Comparison of the spread angle of a swirling jet with a non- swirling jet

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Abstract – *Swirling jets are prevalent in nature and technology. Tornados and dust devils are example from nature where as propulsion systems in turbomachinery are example from technology. Therefor understanding the behaviour of swirling jets and their prominent features is very important to either predict the behaviour or enhance the performance of swirling jets, depending on the application In this paper an experimental results done on spread angle of a 'Swirling jet', released to an ambient environment of fluid are presented. Moreover the swirling jet spread angle is compared with the non swirling jet issued from the same nozzle. The experimental set up was built in house with all the necessary features including a rotating source, to perform the experiments. It was revealed that the spread angle of the swirling jet is greater than the that of the non swirling jet. Also the time dependency of the value of the spread angle of the swirling jet is higher than that of the non swirling jet. It can be recommended that by using swirling flows in industrial applications better spread of materials can be achieved from the beginning of the flow.*

Keywords: *Swirling jet, Spread angle*

1 INTRODUCTION

A flow is said to be "Swirling" when its mean direction of flow is aligned with its rotation axis, implying helical particle trajectories. There are atmospheric conditions that can give rise to swirling flows such as tornados, dust devils and water-spouts. On the other hand swirling flows are also observed in many engineering applications, such as combustion chambers of jet engines, turbo machinery and mixing tanks. In combustion applications, swirling jet's ability to create reverse flow regions near the jet nozzle has been exploited for the purpose of swirl-stabilizing the flame. The efficiency of chemical reactors and mixing devices is enhanced by making use of the faster spreading and more rapid mixing of the jet fluid with its surrounding by swirling compared with non- swirling jets. Therefore understanding the spread angle characteristics of a swirling jet is highly important. The present study focuses on quantify the variation of the spread angle of a swirling jet and compare the same with the non swirling jet issued by the same nozzle. The spread angle of a jet can be defined as the angle between two edges across the diameter of the jet when it is issued from a circular nozzle as shown in figure 1.

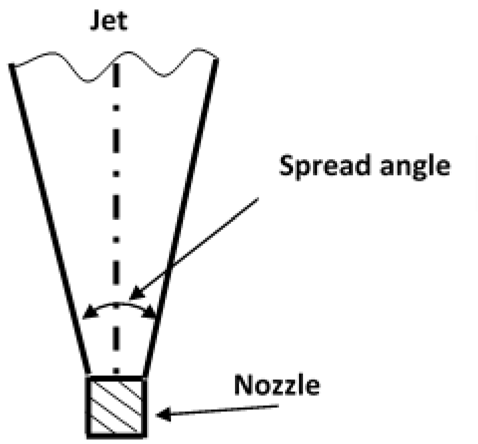

Fig. 1: Schematic diagram of a jet

2 LITERATURE REVIEW

The studies on swirling jets were motivated to analyse the flow characteristics in variety of propulsion systems involving turbo machinery, such as jet engines and turbo-pumps. In gas turbine engines, diesel engines, industrial burners, and boilers, swirling flows were originally used to control the mixing rate between fuel and oxidant streams in order to achieve flame geometries and heat release rates appropriate to the particular process application (Weber et al., 1986). Swithenbank & Chigier (1986) concluded that for a sufficient degree of swirl an internal recirculation zone is generated. This zone allows a high rate of heat release as products of combustion are recirculated and ignite the incoming fuel/oxidant streams where a stable and compact flame is generated. Syred & Beer (1974) also confirmed that this enhances the performance of difficult carbonaceous materials and poor quality gases. Therefore swirling jets have been the subject of numerous studies in the past (Kopecky & Torrance, 1973; Lessen et al., 1974; Leibovich & Stewartson, 1983; Khorrami, 1991; Mayer & Powell, 1992; Billant et al., 1998; Gallaire et al., 2004; Liang & Maxworthy, 2005; Facciolo et al., 2007; Liang & Maxworthy, 2008; Oberleithner et al., 2011; Leclaire & Jacquin, 2011). The common feature that was found is that these jets break down due to a vortex break down. It is also concluded that this breakdown is characterized by a transition of a jet-like axial velocity profile to a wake-like prole with a local minimum on the axis which leads to a stagnation point to be followed by a highly turbulent region of reverse flow farther downstream (Oberleithner et al., 2011). Therefore most recent experimental studies on swirling jets have focused on understanding the fundamental features of vortex breakdown that occurs in the flow (Liang & Maxworthy, 2005, 2008; Martinelli et al., 2007; Oberleithner et al., 2011; Meliga et al., 2012).

Moreover, most of the relevant numerical work available in literature has also been focused on this common vortex break down feature in swirling jets (Melville, 1996; Mùller & Kleiser, 2008a; Qadri et al., 2013; Luginsland, 2015; Luginsland & Kleiser, 2015; Luginsland et al., 2016). In all these studies, it has more or less been revealed that the vortex breakdown mode is consistent with helical mode break down either with single helix or double helix. But the spread angle of a swirling jet before vortex breakdown has not been investigated so far and it has not been compared with the non swirling jet issued by the same nozzle.

3 METHODOLOGY

3.1 Design and fabrication of the experimental facility

The experimental facility was built inhouse and it consists of a transparent wall tank, nozzle arrangement for generating the swirling jet, flow meter, reservoir tank and a control panel to vary the rotating speed of the nozzle.

The schematic diagram of the experimental setup is shown in figure 2. The tank has the cross sectional area of 1m × 1m and height of 1.5m and for the walls of the tank Perspex boards were used. The tank was mounted on a frame fabricated from iron as shown in figure 3. Perspex is transparent material and has required strength to withstand the pressure when the tank is filled with water. The nozzle arrangement was fixed to the centre of the bottom plate as shown in figure 4. The nozzle assembly was made such away that it rotates while issuing the flow or the jet to the ambient environment, i.e. water inside the tank. The required potential head for generating the jet flow was achieved by an overhead tank built separately. A control panel was used to vary the rotation rate of the nozzle. A flow meter fixed in between the flow from the overhead tank to the nozzle arrangement, was used to measure the flow rate.

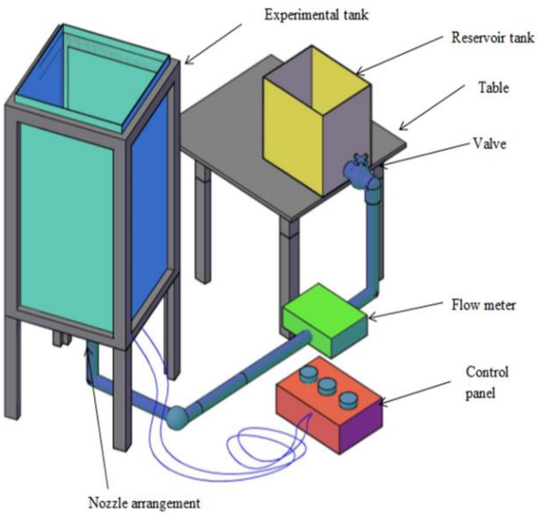

Fig. 2. Schematic diagram of the experimental facility

The nozzle was given the required rotation rate by a motor attached to a pulley and belt system of which the schematic diagram is shown in figure 5. The most important and challenging part of the design of the experimental facility is the designing of the rotating nozzle. The releasing of the flow through the nozzle should be done while rotating and there should be a proper mechanism to accommodate this without leaking the water in the tank, as the nozzle is fixed at the bottom of the tank as shown in figure 3.

Fig. 3. The tank with transparent Perspex walls

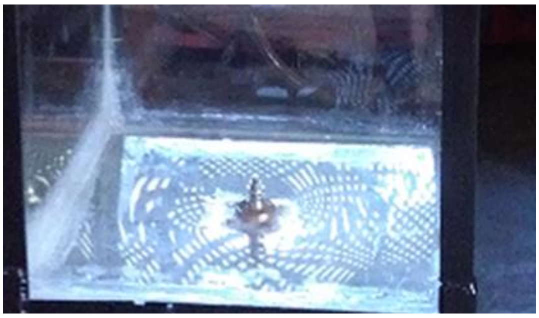

Fig. 4. A closer look of the nozzle assembly fixed to the bottom of the tank

The schematic diagram of the nozzle driving mechanism is shown in figure 4 whereas the fabricated nozzle arrangement is shown in figure 5. The nozzle arrangement was fabricated using steel and to prevent the water leaking while the nozzle is rotating, some water seals were used.

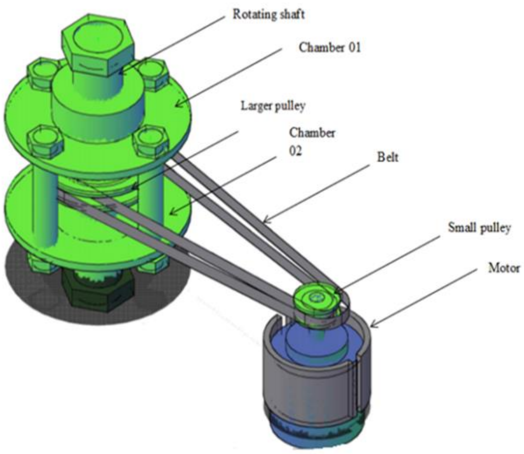

Fig. 5. Schematic diagram of the pulley and belt arrangement fixed to the nozzle assembly

Fig. 6. Fabricated nozzle and pully arrangement

3.2 Flow visualization and data analysis

The flow visualisation technique used in the present study is the use of dye for the swirling jet so that it can be clearly visualised when it flows through the tank of clear water. Blue colour dye was used. The dye was added to the reservoir tank from which the water flow through the swirling jet nozzle. Figure 6 shows a snapshot of the jet flows through the clear water tank. The data gathering was done by means of recording videos of the jet flow and analysing frames of the videos. At first the camera was set using a tripod and the flow area was focused. Then the jet flow was started and at the same time recording of the video was also started. The images were extracted from the videos and then the same were imported to MATLAB software. All the analysis was done using MATLAB software. At first the experiment was done without rotating the nozzle to quantify the spread angle of a non swirling jet. A line was first drawn through the centre of the nozzle of the image selected for analysis from the video recording. Then the radial distance (R) from the centreline to the edge of the horizontal spread was measured and g. also the hypotenuse distance (L) was also measured. The spread angles were calculated by taking the inverse value of sin of the ratio L/H. The distance measurement arrangement for an image on MATLAB user interface is shown in figure 7.

Fig. 7. Snapshot of the jet after 3 s of starting the jet flow.

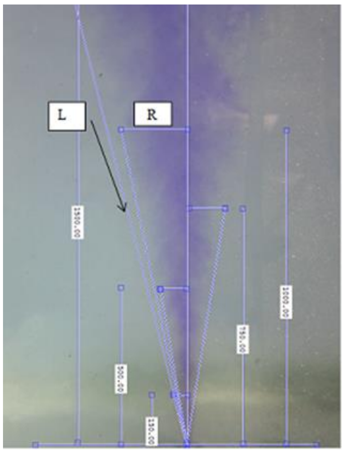

Fig. 8. Snapshot analysis in MATLAB interface

After completing the experiment with non-swirling jet, the whole experiment tank was emptied as the water inside the tank had turned into colour of the ink as shown in figure 9, where the jet is not very clear from the background. Then the tank was filled with clear water and the experiments on swirling jet was performed similar manner as in the case of non swirling jet and the videos were started to record as the jet flow starts. The angular velocity of the rotating nozzle was $4.189\ \mathrm{rad/s}$ and the flow rate was $6.68 \times 10^{-5}\ m^3/s$.

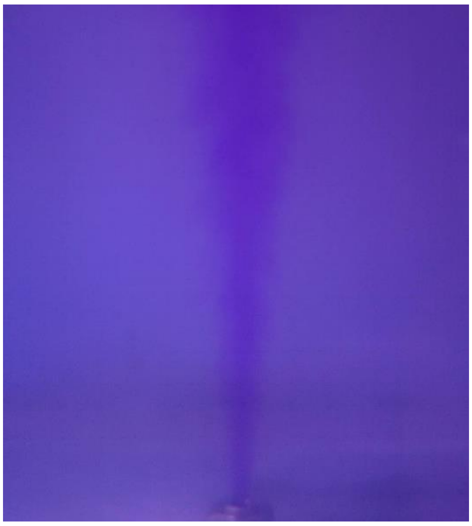

Fig. 9. The colour of the water in the tank after releasing the jet for 180s

4 RESULTS

4.1 Spread angle of the non-swirling jet

The half spread angle was calculated for selected heights from the jet issuing nozzle and at different transient conditions as well. The jet half spread angle was measured right hand side of the centre line and left hand side. Figure 11 shows the snapshot of an image extracted from the video recorded of the jet in MATLAB interface after 60s of starting the jet. The average half spread angle was calculated by averaging values calculated from the right hand side and left hand side and the time i.e. average values from the snapshots during the video, the present frame rate of the camera is 30 frames per minute. The values measured by pixels in the MATLAB interface were converted to millimeters by using the reference as the nozzle diameter. When the image was enlarged and the nozzle diameter to pixel ratio can easily be measured.

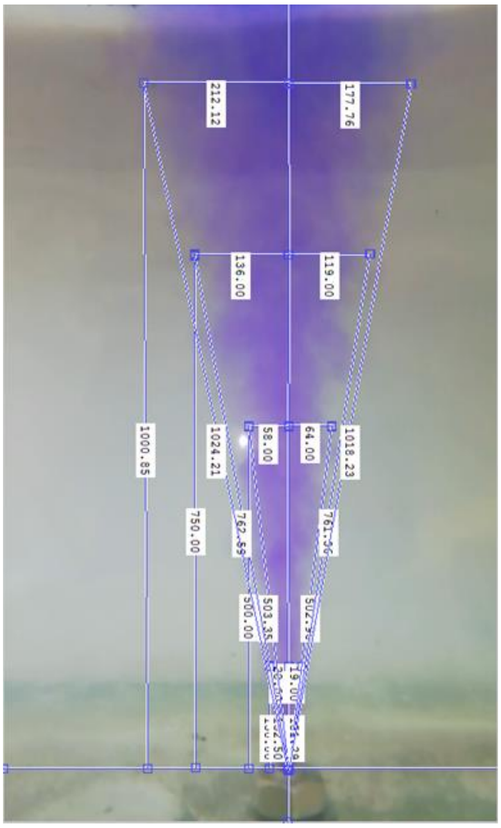

Fig. 10. Snapshot analysis of the jet at 60s after starting the jet

The average of the half spread spatial angle (i.e. average value of the spread angle right to the centreline and left to the same) plotted against the jet height is shown in figure 11. It can be seen from the graph that the half spread angle varies from 7^0 to 10^0 when it is measured independently along the height. By assuming the symmetry the full spread angle of the jet can be calculated by multiplying the half spread angle by two. The jet is observed to be highly time dependent as the spread angle of one location at selected height was measured with time. The variation of the spread angle is shown in figure 12, where the observation height is 132mm from the nozzle.

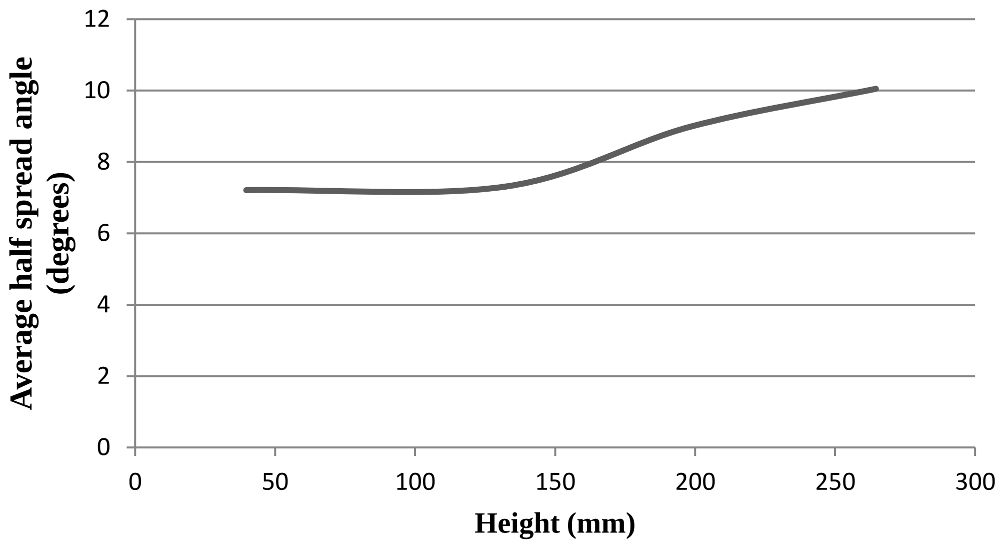

Fig. 11. Variation of the average of half spread angle with the jet height at 60s after starting the jet.

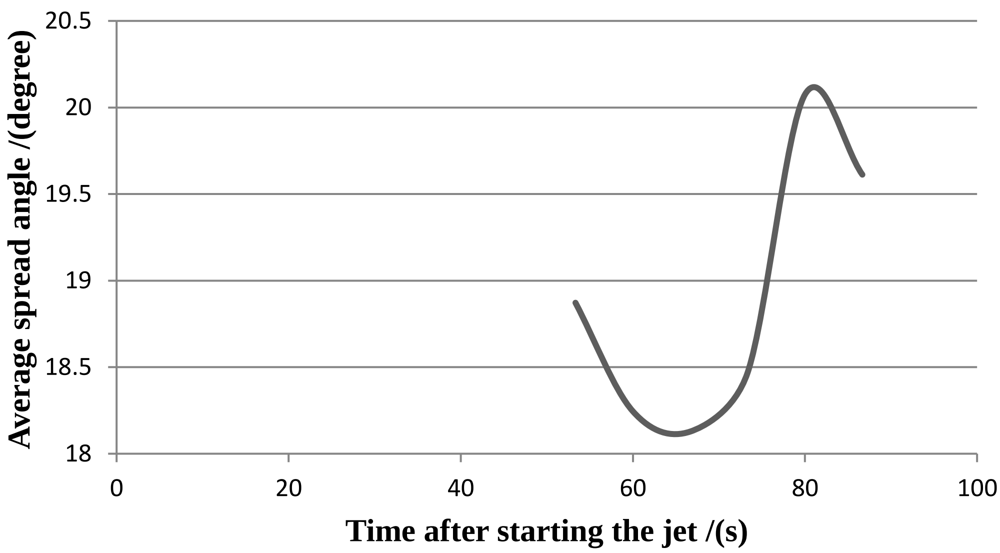

Fig. 12. Variation of the spread angle with time after starting the jet (jet height is 132mm)

4.2 Spread angle of the swirling jet

The variation of the average of the half spread angle of the swirling jet with the height from the nozzle, after 60 s of starting the jet, is shown in figure 12. It can be seen from figure 11, that average of the half spread angle varies between 18^0 to 25^0, which indicated that the full spread angle of the swirling jet is in the range of 36^0 to 50^0. Figure 12 shows the variation of the average half spread angle with the time. It can be seen from the figure that the value of the average half spread angle varies rapidly with time compared to the figure 10, which shows the same for the non swirling jet.

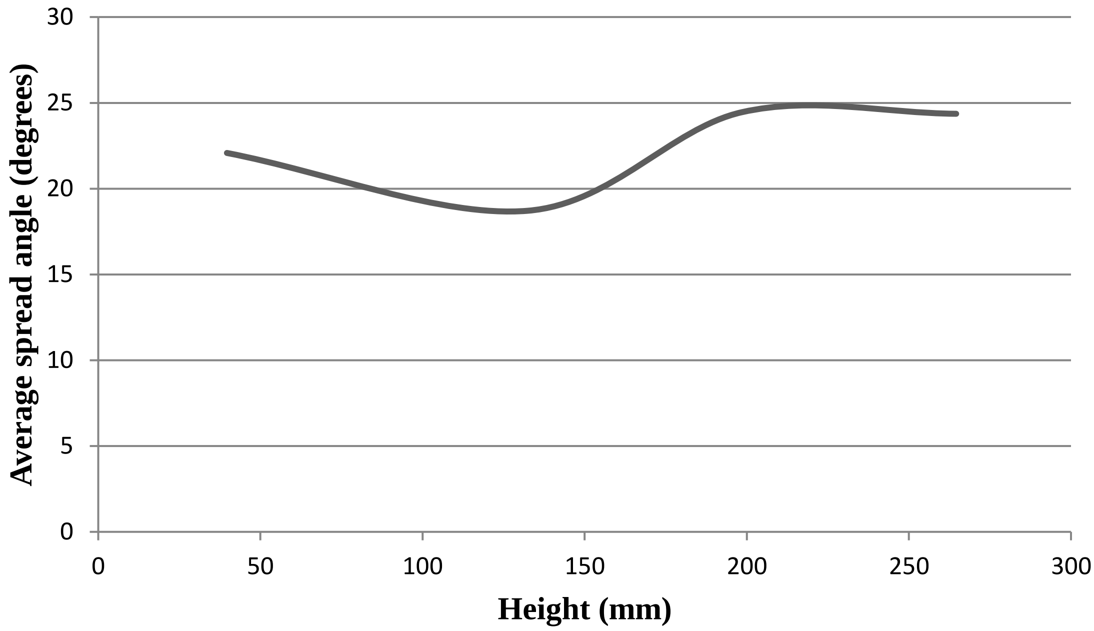

Fig. 13. Variation of average spread angle with the jet height at 60s after starting the jet.

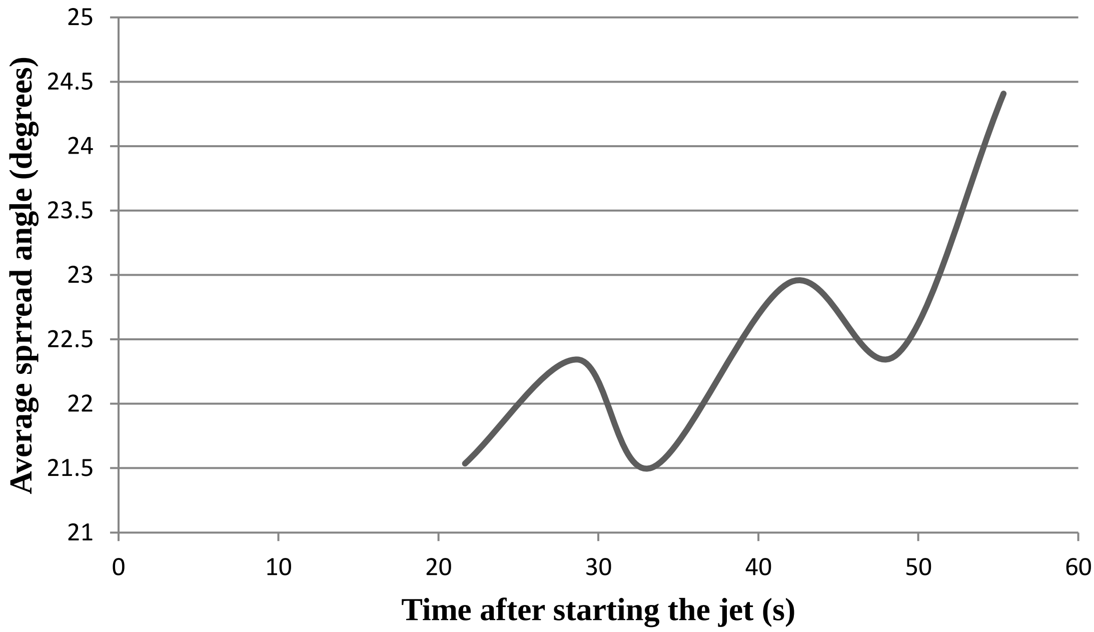

Fig. 14. Variation of the spread angle with time after starting the jet (jet height is 132mm)

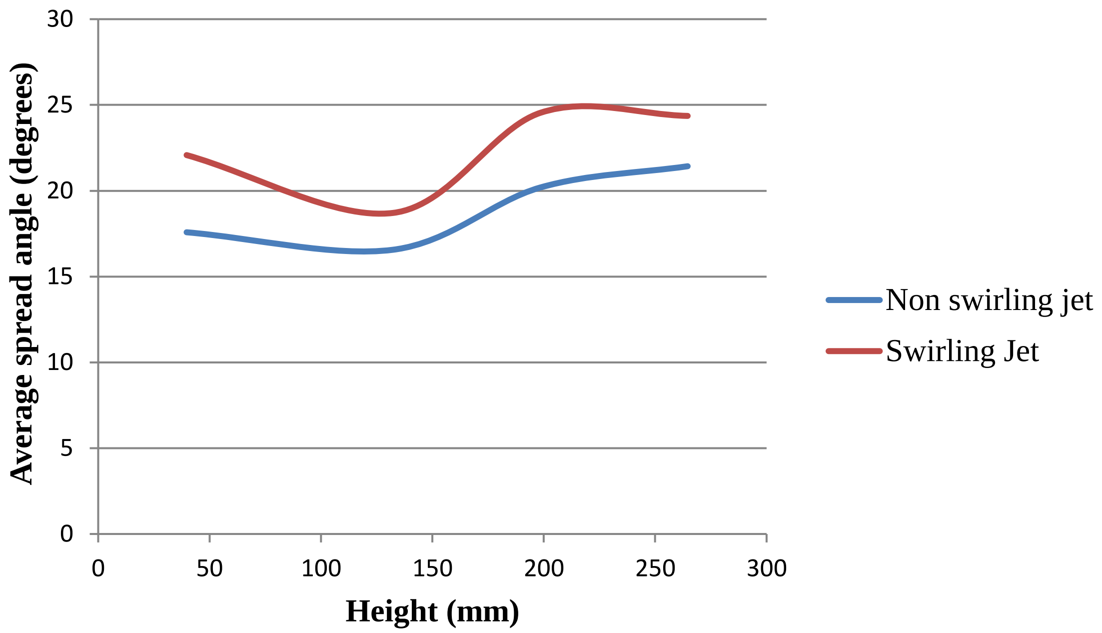

Fig. 15. Variation of the spread angle with height for the non swirling jet and the swirling jet.

5 CONCLUSION

The comparison of the spread angle of a swirling and non swirling jets has not been performed directly by the researchers who have done their studies on swirling jets. In the present study the spread angle of a swirling jet is compared with a non swirling jet. The experimental set up was built in house to carry out the experiment. The challenging part of the experiment set up building was to fabricate the jet issuing nozzle, where the fluid should be ejected while rotating the nozzle. On the other hand the nozzle was fixed at the bottom of the tank so that while rotating no water should be leaked from the bottom of the tank. The dye visualisation techniques was used to gather data and MATLAB was used to analyse the images of dye visualisation. The spread angle of the non swirling jet was observed to vary between 18^0 to 20^0. The measured spread angle value for non swirling jet confirms the accuracy of measurement technique and data analysis technique where the spread angle results of the non swirling jets found by other researchers also lies between the values 18^0 to 20^0. On the other hand from the observation it can be seen that the spread angle value of the non swirling jet is comparatively less time dependant than the swirling jet. It was observed that the spread angle of the swirling jet is greater than that of the non swirling jet for all heights of the jet and varying between 21.5^0 to 24.5^0. Therefore a wider spread angle can be achieved by a swirling jet but too much speed of the nozzle leads to break down of the jet as observed by the many researchers.

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