# PRESSURE DROP OF PERFORATED PLATES AT PARALLEL UPWARD TWO-PHASE FLOW FOR THE WATER–AIR SYSTEM

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Received July 10th, 1975

Pressure drops of thin and thick plates were measured in a column 150 mm in dimater at simultaneous upward water and air flow. Plate geometry: $t = 2$ mm, $d = 10$, 25 mm, $\varphi = 0$ to 5%; $t = 32$, 80 mm, $d = 10$, 25 mm, $\varphi = 0$ to 15%. Linear gas velocities 3 to 12 cm/s, liquid flow rates 2 to 10 l/min. The results are presented graphically. Pressure drop of a heterogeneous mixture at two-phase flow is considerably greater as compared with the single-phase flow. Recommendations are given on suitable design of plate internals for these conditions.

Parallel flow of the gas–liquid mixture over the perforated plate can be met mostly in these cases: *a*) in flooded bubble-type reactors with continuous parallel flow of both phases if the reaction space is divided by horizontal, perforated plates into stages; *b*) in flooded bubble-type reactors with countercurrent flow of phases if the reaction space is divided by perforated plates with downcomers into stages with part of liquid entrained by the gas into the plate situated next above as backflow; *c*) in reactors with the liquid phase in presence of gaseous component or gaseous product with perforated plate forming the bottom carrying a packing while the gas–liquid mixture in the reactor circulates over the plate, or in the case the gaseous product forms partially already in the space below the plate.

All these cases are of great practical importance. There exists a considerable number of studies on pressure drop of plates with a single phase flow while studies on this problem at simultaneous two-phase flow are until-now rare, though losses of energy are in these cases in comparison to those of *e.g.* dry plates considerably higher, even at relatively small content of liquid in the gas. Quantitative data and information on behaviour of pressure drop of perforated plates at two-phase flow in column reactors are necessary for a correct design of column internals and in optimization of reactors. In this study are presented experimental results obtained in this system and some resulting recommendations on selection of the plate geometry.

## EXPERIMENTAL

*Plates.* Two types of plates have been used: thin plates which are at present used in flooded bubble-type columns, $t = 2$ mm, with circular holes $d = 10$, 25 mm in the range of free plate areas $\varphi = 0$ to 5%; thick plates simulating the distributor in packed columns $t/d = 3{\cdot}2$, $t = 32$ to 80 mm, $d = 10$, 25 mm, $\varphi = 0$ to 14%.

*Apparatus.* The measurements were performed in the bottom part of the column with ID 150 mm. The plates were made of brass sheets, thick plate of two brass sheets connected with pipes of the required diameter and length. Plates were attached to the glass cylinder by a flange so that the liquid could not be collected on them and would not form a liquid seal. Gas was introduced into the bottom part of the column below the plate, liquid into the hole in the plate also below the plate. Gas and liquid were fed simultaneously into the space below the plate and after steadying, the over-all pressure drop was measured by a manometer. The pressure tap was situated in the plate so as to measure only the pressure drop of the plate.

*Superficial gas velocity,* related to the free area of the column, was measured in the range 3 to 12 cm/s, liquid flow rate from 2 to 10 l/min. The feed rates correspond to values used in practical application of column reactors with a liquid phase.

## RESULTS AND DISCUSSION

*Thick plates.* Results are presented in graphical form in Figs 1 to 2. Over-all pressure drop in dependence on feed rates and geometrical plate parameters is affected by several mechanisms of pressure drop formation at the given arrangement which can be hardly quantitatively described. In complete disagreement with the results obtained in the single-phase flow for example the pressure drop of plates with two-phase flow decreases at increasing gas flow rate over the plate. The controlling mechanism of occurrence of pressure drop can be under these conditions characterized – in accordance with the visual observations – in a qualitative way in the following manner: at small and medium liquid flow rates (in our case up to 6 l/min) in the whole considered range of gas velocities, a bubbled bed forms in cylindrical holes of the thick plate with the corresponding gaseous porosity and liquid hold up; the pressure drop is then given by the effective height of clear liquid in the hole and by the sum of losses in contraction and expansion of the gas and in friction of the gas in the heterogeneous bed or on the wall of the hole. By increasing the gas flow rate, the gaseous porosity increases in the holes and the effective height of clear liquid decreases as well as the corresponding ratio of pressure drop while the part corresponding to other losses can increase. The resulting effect of such complex mechanism can cause in regions, where pressure drop given by the effective clear liquid height is dominant, the decrease of the over-all $\Delta p$ with increasing gas flow rate. With further increase of the liquid flow rate through the holes of the plate is the effective free area of perforations for the gas obviously considerably decreased which causes an increase especially of that part of $\Delta p$ which corresponds to contraction, expansion and friction. The over-all liquid holdup increases in the holes as well as the part of pressure drop corresponding to it (Fig. 1).

Similarly, the apparently illogical experimental result that at increasing number of holes in the plate (*i.e.* at increasing „free area for pasasge" through the plate) the pressure drop at constant gas flow rate increases, can be explained from certain combinations of free areas and liquid flow rates by a similar mechanism: at increase of the free plate area the whole velocity at constant gas flow rate decreases which affects the porosity in the hole in agreement with conditions of the bubbled bed so that the effective clear liquid height increases and thus the overall pressure drop of the plate can increase as well. Combination of the effects of various liquid flow rates, free plate areas and gas flow rates is causing the existence of minimum on the curve pressure drop in dependence on gas velocity (Fig. 2).

The effect of individual parameters can be explained practically only by an experiment. The rapid increase of pressure drop at small free areas and large liquid flow rates is explained especially by the effect of contribution of expansion, contraction and gas friction. From the experimental data is obvious that an unproperly chosen distributor under conditions of the two-phase flow can considerably affect the energetic situation in the reactor.

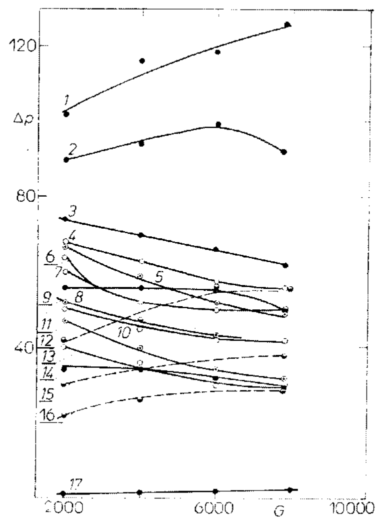


FIG. 1

Pressure Drop (mm $H_2O$) of Perforated Plates in Dependence on Gas Flow Rate (l/h)

● $\varphi$ 2·8%, $t/d$ = 3·2, $t$ 80 mm, $d$ 25 mm. *1* $L$ 10 l/min, *2* $L$ 8, *3* $L$ 6, *8* $L$ 4, *14* $L$ 2, *17* $L$ 0; ○ $\varphi$ = 8·4%, $t/d$ = 3·2, $t$ = 80 mm, $d$ = 25 mm. *4* $L$ = 10 l/min, *6* $L$ 8, *7* $L$ 6, *10* $L$ 4, *13* $L$ 2; ⊙ $\varphi$ = 14·0%, $t/d$ = 3·2, $t$ 80 mm, $d$ 25 mm. *5* $L$ 10 l/min, *9* $L$ 4, *11* $L$ 2; ◒ $\varphi$ = 2·8%, $t/d$ = 0·08, $t$ 2 mm, $d$ 25 mm. *12* $L$ 10 l/min, *15* $L$ 6, *16* $L$ 2.

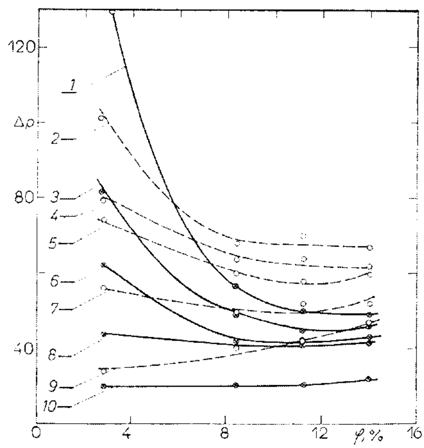


FIG. 2

Effect of Free Plate Area of Thick Perforated Plates on Pressure Drop (mm $H_2O$)

*1* $t/d$ = 3·2, $t$ 80 mm, $d$ 25 mm, $G$ = = 7800 l/h, $L$ 10 l/min; *3* $L$ 8, *6* $L$ 6, *8* $L$ 4, *10* $L$ 2; *2* $G$ = 2000 l/h, $L$ 10; *4* $L$ 8, *5* $L$ 6, *7* $L$ 4, *9* $L$ 2.

In columns of large diameter the distributing plate is for reason of strength of material usually quite thick while the most suitable diameter of perforations can be, with regard to clodging, production simplicity and requirements on its strength, considered to be 25 mm. With diameter of holes in the plate 10 mm at simultaneous flow of both phases, significant pressure pulsations took place which had been caused by plug flow in holes which caused both an increase in pressure drop across the plate as well as a considerable stress of the grid (vibrations) and dangers of transfer of these irregularities from the inlet into the reaction space. Larger holes than 25 mm are not considered to be suitable in reactors of larger diameter nor from the point of view of the plate as the carrier of holdup (usually small ceramic rings *etc.*).

We have determined that under the given conditions and the considered range of phase flow rates is most suitable from the point of view of relatively smallest pressure drops, the free plate area $\varphi = 11$ to 14%. The narrow range of free area demonstrates the importance of a good plate design. When increasing the free plate area (*e.g.* in an effort to distribute uniformly the phase over the cross-section or for production reasons) the pressure drop can be considerable. The increase in free plate area beyond this range can negatively affect the strength of the grid and its production costs and at a certain phase flow rate the pressure drop can increase (Fig. 2).

*Thin plates.* With these plates the bubbled bed is not formed in perforations and thus there is no corresponding contribution of the clear liquid height on pressure drop of the plate which is significant with thick plates (compare *e.g.* the differences on curves[1] *1* and *12* in Fig. 1). It has been found experimentally that from about $\varphi \approx 4\%$ the pressure drop is relatively the smallest and is not further changing considerably with the free plate area (Fig. 3). Below the given value of $\varphi$ the pressure

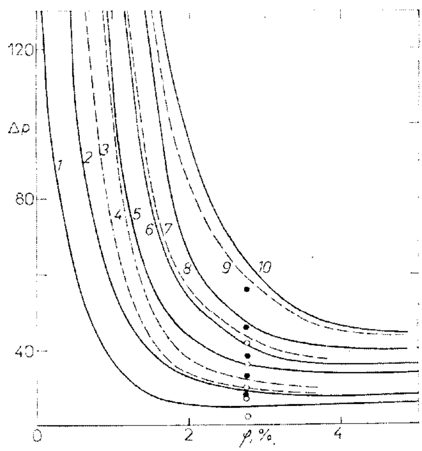


FIG. 3

Effect of Free Plate Area of Thin Perforated Plates on Pressure Drop (mm $H_2O$)

*1* $t/d = 0{\cdot}2$, $d$ 10 mm, $G = 2000$ l/h, $L = 2$ l/min, *2* $L$ 4, *5* $L$ 6, *6* $L$ 8, *8* $L$ 10; *3* $G = 6000$ l/h, $L$ 2, *4* $L$ 4, *7* $L$ 6, *10* $L$ 10; *9* $G = 7000$ l/h, $L = 10$ l/min. ○ $t/d$ 0·08, $d$ 25 mm, $\varphi$ 2·8%, $G = 2000$ l/h, $L$ 10; 8; 6; 4; 2 l/min, from top downwards. ● $G =$ = 7800 l/h, $L$ 8; 6; 4; 2 l/min; from top downwards.

drop is considerably increasing. Pressure drop 900 mm $H_2O$ was obtained for holes 10 mm with liquid flow rates $L = 10$ l/min and $G = 4000$ l/h for $\varphi = 0.5\%$. For maximum flow rates of both phases the obtained pressure drop made several meters of the water column. Let us point here that the free plate area in multistage bubble type reactors with countercurrent flow of both phases and with downcomers must be usually chosen below 1% (ref.[1]) to limit the weeping (material teflon, plates covered with rubber paint *etc.*). The use of such plates for situations where the two-phase flow over the plate can be expected would cause a great operating problems. The size of holes were in our experiments chosen 10 and 25 mm, with the pressure drop for the plate with the holes 25 mm in the region around $\varphi \approx 3\%$ being nearly equivalent to the plates with the hole diameters 10 mm. Larger holes are not advantageous from the point of formation of bubbles (formation of large clusters). For holes under 10 mm at comparable free plate areas, there is a danger of a significant increase of $\Delta p$.

As concerns the minimum pressure drop thin plates as internals should have the minimum free area $\varphi = 4-5\%$. Larger free areas are not suitable because of worse distribution of the gas over the area of the reactor and with respect to complex production of such plates.

## LIST OF SYMBOLS

| | |
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| $d$ | hole diameter |
| $G$ | gas flow rate |
| $L$ | liquid flow rate |
| $t$ | plate thickness |
| $\Delta p$ | over-all pressure |
| $\varphi$ | free plate area |

## REFERENCES

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Translated by the author (M. R.).