R&D NOTES

Flow Resistance of Wire Gauzes

Andrzej Kołodziej
Institute of Chem. Eng. of the Polish Acad. Sci., Bałtycka 5, Pl 44-100 Gliwice, Poland

Joanna Łojewska
Faculty of Chemistry, Jagiellonian University, Ingardena 3, 30-060 Krakow, Poland

DOI 10.1002/aic.11646
Published online November 3, 2008 in Wiley InterScience (www.interscience.wiley.com).

Keywords: catalytic reactor, wire gauze, pressure drop, Ergun model

Introduction

A significant part of dangerous gaseous emissions contain combustible compounds. The examples are vehicle exhaust gases or volatile organic compounds (VOCs). Catalytic combustion appears as a satisfactory remedy for a major part of these emissions. The problem of vehicle emissions has been solved using ceramic monoliths. However, their most important drawback is poor mass transport which may limit the process rate.

Recently, an important research effort has been put to develop new structured catalytic reactors. Catalytic wire gauzes seem to be a very promising design as reactor internals. The idea is not new that catalytic reactors filled with platinum wire gauzes have been used for ammonia oxidation for over 100 years. At present, more sophisticated catalytic woven gauzes are being developed. The catalyst is deposited using various techniques like flame or plasma spraying. Good instances are the gauzes offered by Katator AB (Sweden) and studied by Ahlström-Silversand and Odenbrand[1] or Microlith® described by Lyubovsky et al.[2] Nowadays, knitted gauzes are still becoming more interesting according to Hills et al.[3]

In contrast to growing significance of wire gauzes the studies dealing with their transport and friction phenomena are rather scarce. In fact, the most comprehensive study on the wire gauze pressure drop presented up to now is the one of Armour and Cannon.[4] The model is based on numerous experiments and it took into account the essential geometrical parameters of wire gauzes. The equation proposed was:

$$f = \frac{A_1}{Re} + A_2 \tag{1}$$

where A_1 and A_2 depended on the weave type. The model demonstrates rather high level of generality. Other published models seem less general like those of Ehrhardt,[5] Ingmanson et al.[6] or Wu et al.[7]

We decided to put some experimental and modeling effort into the problem of fluid flow through wire gauzes.

Experimental

The experiments were carried out using a test reactor of a rectangular cross section, 45 × 30 mm, which was filled with several stacked gauzes (from one till 13-gauze sheets for each type of the gauze). The test gas was air under ambient conditions. The Recknagel micromanometer was used to measure the pressure drop assuring accuracy of 0.2 Pa. The range of Reynolds numbers was from 2 to 700 (or gas loadings 0.07 till 4.6 kg m^{-2} s^{-1}).

Three woven gauzes and one-knitted gauze have been designed and manufactured for further investigations. The basic geometrical properties are collected in Table 1.

The experimental results of flow resistances are expressed in terms of Fanning friction factors defined by Darcy-Weisbach equation

$$\frac{\Delta P}{L} = 4f\frac{\rho w_{\mathrm{e}}^2}{2D_{\mathrm{h}}} \tag{2}$$

The derived Fanning friction factors are presented graphically vs. Reynolds numbers in Figure 1 for all the gauzes studied. The lines reflect the correlation of Armour and

Correspondence concerning this article should be addressed to A. Kolodziej at ask@iich.gliwice.pl

Table 1. Parameters of the Structures Studied

Gauze Type	Description	Meshes Per Linear Inch	Meshes Per Linear metre	Wire Diameter d_w, mm	Gauze Thickness L, mm	a, $1/m$	ε	$D_h = 4\varepsilon/a$, mm	θ, deg
1	Woven	61.72	2430	0.16	0.32	8186	0.673	0.329	21.3
2	Woven	30.48	1200	0.30	0.60	4005	0.700	0.699	19.8
3	Woven	23.50	925	0.14	0.28	3020	0.894	1.18	7.4
4	Knitted	17.45	687	0.0977	0.66	1355	0.967	2.85	21.1

Parameter θ concerns the model (see Modelling section).

Cannon.[4] The differences between experiments and the model of Armour and Cannon[4] are important as they exceed 50%, especially for the woven gauzes at higher Re range and for the knitted gauze for the whole flow range. However, the accuracy of the Armour and Cannon[4] model is definitely the best from among the models cited above. Moreover, the models of Ehrhardt[5] and of Wu et al.[7] required important modification of the model constants to fit our experiments even approximately. The Fanning friction factor needs, in fact, separate correlations for each of the gauzes studied. Thus, we decided to develop a new model approach to the problem of friction for wire gauzes.

Modeling

The model of flow should take into consideration both the laminar and turbulent mechanisms together with the transient region. A well known example of such a model is that proposed by Ergun[8] and described, e.g., by Bird et al.[9] The bed of any arbitrary particles was modeled as the bed of spherical particles of the diameter

$$D_s = 6\frac{1-\varepsilon}{a_v} \tag{3}$$

The flow through the bed was assumed to be equivalent to the flow through a straight capillary tube of the diameter D_h.

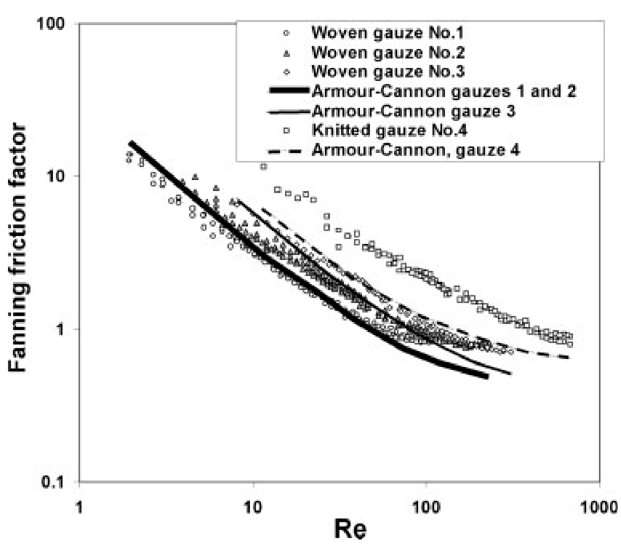

Figure 1. Experimentally derived Fanning friction factors vs. Reynolds numbers for the wire gauzes studied.

The lines reflect the model of Armour and Cannon.[4]

For the laminar range the pressure drop was described using the Hagen-Poisseille equation, for the turbulent one the Darcy-Weisbach equation was applied with a Fanning friction factor f_t for turbulent flow. The terms describing pressure drop for laminar and turbulent flow were assumed to be additive. The original Ergun model was further corrected e.g. by Harris et al.[10] The effective velocity and flow length were defined as:

$$L_e = L\frac{\tau}{\cos(\theta)} \tag{4}$$

$$w_e = \frac{w_0}{\varepsilon}\frac{\tau}{\cos(\theta)} \tag{5}$$

Here, θ is a degree of slope of the flow direction to the axis as proposed by Fowler and Hertel[11] and τ is a tortuosity factor which takes into account extended flow length around the bed particles and it can be calculated according to Carman[12]:

$$\tau = 1 + \frac{1-\varepsilon}{2} \tag{6}$$

The resulting improved Ergun equation is

$$\frac{\Delta P}{L} = \frac{72\eta w_o}{D_s^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\tau^2}{\cos^2(\theta)} + 6f_t\frac{\rho w_o^2}{2D_s}\frac{(1-\varepsilon)}{\varepsilon^3}\frac{\tau^3}{\cos^3(\theta)} \tag{7}$$

The modification of the Ergun model (7) consists in accounting some specific features of the gauze geometry. Instead of a sphere, a model cylinder is assumed of the diameter d_w. The degree of slope θ can be defined, based on the gauze geometry shown in the Figure 2, as

$$tg(\theta) = (L - d_w)N \tag{8}$$

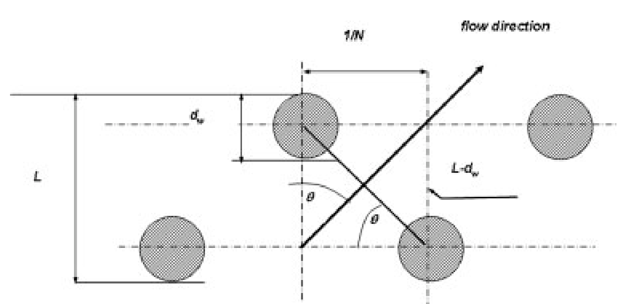

Figure 2. Gauze model to estimate degree of slope θ.

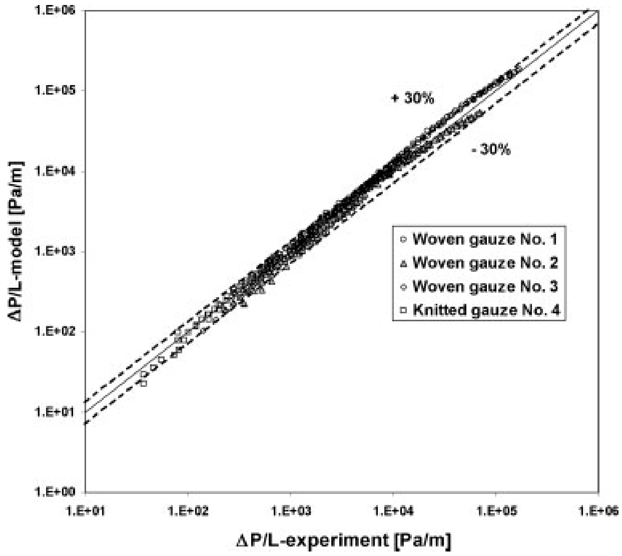

Figure 3. Model accuracy.

Model derived vs. experimental pressure drop.

The capillary channels—meshes of the gauze—should be regarded as very short channels where the laminar flow cannot fully develop. Thus, Fanning friction factor f_{app} for developing laminar flow should be used in a Darcy-Weisbach type Eq. (2). We decided to use an equation for f_{app} according to Shah and London[13]

$$f_{app} \cdot Re = \frac{3.44}{\sqrt{x^+}} + \frac{\frac{1.25}{4x^+} + 16 - \frac{3.44}{\sqrt{x^+}}}{1 + 0.00021/(x^+)^2} \tag{9}$$

For wire gauzes, the elementary channel can be identified with a single mesh and its length should be close to the wire diameter d_w. Thus, the dimensionless channel length is defined according to Shah and London[13] as

$$x^+ = \frac{d_w}{D_h Re} \tag{10}$$

The Reynolds number is defined using hydraulic channel diameter and effective fluid velocity w_e. The well-known Blasius formula was applied for turbulent friction factor f_t. Following the same way as described by Bird et al.,[9] the final equation can be written:

$$\frac{\Delta P}{L} = 4f_{app}\frac{\rho w_o^2}{2d_w}\frac{(1-\varepsilon)}{\varepsilon^3}\frac{\tau^3}{\cos^3(\theta)} + 4f_t\frac{\rho w_o^2}{2d_w}\frac{(1-\varepsilon)}{\varepsilon^3}\frac{\tau^3}{\cos^3(\theta)} \tag{11}$$

The parity plot presenting the accuracy of the above derived model when compared with experimental results is shown in Figure 3 for all the gauzes studied. The gauzes parameters including the degree of slope are given in Table 1.

It should be emphasized that the model presented above doesn't include any constants estimated based on the experimental data. The scatter only incidentally exceeds 30% (exactly: for eight from among 445 experiments performed). The experimental data were, in fact, used to validate the model only, not to estimate any parameters. Therefore, one can expect that the model presented will describe several different wire gauzes with an acceptable accuracy.

Final Conclusions

An experimental program has been performed to study pressure drop for air flow through stacked wire gauzes using four gauze types. The models presented in the literature were not satisfactory to describe all the gauzes studied.

New model was proposed based on the Ergun[8] approach with some assumptions changed. The experiments performed agree with the model within 30%.

The capillary channels of the gauze sheet were modeled as very short circular channels where laminar flow cannot fully develop (so-called developing flow). Theoretical solution of Shah[13] described friction factor for the case. The length of the channels was found to be close to the wire diameter.

The model does not include any constants estimated based on experimental results. The database established during the study was only used for the model validation. Thus the model should be useful for an arbitrary wire gauze of different parameters and weave.

Acknowledgments

The study is supported by Polish State Committee for Scientific Research which funded the projects 3T09C01626 and 3T09C04627. The financial support is gratefully acknowledged.

Notation

Symbols

a = specific surface area, m^{-1}
D_h = hydraulic diameter = $4\varepsilon/a$, m
D_S = model sphere diameter, m
d_w = wire diameter, m
f = dimensionless Fanning friction factor, Eq. (2)
L = bed length or gauze sheet thickness, m
N = number of meshes per linear metre m^{-1}
Re = Reynolds number = $(w_e \cdot D_h \cdot \rho)/\eta$, dimensionless
w = velocity, m s^{-1}
x^+ = dimensionless channel length, Eq. (10)

Greek letters

ΔP = pressure drop, Pa
ε = void volume, dimensionless
η = dynamic viscosity Pa s
θ = angle of flow direction slope to the bed axis deg
ρ = density kg m^{-3}
τ = bed tortuosity factor, Eq. (6), dimensionless

Subscripts

0 = superficial
e = effective
l = laminar range
t = turbulent range

Literature Cited

1. Ahlström-Silversand AF, Odenbrand CUI. Modelling catalytic combustion of carbon monoxide and hydrocarbons over catalytically active wire meshes. *Chem Eng J*. 1999;73:205–216.
2. Lyubovsky M, Karim H, Menacherry P, Boorse S, LaPierre R, Pfefferle WC, Roychoudhury S. Complete and partial catalytic oxidation

of methane over substrates with enhanced transport properties. *Catal Today*. 2003;83:183–197.
3. Hills T, Kons G, Schwab E, Mueller-Everbusch M. Knitted metal fabrics as thin layer catalysts: operational experience in steamcracker gas phase hydrogenation. Poster presented at ICOSCAR-2 conference, Delft, 2005.
4. Armour JC, Cannon JN. Fluid flow through woven screen. *AIChE J*. 1968;14:415–420.
5. Ehrhardt G. Flow measurements for wire gauzes. *Int Chem Eng*. 1983;23:455–465.
6. Ingmanson WL, Han ST, Wilder HD, Myers WT. Resistance of wire screens to flow of water. *Tappi*. 1961;44:47–54.
7. Wu WT, Liu JF, Li WJ, Hsieh WH. Measurement and correlation of hydraulic resistance of flow through woven metal screens. *Int J Heat Mass Transf*. 2005;48:3008–3017.
8. Ergun S. Fluid flow through packed columns. *Chem Eng Prog*. 1952;48:89–94.
9. Bird RB, Stewart WE, Lightfoot EN. *Transport Phenomena*, 1st ed.. New York: Wiley, 1960.
10. Harris DK, Cahela DR, Tatarchuk BJ. Wet layup and sintering of metal-containing microfibrous composites for chemical processing opportunities. *Compos A*. 2001;32:1117–1126.
11. Fowler JL, Hertel RL. Flow of a gas through porous media. *J Appl Phys*. 1940;11:496–502.
12. Carman PC. *Flow of Gases Through Porous Media*, 1st ed. London: Butterworths Scientific Publications, 1956.
13. Shah RK, London AL. *Laminar Flow Forced Convection in Ducts*. New York: Academic Press, 1978.

Manuscript received Mar. 3, 2008, and revision received July 14, 2008.