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Engineering Notes

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Eccentric Drain Port to Prevent Vortexing During Draining from Cylindrical Tanks

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Nomenclature

D	=	diameter of the container, mm
d	=	diameter of the drain port, mm
e	=	eccentricity, mm
H_c	=	critical height of the liquid, mm
H_i	=	initial height of the liquid, mm
R	=	radius of the cylindrical tank, mm
t	=	time of emptying, s
t_o	=	time of emptying from the axial drain port without rotation, s

Introduction

DURING draining of liquid from a circular tank through an axisymmetrically placed circular orifice (drain port), a vortex with an air core forms as the free surface level reaches a critical height H_c. The vortex extends to the bottom port, reducing the effective cross-sectional area of the drain outlet and, consequently, the flow rate [1–4]. The presence of initial rotation can augment the vortex formation, and the flow rate can be further affected [1]. This phenomenon has practical relevance in the fuel feed system in space vehicles and rockets. Because of environmental disturbances, rotational motion can be generated in the liquid-propellant tank, which can in turn affect the rate of outflow to the engines.

Attempts have been made to suppress vortexing using different methods. Baffles were used by Abramson et al. [1] to suppress sloshing, which also prevented vortexing. Ramamurthi and Tharakan [4] used a stepped drain port to arrest vortex formation. Even with initial rotation present in the liquid column, Gowda [5] showed that vortexing can be avoided by using tanks of square and rectangular cross sections. Gowda et al. [6] used a dish-type suppressor to prevent vortexing. Gowda and Udhayakumar [7] showed vane-type suppressor to be effective in preventing the vortex formation.

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In the present study, it is shown that even with initial rotation given to the liquid column, vortexing can be prevented by using eccentric drain holes. The study is carried out with different values of eccentricity parameter e/R.

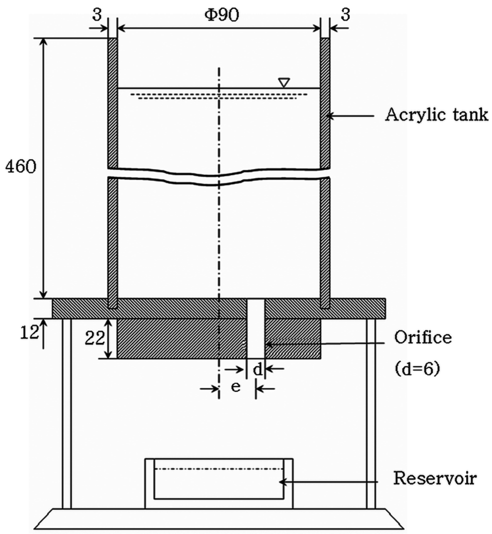
Experimental Arrangement

The arrangement is very similar to that used by Gowda et al. [6,7] and is shown in Fig. 1, in which all dimensions are in millimeters. An acrylic tank is used with an i.d. D of 90 mm and height of 460 mm with a drain hole of 6 mm diameter centrally located at the bottom. Other holes with a 6-mm diameter and at different values of eccentricity e are provided on the bottom flange. Two identical containers were used, because it was found to be difficult to accommodate all the holes at the bottom of a single container. The drain ports with $e = 0$ and 8 mm were accommodated in one of the containers. In the other container, the port with 4-mm eccentricity was made on one side of the center along a diameter, and on the other side along the same diameter, holes with eccentricity equal to 10, 24, and 38 were provided. In the latter, the drain port with $e = 17$ mm was also provided along another diameter perpendicular to that with the other drain ports, to avoid too much clustering. When one of the drain ports was used for draining, the other holes were closed with Scotch tape. Care was taken to see that there was no leakage from the holes closed by the Scotch tape. Rotation was imparted to the liquid (water) in the container by controlled stirring, with the drain port closed by a stopper (Fig. 1a), using a varying number of revolutions of the stirrer over a constant period of time [5–7]. After imparting the rotation, the stopper was removed and draining was started. In all the experiments, 120 rpm was used for imparting the initial rotation to the liquid in the container. At higher values of rpm, the critical height H_c remained nearly constant [5]. The initial height of the water (H_i) in the tank was 350 mm for all the experiments. This height was chosen so that the critical height could be measured accurately and conveniently (similar to [5–7]).

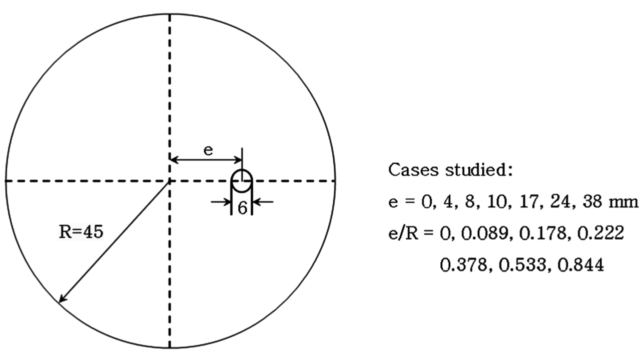
Results

All the results with rotation are obtained at 120 rpm (a typical value around which the critical height H_c does not vary with speed [5]) with $D/d = 90/6$. Results are obtained for values of $e = 0, 4, 8, 10, 17, 24$, and 38 mm. The corresponding eccentricity parameter $e/R = 0, 0.089, 0.178, 0.222, 0.378, 0.533$, and 0.844, where e is the eccentric distance between the center of the axially located drain port and the center of the port located away from the axis along a radius, and R is the radius of the circular tank (Fig. 1b). The parameter used to assess the effectiveness of the eccentric drain port is the ratio t/t_o, where t is the time of emptying and t_o is the time of emptying without rotation through the axially located ($e/R = 0$) drain port.

The normalized critical height is shown in Fig. 2 for the cases without and with rotation imparted. The corresponding normalized draining time t/t_o is shown in Fig. 3. As can be seen in Fig. 2, without rotation being imparted, there is no vortex for all the cases and H_c/H_i is nearly equal to zero. However, with rotation, the vortex with an air core occurs when draining takes place through the axially located port ($e/R = 0$). The air core extends to the bottom port and the draining rate reduces and the emptying time increases (Figs. 2 and 3). For the drain port with $e = 4$ mm ($e/R = 0.089$), the vortex occurs nearly at the same value of H_c/H_i as for the centrally located port. At



a) Cylindrical container



b) Eccentric drain port

Fig. 1 Experimental arrangement; all measurements are in millimeters.

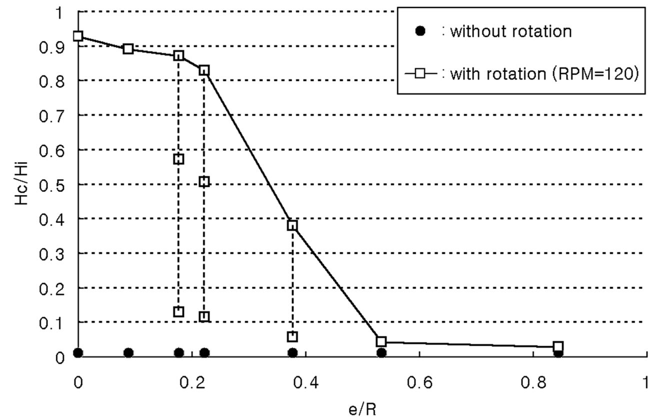


Fig. 2 Effect of eccentricity on the critical height.

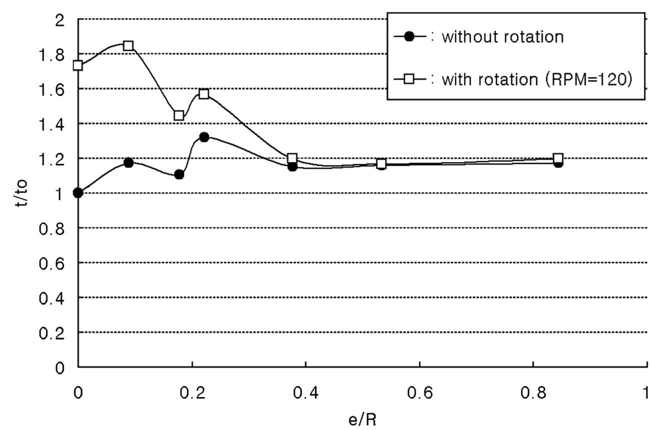


Fig. 3 Effect of eccentricity on the time of draining.

higher values of eccentricity, the vortex occurs at lower values of H_c/H_i. At $e = 8$ mm ($e/R = 0.178$), the following feature was observed: After forming at a value of H_c/H_i of about 0.88, the vortex disappeared after a short time. However, it reappeared at a value of H_c/H_i of about 0.58, as indicated in Fig. 2. With the draining continuing, the vortex again disappeared and reappeared at a value of $H_c/H_i = 0.13$ (Fig. 2). A similar phenomenon also occurred for the next eccentric hole ($e = 10$ mm). The experiments were repeated several times (a minimum of five times) for each case to check this feature, and the same results were obtained every time. At $e = 17$ mm ($e/R = 0.378$), the vortex disappeared and reappeared only once. Though it is difficult to give the exact reasons for the preceding feature, after the vortex disappears and the draining continues, the previously existing background vorticity appears to concentrate and lead to the reappearance of the vortex.

Figure 3 indicates the time of emptying with and without rotation imparted. Without rotation, it is seen that the time of emptying through the eccentric drain ports are about 18 to 20% more than the axially located port. This could be due to the increased entry losses for the former. The time of draining is increased with rotation for lower values of e/R, similar to that for the axially located hole, due to the formation of the vortex. However, for $e/R = 0.4$ and above, the rotation has no effect on the drain time. It is seen from Fig. 2 that vortexing does occur even for e/R around 0.4. However, it will be weak enough to not affect the drain time, as seen in Fig. 2.

The probable physical explanation for the prevention of vortexing with eccentricity of the drain port is the following: When rotation is imparted to the liquid in the container, the two forces coming into picture are the centrifugal force (acting radially outward) and the force due to the pressure gradient (acting radially toward the axis). There will be a balance between these two forces except at the bottom surface, where, due to the boundary effect, the centrifugal forces will be lower than the pressure gradient forces. The pressure decreases toward the axis, with the minimum occurring near the center. When rotation is imparted, a dip occurs on the surface. The drain port located axially is situated at the point of minimum pressure, and the dip almost instantaneously extends to the port with the formation of the vortex with an air core. The drain ports with increasing eccentricity are located in regions of relatively higher pressures; hence, the dip cannot extend to the port, and thus vortexing is prevented. This appears to occur for e/R equal to and higher than 0.4. At lower values of e/R, vortexing does occur, as discussed earlier and shown in Fig. 2.

Conclusions

The results in this paper show that vortexing during draining from a cylindrical tank can be prevented by providing an eccentric drain port. The eccentricity has to be equal to or higher than 0.4. The disadvantage appears to be that the draining time without rotation for the eccentric ports is about 18% higher than that for the axially located port. This is probably due to the increased entry losses for the eccentric ports. This might be overcome or improved by providing a small curvature at the inlet (i.e., a smooth inlet) to the eccentric port so that entry losses are minimized.

Acknowledgement

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