/m^3$ .



**Fig 3.** Cassette with metal mesh of knitted weave: 1 – framework; 2 – mesh

As a result of treatment of experiments there were received following dependences for determination of the pressure loss value of liquid phase in the packing  $\Delta p_L$ :

$$\Delta p_L = \Delta p_{Lh} + \Delta p_{Lv} \quad (4)$$

$$\Delta p_{Lh} = 5,64 \cdot 10^8 \cdot L_h^{-1,36} \cdot \left( \frac{L}{G} \right)^{1,44} \times \left( \frac{\rho_g}{\rho_L} \right)^{0,72} \cdot \frac{v_g^2 \cdot \rho_g}{2 \cdot \varepsilon^2} \quad (5)$$

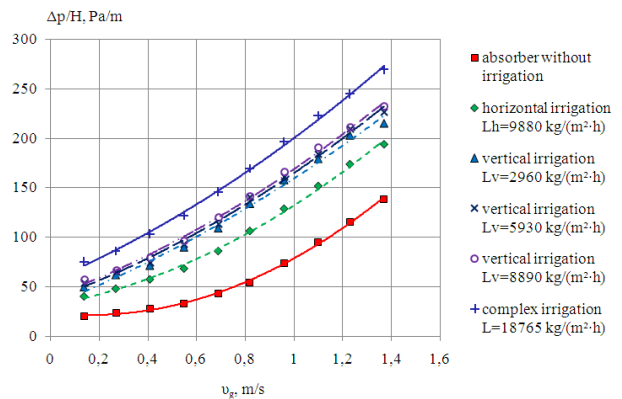
$$\Delta p_{Lv} = 7,01 \cdot 10^8 \cdot L_v^{-1,40} \cdot \left( \frac{L_v}{G} \right)^{1,48} \times \left( \frac{\rho_g}{\rho_L} \right)^{0,74} \cdot \left( \frac{H}{d_f} \right)^{0,1} \cdot \frac{v_g^2 \cdot \rho_g}{2 \cdot \varepsilon^2} \quad (6)$$

in which  $\Delta p_{Lh}$  – pressure loss value of liquid phase in the packing at horizontal irrigation, Pa;  $\Delta p_{Lv}$  – pressure loss value of liquid phase in the packing at vertical irrigation, Pa;  $L_h$  – density of the horizontal irrigation,  $kg/(m^2 \cdot h)$ ;  $L_v$  – density of the vertical irrigation,  $kg/(m^2 \cdot h)$ ;  $G$  – mass gas velocity,  $kg/(m^2 \cdot h)$ ;  $\rho_L$  – liquid density,  $kg/m^3$ .

So, pressure loss value of irrigated (wet) packing  $\Delta p_{wet}$  can be calculated from the following equation:

$$\Delta p_{wet} = \Delta p_{dry} + \Delta p_L \quad (7)$$

in which pressure loss value of dry packing  $\Delta p_{dry}$  can be calculated from expression (1) and pressure loss value of liquid phase in the packing  $\Delta p_L$  can be calculated with help expressions (4)-(6). The hydraulic resistance coefficient of dry fibrous packing is equal  $\xi_{dry} = 3 \div 6$  at value of the Reynolds' criteria for gas phase is equal  $Re_g = 10 \div 15$ .



**Fig 4.** Dependence of pressure loss value of fibrous packing from average air velocity and density of the irrigation

The received dependences (1), (4)–(7) allow to calculate

pressure loss value of irrigated (wet) packing with accuracy sufficient for practical calculations. The deviation of calculated and experimental values does not exceed  $\pm 10\%$ .

During the tests, when liquid (aqueous solution of sodium carbonate) and gas (mix of air and carbonic gas) were in direct, the mass exchange was investigated.

The volumetric mass transfer coefficient  $K_{pv}$  was calculated from basic equation of mass transfer from expression:

$$G_{CO_2} = K_{pv} \cdot \Delta p \cdot V \quad (8)$$

in which  $G_{CO_2}$  – quantity of absorbed carbon dioxide, kmol/h;  $K_{pv}$  – volumetric mass transfer coefficient, kmol/(m<sup>3</sup>·atm·h);  $\Delta p$  – driving force of absorption process, atm;  $V$  – volume of the packing layer, m<sup>3</sup>.

Moreover, in the course of the mass exchange tests concentrations of carbon dioxide (g/m<sup>3</sup>) at the inlet  $z'$  and at the outlet  $z''$  from absorber were under control as well.

The received dates of mass exchange tests have shown, that with increase density of the irrigation the volumetric mass transfer coefficient increases. There was determinate the optimal range of average air velocity at which maximal values of the volumetric mass transfer coefficient are reached.

So, at velocity of a gas stream  $v_g=0,8\div 1,0$  m/s and density of the irrigation about  $L=11360\div 18765$  kg/(m<sup>2</sup>·h) the volumetric mass transfer coefficient  $K_{pv}$  of the order of 110÷180 kmol/(m<sup>3</sup>·atm·h) has been obtained (Fig 5), that agrees well with published dates on absorption of carbonic gas by aqueous solution of sodium carbonate in packing columns (Коуль *et al.* 1967; Астарита 1971; Рамм 1976).

As a result of treatment of experiments there was received following dependence for determination of coefficient absorption of carbonic gas by aqueous solution of sodium carbonate  $K_{pv}$  at complex irrigation (horizontal and vertical irrigations simultaneously):

$$K_{pv} = 5 \cdot 10^4 \cdot v_g^{1,70} \cdot q_L^{1,03} \quad (9)$$

in which  $q_L = \frac{L}{G} \cdot \frac{\rho_g}{\rho_L}$  – irrigation in the relation to the velocity of a gas stream, m<sup>3</sup>/m<sup>3</sup>;  $L=L_h+L_v$  – density of the complex irrigation, kg/(m<sup>2</sup>·h).

The expression (9) is valid for the following conditions:  $v_g=0,14\div 0,82$  m/s,  $L=11360\div 18765$  kg/(m<sup>2</sup>·h).

Moreover, there was received following dependence for determination of height of transfer unit (HTU)  $h_g$  at complex irrigation (Fig 6):

$$h_g = 21,45 \cdot Re_g^{0,34} \cdot Re_L^{-1,03} \quad (10)$$

in which  $Re_L = \frac{v_L \cdot d_f \cdot \rho_L}{\alpha \cdot \mu_L}$  – the Reynolds' criteria for liquid

phase;  $v_L$  – specific speed of a liquid, m/s;  $\mu_L$  – dynamic viscosity of a liquid, Pa·s.

The expression (10) is valid for the following conditions:  $Re_g=2,86\div 16,73$ ,  $Re_L=47,33\div 78,19$ .

The received dependences (9)-(10) allow to calcu-

late the volumetric mass transfer coefficient and height of transfer unit with accuracy sufficient for practical calculations. The deviation of calculated and experimental values does not exceed  $\pm 25\%$ .

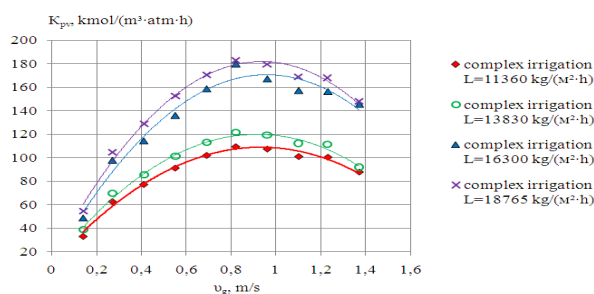


Fig 5. Dependence volumetric mass transfer coefficient from average air velocity and density of the irrigation

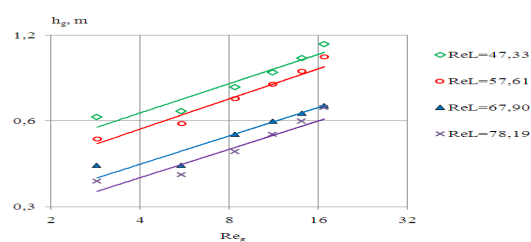


Fig 6. Dependence height of transfer unit (HTU) from Reynolds' criteria for gas phase and Reynolds' criteria for liquid phase

## 4. Conclusions

1. The carried out researches have shown that, besides mist drops' collecting, the absorber with fibrous packing provides high efficiency (up to 78.0 %) removal of gaseous impurities at small pressure loss value.
2. Therefore, the devices with fibrous packing can be introduced into manufacture for complex cleaning of gas emissions.

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