Bulgarian Chemical Communications, Volume 52, Special Issue F (pp. 80-85) 2020 DOI: 10.34049/bcc.52.F.0014

New equations for gas phase pressure drop in expanded metal sheet packing (HOLPACK) for mass and heat transfer processes in packed columns

Kr. A. Semkov*, T. St. Petrova*

Institute of Chemical Engineering, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl. 103, 1113, Sofia, Bulgaria

Received: August 12, 2020; Accepted: August 21, 2020

A horizontal expanded metal sheet packing is designed and investigated for carrying out mass and heat transfer processes in column apparatuses. The packing is made of expanded metal sheet elements placed horizontally with specific orientation at certain distance from one another along the column height. This construction leads to low specific weight and creates condition for highly effective heat and mass transfer at comparatively low gas pressure drop. The packing is studied in details; mathematical models and dimensioning methodology of apparatuses are provided and tested. As a result, the packing was successfully implemented in many processes in the chemical and power industry, as well as in the environmental protection. After a careful critical analysis of the earlier models and equations for determination of the pressure drop of dry and irrigated packing, as well as of loading point gas velocity, some imperfections and, respectively, opportunities for substantial improvement were found. Subsequently, on the base of many years practical (incl. industrial) experience, three new dependences were developed, firstly presented in this work. For the new equations the same experimental data are used as in the old ones; the principal differences evolve from the more appropriate and well-founded structure of the new equations and the better estimation of the geometric dimensions. The proposed equations are derived using dimensional analysis and least squares approach regression. For each equation the main statistic parameters are given. The comparison with the experimental data is illustrated in appropriate diagrams. The accuracy of the new equations is substantially improved, offering a stable base for industrial design and further applications with best performance and energy characteristics.

Keywords: Packed columns; Structured packing; Horizontal expanded metal sheet (HOLPACK) packing; Gas phase pressure drop modeling – new equations; Process intensification.

INTRODUCTION

The horizontal metal sheet packing is patented as a method for mass transfer processes [1]. It is made of expanded metal sheets, placed horizontally on a certain distance along the column height. The sheets are produced on a die by shearing with specially formed knives and subsequent sheet extension, whereupon staggered openings with inclined walls are formed. This product is standardized and is applied for many purposes; if made by thicker metal sheet it usually is used for production of stairs and platforms on different equipment. At first the packing was known as "Horizontal sheet packing", but later for the sake of convenience was called "HOLPACK".

The investigations carried out [1–6] confirmed its very good hydrodynamic and mass transfer characteristics. The favorable indicators of HOLPACK packing made it tempting for using in a large number of technological processes where it found industrial application.

Some of the most important hydrodynamic characteristics of the packing are the gas (vapor) flow pressure drop of the packing and the loading point velocity. They determine the productivity and the energy consumption of the transfer process. Especially the accurate determination of the loading point velocity is of crucial importance for optimal performance of the packing. The maximum efficiency is achieved a little below of the loading point. This is considered as the upper allowed limit of the operating range. Above this gas velocity the hydrodynamic of the flows becomes instable.

After a careful critical analysis of the earlier models and equations [6, 13, 14] for determination of the pressure drop of dry and irrigated packing, as well as of loading point gas velocity, some imperfection and, respectively, opportunities for substantial improvement were found.

The aim of this article to develop more accurate equations for determination of the pressure drop characteristics in order to ensure best operation conditions, respectively, improved performance of the columns with HOLPACK packing.

EXPERIMENTAL

Packing design and main dimensions

Amongst the known heat and mass transfer apparatuses the hollow irrigated scrubbers are distinguished by the lowest, actually near to zero pressure drop. However, they are low-effective

* To whom all correspondence should be sent:
E-mail: semkov@bas.bg t.petrova@iche.bas.bg

because of the non-uniform distribution of the gas across the apparatus cross section and the low values of the mass transfer coefficients. This is due to the absence of elements/structures in which liquid phase to be hit and turbulized while interchange its phase surface. A comparison between the hollow irrigated scrubbers and packed columns shows that the latter avoid the disadvantages of the hollow scrubbers at the expense of significantly increase of the apparatus pressure drop.

Consequently, the development of a hybrid apparatus combining a high mass transfer coefficient and uniform gas velocity distribution in the column with a pressure drop close to that of the hollow irrigated scrubbers appears to be an attractive task.

One convenient solution of this task is replacing the packing by horizontal perforated sheets with large free section, situated horizontally at a distance from one another of several centimeters [1, 6]. The additional pressure drop of the sheets improves the radial uniformity of the gas flow velocity profile. At the same time the hit of the liquid upon the sheets contributes to the liquid phase turbulization and surface renewal [3, 7-9]. The contradiction between the need of large free section for gas flow and low pressure drop, respectively, and the need of possibly larger sheet surface, where the irrigating liquid to be hit, can be solved through appropriate sheet profile and packing geometry optimization. Particularly suitable for design of such packing is the material known as expanded metal sheet (Figure 1-a). A good presentation of the technology of its production is given in (Technical information-mesh, 2015) [10]. It is prevalent for building of factory platforms and stairs, as well as some plate columns constructions. Its widespread use has led to its standardization (e.g. GOST 8706-78). The high productivity of the machines which manufacture expanded metal sheets, the lack of waste of material (like many new metal packings) and the significant (up to 75 %) lengthening of the sheets during its processing to expanded metal sheet determine its low cost. The expanded metal sheets are used also for the production of some corrugated structured packings, e.g. Montz packing type BSH [11, 12]. An essential advantage of this type of sheets is the directing action of the inclined lamellae forming the slits. They orientate the gas flow at an angle towards the sheet cross-section contributing to its radial redistribution. For the liquid phase this slope leads to a marked effect of liquid spreading at irrigation by multipoint distributors. This spreading is very important for a packing because it gives an opportunity for sufficient simplification of the distributing device. To avoid the one-sided direction of the liquid by the lamellae forming each sheet, the sheets are arranged one above another by rotating of 90° in the same direction – the so called “crosswise” arrangement. Thus, at every fourth sheet the orientation of the lamellae results the same. The distance between the sheets is kept by vertical orientated distancing strips. So created packing is mounted in column sections as is illustrated by a top-view photograph in Figure 1-b. Another configuration called “opposite” arrangement with 180° rotation is also investigated, but didn’t find industrial application due to lower efficiency.

The most important hydrodynamic dimensions of the packing can be determined from its geometric sizes using the following equations - see Figure 1-a:

$$d_h = \frac{s(B+4A)}{8X+B};$$

$$a = \frac{8X(s_1/2+\delta)+B(s_1+\delta)}{BC(h_1+h_2)};$$

$$\varepsilon_1 = 1 - \frac{2\delta(B/4+2X)}{BC}, \qquad (1)$$

where the subsidiary parameter X is determined as follows:

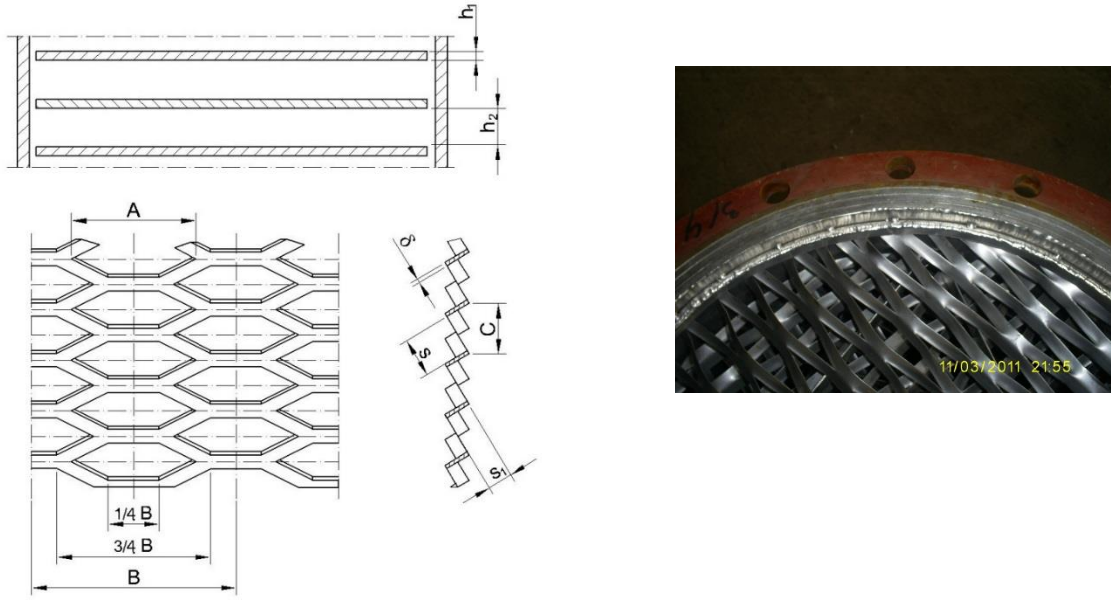
$$X = \frac{1}{2}\sqrt{s^2 + \left(A - \frac{B}{4}\right)^2}. \qquad (1\text{-a})$$

For comparison with other packings the HOLPACK void fraction (free packing volume) can be determined:

$$\varepsilon = \frac{\varepsilon_1 h_1 + h_2}{h_1 + h_2}. \qquad (1\text{-b})$$

According to this parameter, for example, for packing No. 1 (Table 1) with one of the lowest sheet free cross-sections ε_1 = 0.80, the void fraction is ε = 0.974. Hence, the void fraction of the HOLPACK packing is very large (mainly due to the empty volume between the sheets) which is a good precondition for low pressure drop.

The experimental investigation of the gas pressure drop of HOLPACK packing was carried out by Darakchiev and Kolev [6, 13, 14]. In the majority of experiments an air–water system was used. The main characteristics and symbols of the investigated packings are given in Table 1. The selected geometric dimensions cover practically the entire range of industrial interest.



(a) (b)

Fig. 1. Packing elements made of expanded metal sheet: (a) main dimensions and arrangement; (b) Overview photo of a column section.

Table 1. Main characteristics of Holpack packing used at the research of pressure drop

No.	Symbol	*A* mm	*B* mm	*C* mm	δ mm	*s* mm	s_1 mm	h_1 mm	h_2 mm	d_h mm	ε_1 %	*a* m^2/m^3
						D_c = 190 mm						
1*	◇	22.2	30.7	6.4	1.0	4.8	4.2	3.2	20	6.2	76.6	76.6
2	□	22.2	30.7	6.4	0.8	5.0	4.0	3.0	40	6.5	81.2	37.8
3	⊕	22.2	42.7	7.7	1.0	4.5	6.2	4.6	20	6.4	86.0	63.1
						D_c = 470 mm						
4	■	85.0	114	36.0	4.0	16.0	24.0	17.5	10	20.8	83.0	61.6
5	◕	90.0	121	27.0	1.5	13.0	16.5	13.2	50	17.1	91.6	22.1

* The sheets are covered with polyethylene.

RESULTS AND DISCUSSION

The new equations presented below were derived using the dimensional analysis and the least squares approach regression. The confidence intervals of the constants determined refer to 95% reliability, based on Student distribution. After each equation the main statistic parameters as the mean arithmetic error (absolute value) and the standard deviation, as well as the number of figures illustrating the comparison with the experimental data are given.

The structure of the equations is proposed striving to be closer to the real physical phenomena.

- Pressure drop of dry HOLPACK packing (ΔP_0)

$Eu = K.N_1\left(\frac{H}{d_h}\right)\left(\frac{h_1}{d_h}\right)^{n1} \mathrm{Re}_G^{n2}$;	(2)

Here the equation form reflects the flow pressure drop in tubes and channels. The *Euler* number (*Eu*) is defined as a ratio between the static pressure drop of the packing and the dynamic pressure (see Eq. 5). The main difference from the old equation is that the free cross-section of the packing sheet (ε_1) is not involved as main dimensionless variable.

- Pressure drop of irrigated HOLPACK packing (ΔP)

$\frac{\Delta P}{\Delta P_0} = K.\mathrm{Re}_L^{n1}\left(\frac{s_1}{d_h}\right)^{n2} \mathrm{Re}_G^{n3}$;	(3)

- Loading point gas velocity (w_{0G})

$MFr_G = K.\left(\frac{s_1}{d_h}\right)^{n1} Fr_L^{n2}$;	(4)

Here the MFr_G is a newly introduced dimensionless number (Modified gas Froude

Number), Eq. (5), proportional to the gas flow load factor $F = w_0\sqrt{\rho_G}$.

The dimensionless numbers are defined as:

$$Eu = \frac{2\Delta P_0 \varepsilon_1^2}{w_0^2 \rho_G}; \quad Re_G = \frac{w_0 d_h}{\nu_G \varepsilon_1};$$
$$Re_L = \frac{L_0 d_h}{\varepsilon_1 \nu_L}; \quad Fr_L = \frac{L_0^2}{g d_h \varepsilon_1^2};$$
$$MFr_G = \sqrt{\frac{w_{0G}^2}{\varepsilon_1^2 d_h g}\left(\frac{\rho_G}{\rho_A}\right)} \quad (5)$$

It should to be pointed out again that ε_1 is the packing sheet free cross-section and is not equal to the packing void fraction ε .

After processing the experimental data, the constants in equations (2-4) and confidence intervals are presented in Table 2.

According to the values from Table 2 and accounting for the reliable accuracy of the constants the following final form of the equations for practical engineering is proposed:

Table 2. Experimental constants, their confidence intervals at 95% reliability

Constant	K	n1	n2	n3
Eq. (3)	$\left(0.0343+\frac{2.16}{Re_G}\right)$	2.47±0.17	0.112±0.0.65	
Eq. (4)	$0.884^{+0.128}_{-0.112}$	0.173 ± 0.017	-0.253 ± 0.067	-0.0542 ± 0.018
Eq. (5)	$1.97^{+0.37}_{-0.31}$	0.900 ± 0.149	-0.0112 ± 0.021	

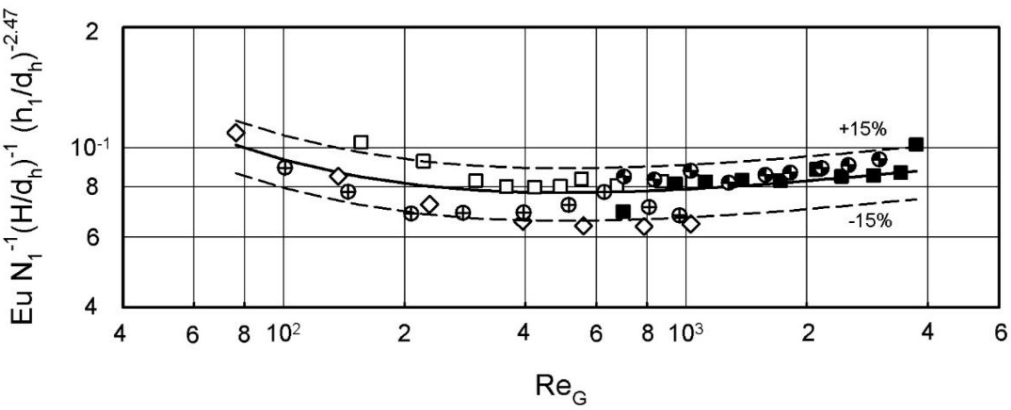


Fig. 2. Comparison of experimental data with the pressure drop of dry HOLPACK packing calculated by Eq. (6).

➢ Pressure drop of dry HOLPACK packing (ΔP_0)

$$Eu = \left(0.0343+\frac{2.16}{Re_G}\right) N_1 \left(\frac{H}{d_h}\right)\left(\frac{h_1}{d_h}\right)^{2.47} Re_G^{0.112} \quad (6)$$

The mean relative arithmetic error is 7.88% and the standard deviation is 12.6%. The comparison with experimental data is depicted in Figure 2.

➢ Pressure drop of irrigated HOLPACK packing (ΔP)

$$\frac{\Delta P}{\Delta P_0} = 0.884 Re_L^{0.172}\left(\frac{s_1}{d_h}\right)^{-0.25} Re_G^{-0.054}; \quad (7)$$

The mean relative arithmetic error is 5.5% and the standard deviation is 8.6%. The comparison with experimental data is depicted in Figure 3.

➢ Loading point gas velocity (w_{0G})

$$MFr_G = 1.97^{+0.37}_{-0.31}\left(\frac{s_1}{d_h}\right)^{-0.90} Fr_L^{-0.112}; \quad (8)$$

The mean relative arithmetic error is 4.56% and the standard deviation is 7.67%. The comparison with experimental data is depicted in Figure 4.

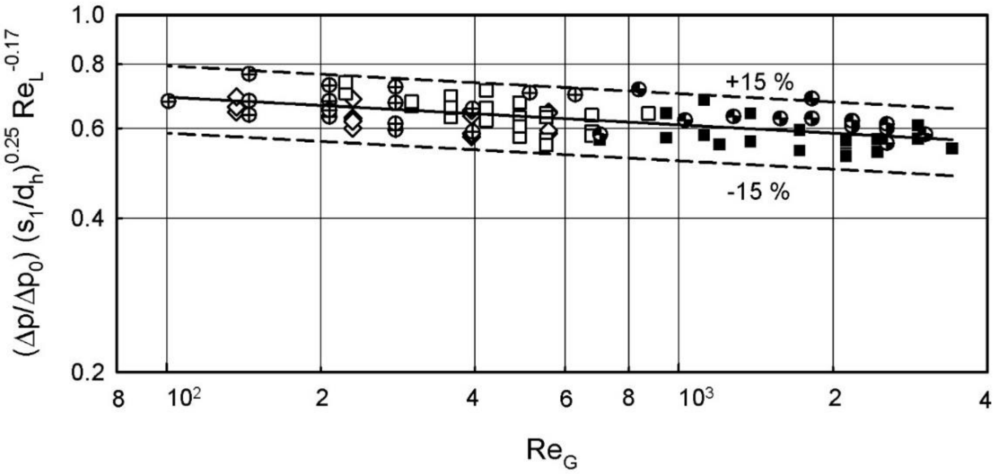


Fig. 3. Comparison of experimental data with the pressure drop of irrigated HOLPACK packing calculated by Eq. (7).

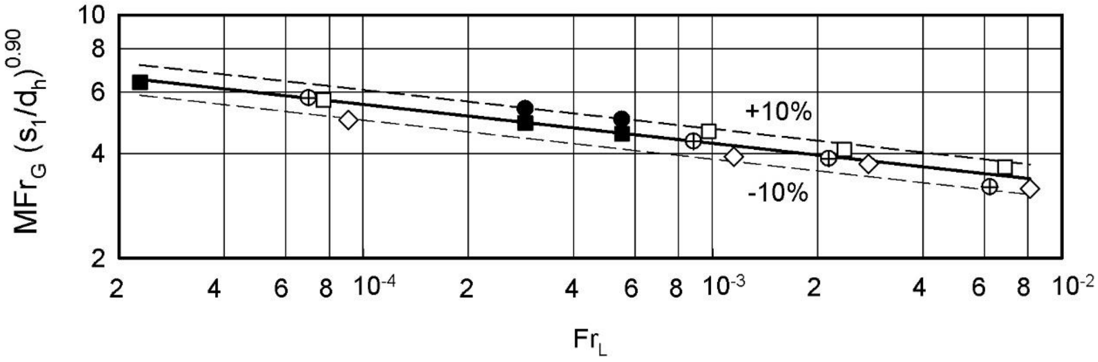


Fig. 4. Comparison of experimental data with the loading point velocity of irrigated HOLPACK packing calculated by Eq. (8).

CONCLUSION

The HOLPACK packing is a highly effective device for gas (vapor|)-liquid transfer processes.

The development of new more accurate equations for determination of the pressure drop and especially of the loading point velocity provides further opportunity for process performance improvement in a wide area of industrial applications.

Acknowledgements: *This paper was supported by the Bulgarian Ministry of Education and Science under the National Research Programme "Low-carbon energy for transport and domestic use (EPLUS)" (approved by DCM No. 577/17.08.2018 and Grant Agreement DO1-214/28.11.2018).*

NOMENCLATURE

A - slit length of expanded metal sheet (Fig. 1 - a), *m*;

B - slit longitudinal (longways) step of expanded metal sheet (Fig. 1-a), *m*;

C - slit transversal (breadthways) step of expanded metal sheet (Fig. 1-a), *m*;

D_c - column internal diameter, *m*;

d_h - hydraulic diameter of the slit, m;

$F = w_0\sqrt{\rho_G}$ - gas (vapour) load factor (F-factor);

g - gravity acceleration, m/s^2

H - packing height, m;

h_1 - thickness of the expanded metal sheet (Fig. 1-a), m;

h_2 - distance between the expanded metal sheets (Fig. 1-a), m;

L - liquid superficial velocity, $m^3/(m^2\,s)$;

N_1 - number of expanded metal sheets per 1 m packing height, -;

s - slit width of the expanded metal sheet (Fig. 1-a), m;

s_1 - lamella width of the expanded metal sheet (Fig. 1-a), m;

w - gas (vapor)velocity, m/s;

Greek symbols

ΔP - pressure drop of the wet (irrigated) packing, Pa;

ΔP_0 - pressure drop of dry packing, Pa;

δ - thickness of metal sheet (Fig. 1), m;

ε - volume void fraction of horizontal expanded metal packing, %;

ε_1 - free cross-section area of the expanded metal sheet, %;

μ - dynamic viscosity, $Pa.s$;

ν - kinematic viscosity, m/s^2;

ρ - density, kg/m^3;

Subscripts

A - air;

G - gas phase;

L - liquid phase;

0 - related to the overall cross-section;

$0G$ - related to the loading point.

REFERENCES:

1. N. Kolev, R. Darakchiev, A method for performing of mass transfer processes, Bulg. Patent No 16783/17.06.1971.
2. N. Kolev, Packed bed columns: For absorption, desorption, rectification and direct transfer, 1st edn., Elsevier, Amsterdam, 2006. https://doi.org/10.1016/B978-0-444-52829-2.X5000-6
3. T. K. Sherwood, R. L. Pigford, C. R. Wilke, Mass Transfer, 3rd edn., McGraw-Hill, New York, USA, 1975.
4. K. Semkov, N. Kolev, *Commun. Dept. Chem., Bulg. Acad. Sci*., **22** (2), 329 (1989) (in Bulgarian).
5. N. Kolev, K. Semkov, *Chem. Eng. Process.*, **1991**, **29**, 83-91. https://doi.org/10.1016/0255-2701(91)87017-W
6. N. Kolev, R. Darakchiev, *Verfahrenstechnik*, **7** (7), 214 (1973) (in German).
7. R. Higbie, *Trans. Am. Inst. Chem. Eng.*, **31**(2), 365 (1935).
8. P. V. Danckwerts, *Ind. Eng. Chem*., **43** (6), 1460 (1951). https://doi.org/10.1021/ie50498a055
9. N. Kolev, K. Winkler, R. Darakchiev, E. Brosh, *Sov. Chem. Ind.*, **18**(8), 4 (1986).
10. Explaining expanded metal mesh. Available online: http://www.nilesfence.com/files/technical-information-mesh.pdf (Accessed Dec. 2015).
11. Z. Olujic, A. F. Seibert, J. R. Fair, *Chem. Eng. Process.*, **39**, 335 (2000). https://doi.org/10.1016/S0255-2701(99)00095-1
12. Rib mesh packing type BSH. High performance packing for thermal mass exchange, Available online: http://montz.de/en/products/montz-structured-packings/rib-mesh-packing-type-bsh, (Accessed Dec. 2015).
13. N. Kolev, R. Darakchiev, *Chem.-Ing.-Tech.*, **46** (1), 33 (1974) (in German). https://doi.org/10.1002/cite.330460109
14. R. Darakchiev, Hydrodynamic and mass transfer characteristics of a horizontal packing of expanded metal sheets. PhD Thesis, Bulgarian Academy of Sciences, Sofia, 1974 (in Bulgarian).