*Chemical and Petroleum Engineering, Vol. 40, Nos. 1–2, 2004*

# OPTIMIZATION OF HYDRAULIC PARAMETERS OF RETICULATED AGITATORS FOR DEMINERALIZATION PLANTS

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In recent years, active measures have been taken for broad-scale exploitation of oil and gas reserves within continental shelves. Not excluded is the fact that the demand for demineralization of sea water for residential and commercial needs has increased significantly over time in these regions.

At the present time, woven grids are widely used in hydraulic and aerodynamic systems [1–4] that control the work of liquid and gas media for subsequent physicochemical transformations (electrochemical, catalytic, ion-exchange, thermal). A disadvantage of the grids employed is their simple structure, which does not create conditions that permit control of liquid-flow agitation during execution of the indicated processes. Agitation leads to activation of a flow effect on the near-boundary layer, and to a reduction in the clearance dimensions of the plant.

The possibility of controlling the hydraulic and aerodynamic parameters of three-dimensional break-through grids over a broad range supporting optimal operating conditions has been ascertained on the basis of many years' experience with these grids [5–7]. Grids fabricated by the waste-free break-through/draw-out method offers a number of advantages over woven grids in terms of hydraulic parameters. They are universal owing to the broad possibility of varying the three directions of motion of the front of the liquid medium, which ensures a controllable flow regime. Moreover, they can be fashioned from any moldable metallic and polymeric materials.

Let us examine the hydraulic and aerodynamic characteristics of three-dimensional break-through grids, which are required to evaluate the effect on their linear parameters as assigned by automated machinery. Chuvpilo [7] cites three possible effects of a rhombic break-through grid on the movement of the front of the liquid medium flowing within its channels (I – across the smooth plane of the grid; II – along the smooth plane of the grid and perpendicular to the small diagonal of the rhombus; and, III – along the smooth plane of the grid and perpendicular to the large diagonal of the rhombus), and their interrelation for the free (A), deflecting (B), and blind (C) zones of the channel section.

The hydraulic resistance of a break-through grid for separator-agitators of electrodialysis demineralization plants can be calculated by treating the grid as bundles of parallel tubes:

$$\Delta p = \lambda \frac{L}{d_{\text{eq}}} \frac{\rho_0^2}{\rho_{\text{m}}} \frac{u_0^2}{2},$$

where $\Delta p$ is the head loss over a length $L$, $\lambda$ is the coefficient of hydraulic resistance of the break-through grid, which takes into account the effect of the moving front of the medium, $\rho_0$ is the density of the medium in the inlet section, $u_0$ is the average velocity of the flow proceeding into the inlet section, $d_{\text{eq}}$ is the equivalent diameter of the grid [see expression (1) below], and $\rho_{\text{m}}$ is the average density of the medium at the inlet and outlet (in the special case, $\rho_0 = \rho_{\text{m}}$).

The following experimental relationships are used for laminar and turbulent flow regimes of the medium:

$$\lambda = A_l/\text{Re}; \quad \lambda = A_{\text{t}}/\text{Re}^m,$$

Moscow State University of Engineering Ecology (MGUIÉ). Translated from Khimicheskoe i Neftegazovoe Mashinostroenie, No. 1, pp. 11–12, January, 2004.

 0009-2355/04/0102-0014 

where $A_l$ and $A_t$ are experimental coefficients for the laminar and turbulent flow regimes of the medium, Re is the Reynolds number, and $m$ is an exponent.

Table 1 lists parameters for two types of waste-free break-through rigid-vinyl-plastic grids (Fig. 1) [type 1 is manufactured by the Expanded Metal and K$^{o}$ Company (Great Britain), while type 2 is produced on an automated ABS-1 machine (Russia)] for separators-agitators in electrodialysis demineralization plants.

Considering the variable structure of the break-through grid, the equivalent diameter $d_{eq}$, which enters into the Reynolds number, must be determined for the hydraulic calculations:

$$d_{eq} = \frac{4 f_{eq}}{\chi_{eq}},$$

or

$$d_{eq} = \frac{2(1 - K_v)(2\tau \sin\gamma + \delta \cos\gamma)}{1 + 0.5K_k}, \qquad (1)$$

where

$$K_v = \frac{\tau\delta}{t(2\tau \sin\gamma + \delta \cos\gamma)};$$

$$K_k = \frac{2(\delta + \tau) - \delta k / T}{t}.$$

The equivalent wetted perimeter should be computed for all three moving fronts of the medium:

$$\chi_{eq}^{I} = \frac{Tt(2 + K_k)}{2\tau \sin\gamma + \delta \cos\gamma};$$

$$\chi_{eq}^{II} = t(2 + K_k);$$

$$\chi_{eq}^{III} = T(2 + K_k).$$

The equivalent sectional area of the channel is also calculated for the three moving fronts of the medium:

$$f_{eq}^{I} = Tt(1 - K_v);$$

$$f_{eq}^{II} = t(1 - K_v)(2\tau \sin\gamma + \delta \cos\gamma);$$

$$f_{eq}^{III} = T(1 - K_v)(2\tau \sin\gamma + \delta \cos\gamma).$$

In certain cases, it is necessary to know the relationship between the total-surface area of the grid and the volume $S_{sp}^{v}$ (mass $S_{sp}^{m}$) of the medium wetting this surface:

$$S_{sp}^{v} = \frac{K_k}{(1 - K_v)(2\tau \sin\gamma + \delta \cos\gamma)};$$

$$S_{sp}^{m} = \frac{10^3 K_k}{\rho(1 - K_v)(2\tau \sin\gamma + \delta \cos\gamma)}.$$

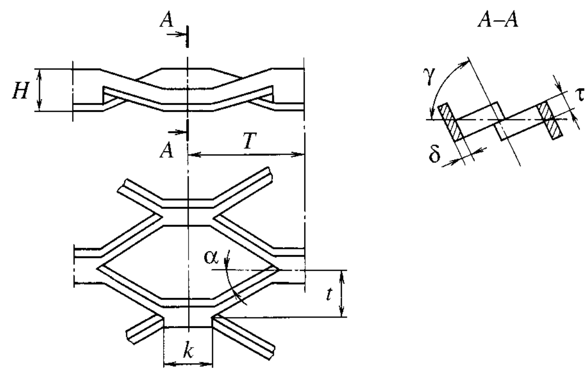


Fig. 1. Diagram showing break-through grid.

TABLE 1

| Indicator | Grid | |
|---|---|---|
| | Type 1 | Type 2 |
| Thickness δ of blank, mm | 0.55 | 0.65 |
| Spacing *T* of transverse blade feed, mm | 3.00 | 4.25 |
| Spacing τ of blank feed, mm | 0.42 | 0.39 |
| Draw spacing *t*, mm | 1.50 | 1.77 |
| Grid thickness *H*, mm | 1.00 | 1.00 |
| Width *k* of cross piece at connection between grid cells, mm | 1.50 | 2.50 |
| Angle γ of three-dimensional rotation of crosspiece after break-through with respect to plane of blank | 60° | 60° |
| Angle α of draw | 45° | 44° |
| Grid-opening factor $K_o = 1 - (\tau/t)$ | 0.72 | 0.78 |
| Catalyst space factor $K_c$ for grid | 1.11 | 0.97 |
| Concentration factor (ratio of total surface area of waste-free grid to area of catalyst plane) $K_v$ | 0.154 | 0.143 |
| Specific surface area of grid | | |
| with respect to volume $S_{sp}^{v}$, $mm^{-1}$ | 1.31 | 1.13 |
| with respect to mass $S_{sp}^{m}$, $mm^2/g$ | 1310 | 1130 |
| Equivalent area of flow section, $mm^2$ | | |
| $f_{eq}^{I}$ | 3.81 | 6.45 |
| $f_{eq}^{II}$ | 1.27 | 1.52 |
| $f_{eq}^{III}$ | 2.54 | 3.64 |
| Equivalent wetted perimeter, mm | | |
| $\chi_{eq}^{I}$ | 14.00 | 22.40 |
| $\chi_{eq}^{II}$ | 4.67 | 5.26 |
| $\chi_{eq}^{III}$ | 9.35 | 12.60 |
| Equivalent diameter of grid, mm | | |
| $d_{eq}$ from formula (1) | 1.09 | 1.15 |
| experimental $d_{eq}^{ex}$ | 1.05 | 1.14 |

TABLE 2

| Item No. | Moving front of medium | Computed coefficient | Grid | Moving front of medium | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | I | | II | | III | | |
| | | | | $\lambda_A$ | $\lambda_B$ | $\lambda_A$ | $\lambda_B$ | $\lambda_A$ | $\lambda_B$ | $\lambda_C$ |
| 1 | I | $\lambda_A$ | Type 1 | 1 | 2.34 | 1.45 | 1.35 | 2.80 | 2.80 | 1.40 |
| 2 | | $\lambda_B$ | | 0.43 | 1 | 0.61 | 0.57 | 1.20 | 1.20 | 0.60 |
| 3 | II | $\lambda_A$ | Type 1 | 0.69 | 1.64 | **1** | 0.95 | **1.94** | 1.94 | 0.97 |
| 4 | | $\lambda_B$ | | 0.74 | 1.75 | 1.05 | 1 | 2.04 | 2.04 | 1.02 |
| 5 | III | $\lambda_A$ | Type 1 | 0.36 | 0.84 | 0.52 | 0.49 | 1 | 1 | **0.50** |
| 6 | | $\lambda_B$ | | 0.36 | 0.84 | 0.52 | 0.49 | 1 | 1 | 0.50 |
| 7 | | $\lambda_C$ | | 0.72 | 1.66 | 1.03 | 0.98 | 2.00 | 2.00 | 1 |
| 8 | I | $\lambda_A$ | Type 2 | 1 | 2.72 | 1.41 | 1.52 | 4.60 | 4.60 | 1.78 |
| 9 | | $\lambda_B$ | | 0.37 | 1 | 0.52 | 0.56 | 1.24 | 1.24 | 0.48 |
| 10 | II | $\lambda_A$ | Type 2 | 0.71 | 1.92 | **1** | 1.07 | **2.37** | 2.37 | 0.92 |
| 11 | | $\lambda_B$ | | 0.66 | 1.78 | 0.94 | 1 | 2.20 | 2.20 | 0.85 |
| 12 | III | $\lambda_A$ | Type 2 | 0.22 | 0.81 | 0.42 | 0.45 | 1 | 1 | **0.39** |
| 13 | | $\lambda_B$ | | 0.22 | 0.81 | 0.42 | 0.45 | 1 | 1 | 0.39 |
| 14 | | $\lambda_C$ | | 0.56 | 2.08 | 1.08 | 1.18 | 2.55 | 2.55 | 1 |

Table 2 presents computed coefficients $\lambda_A$, $\lambda_B$, and $\lambda_C$ in zones A, B, and C, respectively, for an electrodialysis demineralization plant, which facilitate determination of conditions for medium conversion from one state to another for control of processes involving physicochemical transformations. For example, the number 1.94 (in the third row) indicates that conditions for the flow of liquid for the grid manufactured by the Expanded Metal and K$^o$ Company in zone A of moving front II of the medium are 1.94 times better than those in zone A of moving front III of the medium.

In a similar case for the grid fabricated on the automated ABS-1 machine, the number 2.37 (tenth row in Table 2) indicates better conditions for conversion to a turbulent regime while retaining more favorable conditions for flow resistance, which are characterized by relationships between the deflecting and blind zones (the numbers 0.50 and 0.39 in the fifth and twelfth rows of Table 2).

The following values of the coefficient $\lambda_A^{II}$ were obtained as a result of the hydraulic investigations of break-through grids for an electrodialysis demineralization plant, which were produced on the automated ABS-1 machine with the parameters indicated in this study:

$$\lambda_A^{II} = \frac{664}{Re} \quad \text{for} \quad Re \le 10.6$$

for a laminar flow regime, and

$$\lambda_A^{II} = \frac{302}{Re^{0.667}} \quad \text{for} \quad Re \ge 10.6 \qquad (2)$$

for a turbulent flow regime.

Values of the coefficient $\lambda_A^{II}$ for break-through grids fabricated by the Expanded Metal and K$^o$ Company with the parameters cited in this study are as follows:

$$\lambda_A^{II} = \frac{1660}{Re} \quad \text{for} \quad Re \le 26.5$$

for a laminar flow regime, and

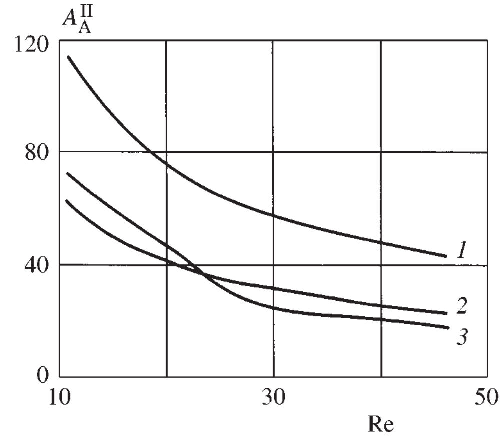


Fig. 2. Dependence of coefficient $\lambda_A^{II}$ on number Re: *1*, *2*) from formulas (3) and (2); *3*) according to author's data (experiment).

$$\lambda_A^{II} = \frac{557}{Re^{0.667}} \quad \text{for} \quad Re \geq 26.5 \tag{3}$$

for a turbulent flow regime.

Figure 2 shows the effect of Reynolds number on the coefficient $\lambda_A^{II}$ of hydraulic resistance to movement of the flow.

Analysis of break-through grids produced by the Expanded Metal and K$^{o}$ Company (curve *1*) and grids manufactured on the automated ABS-1 machine indicated that the critical Reynolds number is higher in the first case (26.5). This inevitably led to an increase in the length of the contact (membrane) portion of the apparatus, and the clearance dimensions of the electrodialysis demineralization plant, to greater head losses (by 2.5 times), and, consequently, to an increase in the energy consumed by the circulation pumps.

Results of the hydraulic investigations therefore confirm the computational and experimental relationships cited, which can be used to optimize the operating conditions of electrodialysis demineralization plants employing break-through grids.

## REFERENCES


1. B. Eckhart, *Chem. Engr. Techn.*, **36**, No. 7, 747–748 (1964).
2. V. A. Sheiman, I. A. Aleksandrov, and V. S. Svezhentsev, "New designs of fractionating towers," *Khim. Neft. Mashinostr.*, No. 9 (1967).
3. L. D. Ushakov, "Conditions for water movement in the chambers of electrodialysis demineralization vessels," *Tr. Vses. Nauchno-Issled. Inst. Vodosnab., Kanaliz., Gidrotekhn. Sooruzh. Inzh. Gidrodeol.*, No. 6 (1967).
4. L. M. Shiller, *Liquid Movement in Pipes* [in Russian], Otdel Nauchno-Tekhnicheskoi Informatsii, Moscow (1939).
5. A. V. Chuvpilo, "Analysis of specific characteristics of grids produced by the method of waste-free break-through/drawing," *Analysis, Design, and Investigation of Equipment for Production of Power Supplies* [in Russian], No. 1, Énergiya, Moscow (1968).
6. A. V. Chuvpilo, "Hydraulic and aerodynamic parameters of waste-free grids," *Analysis, Design, and Investigation of Equipment for Production of Power Supplies* [in Russian], No. 2, Énergiya, Moscow (1969).
7. A. V. Chuvpilo, "Procedure for enhancing the efficiency of platinum catalysts of a break-through grid," *Khim. Neft. Mashinostr.*, No. 5, 5–7 (2003).