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LIQUID PHASE LEAKAGE IN THE FREE VOLUME SECTION OF COLUMN APPARATUSES FILLED WITH "HONEYCOMB" PACKINGS

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Abstract

Among all types of packings for packed-bed columns, the vertical-wall "honeycomb" packings show the lowest pressure drop per transfer unit, i.e. the lowest energy consumption for carrying out absorption processes. A limitation for its practical application is the possibility for tearing the liquid film flowing over the packing's wall and its leakage in the free volume of the packing in the form of drops and trickles. This leads to two effects. The first one is positive, related to the increasing of the total interphase surface area due to the additional surface of the drops and trickles. The second effect is negative, because of the increasing rate of longitudinal mixing in the liquid phase due to the different velocity of the liquid film and leaky liquid. The influence of the viscosity and surface tension of the liquid phase over the leakage from packings manufactured from different materials is studied. The flowrates under which there is no leakage in the two different ways for arrangement of the "honeycomb" packings are obtained

Key words: *packed-bed columns, Honeycomb packings, leakage of the liquid phase*

1. INTRODUCTION

Packed-bed columns are most widely used apparatuses for heat and mass-transfer processes. The reason for this is their simple construction and maintenance and most of all the possibility for carrying out the process at conditions close to the full counter current flow i.e. at maximum driving force of the process. The packing with vertical walls and especially the "honeycomb" packings are characterized with the lowest pressure drop for transfer unit which means with the lowest energy consumption at a given mass-transfer efficiency. A disadvantage of this packing is the leakage of the liquid phase in the free volume section of the column apparatus. This phenomenon is manifested when the liquid phase tears from the packing's wall where it normally flows on in the form of liquid films and falls in the free volume of the packings in the form of trickles and drops. When the leakage exists it leads to two effects on the performance of the packed-bed columns. The first one is positive and is connected with a slightly increase of the total interphase area due to the additional surface of the drops and trickles. The second effect is negative, because of the increasing rate of longitudinal mixing in the liquid phase due to the different velocity of the liquid film and leaky liquid. As the effect of the increase of the surface is negligible it is necessary to evaluate the effect of the leakage of the liquid phase. The aim of the present work is to derive information for the leakage of the liquid phase from different "honeycomb" packings and for the influence of the physicochemical properties of the liquid phase in the two possible ways of arrangement of those packings.

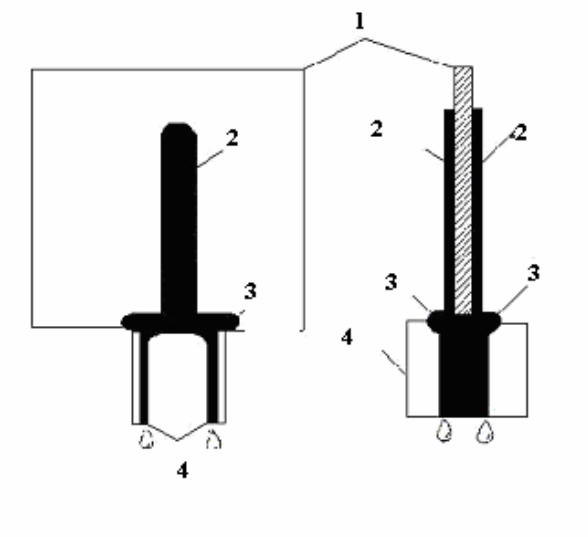
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2. PRINCIPLE APPROACH

The liquid flow over a vertically-walled packing element can be presented [1] as a flow of a trickle over a vertical plate. Schematically this is given in Fig.1 a, where 1 is the plate, 2 is the liquid film. When the materials for packings manufacturing are well wettable a liquid channel 3 is formed on its edge due to the capillary forces. The deposition of two other plates 4 perpendicular to the first one and symmetrical to the liquid film can represent a simple physical model of two subsequent rows of packing with vertical walls. The leakage of the liquid phase starts from the capillary channel 3. In Fig 1b a cross section of the plate 1 from Fig. 1 irrigated on both sides is shown. When the irrigation is stopped the liquid film disappears but the liquid channel 3 remains. Due to the interaction of the capillary, viscosity, inertia and surface forces there are the following possibilities:

1. At predominating capillary forces the channel 3 is formed and there is no leakage between the two plates 4.
2. At predominating inertia forces namely at high liquid flowrates at a given width of liquid film flowing over the plate, or at great distances between the plates 4 the liquid will flow between them.

The hydrodynamic pressure of the channel 3 is responsible for the movement of the liquid towards the plates 4. In [1,2] the research of the leakage from different packing materials consisted of measuring the maximum liquid flowrate at which leakage is not observed with the experimental setup shown in Fig.1 As mentioned above the formation of the liquid channel 3 is in a close relationship with the wettability of the material. Detailed investigation of the wettability of packings' materials is performed in [3-7].



a b

Fig.1 Physical model of the leakage from vertically-walled packings.
1-Test plate; 2-Film flow; 4-Liquid channel, 4-Plates placed symmetrically to the film flow and perpendicular to the tested plate.

The formation of the capillary channel 3 in the case of "honeycomb" packing is similar to this of a single plate but is more stable due to the additional influence of the capillary forces in the corners of

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the packing's walls. This can be easily illustrated in Fig. 2. Due to this the leakage in the case of a real "honeycomb" packing should be observed probably at higher liquid flowrates.

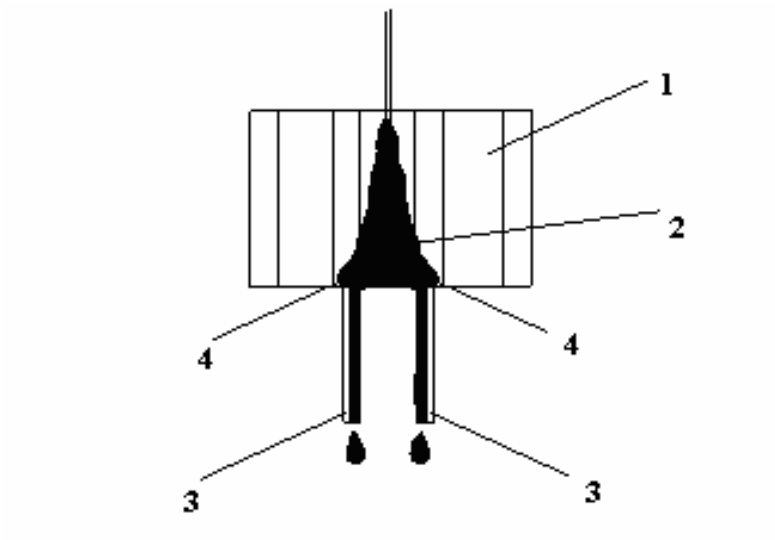


Fig.2. Liquid film flowing over a vertical wall of a "honeycomb" packing.
1-Packing element, 2-Lquid film; 3-Walls of the next row of packing; 4-Points of additional influence of the capillary forces of the walls

On the analogy of the previous figure the leakage from a "honeycomb" packing can be determined by placing vertical plates symmetrical to liquid film and perpendicular to the walls of the packing [8]. In the present investigation instead of plates plexiglass prisms were used.

3. EXPERIMENT

The experimental installation is given in Fig. 3. The liquid phase flows from the Marriot's vessel for constant flowrate, trough valve 6, rotameter 7, syringe needle 8 and forms the liquid film 2 over the packing element 1.The packing element is supported by the base 9. The plexiglass prism 3, substituting the next packing row, is placed under the packing element. It leads away the liquid from the capillary channel formed at the edge of the wall.

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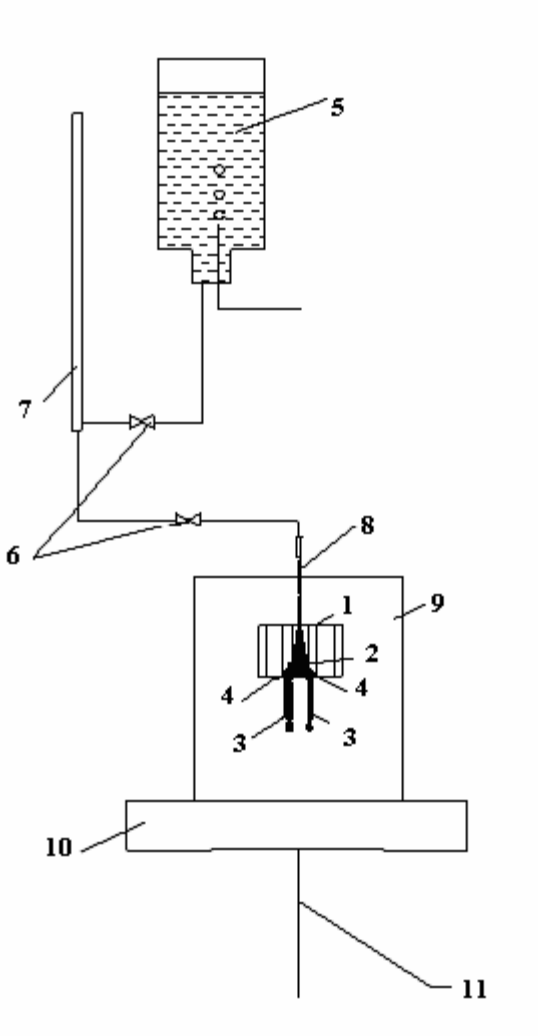


Fig.3. Experimental installation
1-Packing element; 2-Liquid film;3-Plexiglass prism; 4- Points of additional influence of the capillary forces of the walls; 5- Marriot's vessel; 7-Rotameter; 8-Syringe needle; 9- Supporting base; 10-Liquid collector; 11-Leadout pipeline.

There are two manners for arrangement of the "honeycomb" packings in the column apparatus. The leakage of the liquid phase is determined by the distance between the contact points of two successive packing rows. In the first case, Fig. 4a, the distance between two adjacent contact points is equal to the diameter of the circumference inscribed into the hexagonal cell. In the other, Fig. 4b, this distance is equal to the diameter of the described circumference.

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a **b**

Fig. 4. Scheme of the two possible manners of arrangement of "honeycomb" packings in the column apparatus;
a-the distance is the diameter of the inscribed circumference (minimal distance); **b**-the distance is diameter of the described circumference (maximum distance)

The plexiglass prism was fitted under the packing elements in the two possible manners of arrangement and the maximum flowrate at which the liquid phase flows only on the walls of the prism (no leakage) were measured. Similar investigation was carried out in [8] but there instead of a plexiglass prism, two plates of porous sintered PVC substituted the walls of the next rows. Since the porous sintered PVC has the ability to "soak in" part of the liquid, leakage was observed at higher flowrates in most of the cases.

In the present investigation six ceramic packings with different geometric characteristics, two packings from porous sintered PVC, two packings from the material KR and two packings of polystyrene were involved. The material KR is received on the base of phenolformaldehyde resin soaked into different carriers.

One of the polystyrene packings was with boundary layer turbulizers and the other is with smooth walls. The boundary layer turbulizers are grooves stamped in the wall of the packing which affect the boundary layer. The geometrical characteristics of the investigated packings are given in Table 1.

Table 1. Geometric characteristics of the investigated packings.

Material	***d,* *diameter of the inscribed circumference,* mm**	***h,* *height of the packing element,* mm**
Ceramics	9.75	20
Ceramics	10.3	50
Ceramics	11.1	50
Ceramics	13.2	50
Ceramics	17	50
Ceramics	17.3	50
PVC	19	50
PVC	9	50
Material KR-paper	19	50
Material KR -cardboard	19	50
Polystyrene	19	50
Polystyrene with turbulizers	19	50

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A photo of both PVC packing and the packing from the material KR over paper are represented in Fig. 5.

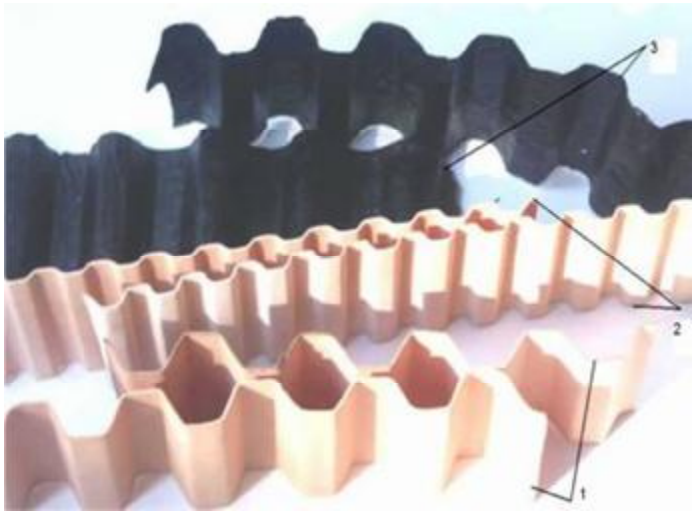


Fig.5. Photo of the PVC packings and the packing from the material KR over paper.
1,2 PVC packings; 3-KR

The physicochemical properties of the liquid phases that were used for carrying out the experiments are given in Table 2. The viscosity was measured by the falling ball method and the surface tension with tensiometer by the Wilhem's plate method.

Table 2. Physicochemical properties of the liquid phases

Liquid	***Surface tension*** **N/m.10^3**	***Viscosity*** **Pa.s.10^3**
Water	72	1
Water salution of glycerol	51.6	30.14
Water salution of glycerol	50.6	8.65
Water salution of glycerol	43.7	5.65
Water salution of surfactant*	37.8	1
Ethanol 96%	22.6	1

* As a surfactant Epicol ESC70 was used (alkyl ether sulphate sodium salth (R-O-(CH_2 CH_2 O)$_3$-SO_3Na R-C_{12}-C_{14}))

3. RESULTS AND DISCUSSION

3.1. Influence of the viscosity

The influence of the viscosity has two opposite directions. First, because of the higher wettability at higher viscosity the horizontal capillary channel should be longer. Second, the higher viscosity means higher pressure drop in the capillary channel movement in horizontal direction.

The maximum flowrate at which leakage is not observed as a function of the viscosity at minimal distance of arrangement (equal to the diameter of the inscribed circumference) for the ceramic packings is given in Fig.6.

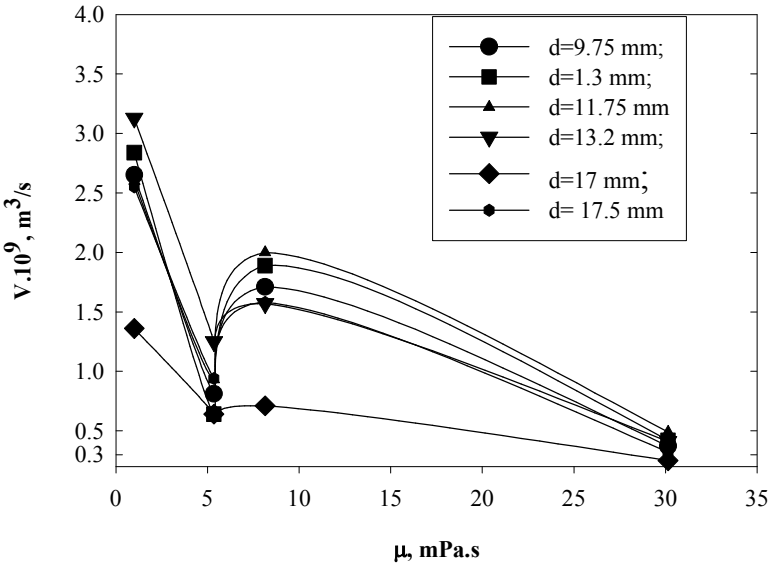


Fig. 6. Maximum flowrate at which leakage is not observed as a function of the viscosity at minimal distance of arrangement (equal to the diameter of the inscribed circumference) for the ceramic packings

The figure shows that the increase of the viscosity leads to an increase of the flowrate at which the leakage is demonstrated. This can be explained with the fact that the raise of the viscosity leads to a raise in the pressure drop of the capillary channel. At viscosity of 5,65 mPa.s there is a radical drop of leakage flowrate. This is due to the fact that this solution has a significantly low surface tension. The mentioned effects are manifested with all other packings.

At maximum distance of arrangement (Fig 4 b) at the highest viscosity (30.14 mPa.s) leakage flowrate for some of the packings cannot be determined because the liquid flows between the walls practically in any flowrate .The reason for this is that the liquid with high viscosity cannot pass through the corners of the hexagonal cell that cause extra pressure drop for the capillary channel.

In Fig. 7 the leakage flowrate as a function of the diameter of the inscribed circumference is presented. It can be seen that the curve passes through a slight maximum with the increase of the diameter. This is due to the larger surface of the packing walls where a wider liquid film could be obtained with a longer capillary channel.

Fig. 8. is a comparison of the flowrates in both cases of arrangement for the same packings. The flowrates for the small packing are always higher then these for the big one.

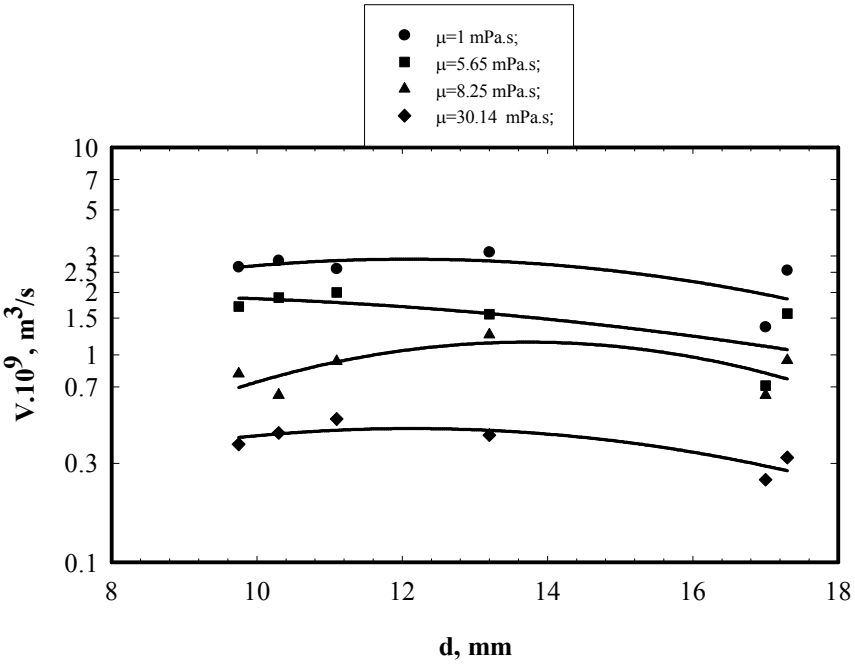


Fig 7. Flowrate as a function of the diameter of the inscribed circumference for ceramic packings at minimal distance of arrangement.

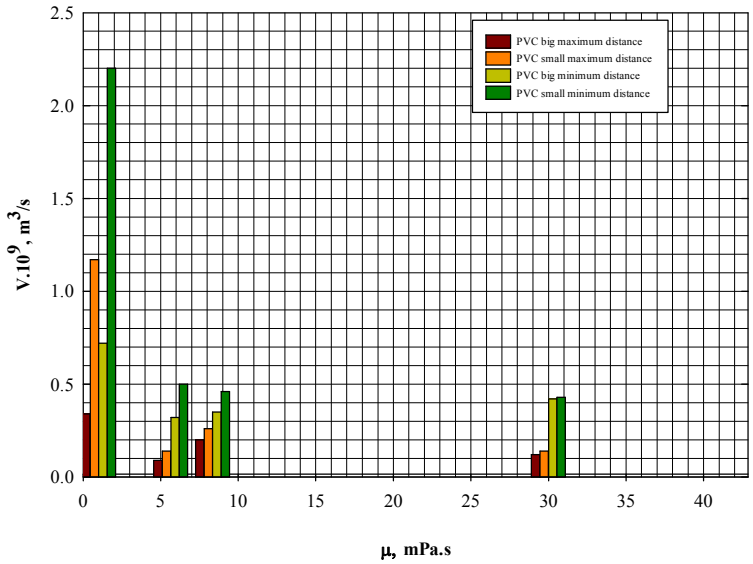


Fig. 8. Comparison of the leakage flowrate for the PVC packings at both manners of arrangement

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The leakage for the material KR at maximum distance was determined only in case of water as irrigating liquid. When using glycerol, there is leakage in any flowrate. In Fig. 9 a comparison of the flowrates at minimum distance of arrangement is demonstrated. The material over paper shows leakage at higher flowrates due to the better wettability of this material.

The situation with the polystyrene packing at maximum distance of arrangement is the same as with the material KR. For the polystyrene packings leakage flowrates for viscosity 30.14 mPa.s cannot be determined. In Fig. 10. a comparison of the flowrates at minimum distance of arrangement is demonstrated. The packing with turbulizers shows leakage at higher flowrates due to the grooves that lead the liquid in horizontal direction.

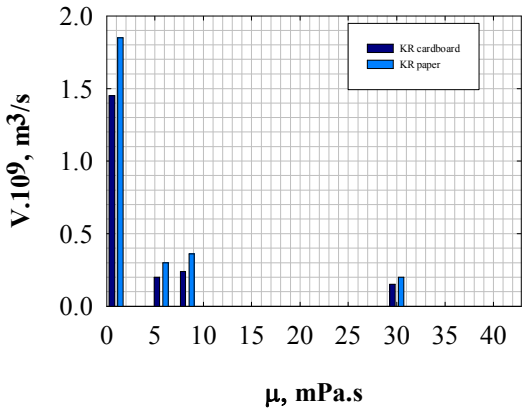


Fig. 9. Comparison of the leakage flowrate for the KR packings at minimum distance of arrangement.

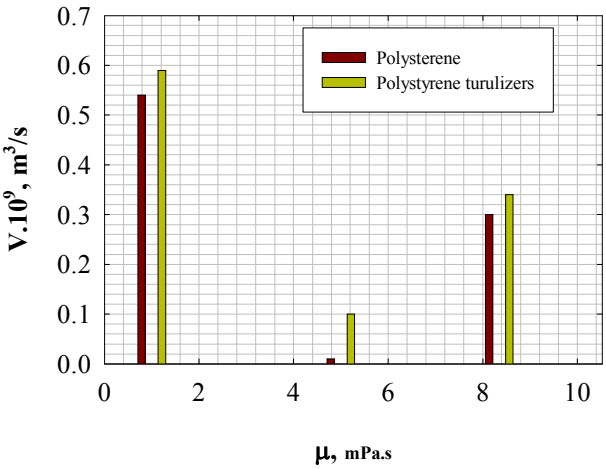


Fig. 10. Comparison of the leakage flowrate for the Polystyrene packings at minimum distance of arrangement

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3.2 Influence of the surface tension

The influence of the surface tension is represented again with two opposite directions. First, the decrease of the surface tension leads to a better wettability in most of the cases and thus to a longer capillary channel. Second, the lower surface tension gives a possibility for easier tearing of the liquid channel and thus to a leakage at lower flowrates.

Figs. 11 and 12 represent the comparison of the flowrates for the ceramic packings at maximum and minimum distance of arrangement respectively.

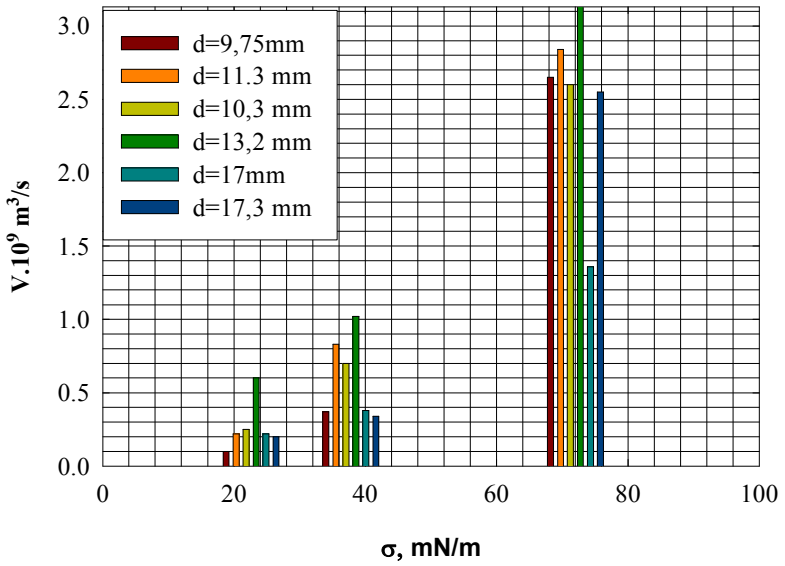


Fig. 11. Comparison of the flowrates for the ceramic packings at maximum distance of arrangement.

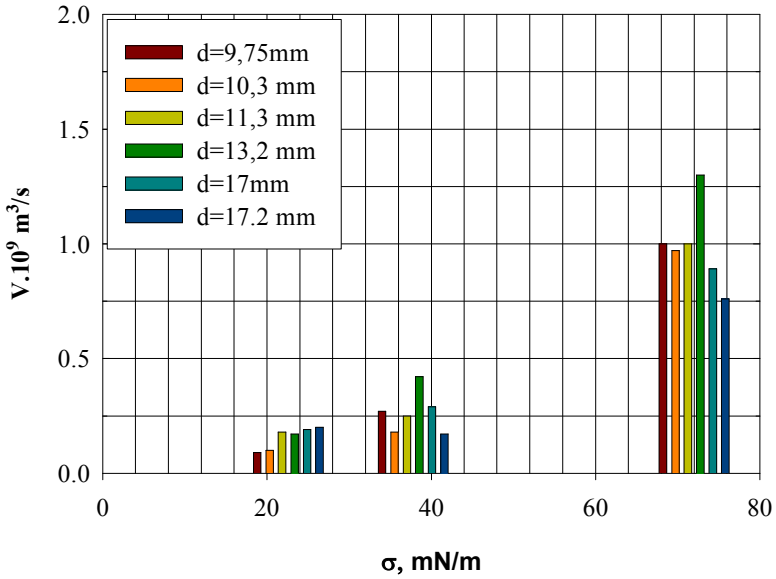


Fig. 12. Comparison of the flowrates for the ceramic packings at minimum distance of arrangement.

The next two figures (Figs. 13, 14) show the leakage flowrate as a function of the diameter of the subscribed circumference for the same packings at both manners of arrangement. The curves pass through a maximum that can be explained with the increase of the film width flowing over the packing's wall with the increase of its dimensions.

The comparison of the leakage flowrates for the PVC packings at maximum and minimum distance of arrangement is given in Fig. 15. The bigger packing has again lower flowrates then the smaller one.

The leakage flowrates for the materials KR are represented in Fig.16. Due to the better wettability, the material KR over paper shows better properties. Flowrates at maximum distance of arrangement cannot be determined.

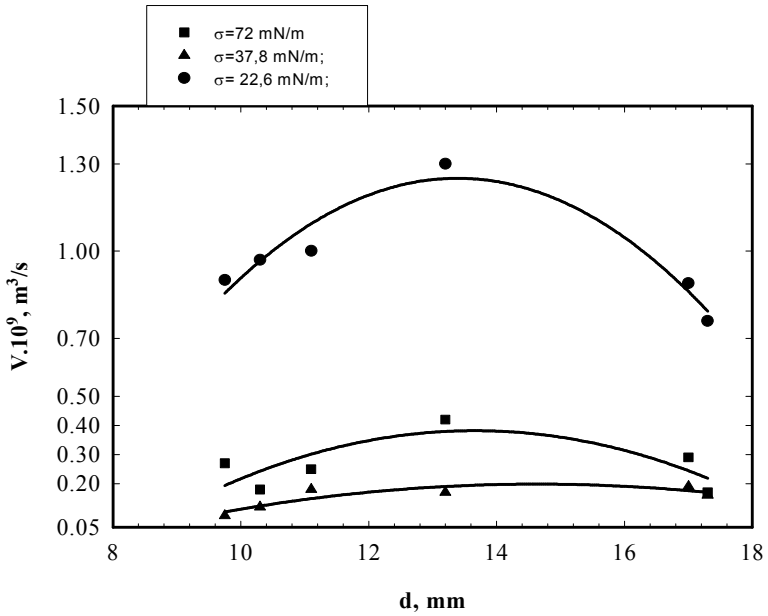


Fig. 13. Leakage flowrate as a function of the diameter of the subscribed circumference for ceramic packings at maximum distance of arrangement

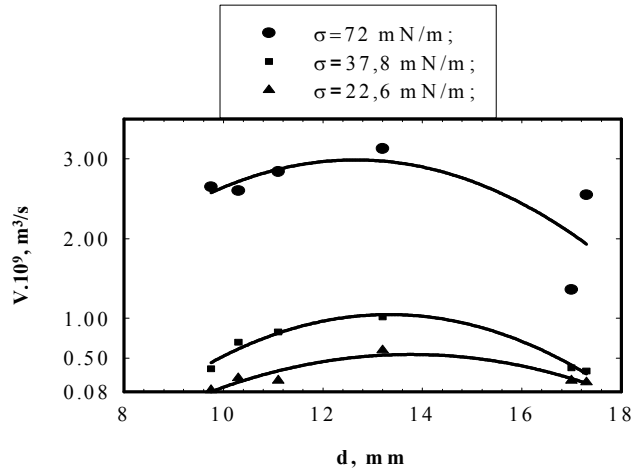


Fig. 14. Leakage flowrate as a function of the diameter of the subscribed circumference for ceramic packings at minimum distance of arrangement

Fig. 17. is a comparison between the two polystyrene packings. The polystyrene packing with turbulizers has better characteristics.

It is seen that the decrease of the surface tension leads to a significant drop in the leakage flowrates for all investigated packings.

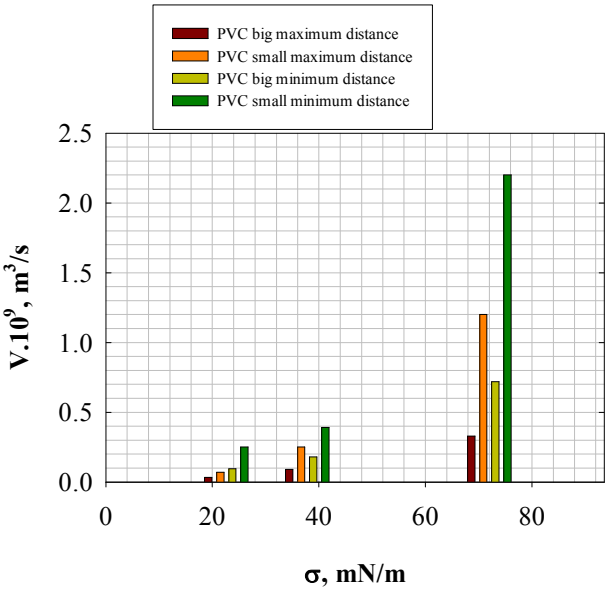


Fig.15. Comparison of the leakage flowrates for the PVC packings at maximum and minimum distance of arrangement

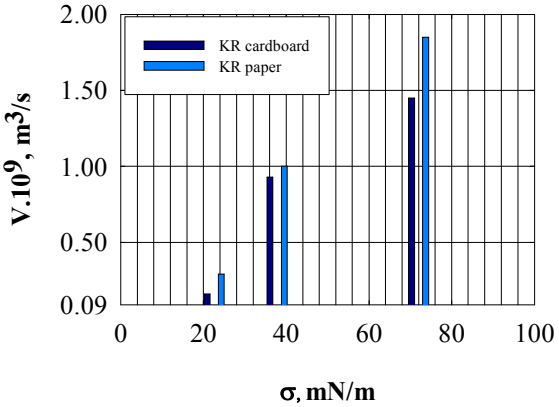


Fig.16. Leakage flowrates for the KR packings at minimum distance of arrangement

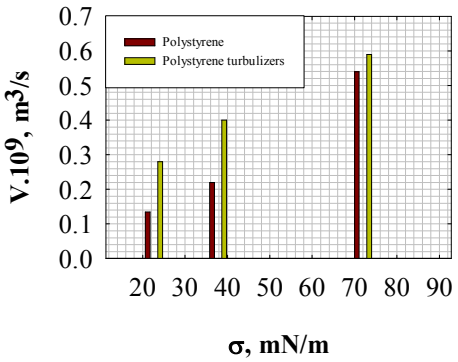


Fig.17. Leakage flowrates for the Polystyrene packings at minimum distance of arrangement

3.3. Comparison of the results with data obtained in previous investigations

It has to be mentioned that previous investigation with plates [2] was carried out with preliminary wetted and dry plates. The leakage flowrate data for the preliminary wetted are always higher than those for the dry. The comparison here is made with the dry plates data.

In the investigation with real packings the leakage flowrates measured with two plates of porous PVC under the packing element are higher than those with a plexigalss prism. The latter is due to the soaking effect of the plates.

The leakage flowrates results for the ceramic packings with water as liquid obtained in the present research are higher (Table 3) than those measured with plates in [2]. Probably this is due to the capillary forces at the corners of the packings. The only exception is the packing with the smallest dimensions, where the leakage flowrate at maximum distance of arrangement is lower. The short wall does not allow formation of a film with a significant width, which combined with the small diameter results in a shorter capillary channel.

The investigations carried out with water solution of surfactant for ceramic packings show the opposite i.e. the measured flowrates in [2] are higher than the data of the present study for maximum distance and close to those of the minimum distance. The reason is that the corners are an extra pressure drop for the unstable capillary channels with low surface tension.

The flowrates measured with plates [2] for the materials KR and PVC and water as irrigating liquid have intermediate values between these in the present study for maximum and minimum distance of arrangement. KR over paper-1.85cm^3/s for minimal distance of arrangement 0.61 cm^3/s for maximum distance of arrangement and 1.14 cm^3/s measured with plates. For big PVC the values are as follows: plates 0.55 cm^3/s, maximum distance-0.33 cm^3/s, and minimum distance-0.72 cm^3/s. In the investigations with surfactant the results for the PVC packing are similar: plates -0.22 cm^3/s, maximum distance of arrangement-, 0.09 cm^3/s and minimum distance of arrangement- 0.36 cm^3/s.

Leakage flowrates for the polystyrene plates [2] were not obtained. In this case liquid film failed to form and the liquid ran on the plate surface in the form of liquid drops. In the present work leakage flowrates were determined for polystyrene packings for some of the investigated liquids. The explanation of this can be found in two phenomena. First, the plates used in [2] are relatively high. For the rugged materials a higher plate means longer action of the capillary forces. For the smooth materials where the capillary forces are small the high plate leads to tearing of the film. When the plate (or the packing element) is short the film velocity after the feeding needle is high leading for the

smooth materials to a greater film width. Second, the walls of the used prism are thicker and the contact areas with the upper packing element are larger. The latter observation can be used as a precaution avoiding leakage.

Table 3. Comparison of the leakage flowrates in the different investigations carried out with water for ceramics.

d, mm	**V at maximum distance of arrangement, present study 10^9 m^3/s**	**V at minimum distance of arrangement, present study 10^9 m^3/s**	**V measured with plates, [2] 10^9 m^3/s**
9.75	0.9	2.65	2.33
10.3	1.0	2.84	0.77
11.1	0.97	2.6	0.75
13.2	1.3	3.12	0.73
17	0.89	1.36	0.58
17.2	0.76	2.55	0.57

3.4. Transition from a single trickle and a packing element to liquid superficial velocity

In order to use the results obtained in the present investigation a transition from a single trickle and a packing element to liquid superficial velocity has to be made. From simple geometrical considerations the relationship between flowrate of a single trickle and liquid superficial velocity is as follows:

$$L = V.a./4.r \qquad (1)$$

$$L = V.a/4.R\ , \qquad (2)$$

where,

L is the liquid superficial velocity , m^3/m^{2}s;

V-the flowrate of the single trickle, m^3/s

a-is the specific surface area of the packing, m^2/m^3;

R-diameter of the subscribe circumference depending on the type of arrangement; m

r- diameter of the inscribe circumference depending on the type of arrangement, m.

4. CONCLUSIONS

The increase of the viscosity and the decrease of the surface tension of the liquid phase lead to a decrease of the leakage flowrates. The flowrates lines pass trough a maximum with the increase of the diameter for the ceramic packings. This can be used for determination of optimum geometrical characteristics in respect of the leakage of the liquid phase. Probably same observation can be done for all packings from rugged materials. With similar investigations the optimum diameter of other packings of rugged material can be obtained. The shorter element height can be a precaution avoiding leakage for the smooth ones. Arrangement of two different types of packings one after another can be

also used, for example packing with thicker walls or with soaking properties like PVC packing under some classical types.

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REFERENCES

1. Kolev, N., Razkazova-Velkova, E. (1998) Liquid Phase Leakage in the Free Volume of Columns with Vertical-Wall Packing Comptes rendus de l' Academie bulgare des Sciences, Tome 52, No 9-10, pp.55-58.

2. Dzhonova-Atanasova, D., Razkazova-Velkova, E., (2010) Influence of the physicochemical properties of the liquid phase on the leakage in the free volume section of column apparatuses filled with vertically walled packings, Summer School organized under a contract No BG051PO001-3.3.04 /28.08.2009, Burgas,7-10 July 2010, pp. 125-133.

3. Razkazova-Velkova, E., Kolev, N., (1998), Comparison of Wettability of Packing's Materials Used in Column Apparatuses,Comptes rendus de l' Academie bulgare des Sciences, Tome 52, No 7-8, pp.43-46.

4. Nicolaiewsky, E.M.A., Tavares, F. W., Rajagopal, K., Fair, J. R., (1999), Wetted area in structured packed columns. I. Influence of viscosity, ICeaP-4, The Forth Italian Conference on Chemical and Process Engineering, Florence, Italy, May 2-5. pp.519-523.

5. Nicolaiewsky, E.M.A., Tavares, F. W., Rajagopal, K., Fair, J. R., (1999), Wetted area in structured packed columns. II. A new model relating surface texturing and wettability, ICeaP-4, The Forth Italian Conference on Chemical and Process Engineering, Florence, Italy, May 2-5 pp.461-464.

6. Nicolaiewsky, E.M.A., Tavares, F. W., Rajagopal, K., Fair, J. R., (1999) Liquid film flow and area generation in structured packed columns Powder Technology 104 pp. 84-94 Number 1, 3 August pp. 84-94.

7. Razkazova-Velkova, E. N., Dzhonova-Atanasova, D. B.,(2010), Influence of the viscosity and surface tension of the liquid phase on the wettability of different packing materials for column apparatuses, Journal of International Scientific Publications, Materials, Methods and Technologies, pp.194- 204; http://www.science-journals.eu/mmt/ISP- MMT-4-1-2010.swf.

8. Dzhonova-Atanasova, D., Razkazova-Velkova, E., Kolev, N.,(2004) Influence of the viscosity and surface tension of the liquid phase on the leakage in the free volume of "Honey comb" packings, Fifth National Conference of Chemistry, 1st of October, 2004, Sofia p.188 (in Bulg.)