Full Papers

Optimization of Hydrodynamic Cavitation Using a Model Reaction

By *Nilesh P. Vichare, Parag R. Gogate,* and *Aniruddha B. Pandit**

The decomposition of potassium iodide to liberate iodine, the model reaction to study cavitational effects, has been carried out under different cavitational conditions. The effect of various parameters (inlet pressure, flow geometry of orifice plates) on the iodine liberation rate has been studied. It is found that the flow geometry of the orifice plates considerably affects the rate of the iodine liberation. Recommendations are given for the arrangement of the holes in order to achieve maximum benefits from the hydrodynamic cavitation. The experimental results obtained in the present work are very much consistent with the results based on the theoretical model developed for the hydrodynamic cavitation. Due to this fact, it can be said that the model can be extended to any geometry of construction in the hydrodynamic cavitation setup and will be helpful in designing cavitational reactors.

1 Introduction

In hydrodynamic cavitation, the overall cavitational effect depends on the intensity of turbulence and the number of cavities generated [1]. In the case of the orifice plates, the permanent pressure drop across the orifice plate is always high and the intensity of turbulence increases with a decrease in the orifice opening to pipe diameter ratio (β). The presence of turbulence makes cavitation transient which otherwise would have been stable and the increase in turbulence makes the collapse of cavities more violent, generating large magnitude pressure pulses [1]. Yu *et al.* [2] made the detailed numerical study of the collapse of cavities in the shear layer formed behind the bluff bodies. A comparison of the cavity collapse in the shear layer and in the quiescent liquid shows that an increase in turbulence in the shear layer increases the rate of cavity collapse significantly.

For the orifice plates having almost the same free area or flow area, the pressure drop across the orifice remains the same, resulting in the same power dissipation per unit mass of liquid (P_M). However, the same flow area can be accommodated by using multiple-hole orifice plates with different combinations of the number of holes and the size of the holes. Thus, the scale of turbulence, intensity and frequency of turbulence can be altered [3]. As the power input remains the same using these plates, the cavitational yield can be improved by varying the flow geometry of the orifice plates.

In the earlier work [3], the effect of various parameters, such as the inlet pressure, downstream pressure, perimeter of the holes, on the cavitational yield has been studied developing a sound theoretical model for the hydrodynamic cavitation. The present work aims at confirming the results obtained earlier with the help of a model chemical reaction and also at developing some guidelines for the arrangement of the orifice plates in the design of the hydrodynamic cavitational reactor in order to achieve maximum benefits. To study the global effect of the operating parameters and the fraction of the overall flow area occupied by the shear layer on the chemical reactions in the presence of cavitating conditions, one of the reactions, i.e. the decomposition of potassium iodide, which requires a cavitational effect has been considered. The chemistry part of the model reaction has been studied in detail by Suslick *et al.* [4]. Senthilkumar [5], using two multiple-hole orifice plates, has studied the cavitational effect of hydrodynamic cavitation on the potassium iodide decomposition. Turbulence in the shear layer and the area occupied by the shear layer were found to be important factors affecting the cavitational yield. The iodine liberation with the plate having smaller diameter holes was found to be higher than that with the plate having large diameter holes for the same flow area. In the present study, six orifice plates with different geometries have been used to study the cavitational effects in hydrodynamic cavitation and the potassium iodide decomposition to liberate iodine has been studied using these plates.

2 Salient Features of the Model

In the earlier work [3], a simplified and unified model has been proposed to study the cavitation phenomena in the hydraulic devices. The dynamics of a cavity is strongly dependent on the surrounding pressure field and its time variation around the cavity. Hence, a fluid turbulence model analogous to the acoustic cavitation was used accounting for the turbulence effects due to the presence of constrictions in the flow field. The turbulent pressure obtained from the above model was then used to solve the cavity dynamics equation, i.e. the Rayleigh-Plesset equation for growth and collapse phases

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of a cavity cluster. The effect of operating parameters, such as the inlet pressure, geometry of the plates, was studied with the help of numerical simulations, whereas the present work aims at confirming these results with the help of the model reaction, i.e. the decomposition of potassium iodide. The details of the model development and predictions can be obtained in the earlier work [3].

3 Experimental

The experimental setup is shown in Fig. 1. The setup includes a holding tank of 100 liter volume, a centrifugal pump (2900 rpm, 5.5 kW, Calama Industries Ltd, Noida, India), control valves (V1, V2, V3), flanges to accommodate the orifice plate, a mainline and a bypass line. The discharge branches into two lines; the mainline and the bypass line. The mainline consists of a flange which houses the orifice plate and a hard glass tube is next to the flange for visual observation. The bypass line is provided to control the liquid flow through the mainline. Both the mainline and the bypass line terminate well inside the tank below the liquid level in order to avoid any induction of air into the liquid due to the plunging liquid jet. The control valves (V1, V2, V3) are provided at appropriate places to control the flow rate through the mainline. The inside diameter of the delivery line of the centrifugal pump is 38 mm.

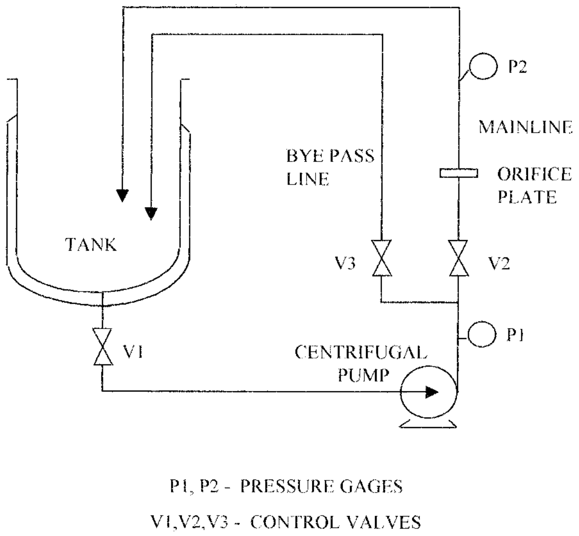

Figure 1. Hydrodynamic cavitation reactor setup.

Multiple-hole orifice plates are considered in the present study. Six plates of different geometries have been used in order to study the cavitational effect of hydrodynamic cavitation. All the plates are made up of stainless steel (SS316). The diameter of each plate is 40 mm. Detailed information on the plates is given in Tab. 1 and the arrangement of the holes on the plate is shown in Fig. 2.

During experimentation, valves V1 and V2 are always kept fully open, while initially bypass valve V3 is kept fully open. Valve V3 was then partially throttled to keep the inlet pressure to a fixed value (say 50 psig for a particular set of experiments). The sample was collected after 10, 20, 30, 45 and 60 minutes of operation at the same operating inlet pressure. Each sample was analyzed with a UV-VIS spectrophotometer (Chemita 2500) at the wavelength of 355 nm. The absorbance was measured, from which the iodine concentration can be determined using a precalibrated chart [5]. Similar procedure was repeated for all the plates at the same inlet pressure (50 psig). To study the effect of inlet pressure on the KI decomposition, plate 2 was studied at various inlet pressures (10–60 psig) for a fixed time of operation (15 minutes).

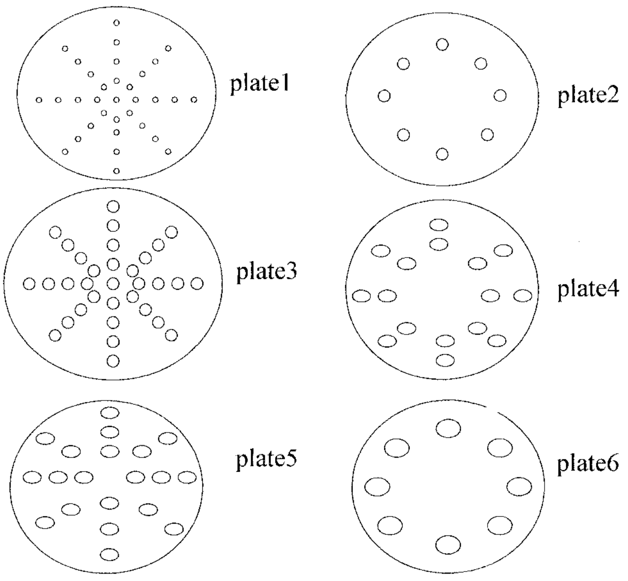

Figure 2. Arrangement of holes of orifice on the plates.

It should be noted here that the experimental conditions are not constant in the initial period, say in the initial 5–10 minutes, as there is some degassing effect [6]. As time progresses, the dissolved gases are removed from the solution and the operation becomes stable. Senthilkumar *et al.* [6] have also obtained similar results with the degassing effect. Hence, in the present work, the effect of various parameters, such as geometry, flow area and the cavitation number, is studied for time periods in excess of 30 minutes up to 60 minutes.

4 Results and Discussion

4.1 Hydraulic Characteristics of Orifice Plates

The variation of the total flow rate with the inlet pressure is shown in Fig. 3(a), which is similar to the characteristic curve for a centrifugal pump discharging liquid through different cross-sectional flow areas. The overall efficiency of the centrifugal pump is shown as a function of the inlet pressure for an orifice plate in Fig. 3(b). The trends are the same as the efficiency V/s discharge pressure relationship of the centrifugal pump, i.e., the overall efficiency increases with an increase in inlet pressure passing through a maximum value.

Table 1. Flow geometry of orifice plates.

Plate number	Number of holes	Diameter of each hole (d_h) (mm)	Flow area (mm^2)	α (mm^{-1})	β_0	Total perimeter of holes (mm)
Plate 1	33	1	25.92	4	0.0206	103.67
Plate 2	8	2	25.13	2	0.02	50.265
Plate 3	33	2	103.67	2	0.0825	207.34
Plate 4	16	3	113.1	1.3333	0.09	150.796
Plate 5	20	3	141.4	1.3333	0.1125	188.495
Plate 6	8	5	157.1	0.8	0.125	125.663

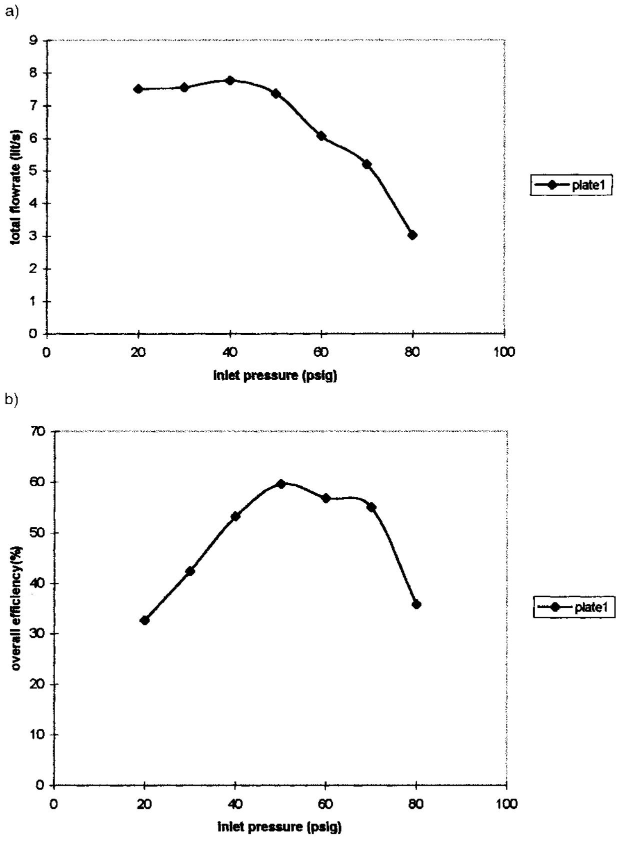

Figure 3. Flow characteristics of orifice plates, I: Variation of efficiency and total flow rate with inlet pressure.

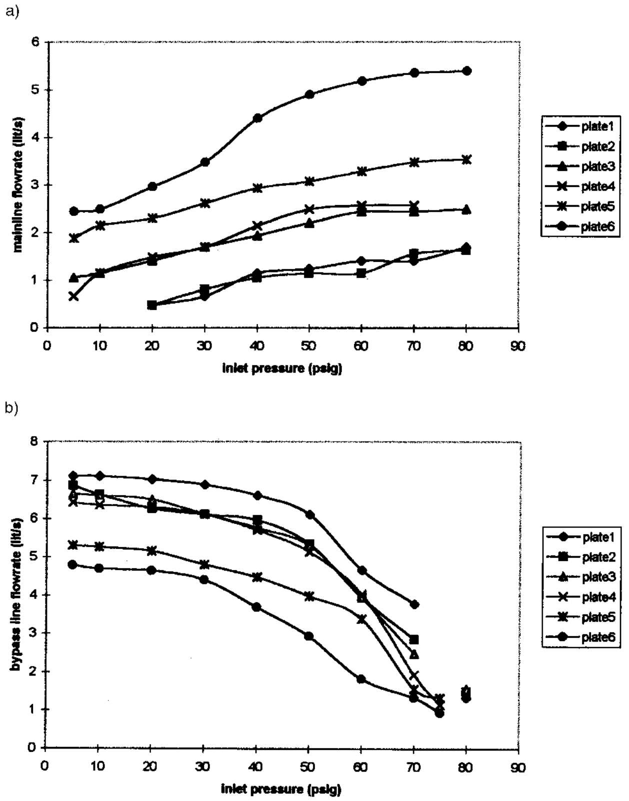

Figure 4. Flow characteristics of orifice plates, II: Variation of mainline and bypass line flow rate with inlet pressure.

The variation of the mainline flow rate and bypass line flow rate with the inlet pressure for six plates is shown in Figs. 4(a) and 4(b), respectively. The figures indicate an increase in the flow rate through the mainline and a decrease in the flow rate through the bypass line with an increase in inlet pressure (5 to 80 psig). Due to a larger size of the opening, the mainline flow rate for plate 6 (8 holes of 5 mm diameter) is higher than for the other plates while for plate 1 (33 holes of 1 mm diameter) the mainline flow rate values are lower than for other plates at the same inlet pressure.

The cavitation number (C_v) is a dimensionless number used to characterize the conditions of cavitation in hydraulic devices. The cavitation number is defined as[1]:

$$C_v = \frac{p_2 - p_v}{\frac{1}{2}\rho_l {v_o}^2} \qquad (1)$$

where p_2 is the fully recovered downstream pressure, p_v is the vapor pressure of the liquid, v_o is the liquid velocity at the orifice which can be estimated from the knowledge of the flow rate through the mainline and the size of the orifice opening. Tab. 2 indicates the orifice velocity and cavitation number for all the plates at different inlet pressures. The variation of the cavitation number with the inlet pressure is shown in Fig. 5 for different plates. The figure indicates a decrease in the cavitation number with an increase in the inlet pressure, which is similar to that observed with a single-hole orifice plate [5]. The results of the simulations in hydrodynamic cavitation done in the earlier work [3] also indicate a decrease in the cavitation number with an increase in the inlet pressure.

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[1] List of symbols at the end of the paper.

Thus, the present study confirms the results obtained by the theoretical simulations of the hydrodynamic cavitation process. As an increase in inlet pressure increases the liquid flow rate through the mainline, the orifice velocity (v_o) also increases, which subsequently reduces the cavitation number. But a decrease in the cavitation number is usually accompanied by an increase in the number of cavities generated [7]. Thus, the overall effect of the inlet pressure on the cavitational yield will be a combined effect of the cavitation number which affects the intensity of cavitation and the number of the cavities that are being generated. Senthilkumar and Pandit [3] have shown that a decrease in the cavitation number results in a decrease in the cavitation intensity (collapse pressure), but at the same time the number of cavities getting generated and collapsing per unit time increases.

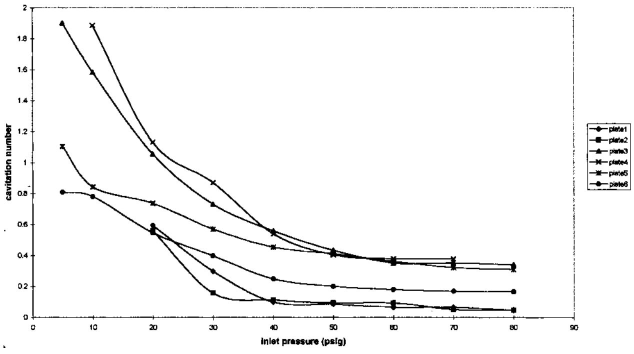

Figure 5. Variation of cavitation number with inlet pressure.

4.2 Effect of Time of Operation on Iodine Liberation

Fig. 6 shows the effect of iodine liberation with respect to time at a fixed inlet pressure (50 psig) for all the six plates. A parameter (α), characteristic of the orifice plate having a unique cross-sectional flow area which takes into account the increase in the area of the shear layer, is defined as the ratio of the total perimeter of the holes to the total area of the opening,

$$\alpha = \frac{Total\ perimeter\ of\ holes}{Total\ area\ of\ opening} = \frac{4}{d_h} \tag{2}$$

where d_h is the diameter of the hole opening.

Thus, the value of α ranges between 0.8 m^{-1} for plate 6 and 4 m^{-1} for plate 1, and there is an increase in iodine liberation for plate 1 which is almost 3 times more than for plate 6. The variation in iodine liberation with α is shown in Fig. 7 for 60 minutes of operation. If the plates having the same flow areas (plate 1 and plate 2, plate 3 and plate 4, plate 5 and plate 6) are compared, then the iodine liberation for the plate having the larger value of α (i.e. smaller d_h) is more. For the plates having the same value of α (plate 2 and plate 3, plate 4 and plate 5), the iodine liberation is higher with the plate having more holes, i.e. a larger total perimeter of the holes. A similar trend though qualitative in nature has been reported by Senthilkumar and Pandit [3].

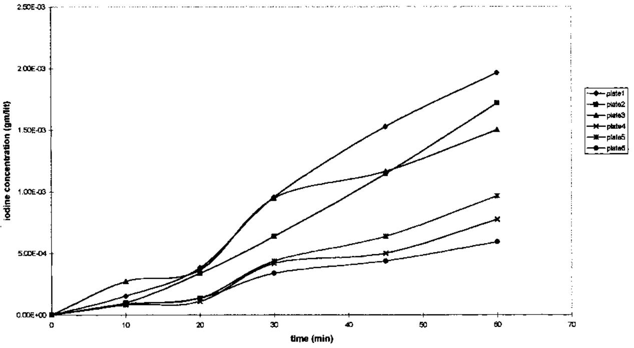

Figure 6. Variation of iodine liberation with time.

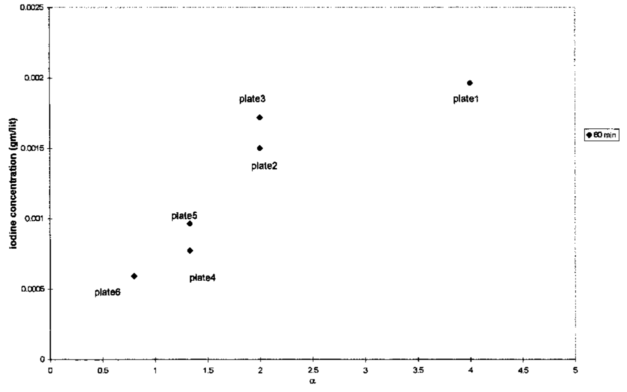

Figure 7. Variation of iodine liberation with flow parameter, α.

Another parameter, β_0, can be defined as the ratio of the total flow area or area of the hole opening to the cross-sectional area of the pipe. The range of β_0 for the present study is 0.02–0.125 (Tab. 1). For the plates having almost similar flow areas (same value of β_0), there is not much difference in the permanent pressure drop as the entire head of liquid is lost on the passage through the orifice plate. This results in similar levels of the power dissipation into the liquid for the plates having the same value of β_0 (plate 1 and plate 2, plate 3 and plate 4, plate 5 and plate 6). For the same value of β_0, the scale of turbulence, which is defined as, $l = 0.08(d_h+d_p)/2$, increases with an increase in the hole size. The frequency of turbulence (f_T) is higher for the plate having a small hole size as it varies inversely with the later ($f_T = v'/l$). If two plates having the same value of β_0 are compared, then the iodine liberation with the plates having a small hole size (high turbulence frequency and intensity) is more (Fig. 6). Hence, the cavitational yield can be improved by using the plate which provides the maximum turbulence or turbulence intensity and the larger shear layer area. This result is consistent with the prediction of the model proposed by Moholkar and Pandit [1] accounting for the effect of the turbulence on the cavity collapse pressure.

4.3 Effect of Inlet Pressure

Fig. 8 shows the effect of the inlet pressure on iodine liberation for plate 2 for a fixed time (15 min) of operation.

Table 2. Flow characteristics of orifice plates.

Inlet pressure (psig)	Plate 1			Plate 2		
	Mainline flow rate (lit/sec)	Orifice velocity, v_o (m/s)	Cavitation number, C_v	Mainline flow rate (lit/sec)	Orifice velocity, v_o (m/s)	Cavitation number, C_v
20	0.4684	18.072	0.5945	0.4684	18.637	0.559
30	0.6626	25.566	0.297	0.8114	32.284	0.156
40	1.1477	44.28	0.099	1.0476	41.6826	0.1117
50	1.2396	47.827	0.08488	1.1477	45.665	0.0931
60	1.4051	54.213	0.066	1.1477	45.665	0.0931
70	1.4051	54.213	0.066	1.5537	61.82	0.0508
80	1.689	65.166	0.0457	1.623	64.577	0.0465

Inlet pressure (psig)	Plate 3			Plate 4		
	Mainline flow rate (lit/sec)	Orifice velocity, v_o (m/s)	Cavitation number, C_v	Mainline flow rate (lit/sec)	Orifice velocity, v_o (m/s)	Cavitation number, C_v
5	1.04758	10.1047	1.9015	0.6623	5.856	5.662
10	1.1477	11.07	1.584	1.1477	10.1478	1.885
20	1.4055	13.557	1.056	1.4816	13.1	1.1314
30	1.6893	16.294	0.731	1.6894	14.937	0.8702
40	1.9317	18.6327	0.559	2.1466	18.98	0.539
50	2.1974	21.1956	0.432	2.4787	21.9165	0.4042
60	2.434	23.477	0.352	2.566	22.688	0.3772
70	2.434	23.477	0.352	2.566	22.688	0.3772
80	2.479	23.912	0.334			

Inlet pressure (psig)	Plate 5			Plate 6		
	Mainline flow rate (lit/sec)	Orifice velocity, v_o (m/s)	Cavitation number, C_v	Mainline flow rate (lit/sec)	Orifice velocity, v_o (m/s)	Cavitation number, C_v
5	1.874	13.256	1.105	2.434	15.496	0.8085
10	2.1466	15.184	0.842	2.4787	15.78	0.7797
20	2.2954	16.2366	0.7365	2.963	18.86	0.5458
30	2.6085	18.45	0.57	3.475	22.1225	0.3967
40	2.926	20.697	0.453	4.395	27.98	0.248
50	3.0723	21.732	0.411	4.8914	31.14	0.2
60	3.2796	23.198	0.3608	5.1752	32.496	0.1788
70	3.4746	24.577	0.3214	5.342	34	0.168
80	3.5373	25.02	0.31	5.383	34.268	0.165

The iodine liberation increases linearly with time up to a certain pressure and then decreases. The mainline flow rate increases with an increase in inlet pressure resulting in an increase in the number of passes of the liquid through the orifice plate. This increase in the number of passes causes the liquid to go through the holes several times and to experience the cavitational zone for a longer interval, due to which the cavitational yield increases. Fig. 8 also clearly indicates that there is no significant iodine liberation due to only pump recirculation, i.e. without the presence of orifice plates in the mainline. Thus, it can be said that the presence of orifice plates or some constriction is a must for the generation of cavitation and the useful effects of the same.

Senthilkumar and Pandit [3] have shown that with the increase in inlet pressure the pressure drop across the orifice increases, resulting in an increase in the cluster collapse intensity. This results in an increase in the magnitude of pressure generated with the collapse of the cavities thereby increasing

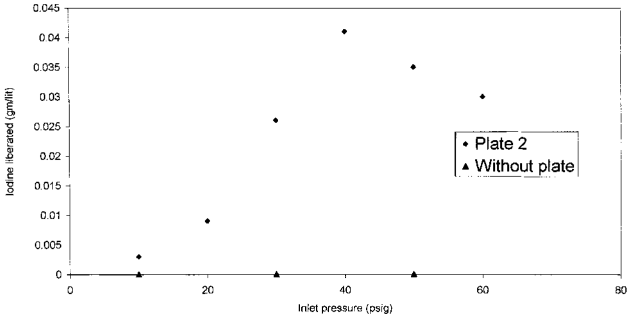

Figure 8. Variation of iodine liberation with inlet pressure for plate 2 and for a system without plates.

the amount of the cavitational effects. The cavitational intensity predicted by simulation studies can be compared in terms of iodine liberation values. The cavitational intensity exhibits the optimum with respect to inlet pressure or pressure drop [3] which can also be observed from iodine liberation v/s. inlet pressure plot. The decrease in the cavitational yield, as observed in the case of the decomposition of KI in the present work for a longer time period and for higher discharge pressures, can be explained if one compares the cavitation number values at different inlet pressures (Fig. 5) with the cavitational yield at the same inlet pressures (Fig. 8). One can see that up to an inlet pressure of 40 psig, the cavitation number decreases with an increase in the inlet pressure and beyond 40 psig, only a marginal decrease in the cavitational number has been observed. Thus, up to an inlet pressure of 40 psig, a steady increase in the iodine concentration has been observed, reaching its maximum at 40 psig. The cavitation number at this discharge number (Tab. 2) for plate 2 is approximately 0.11. Yan and Thorpe [8] have also reported a similar observation regarding the variation of the cavitation number with the inlet pressure and a correlation is given for the estimation of the critical cavitation number. The critical cavitation number is the cavitation number for the onset of choked cavitation, i.e. the formation of a vapor cloud resulting in a cavity collapse in a compressible vapor cloud resulting in substantially reduced collapse pressures. The critical cavitation number depends on the ratio, β, which is the ratio of the diameter of the holes in the orifice to the diameter of the pipe. The cavitation number is reported to remain constant beyond choked cavitation. The correlation given by Yan and Thorpe [8] gives a critical cavitation number in the range between 0.005 and 0.08 for β values ranging from 0.026 to 0.13 respectively, for the present case, depending on the geometry of the holes. These values of the critical cavitation number are somewhat lower than those observed in the present work. This may be due to the fact that a single hole was used in the studies of Yan and Thorpe [8] as against multiple holes used in the present work. This geometry is likely to result in a larger number of locations for the inception of cavitation due to the larger area covered by the shear layers. This would also result in a larger value of the cavitation number for choked cavitation, as is observed in the present study (Tab. 2). This phenomenon of supercavitation could result in the lowering of the KI decomposition rate, as observed in this case.

4.4 Effect of Cavitation Number

The number of passes of the liquid through the orifice plate can be calculated as follows,

Number of passes of the liquid =

$$\frac{\mathit{flowrate\ through\ mainline}}{\mathit{Volume\ of\ holding}\ \mathrm{tan}k} \times \mathit{time\ of\ operation} \tag{3}$$

The variation of the iodine liberated per pass with the cavitation number for plate 2 is shown in Fig. 9. For a particular plate, the increase in inlet pressure decreases the cavitation number and hence, the iodine liberation is higher at a lower cavitation number. But at a fixed inlet pressure, the flow rate through the mainline is different with all the six plates (Fig. 4(a)). Therefore, it is necessary to study the cavitational activity of all the plates under comparable conditions (fixed inlet pressure, same time of operation). Fig. 10 shows the effect of the cavitation number on the iodine liberation per pass for different plates at a fixed inlet pressure (50 psi) for 30 minutes, 45 minutes and 60 minutes. The graph indicates a higher iodine liberation at a lower cavitation number, i.e. for plate 1 at any time. The iodine liberation decreases with an increase in the cavitation number. At a lower cavitation number, the number of cavitation events and the number of cavities generated are high while cavity collapse intensities are low [3,5]. The results obtained here are quite consistent with the simulation results obtained in the earlier work and the detailed explanation can be seen in earlier sections.

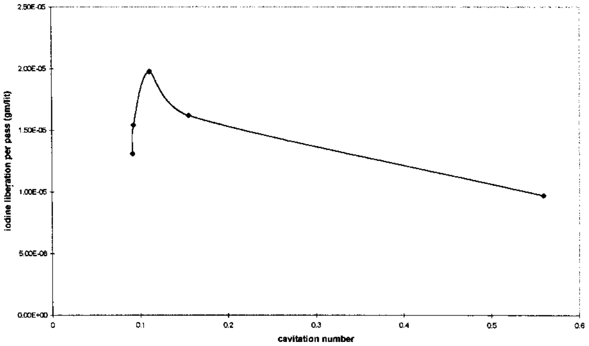

Figure 9. Variation of iodine liberation per pass with cavitation number for plate 2.

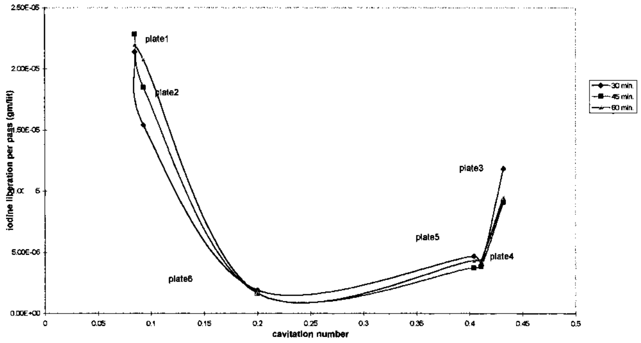

Figure 10. Variation of iodine liberation per pass with cavitation number at different times of operation for different plates.

However, for plate 4, plate 5 and plate 3, the iodine liberation is higher than that with plate 6 even at a high cavitation number. This increased iodine liberation is due to an increase in the total perimeter of the holes, and the effect of the total hole perimeter is discussed later.

The cavitation number is a strong function of the average velocity of the liquid at the orifice, v_o, (Eq. 1) which in turn depends on the flow rate and the total flow area. The effect of the flow geometry on cavitation can be further extended by considering a new parameter, the modified cavitation number ($C_v^{/}$). The modified cavitation number is expressed as follows,

$$C_v^{/} = \frac{C_v}{\left(\frac{Total\ perimeter\ of\ holes}{Perimeter\ of\ pipe}\right)} \tag{4}$$

Fig. 11 shows the effect of the modified cavitation number on the iodine liberation per pass of liquid for a fixed time interval (30 minutes, 45 minutes and 60 minutes). The figure indicates a higher iodine liberation per pass for plate 1 due to a higher turbulence (lower cavitation number) and a decrease in iodine liberation with an increase in $C_v^{/}$ due to a decrease in the total perimeter of the holes. For plate 1, the orifice velocity of the liquid (v_o) is very high which results in a low value of $C_v^{/}$, but the frequency of turbulence (f_T) is high and as this plate provides more area of shear layer, better cavitational effects can be obtained which increases the iodine liberation. If the plates having almost the same flow area (plate 1 and plate 2, plate 3 and plate 4, plate 5 and plate 6) are compared, then the total perimeter of the holes is always high for the plates having a larger number of holes though a small size of the hole. Thus, for the same flow area, the iodine liberation can be increased by decreasing $C_v^{/}$ or increasing the total hole perimeter, i.e., by arranging more openings of small size on the plate.

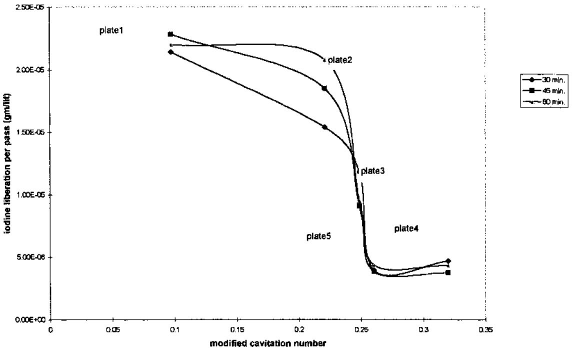

Figure 11. Variation of iodine liberation per pass with modified cavitation number at different times of operation for different plates.

4.5 Effect of Perimeter of Holes

The values of the mainline flow rate and cavitation number for plate 3, plate 4 and plate 5 at a fixed inlet pressure (50 psig) are comparable (0.4–0.415, Fig. 5). So the cavitational conditions at 50 psig inlet pressure for these plates are almost the same. In order to study the effect of the size of the hole opening on the iodine liberation under similar cavitational conditions, plate 3, plate 4 and plate 5 are considered in the analysis. The total perimeter of the holes for plate 3, plate 5 and plate 4 are 207.34 mm, 188.495 mm and 150.79 mm, respectively. The iodine liberation increases with an increase in the total perimeter of the holes for a fixed time interval, as shown in the Fig. 12. The effect is more pronounced for longer time intervals. For the initial time period (up to 20 minutes), not much variation in iodine liberation with the total perimeter of the holes is observed due to the degassing effect [3]. As time progresses, dissolved gases are removed from the solution and the operation becomes stable.

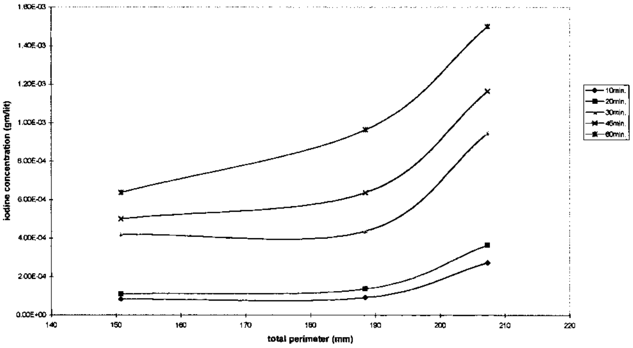

Figure 12. Variation of iodine liberation per pass with total perimeter of holes at different times of operation.

The iodine liberation for plate 3 is higher compared with that for plate 4 due to the small size of the opening indicating the effect of the total perimeter (Fig. 11) and α (Fig. 7). For a larger size of the opening ($d_h > 3$mm) the difference in the iodine liberation values is not significant; however, for a low size of the opening ($d_h = 2$ mm. and $d_h = 1$ mm.) the amount of the iodine liberated is higher (Fig. 6) for the plates having a larger total perimeter. This possibly can be explained on the basis of the generated cavity size and the resonant dominant turbulent pressure fluctuating frequency, ($f_T = v^{/}/l$).

The cavitational yield is defined as the ratio of the cavitational effect to the energy supplied to the system. The cavitational effect can be measured in terms of iodine liberation in the present study. The cavitational yield is expressed as,

$$Cavitational\ yield\ (gm/J) = \frac{Iodine\ liberated}{H \rho_l g Q_m t} \tag{5}$$

where, H is the pressure head of the flowing liquid, Q_m is the mainline flow rate and t is the time interval of operation. The cavitational yield for the six plates is shown Fig. 13 at different time intervals as a function of β_0. The cavitational yield with plate 1 is almost 10 times higher than that with plate 6. The decrease in hole size decreases the scale of turbulence (l) and increases the turbulent frequency (f_T) and the collapse of the cavities is more violent which enhances the cavitational effect and increases the cavitational yield. Also, as discussed earlier for the same flow area, the decrease in hole size increases the

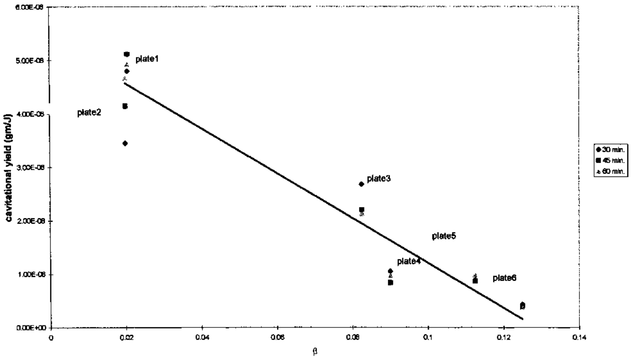

Figure 13. Variation of cavitational yield with flow parameter, β_0, for different plates and at different times of operation.

number of holes and hence, the total perimeter, increasing the probability of the cavity-experiencing shear layer surrounding the issuing liquid jet resulting in a more violent collapse.

5 Conclusions

The multiple-hole orifice plates have been characterized under different cavitational conditions. The flow characteristics of the orifice are similar to the operating characteristic curves for a centrifugal pump.

In hydrodynamic cavitation, altering flow geometry or increasing turbulence frequency and the fraction of the flow area occupied by the shear layer can enhance the cavitational yield. The optimum frequency of turbulence can be achieved by manipulating the flow conditions and geometry of the cavitation device. For the plates having the same flow area, it is advisable to use the plate with a small-size opening in order to get benefit of the high area of the shear layer. For larger hole sizes ($d_h > 3$ mm), the frequency of turbulence (f_T) is likely to be much lower than the natural oscillation frequency of the generated cavity. On the contrary, for smaller hole sizes, the value of f_T increases leading to a more efficient collapse, i.e., energy released per cavity increases with an increase in the frequency of turbulence.

The rate of the iodine liberation also increases with an increase in the inlet pressure, as was observed based on the results of the model in the earlier work. Hence, it is also recommended to have a higher inlet pressure and also faster recovery of the downstream pressure in the setup. The results of the numerical simulations in hydrodynamic cavitation [3] are consistent with these experimental observations. Care should be taken while increasing the inlet pressure or the total pressure drop across the orifice that the cavitation number for the supercavitation as described earlier is not reached.

The results of the present work on the model reaction, i.e. the decomposition of KI, clearly confirm the various findings of the earlier work [3] and hence, the model can be used with a substantial degree of confidence during the design of the hydrodynamic cavitational setup. Also in the case of the orifice plates, the arrangement of the plates is also an important factor and it should be such that the same area is arranged with smaller diameter holes and subsequently a larger number of the holes distributed evenly over the total flow area of the pipe.

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Symbols used

C_v	[–]	cavitation number
C_v'	[–]	modified cavitation number
d_h	[m]	diameter of the hole opening
d_p	[m]	diameter of pipe
f_T	[kHz]	turbulent pressure fluctuating frequency
H	[N/m^2]	pressure head of liquid
g	[m/s^2]	acceleration due to gravity
l	[m]	scale of turbulence
P_M	[W/kg]	power dissipation per unit mass of the liquid
p_1	[N/m^2]	inlet pressure
p_2	[N/m^2]	fully recovered downstream pressure
p_v	[N/m^2]	vapor pressure
Q_m	[m^3/s]	mainline flow rate
t	[sec]	time of operation
v'	[m/s]	fluctuating component of mean velocity
v_o	[m/s]	liquid velocity at orifice

Greek symbols

ρ_l	[kg/m^3]	density of liquid
α	[m^{-1}]	parameter characterizing flow geometry
β_0	[m^{-1}]	parameter characterizing flow geometry
β	[–]	orifice to pipe diameter ratio

References

[1] Moholkar, V. S.; Pandit, A. B., *AIChE J.* 43 (1997) No. 6, p 1641.
[2] Yu, Po-wen; Ceccio, S. L.; Tryggvason, G., *Phys. Fluids* 7 (1995) No. 11, p. 2608.
[3] Senthilkumar, P.; Pandit, A. B., Modeling Hydrodynamic Cavitation, *Chem. Eng. Technol. 22* (1999) No. 12, p. 1017.
[4] Suslick, K. S.; Millan, M. M.; Reis, J. T., *J. Am. Chem. Soc. 119*, No. 39, pp. 9303–9306.
[5] Senthilkumar, P., M. S. Thesis, University Mumbai (India) 1998.
[6] Senthilkumar, P.; Sivakumar, M.; Pandit, A. B., Experimental Quantification of Chemical Effects of Hydrodynamic Cavitation, *Chem. Eng. Sci. 55* (2000) p. 1633.
[7] Tullis, J. P., *J. Hydraulics Division HY12* (1971) p. 1931.
[8] Yan, Y.; Thorpe, R. B., *Int. J. Multiphase Flow 16* (1990) No. 6, p. 1023.
[9] Shirgaonkar, I. Z., Ph. D. Thesis, University Mumbai (India) 1997.