Design development and evaluation of the efficiency of the regular separation pack

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Abstract. Practically all enterprises of gas and petrochemical industry use separation packs, which can be used as separators and as an element of heat of mass exchange equipment. The article presents the design of a regular separation pack composed of corrugated metal sheets, as well as the method of measuring its main technological parameters using the finite element method. Dependence of energy consumption and separation quality on design features of the pack is established.

1. Introduction
Internal device of process devices - pack is the main element affecting efficiency of hydromechanical, heat and mass exchange devices. Different types of packs are used to contact different media in equipment. The requirements for packs are incompatible. So irregular packs have low cost, are easy to maintain and have low sensitivity to initial liquid distribution. However, regular packs have a great advantage in that they have less hydraulic resistance.

Recently, regular packs have gained great popularity, which in turn are divided into individual block packs.

Regular packs with individual stacking consist of separate elements, which are located in the body of the apparatus in a certain way relative to each other. Pack elements in layers adjacent in height are laid so that there are no through channels. To facilitate assembly of this pack, the individual parts may be assembled in advance into containers. This makes the process of installation and manufacture of custom-laid regular packs quite labour-intensive and complex, so that packs of this type are not widely used in the industry. Therefore, when talking about regular packs, it is almost always regular block packs that imply. They have recently become widespread.

Regular unit packs are installed in units (packages). Because of this, they got their name. The block is usually formed by set punched, corrugated, corrugated, is punched - the corrugated or mesh sheets having various design features and a certain spatial orientation on the relation to each other. The sheet shapes used in the manufacture of the packs, the arrangement of the sheets relative to each other, the dimensions of the bags, etc. are manipulated to increase the efficiency of the pack.

For the pack to be effective, its design must meet the following requirements:

- have maximum specific surface area and free volume fraction;
- high strength and chemical resistance;
- low cost;
- low hydraulic resistance;
• good wettability;
• uniform distribution of contacting flows over the whole section.

2. Design of separation pack
Based on the performed survey, the design of a regular pack made of corrugated metal sheets is proposed (figure 1).

![Corrugated Sheet Model Used for Pack Manufacturing](image1)

**Figure 1.** Corrugated Sheet Model Used for Pack Manufacturing.

The pack is a stack of vertically mounted corrugated metal sheets. Corrugations of sheets are arranged crosswise at an angle of 90 ° to each other (figure 2). This structure allows achieving high free volume due to distance in cavities of sheets, as well as pack of such structure has low hydraulic resistance. In addition, this arrangement of the sheets causes the product to travel a complex path, separating and mixing the streams. This redistribution of flows improves the separation process.

![Model of packing package made of corrugated sheets](image2)

**Figure 2.** Model of packing package made of corrugated sheets.
The proposed regular pack works as follows: The flow of gas (steam) passes from bottom to top. By positioning the foxes in the pack, the flow is deviated from the original path and divided into separate streams. These streams move zigzag through the channels, constantly changing the direction of movement. Due to inertia forces liquid phase is deposited on walls of channels. Over time, the liquid layer on the walls increases, creating a film that, under the influence of gravity forces, drains down and the purified gas is discharged at the top of the pack.

3. Main performance indicators of separation pack

In the design of the regular separation pack in question, inertial forces are generated by changing the direction of movement of the particle paste. Various geometric features of gas cleaning devices result in a change in the flow velocity and an increase in the aerodynamic resistance of the pack, so the main task in the development of such devices is to find the optimal ratio of cleaning efficiency to aerodynamic resistance.

The main characteristics of the packs are particle capture efficiency and aerodynamic resistance:

- Capture efficiency (degree) is the most important characteristic of the trap, which is oriented in the selection of the pack.

\[ \xi = \frac{M_{\text{catch}}}{M_{\text{in}}} \times 100 = \frac{M_{\text{in}} - M_{\text{out}}}{M_{\text{in}}} \times 100 = \frac{M_{\text{catch}}}{M_{\text{catch}} + M_{\text{in}}} \times 100, \]

where \( M_{\text{in}}, M_{\text{catch}} \) and \( M_{\text{out}} \) - mass of droplets of particulate impurities contained in the gas, respectively, at the inlet to the catcher (i.e., prior to purification) trapped in the pack and at the outlet of the pack after purification.

The resistance of the separation packs, as well as other dry packs, is estimated by the pressure drop of the gas before and after the trap. The pressure drop, the resistance coefficient, is determined from the Weisbach equation:

\[ \Delta P = \frac{\xi V^2}{2g}, \]

where \( \Delta P \) - pressure difference;
\( \xi \) - coefficient of local resistance;
\( V \) - average liquid flow rate, m/s;
\( g \) - acceleration of gravity.

\( V^2/2g \) value is called the velocity (or dynamic) head.

Separation intensity by analogy with mixing processes can be distinguished by an additional indicator characterizing the rate of achievement of the specified result. It is useful to evaluate it with the help of geometric parameters of the device, namely with the help of height of the unit. The higher the impact intensity, the lower the height of the separation pack is required.

4. Selection of optimal height of separation pack unit

The effect of the height of the separation pack unit on the efficiency of collecting the dispersed phase and its resistance were investigated. For this purpose three-dimensional models of channel formed by two adjacent corrugated sheets are built at block height from 100 to 350 mm, dimensions of corrugation (h) were set to 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm.

As a result of the simulation of the separation process, by means of a regular pack, changing the height of the pack unit and the size of the corrugation of the pack member, results were obtained on the main parameters of the separation process, namely the particle capture efficiency and resistance of the separation pack, as shown in Table 1.
Table 1. Separation pack capture efficiency, $\varepsilon$, %.

| Pack block height, $L$, mm | Size corrugations, $h$, mm | Flow rate, m/s |
|---------------------------|----------------------------|----------------|
|                           |                            | 0.5 | 0.75 | 1   | 1.25 | 1.5 | 2   | 2.5 | 3   | 3.5 |
| 100                       | 10                         | 94  | 94   | 92  | 94   | 94  | 92  | 92  | 93  | 95  |
| 150                       | 15                         | 61  | 63   | 66  | 68   | 63  | 66  | 70  | 78  | 88  |
| 200                       | 20                         | 54  | 56   | 60  | 59   | 62  | 68  | 69  | 73  | 73  |
| 250                       | 25                         | 51  | 52   | 53  | 52   | 51  | 54  | 53  | 53  | 57  |
| 300                       | 30                         | 54  | 52   | 53  | 54   | 58  | 59  | 61  | 66  | 71  |
| 350                       | 35                         | 47  | 45   | 47  | 55   | 54  | 58  | 55  | 50  | 57  |

For visual display of obtained results of particle trapping efficiency and resistance of packing, graphs of change of trapping efficiency at different sizes of unit are built (figures 3, 4).

Figure 3. Particle capture efficiency at $L$ 100 to 350 mm, $h$ 10 to 35 mm.

Figure 4. Dependence of the average pressure value on the flow rate.
By analyzing the obtained data, it should be noted that as the speed increases, there is an increase in the number of deposited particles on the inner elements of the pack. This is due to the increase in inertial forces acting on the trapped particles, which positively affects the efficiency of the pack.

As the height of the pack unit \( L \) increases and the size of the corrugation \( h \), the particle trapping quality decreases, so the pack with dimensions \( L = 100 \text{ mm} \) and \( h = 10 \text{ mm} \), on average trapping by particle 41\% more than \( L = 350 \text{ mm} \) and \( h = 35 \text{ mm} \). This confirms that, during separation, the distance to the surface to be deposited is more important than the travel time of the particle in the pack channel. The resistance determined by the pressure drop is proportional to the square of the flow rate, which correlates with the Darcy–Weisbach equation and indicates the adequacy of the resulting data. The results of the studies showed that the simultaneous change in the height of the pack unit \( L \) and the size of the corrugation \( h \) practically does not affect the resistance of the unit as a whole, i.e. the said changes in the geometry of the pack compensate each other.

Thus, in order to increase the efficiency of particle collection during separation, it is necessary to use a regular separation pack with a corrugated size \( h = 10 \text{ mm} \). However, the manufacture of such a pack requires more material, which in turn increases the cost of the separation pack.

5. Conclusion
It has been found that the particle trapping efficiency is directly proportional to the particle flow rate and inversely proportional to the size of the crimp of the pack member. Therefore, the separation process is preferably carried out at high speeds and small corrugated sizes.

A similar relationship is observed with another main characteristic of the efficiency of the separation pack - resistance. It follows from the results of the studies that the increase in speed leads to a sharp increase in aerodynamic resistance, which increases the load on the system’s injection machines.

References
[1] Ponomarenko V S and Arefyev Yu I 1998 Cooling Towers of Industrial and Energy Enterprises: Reference Manual, ed V S Ponomarenko (Moscow: Energoatomizdat) p 376
[2] Afanasenko V G, Khafizov F Sh, Khafizov N F, Ivanov S P and Boev E V 2007 Development of designs for polymeric water traps in cooling towers using centrifugal separation forces Chemical and Petroleum Engineering 3 (11-12) 653–6
[3] Dmitriev A V, Dmitrieva O S and Nikolaev A N 2012 Features of circulating water cooling in vortex chambers in winter Ecology and industry of Russia 9 12-3
[4] Jaiho L 2018 Evaluation of impacts of cooling tower design properties on the near-field environment Nucl Eng Des 326 65-78
[5] Dehaghani S and Ahmadikia H 2017 Retrofit of a wet cooling tower in order to reduce water and fan power consumption using a wet/dry approach Appl Therm Eng 125 1002-14
[6] Kulakov P A, Rubtsov A V, Afanasenko V G, Zubkova O E, Sharipova R R and Gudnikova A A 5 December 2019 Influence of technical condition parameters on the residual resource of capacitive equipment Journal of Physics: Conference Series 1399 055052
[7] Xu-Xu J, Barrero-Gil A and Velazquez A 2016 Dual mass system for enhancing energy extraction from Vortex-Induced Vibrations of a circular cylinder Int J. of Marine Energy 16 256-61
[8] The filler block of the cooling tower: 105732 patent of the Russian Federation. No. 2010152997/06; stated. 23.12.2010; publ. 20.06.2011. Bul. No. 17. 5 p
[9] Naik B and Muthukumar P. 2017 Anovel approach for performance assessment of mechanical draft wet cooling towers Appl Therm Eng 121 14-26
[10] Naik B, Choudhary V, Muthukumar P and Somayaji C 2017 Performance Assessment of a Counter Flow Cooling Tower Energy Procedia 109 243-52
[11] Madyshev I N, Dmitriev A V and Khafizova A I 2019 Estimation of Cooling Capacity of Reagent-Free Evaporative Cooling Tower International Multi-Conference on Industrial Engineering and Modern Technologies p 8934757
[12] Xiong X, Li Land Zhou X 2017 Numerical Analysis and Optimization Research on Backflow
Effect of Cooling Tower *Procedia Engineering* **205** 2003-10

[13] Kondranin T V, Tkachenko B K and Bereznikova M V 2005 *Using the PC programs in researching the liquid and gas mechanics* (Textbook-M.: MPhTI)

[14] Boev E V, Ivanov S P, Afanasenko V G and Nikolaev E A 2009 Polymeric drop-film sprinklers for cooling towers *Chemical and Petroleum Engineering* **45** 454-9

[15] Singh K and Das R 2017 Simultaneous optimization of performance parameters and energy consumption in induced draft cooling towers *Chemical Engineering Research and Design* **123** 1-13

[16] Dmitriev A V, Makusheva O S and Nikolaev N A 2011 Cooling of return water from industrial plants in vortex chambers *Chemical and Petroleum Engineering* **47** 462-7

[17] Li S, Moradi A, Vickers B and Flynn M R 2018 Cooling tower plume abatement using a coaxial plume structure *International Journal of Heat and Mass Transfer* **120** 178-93