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INFLUENCE OF THE VISCOSITY AND SURFACE TENSION OF THE LIQUID PHASE ON THE WETTABILITY OF DIFFERENT PACKING MATERIALS FOR COOLUMN APPARATUSES

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Abstract

The study aims preliminary determination of the wettability of materials appropriate for design of packings for column apparatuses. Some classical and two new packing materials are investigated at dynamic conditions by measuring the width of a film flowing over a plate of every of them. The influence of the viscosity and surface tension of the liquid phase is presented. Dimensionless equations for calculation of the film width at different physicochemical properties of the liquid phase are given in the paper.

Key words: *Packed-bed columns, packings, wettability, dimensionless equation*

1. INTRODUCTION

Packed–bed columns are among the most appropriate apparatuses for caring out mass and heat transfer processes. The main reasons for this is their easy maintain, simple construction and most of all the possibility to work near to the conditions of full counter current flow i.e. at maximum driving force.

One of the most important characteristics of the packings for column apparatuses is their effective surface area because the mass transfer takes place on it. It includes the effective wetted area and the surface of the jets and drops in the free volume of the packing. That is why the preliminary investigation of the wetted area is essential for the estimation of the packings efficiency. The good wettability of the material used for packings is very important especially when it is designed to operate at low or extremely low liquid superficial velocity. The research in this area gives the possibility to select the proper material before making the packing, and thus to save resources and time for investigations. Usually the contact angle is used as a characteristic of the wettability. It is known [1-4, 6] that changing the microform of the surface and making it with small capillary channels with different form and directions it is possible to obtain a good wettability for a material which without this treating is badly wettable. The effect is similar when the material is made porous [7]. A good possibility to compare together different materials for packings is to investigate the width of the liquid film flowing down on a vertical plate of that material [6, 7]. The aim of this work is to investigate the influence of the physicochemical properties of the liquid on the width of the liquid film.

2. EXPERIMENTS

The experimental installation is presented in Fig.1. The liquid is fed from Mariotte vessel (1) providing a constant flow-rate and is fed through a syringe needle (2) on a vertical plate (3) of the test material. The liquid phase is spread forming a film (4) over the plate surface. The film width is measured at different flowrates varying from 0.01 to 2 cm^3/s. The width of the film is measured with a

caliper at several distances from the source point and the results are averaged. The measuring points are enough far (about 20 *mm*) away from the feeding source and edge of the plates in order to consider the film as endless. The flow-rates are determined with accuracy of 0.1 cm^3/s by means of measuring cylinder and chronometer. The experiments are carried for dry and preliminary wetted plates. The second type of experiments is made because the film widths for the preliminary wetted materials are always higher, sometimes even several times, than these for the dry ones. This is due to the increase of the capillary and adhesive properties of the wet surface of the materials. The latter observation can be used for extension of the wetted area of the packing. This can be achieved even when operating at low liquid superficial velocities by working at higher liquid superficial velocities first and then with the needed ones.

Experiments have been carried out for the following packing materials:

- Sintered, porous polyvinyl chloride –PVC;
- Ceramics;
- Newly obtained on the base of phenol formaldehyde resins material KR;
- Zinc-plated iron;
- Stainless steel;
- Polystyrene.

Although the zinc-plated iron is not used in the packing manufacturing the investigations of this material was made for comparison. The plate was intentionally chosen to be with partial destroyed coverage in order to be better wettable.

The liquids used and their viscosity and surface tension are given in Table 1.

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

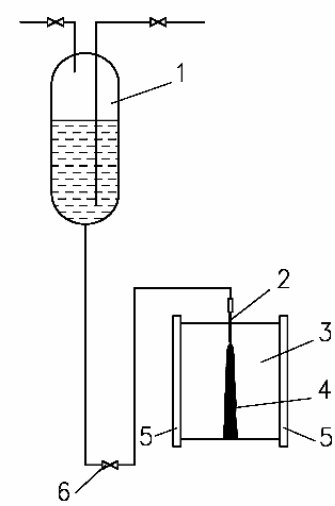

Fig. 1. Scheme of the experimental installation.

(1) Marriotte vessel, (2) syringe needle, (3) plate of the investigated material, (4) liquid film, (5) supporting frame for the investigated material, (6) regulating valve.

Table 1. Test liquids and their properties at room temperature 20°C

Systems	*Composition*	*Density*	*Viscosity*	*Surface tension*
	Vol.%	*kg/m³*	*mPa.s*	*mN/m*
Water	100	1000	1	72.75
Glycerol-water	73	1190	26.4	48.5
Glycerol-water	70	1175	16.3	40.2
Surfactant-water	0.0025	1000	0.9821	39.6

3. RESULTS AND DISCUSSION

As it was mentioned above the film width is always higher for the wetted materials due to the increase of the capillary forces and the adhesion in this case. The difference in the film width for wet and dry ceramics as a function of the liquid (water) flow-rate is shown in Fig. 2. It can be seen that the film width for the wet material can be several times higher than this for the dry one.

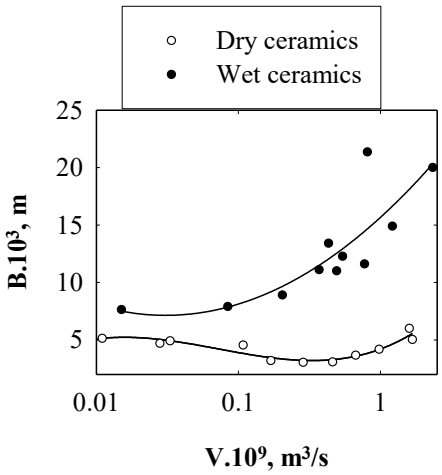

Figure 2. Comparison of the film width for dry and wet ceramics as a function of the liquid (water) flow-rate.

Moreover in [4,6] was found that the curves are reproducible with decreasing flowrates (wet plates). The film flowing over dry materials forms many curves. There are two shapes of the film while the plate is preliminary wetted-with a spindle and a bell form. The first type is observed when the material is well wettable. In this case it forms a small channel at the lower edge of the plate that is with about 5 mm height and is always longer than the film flowing over the plate. The second form is observed when the materials are not so well wettable.

The influence of the viscosity and the surface tension for dry ceramics is shown in Fig.3 and Fig.4 respectively.

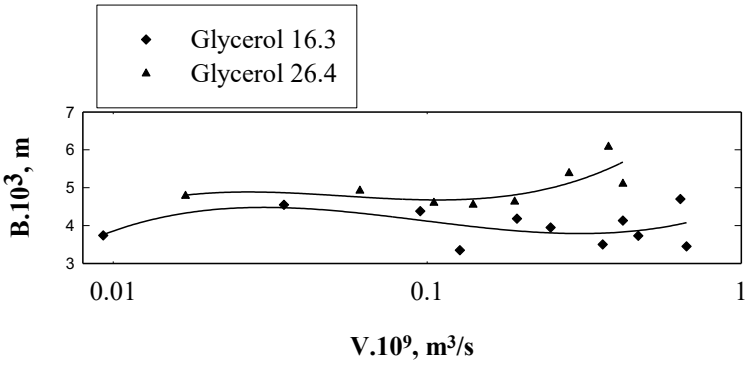

Fig. 3. Comparison of the film width as a function of the flow-rate for liquid with different viscosity for dry ceramics

It is observed, that the evolution of the film width with increase of the flowrate goes through a minimum, caused by a "sucking" effect related to the static pressure reduction in the film according to Bernoulli low. At first this phenomena was mentioned in [7]

This minimum is better noticeable for the porous rugged materials (PVC, ceramics and KR). The minimum is not so "deep" for preliminary wetted materials and with the rise of the viscosity of the liquid used for irrigation. These phenomena can be probably explained with the fact that the ruggedness of the materials decreases the film velocity and thus the sucking effect is at lower flow-rates. Both preliminary wetting and higher viscosities reflect on smoothing of the surface of the materials. In [4, 6] this phenomena was not observed probably for the following reasons: higher flow rates, higher viscosities of the liquid and carrying out the experiments with decreasing flow-rates (wet plates). The observations mentioned above can be easily illustrated in the figures that compare the wettability of the materials depending on the liquid used for irrigation or the condition of the material (preliminary wetted or dry). The decrease of the minimum for wet and dry materials can be appreciated while comparing Fig.5 and Fig 6 for dry and wet materials irrigated with water. In Fig.7. comparison of the wettability of wet materials irrigated with glycerol 16.3 *mPa.s* is shown. Here the curves are almost straight lines.

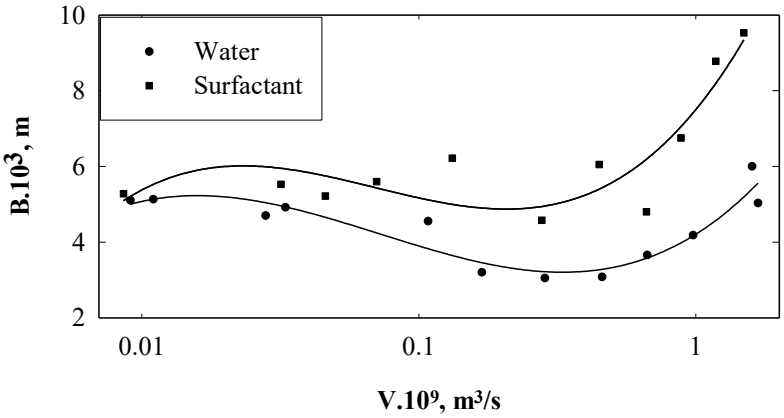

Fig. 4. Comparison of the film width as a function of the flow-rate for liquid with different surface tension for dry ceramics

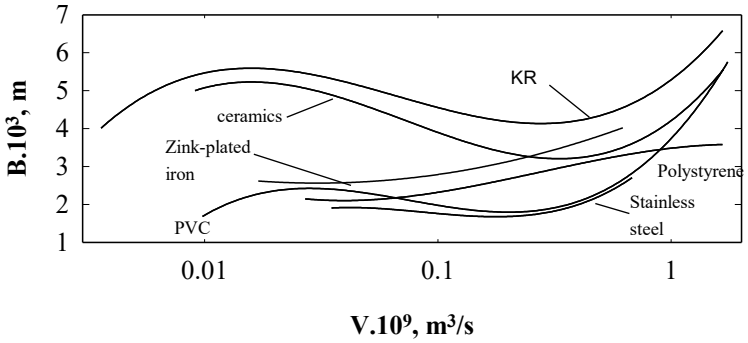

Fig. 5. Comparison of the film width as a function of the flow-rate for dry materials irrigated with water

Different authors show different influence of the viscosity on the wetted surface area [4-6, 8] using different liquid systems. These results are systematically shown in [4,6]. In this investigation the film width for the dry materials rises with the increase of the viscosity and the decrease of the surface tension. The only exceptions are the following:

- -KR –the rise of the viscosity does not reflect in a rise of the film width. It is commensurable for water and glycerol.
- -PVC-the increase of the surface tension does not lead to an increase of the film width.

The curves for the different liquids for the preliminary wetted materials are indistinguishable except the following:

- PVC- the rise of the viscosity leads to an increase of the film width;
- Zinc plated steel –the decrease of the surface tension leads to decrease of the film width.

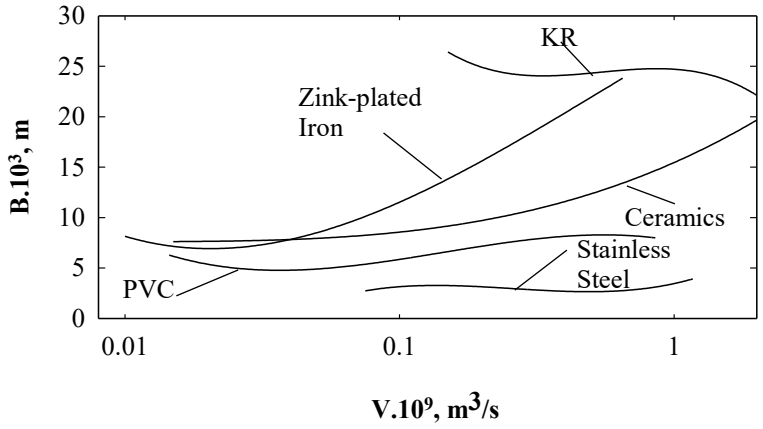

Fig. 6. Comparison of the film width as a function of the flow-rate for wet materials irrigated with water

The rise of the viscosity and the preliminary wetting decreases relatively the difference in the wettability of some of the materials mainly the nonporous ones. That means that the preliminary wetting and higher viscosity can result in increase of the wetted surface of the packings for some materials. Probably this is the reason for the increase of the surface in [8].

The stainless steel and the polystyrene do not form films under some values of the liquid flowrate and with some of the investigated liquids. In these cases the liquid is flowing down the plates in the form of drops. The investigated flowrates for some of the preliminary wetted materials are higher than for the dry ones. The reason was that the moving film at the lower flowrates is not well visible for those materials.

The comparison of the wettability shows that the material KR always has the highest film width when dry and preliminary wetted and for all investigated liquids. It is followed by the ceramics. (Fig. 5, Fig6 and Fig.7).

In [7] the PVC shows very good wettability properties. At the present investigation carried out few years later it was found that the film width over this material has decreased drastic. This is due to some processes of ageing of this material that reflect in blocking of its pores and thus decreasing of possibility of the film to leak on the plate's surface. A comparison of the film width of the PVC given in [7] with the results received in the present investigation is shown in Fig 8.

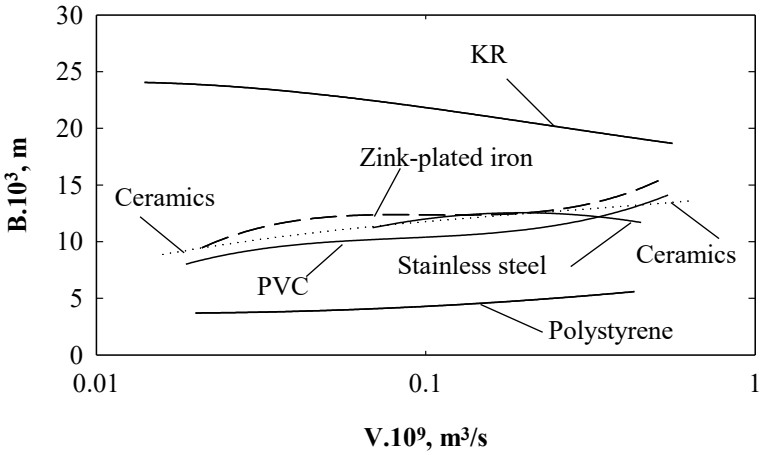

Fig.7. Comparison of the film width as a function of the flow-rate for wet materials irrigated with glycerol 16.3

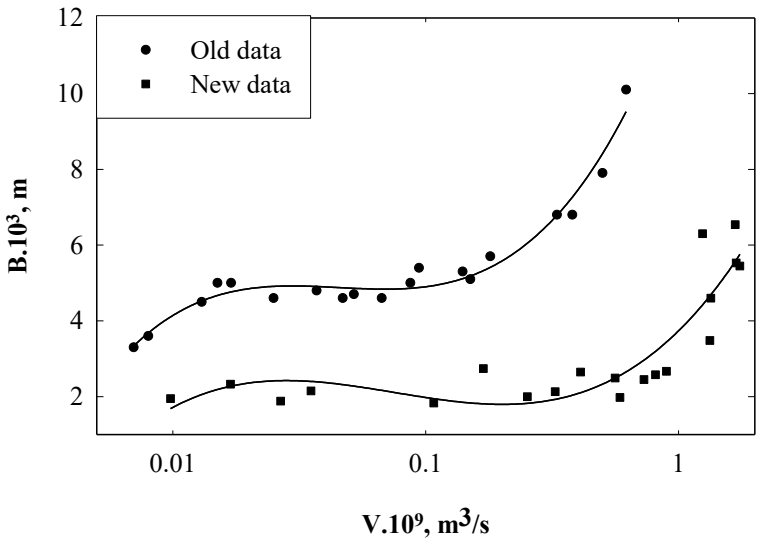

Fig. 8. Comparison of the film width for dry PVC new data and old data

4. EQUATIONS FOR CALCULATION OF THE FILM WIDTH

The ratio film width- film thickness (B/δ) is a function of

$$B/\delta = f(\sigma, \mu, \rho, V, \delta_m, g) \quad (1)$$

where:

σ- surface tension of liquid, N/m;

μ- dynamic viscosity of liquid, Pa s;

ρ- density of liquid, kg/m^3;

V - volumetric flow rate, m^3/s;

δ_m- roughness of the material, m;

g- acceleration of gravity, m^2/s;

The most appropriate form for the equations for determination of the film width is found to be the following:

$$B/\delta = K.((Ca+Vt^{-1})/(Ca^{0.5}) \quad (2)$$

where:

$Ca = \frac{\mu v}{\sigma}$ Capillary number of film flow, (3)

$$Vt = v.\delta/V \quad (4)$$

$v = \frac{\rho g \delta^2}{3\mu}$-mean film velocity, m^2/s (5)

In our case the dimensionless ratio Vt is used because there is no precise information about the exact surface structure of the investigated materials, moreover the preliminary wetting changes this properties. The rise of the flow-rate reflects also in smoothening of the plates' surface. The ratio v/V is very important for both formation of the film width and film thickness.

The parameters are calculated as follows:

The film thickness is calculated according to Nusselt's equation for film flow:

$$\delta = \sqrt[3]{\frac{3G\mu}{\rho^2 g}} \quad (6)$$

$L=V\rho$-mass flow rate, kg/s

$G=L/B$- mass flowrate of liquid per unit wetted perimeter, kg/m s,

The obtained coefficients K are presented in Table 2. The maximum and the mean errors of the equation are also given in it. Other combinations including Re number were also tried but the received equations give worse accuracy.

The coefficient K is different not only for every of the investigated materials but also for the same material depending on its condition (preliminary dry or wetted). The reason for this is that it includes the wetting angle that is different for dry and wet materials.

Table 2. Coefficients *K* in Eq.2 for calculation of the film width

Material	***Liquid***	***K***	*Standard error of the coefficien*	***R***	***Mean error %***	*Max. error %*
Ceramics dry	***Water***	211.6	0.2	0.999	0.5	4.3
	Glycerol 16.3	293	5	0.994	0.4	4.1
	Glycerol 26.4	271	3	0.996	2.6	5.9
	Surfactant	286	0.4	0.999	0.54	1.6
Ceramics wet	***Water***	211.6	0.04	0.999	0.062	0.2
	Glycerol 16.3	305.1	0.5	0.999	0.5	1.5
	Glycerol 26.4	279.6	0.5	0.999	0.41	0.8
	Surfactant	525. 6	0.5	0.999	0.3	0.6
KR dry	***Water***	211.5	0.2	0.999	0.6	3.2
	Glycerol 16.3	293	5	0.995	4.7	9.2
	Glycerol 26.4	273	3	0.996	2.3	2.9
	Surfactant	285.8	0.4	0.999	0.7	1.8
KR wet	***Water***	211,9	0.02	0.999	0.051	0.2
	Glycerol 16.3	308.3	0.3	0.999	0.4	1.1
	Glycerol 26.4	280.7	0.4	0.999	-	-
	Surfactant	287.33	0.03	0.999	0.3	0.5
PVC dry	***Water***	209.3	0.4	0.999	1.1	3.2
	Glycerol 16.3	272	2	0.996	4	9.7
	Glycerol 26.4	485	11	0.987	4.2	7.9
	Surfactant	285.3	0.9	0.999	1.7	4.7
PVC wet	***Water***	211.66	0.08	0.999	0.1	0.6
	Glycerol 16.3	305.5	0.5	0.996	0.5	1.5
	Glycerol 26.4	278.8	0.8	0.998	0.4	0.7
	Surfactant	286.4	0.1	0.999	0.1	0.2

Stainless steel -dry	***Water***	208	1	0.999	1.02	1.9
	Glycerol 16.3	290	8	0.992	5.8	8.1
	Glycerol 26.4	267	11	0.991	3.7	4.2
	Surfactant	497	8	0,993	3.7	7
Stainless steel -wet	***Water***	209.2	0.7	0.999	0.8	1.5
	Glycerol 16.3	305	0.6	0.999	0.5	1,3
Zinc-plated iron dry	***Water***	211	0.3	0.999	0.3	0,71
	Glycerol 16.3	289	7	0.992	4.9	8.1
	Glycerol 26.4	276	4	0.998	4,6	9.9
	Surfactant	284	2	0.999	2.5	5.1
Zinc-plated iron wet	***Water***	388,9	0.07	0.999	0.041	0.075
	Glycerol 16.3	554	2	0,998	0.9	1.4
	Surfactant	524.3	0.6	0.999	0.3	0.6
Polystyrene dry	***Water***	208.9	0.8	0.999	0.9	1.6
	Glycerol 16.3	277	4	0.982	3.2	4.4
	Surfactant	282	2	0.999	1.3	2.5
Polystyrene wet	***Glycerol 16.3***	512	12	0.971	3.7	6.6

5. CONCLUSION

The influence of the surface tension and the viscosity of the liquid on the wettability of materials appropriate for packings are studied for dry and preliminary wetted ones. The formation of the film width with the increase of the flowrates passes through minimum due to the caused by a “sucking” effect related to the static pressure reduction in the film according to Bernoulli low. Dimensionless equations for calculation of the film width are derived.

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Nomenclature

Latin alphabet:

B - film width, m;
G - mass flowrate of liquid per unit wetted perimeter, kg/m s;
g - acceleration of gravity, m^2/s;
K - coefficient in Eq. 2;
L - mass flow rate, kg/s;
V - volumetric flow rate, m^3/s;
v - mean film velocity, m^2/s;

Greek alphabet:

δ - film thickness, m;
δ_m- roughness of the material, m;
ρ - density of liquid, kg/m^3,
μ - dynamic viscosity of liquid, Pa s,
σ - surface tension of liquid, N/m

Dimenssionless ratios:

$Ca = \frac{\mu v}{\sigma}$ Capillary number of film flow,

$Vt = v.\delta / V$;