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PROCESSES AND DEVICES
OF CHEMICAL MANUFACTURES

Uniform Distribution of the Liquid in a Heat and Mass Exchanger with a Regular Nozzle

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INTRODUCTION

The apparatus with a nozzle are of wide use in a industry at proceeding the heat and mass exchange processes with a simultaneous contact of liquid and gas phases. Examples of such processes are in the chemical engineering: absorption and rectifying processes in column apparatus of an oil distillation, scrubbing column, scrubbers, and regenerators, and in power engineering: an evaporation cooling in a cooling tower.

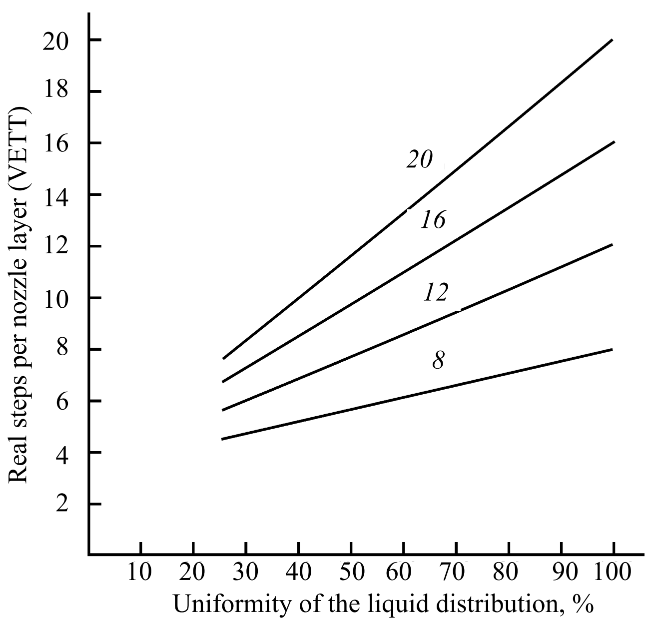


Fig. 1. The effect of the uniformity of the liquid distribution on the mass exchange features of the packed column according to data Koch–Glitsch Company [3]. (*8, 12,16, 20*) Number of the steps per the regular nozzle layer at the basis value of VETT of the system (100% uniformity of the distribution).

The regular as well as irregular contact devices, nozzles, and in the cooling tower mainly regular ones are used in the columns for an increase in the surface contact of the phases. The efficiency of technological processes in industrial apparatus with a nozzle significantly depends on a completeness of a coating the nozzle surface by a film of the liquid [1–3]. The influence of the uniform distribution of a sprinkle density on the operational efficiency of an industrial mass exchange packing column are pictured on the Fig. 1 where research results of Koch–Glitsch Company [3] are depicted. A value of a layer that is equivalent to a mass transfer unit or a theoretical tray (VETT) is assumed as the layer height at the absorption or at the distillation. VETT characterizes an efficiency of the nozzle design.

From Colburn model for VETT computation under absorption conditions [12]

$$\mathrm{VETT} = \frac{1}{1-\lambda}\ln\left[1+(1-\lambda)\frac{\varphi}{1-\varphi}\right]$$

we conclude that the column efficiency depends on consumption parameters of reacting flows, physical properties of the liquid and the gas, a type of the nozzle, and the primary distribution of the sprinkling liquid. In equation (1)

$$\varphi = \frac{y_1-y_2}{y_2-mx_2}; \qquad \lambda = \frac{mG}{L}; \tag{1}$$

y_1 is a mole fraction of an absorbed constituent in the gas coming in bottom section of the column, y_2, the mole fraction of the absorbed constituent in the gas output from the upper section of the column, x_2, the mole fraction of the absorbed constituent in the liquid coming to the upper section of the column, *m,* a tangent of the slope angle of an equilibrium line, *G* and *L* are flow of the gas, and the liquid, respectively.

The influence of the nonuniform distribution of the flows on the efficiency of the mass exchange significantly grows at an increase in the sizes of the apparatus of the diameter of more than 600 mm [12].

Special experiments [3] of the Koch–Glitsch Company show that the columns with high layers of the effective nozzles are very susceptible to the liquid uniformity estimated by Koch–Glitsch technique in terms of percentage. According to [3] the uniformity of 100% corresponds to an ideal uniform distribution of the liquid in the nozzle, and the uniformity of 0% demonstrates that a part of the nozzle surface is not sprinkled totally.

Analysis of the Known Constructions of the Distribution Devices

The inlet section of the nozzle is of the most interest for practice whose good sprinkle is provided by high efficiency of the whole construction. Since mainly the irregular packed nozzles are characterized in certain measure by a redistribution of the liquid it is important to provide uniform distribution of the liquid at the inlet just in the regular structured nozzles that nowadays is of wide use in industry [3–7, 13]. It should be noted that the problem of the uniform distribution of the liquid also is actual for the evaporation cooling in the cooling towers.

Meanwhile as the experience of the industrial application, and also reported results of the targeted research [3–5] show even improved constructions of water dispensers of the packed columns do not provide the uniform distribution of the liquid at the inlet of the nozzle layer. The same note relatives to the device of the evaporation cooling [2].

The experimental results of the research on the liquid distribution in the columns with the help of the fluted water dispersers developed by various companies are pictured in the Fig. 2. Experimental data of [5, 10] about the distribution devices of a jet-type are depicted in Fig .3.

The real liquid distribution as showed by experimental data is far from uniform.

The efficiency of the nozzle use of anything type for performing the heat and mass exchange processes can be determined by a wettability of the high layer of the nozzle by the following relation

$$\eta = \left(\frac{F_{\mathrm{w}}}{F_{\mathrm{n}}}\right)^n \times 100\,\%. \qquad (2)$$

where η is the nozzle efficiency, that is its wettability; *n,* an exponent, $n = 2/3$ [5]; F_{w}, the area of the wetted surface, m^2, F_{n}, is the area of the nozzle surface, m^2.

The comparative characteristics of the water disperser of fluted, jet, and tray types according to [5] are presented in Table 1 where are showed for comparison also data of ΔP of the regular nozzle Mellapak 250X (Sulzer Chemtech) [11] at calculation of 1 m of the layer of the nozzle height at a speed of $W_{\mathrm{o}} = 2$–2.5 m s^{-1} and at a whole section of the empty apparatus.

The targeted developed and produced by companies [3, 4, 8] the modern constructions of the disperser provide up to 100–150 points of the sprinkle per 1 m^2 of the cross section area in a column.

In [6] it was reported information about developing new liquid disperser that can provide up to 600–800 sprinkle points per 1 m^2 of the cross section area.

Analysis of known construction of the industrial and pilot dispersion devices leads to conclusion that the problem of the uniform liquid distribution over the whole cross section in the apparatus with the regular nozzle

The comparison of the efficiency of the various types of the liquid dispensers

The dispenser type	Efficiency of the nozzle η, %	Aerodynamic resistance ΔP, Pa	Coefficient of the hydraulic resistance, ξ
Flute	27	28 000	5180
Jet	27	0.97	0.2
Tray perforated	94	146	27
Nozzle Mellapak 250X	–	130–180	–

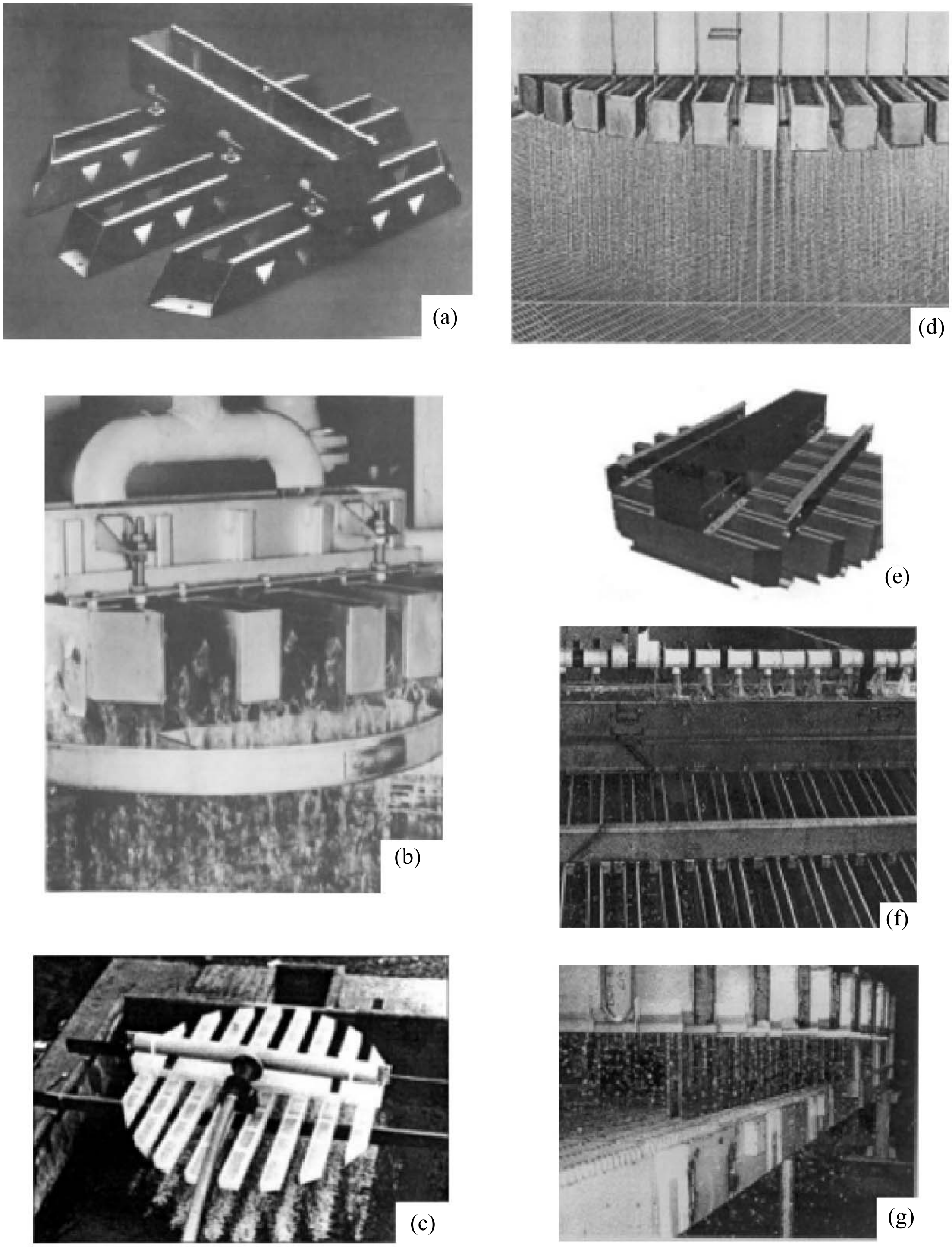


Fig. 2. The liquid dispersers of the flute type for the column of the various companies: (a, b) RASCHIG [8], (c) GLITSCH (Bulletin 345, 1986), (d) NORTON, (e, f, g) Beijing ZEHUA Chemical Engineering Co., Ltd. [4].

is very actual. A solution of this problem for optimum designing the processes of the heat and mass exchange is of a special interest [3–6, 8, 10, 12, 13].

The following essential disadvantages of the known constructions can be noted: – both the flute disperser and the jet one necessitate an additive space for their installation in the volume of the heat and mass exchange apparatus. Thus the apparatus sizes and its metal consumption increase and that is very essential effect for the column in the chemical industry operated under

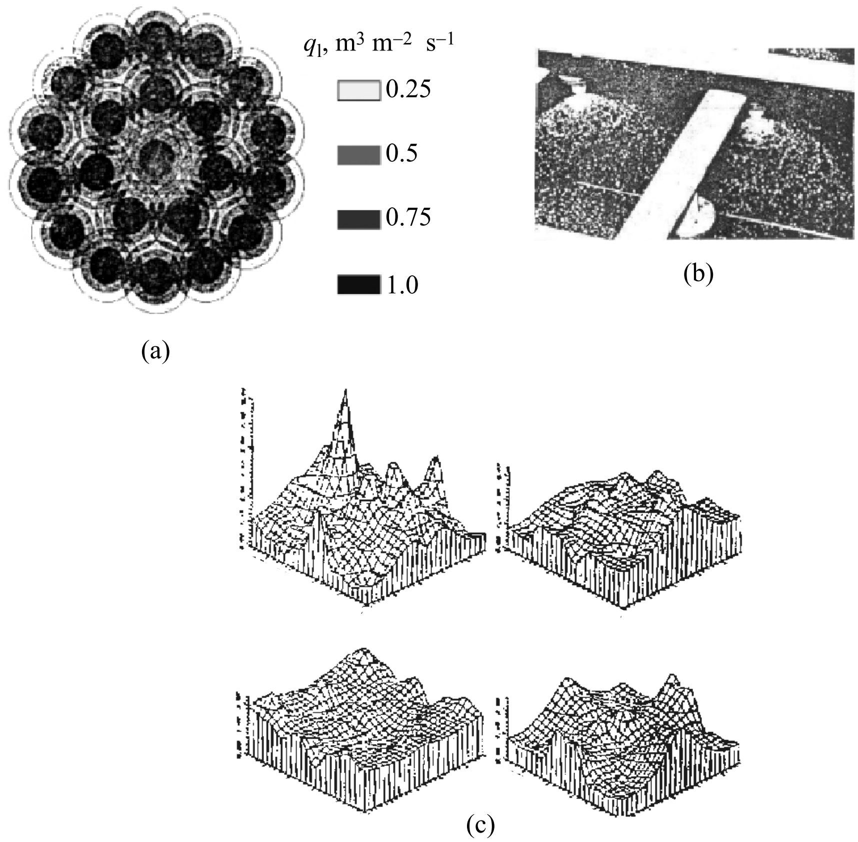


Fig. 3. Distribution of the sprinkle density with the help of the jets of the different construction: (a) centrifugal-stream jet [5], (b, c) the liquid distribution through the system of the water feeding tangential jets in a pilot cooling tower in Pisa (Italia) under conditions of the counter current according to [10]. The water flow is 100 $m^3 h^{-1}$, the air velocity is 3.5 $m s^{-1}$.

pressure with aggressive media;

– an installation of several addition redistribution devices along the height in the packed column are usually required and that also increases the size of columns.

– as a whole the uniform liquid distribution over the total cross section of the apparatus with the regular nozzle due to a use of the special dispersers of the flute type and with the jets is not provided completely;

– hydraulic resistance of the flute disperser remembered in a literature exceeds more than an order of magnitude the resistance of the regular nozzle used in the heat and mass exchangers composed from helicoidal elements.

Experimental Technique and Results of the Research on a Spreading the Single Stream of the Liquid into the Regular Nozzle

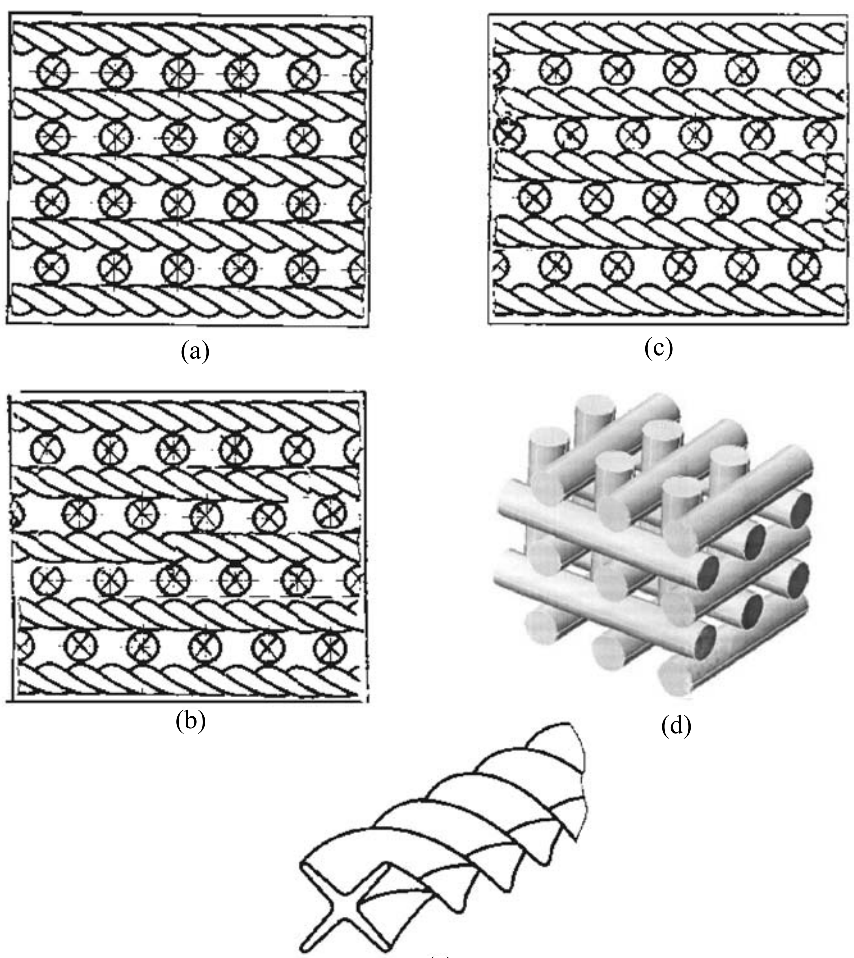
The different modifications of the developed regular nozzle of polymeric helicoidal elements were studied. The general view of these nozzles is on Fig. 4. The set of the nozzles was placed over the water in the water pond of the laboratory bench of Vedeneev VNIIG. The single liquid stream was fed in the course of the test on the top section of the nozzle set of 1×1 m^2 in its center. The water flow was 1 l min^{-1}. A height of the nozzle set was varied in a range (1–10)d, where d is the diameter of the helicoids (d = 75 mm).

The liquid spreading over the nozzle and the sprinkle points in the course of the test were visually remarked and additionally controlled by a photometry. Graphical treatment of the test results as a dependence of the sprinkle points number N on the dimensionless height of the nozzle set H/d for the nozzle -2D and PN-3D is pictured on Fig. 5. As shown the dependence $N = f(H/d)$ in the studied ranges is linear type and described by equation (3)

$$N = k\,(H/d) + b. \tag{3}$$

The values of the equation (3) coefficients are

– for the nozzle PN-2D – k = 16.5; b = –10;
– for the nozzle PN-3D – k = 22.6; b = 28.



(a) (c) (b) (d) (e)

Fig. 4. Fragments of the nozzle set with various types of the set of tne helicoids: (a) corridor (PN-2Dkd), (b) chess board (PN-2Dch), (c) as "skewed channel" (PN-2Dkk); (d) with vertical insets (PN-3D) (here helicoids are shown as the cylinders); (e) the general look of the a helicoid.

RESULTS AND DISCUSSION

A scheme of the spreading the liquid film over the surface of each helicoidal element is depicted on Fig. 6.

The liquid film reached the point k on the bottom section of a sinusoidal element of the helicoid surface, breaks away from the upper helicoidal element and flows down as drops or streams to the lower helicoidal element of the nozzle. Moreover the flowing down to the lower helicoidal elements of the nozzle set occurs also in the point of contact of the nozzle elements adjacent by the height (points M and N on the Fig. 6).

The complete spreading the single stream over the whole cross section of the nozzle set with the area $F = 1\ m^2$, performed in a range of 6–8 of the diameters of the helicoidal elements along the height of the nozzle layer.

A comparison of the liquid spreading over two regular nozzles of Norton Company and of the suggested in this paper is depicted on the Fig. 7. As shown a spreading angle over the Norton nozzle element is 35º, and over the nozzle composed from helicoidal elements, 90º. Advantages of the nozzle PN-2D is obvious.

A determined property of the regular nozzle from the helicoidal elements of the stream autodistribution in a result of the experiments is understood through a whole of a geometrical form of the helicoidal elements and of the structure of these elements packed in the sets. An employment of the developed nozzle provides the uniform distribution of the liquid in the nozzle column and simultaneously 15–20% of decrease in the common size of these apparatus by a removal of the redistribution trays.

It is important that under these conditions a decrease in the total hydraulic pressure of the apparatus by two

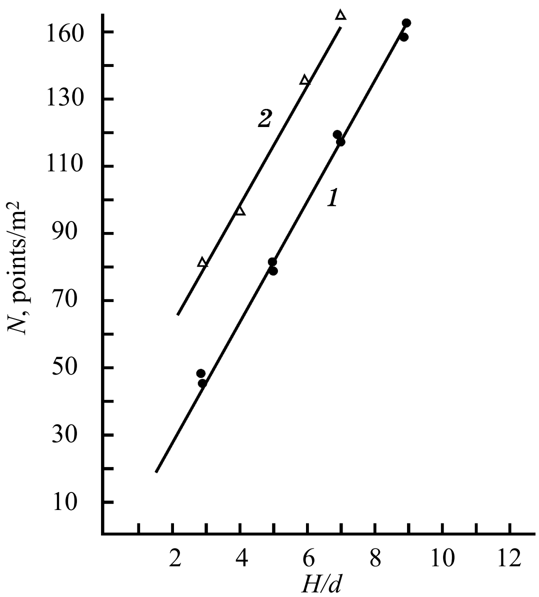


Fig. 5. The dependence of the spreading the single liquid stream in the nozzle sets PN-2D and PN-3D on the value of the relative height of the set *H/d*. (*1*) nozzle PN-2Dkd (*2*) nozzle PN-3D; (*N*) number of the sprinkle point per 1 m^2 of the area of the nozzle set, points m^{-2}; (*H/d*) the number of the helicoid rows in a nozzle set; (*d*) the helicoid diameter.

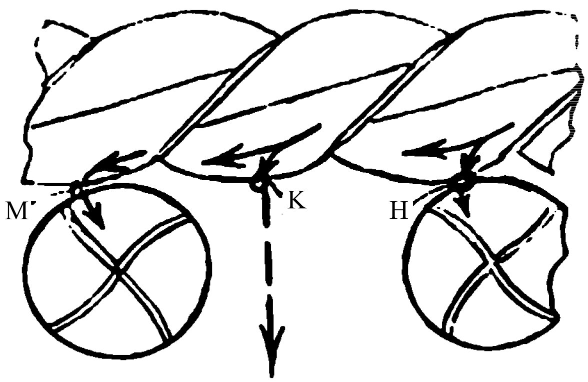


Fig. 6. The scheme of the spreading the liquid film over the surface of the individual helicoidal elements in the rows adjacent by the height. K, M, H the point of the liquid film removal.

orders of magnitude occurs in comparison with the known flute disperser.

The established liquid autodistribution of the nozzle composed from the helicoidal elements enables their effective application even under extreme conditions of the cooling tower at part of the unavailable jet.

Employment of the developed nozzle is efficient in the nozzle columns of the chemical industry as well as in heat power engineering at a reconstruction and designing

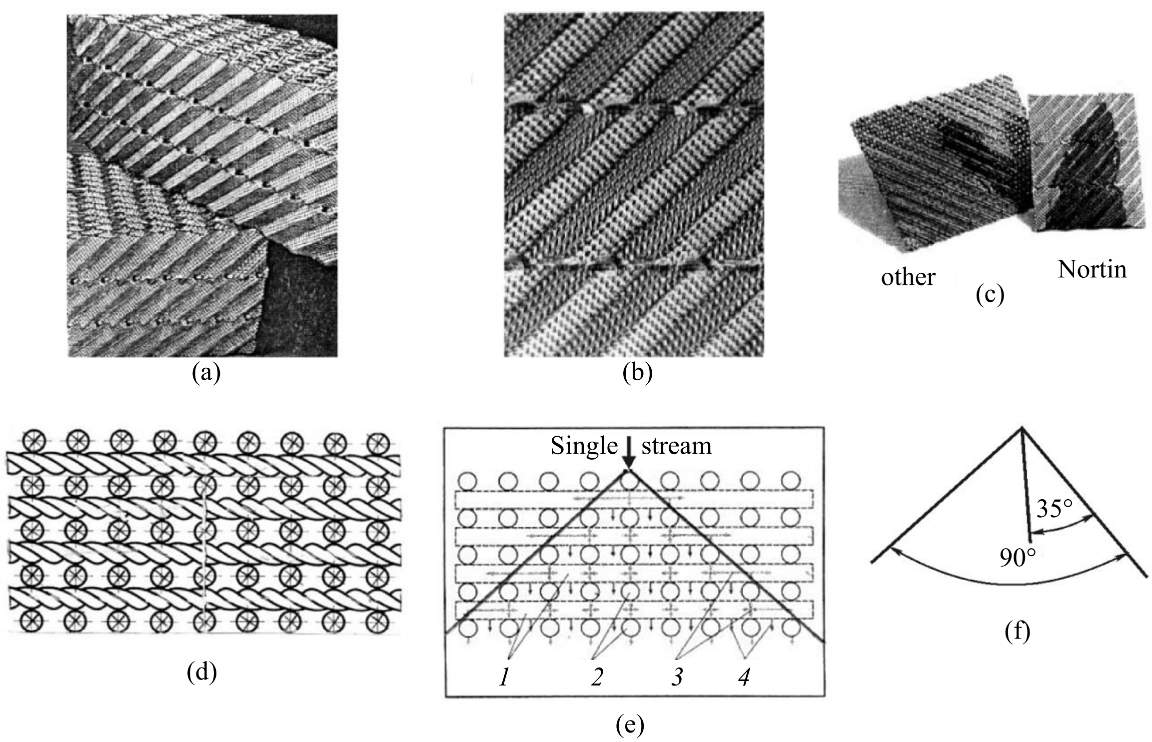


Fig. 7. Comparison of the liquid spreading over the various nozzles. (a) general look of the set of the nozzles NORTON, (b) the element of the nozzle NORTON; (c) the liquid spreading over the element of the nozzle NORTON along the length [13], (d) the general look of the nozzle PN-2Dkd, (e) the scheme of the liquid spreading over the nozzles PN-2Dkd, (f) comparison of angles of the liquid spreading over the nozzles NORTON (35°) and PN-2Dkd (90°). Schemes of the vortex contact devices (a) axial vortex generator, (b) blade vortex generator (c, d) tangential vortex generator.

a new mechanical-draft tower of the system recycle water supply.

CONCLUSIONS

(1) The construction of the regular nozzle composed from polymeric helicoidal elements with the effective redistribution effect on the liquid flow was developed.

(2) The redistribution effect of the regular nozzle of PN-2D and PN-3D grades on the liquid flow along their height in the whole volume of the nozzle set was established.

(3) The features of the redistribution effect of the nozzle in the case of an input of the single liquid stream on the upper nozzle layer of PN—2Dkk, PN-2Dkd, PN-2Dch modifications, and also of PN-3D grade were studied.

(4) The dependence of the jet point number in the nozzle volume on the nozzle height (on a number of the helicoidal element rows) was determined. This dependence is of the linear type. The complete spreading of the single liquid stream over the nozzle area of 1 m^2 is attained in the range of 6–8 of the diameters of the helicoidal elements along the nozzle set.

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