AEROSOL ASSESSMENT DURING LIQUID JET IMPACT ONTO LIQUID AND ELASTIC TARGETS

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ABSTRACT

An experimental investigation was conducted to determine the aerosol generation and the amount of splattering fraction during liquid jets impact normally onto a solid surface covered by a various thickness of liquid layer as well as stationary and rotating elastic target (gelatin layer). In turbulent liquid jet impingement with these targets, a spray of droplets often breaks off the liquid layer formed on the impacted target leads to environmental problems and can alter the efficiencies of the performance of jet impingement processes. The experiments were conducted for turbulent jet Reynolds number from 4.5×10^4 to 9.8×10^4 at nozzle to target separation of $6.25\leq L/d\leq78$ and jet Weber number range from 8400 to 2.35×10^4. Jets were produced from a convergent nozzles of diameter 5 and 8 mm, with fully developed turbulent flow upstream of the nozzle exit. The target surface condition, type and thickness appear to play a significant role in determining the amount of liquid jet splattering fraction. The liquid layer reduces the high edge impact pressures, which occur on dry solid targets and as the liquid layer height is increased, the splatter fraction drops sharply. Despite the cushioning effect of the elastic gelatin layer, in some cases, a gelatin layer can enhance the amount of splatter fraction.

Keywords: Liquid jet impingement, Jet splattering, Airborne contaminants, Aerosol formation

INTRODUCTION

Turbulent liquid jet impingement on different types of targets is of interest to engineers due to their occurrence in diverse applications. Liquid jets which impinge on different types of targets often splatter violently, expelling a shower of droplets from the liquid film formed in the target. Typical examples include on all sorts of painting applications, surfaces coating operation, cleaning processes and metal jet forming operation using a turbulent liquid jet impingement. This splattering of liquid droplets leads to problems of airborne aerosol formation are indicative of lowered cooling efficiency, lessened cleaning ability, or reduced coating efficiency, depending on the specific application of the impinging jet. In cleaning processes, where impinging jets are used for debris removal, splattered liquid can produce airborne contamination. In metal jet forming operation, splattering is a primary cause of reduced yield. In situations involving toxic chemicals, the splattered droplets create a hazardous aerosol whose may greatly create an air pollution problems and consequently the operators who they use this technique. Previous studies of liquid jets splattering have demonstrated that it is driven by the disturbances on the surface of the impinging jet [1,2]. Thus, undisturbed laminar jets do not splatter, unless they are long enough to have developed significant disturbances from capillary instability. Turbulent jets, on the other hand, develop surface roughness as a result of liquid side pressure fluctuations driven by the turbulence, and they are highly susceptible to splattering. Errico [1] induced splattering of laminar jets by creating surface disturbances with a fluctuating electric field. His results showed that splattering commenced at progressively lower jet velocity when the amplitude of disturbance was increased. He also showed that splattering appeared on the liquid film on the target as the disturbances from the jet spread radially. When a turbulent jet strikes a target, similar traveling waves originate near the impingement point and travel outward on the liquid film. When the jet disturbances are sufficiently large, these waves sharpen and break into droplets. All observations indicate that the amplitude of these disturbances on the jet govern splattering. They further indicate that splattering is non-linear instability phenomenon, since the liquid film is clearly stable to small disturbances but unstable to large ones [3]. Bhunia and Lienhard [4], stated that a very little aerosol splattering occurs with a very small nozzle to surface separation L/d and related that to the jet surface disturbance growth rate which tends to be asymptotic. Earlier Chen and Davis [5] attempted to measure the amplitude of surface disturbances on turbulent liquid jets. They found that the growth of disturbances is the probable cause *of the increase in the splatter aerosol.* Experimental study [6] and numerical study [7] have been done, in particular on the interaction of the shock wave generated on the flat fixed plate during the jet impingement. The calculated results of these studies illustrate the dependence of the liquid splattering fraction on the jet nozzle pressure ratio and the nozzle-solid target distance. Experiments have been conducted [8], to investigate the mechanisms of the liquid jets impacts on the surfaces associated with liquid cavitation during the impingement. The liquid cavitation behavior was directly related to the behavior of the compressive waves caused by the impact of the liquid jet. Predicting the jet breakup and aerosol formation and measurements of the aerosol drop sizes as well as the aerosol concentration for different nozzles are experimentally investigated [9, 10].

It is well known that a thin liquid layer has a cushioning effect on the friction stresses between two sliding or impacting surfaces [11, 12]. This cushioning effect also appears during liquid jet impact on solids. A technique of forming a thin water layer on rotor blade surfaces has been successfully applied in the low pressure region of large steam turbines to minimize blade erosion [13]. Pioneering work on high speed liquid jet impact onto wetted solids was done by Brunton [14]. He found that the depth of deformation for impacts on aluminum plates was decreased with increasing liquid layer thickness and that on wetted plates, the shear damage caused by side jetting was greatly reduced. On a dry surface (rigid target), the impact pressure at the center of contact is ρCV (Bowden and Field [11]) while at the contact edge, pressures as high as 3 ρCV can develop due to the shock wave detachment geometry [15, 16] where ρ and C are the liquid density and shock wave velocity, and V is the impact velocity. Shi and Field [17] illustrated that the impact on a dry solid causes a wavy structure in outer annular region, however, this wavy structure is not observed on wetted plate. El-Minshawy [18] found that liquid jet splattering during the impingement with solid fixed flat and cylindrical targets is strongly dependent on Re, liquid jet length to nozzle diameter, jet Weber number, liquid temperature and air drag around the jet. The role of rotation speed and the radial location of the impingement on the amount of jet splattering for rotating solid flat and cylindrical solid targets has been described. Garimella and Nenaydykh [19], studied the nozzle geometry effects in liquid jet impingement, the nozzle diameter in this study found to have a definite effect on the impingement process.

However, research on the liquid jets splattering has been rather limited, since most of the previous research has been made on the interactions of the liquid jet impingement with a fixed flat surface that has developed aerosol formation. The surface type and surface rotation are not changed in the previous experiments. The present paper is concerned with the experimental investigation of liquid jet splattering that has developed aerosol formation, with the jet impact on water layers with different height as well as stationary and rotating elastic target.

EXPERIMENTAL APPARATUS AND PROCEDURE

The device used for producing liquid jets impinging on water layer as well as elastic targets is shown schematically in Figure 1. The experiments were performed to measure the amount of splatter fraction for a fully developed turbulent liquid jet. The liquid jets were produced using convergent nozzles having diameters of 5 and 8 mm which received liquid water from a 0.125 m^3 main water tank. The water flow was supplied to the nozzle using a centrifugal pump driven by 1 kW motor through a constant cross section pipeline (25 mm in ID). The water loop was provided by a by pass, so different water flow rates can be obtained. In addition, also the flow rate to the nozzle is adjusted by means of a flow-regulating valve. To ensure a fully developed liquid flow at the nozzle inlet, the pipe line length to the nozzle was made >100 times of the pipe diameter. The nozzle exit was carefully made, so that a uniform incoming flow was achieved without any surface disturbances. Jets were issued into still ambient air.

The water was poured in a cylindrical container located beneath the nozzle exit. The vertical wall of the container was provided with three pairs of slots. Each pair of slot was located at opposite direction and at the same levels. Three levels of 10, 20 and 30 mm water height were tested. Each slot was covered and fastened by two screw bolts. So, to obtain a water layer with the selected height, the related pair of slots was set open while the other was kept closed. For the second case of the study, a gelatin elastic layer was prepared by dissolving 250 percent by weight of gelatin in a hot water at 330 K and then pouring the mixture into a mold with 50 cm diameter. Each of the mold faces has been lightly greased. After slow cooling, the mold was disassembled and the gelatin soft sheet was removed and then placed horizontally on a 50 cm diameter solid disc. By changing the distance of the mold gap, gelatin soft layers with various thickness were obtained.

The first set of experiments examines the water jets splattering due to the impingement on fixed water layer or a fixed gelatin layer located normal to the jet exit axis. The second set of experiments is performed with the liquid jet impingement on various thickness rotating gelatin layers rotating at different speeds. The gelatin target was rotated by an electric motor, provided with a gear box. It was arranged to give variable output rotating speeds to the rotating target. The electric motor and the gear box were mounted on a table under the collecting water tank. The position of the gear box was arranged to pass the motion to the rotating target through two pulleys and a belt. The rotation speeds of the rotating target were measured by a digital speedometer which gives the number of revolutions per minute directly.

The present work examines and measures the amount of splattered fraction of the incoming liquid jet, Q_s/Q, which is defined as the ratio of the flow rate of splattered liquid due to the jet impingement with the target Q_s to the total incoming jet flow rate Q. To operate the apparatus, the liquid flow rate incoming from the nozzle of the unsplattered liquid jet without target Q, was first measured. This is achieved by setting the water flow rate from the nozzle and then collecting a known volume flow rate on the collecting tank underneath the nozzle outlet at a specified time. The liquid jet impingement experiments are then carried out, and the amount of liquid that remained in the liquid layer on the target after splattering Q_r, was then measured by directing it towards the collecting tank beneath the target.. Sub-tracting both values of liquid flow rates Q and Q_r, the amount of the splattering flow Q_s due to the jet impingement can be calculated. This splattered liquid droplets, on the other hand, remained airborne and fell well beyond the collecting tank.

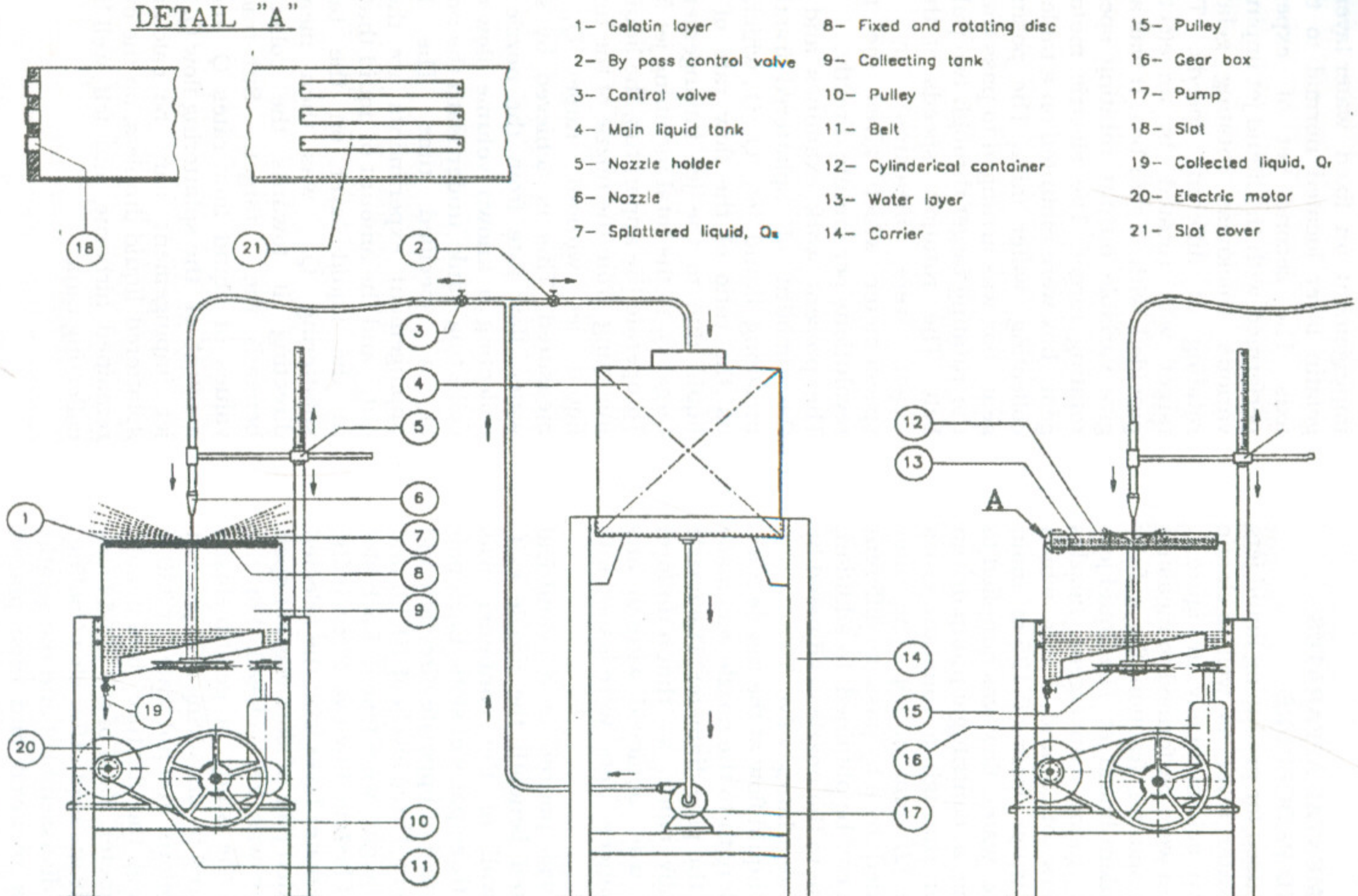

Figure 1 A schematic flow diagram of the experimental apparatus

The experiments are carried out with a single jet at different jet Reynolds number in the range of 4.5×10^4 to 9.8×10^4. In the present investigation the nozzle exit to target spacing was varied from 50 to 624 mm. This corresponds to nondimensional nozzle to target separation, L/d, in the range of $6.25 \leq L/d \leq 78$. The liquids used in these experiments were water and solutions of approximately 0.25, 0.5, 0.75 and 1 percent by volume of detergent in water. So, liquids with various surface tension σ, can be obtained and consequently different jet Weber number in the range of 8400 to 2.35×10^4 can be investigated. The disintegration phenomena of the liquid jets impact on 5, 10, and 20 mm thick elastic gelatin layer was investigated.

The measuring technique for the amount of splattering fraction Q_s/Q in the present work facilitated a precise measurements. Typically the uncertainty in the splattering fraction amount was below ±5 percent for $Q_s/Q>0.2$ and was below ±8 percent for $Q_s/Q<0.2$. Uncertainties in the Reynolds numbers and Weber numbers were below ±3 percent. These low uncertainties may be credited to the direct measurement of liquid flow rate. Uncertainty in L/d was below ±2 percent. Some of the measurements were repeated to avoid substantial uncertainty and to verify the reproducibility of the data.

RESULTS AND DISCUSSION

The independent physical parameters involved in this problem are L, d, ρ, u, σ, and μ for a stationary target, another parameter is considered for a rotating target which is the rotating speed of that target, N. Dimensional analysis based on these parameters shows that the fraction of liquid splattered, can be dependent on three dimensionless groups, namely, L/d, jet Reynolds number, Re, and jet Weber number, We, for the liquid issues from the nozzle and target rotation speed for the rotating targets. Independent variation of these groups was accomplished by independent variation of d, L, u, σ, and N.

The amount of splattered fraction of the incoming liquid jet impinges on water layers with different thickness in still air was measured for a variety of nozzle to target separation, L/d. Tests were performed for both nozzle diameters of 5 and 8 mm, with jet Reynolds number of 9.8×10^4. Representative splatter fraction profiles are presented in Figures 2 and 3. The amount of flow rate of splattered liquid, Q_s, is normalized with the total flow rate of the incoming jet, Q, and plotted as a function of nozzle to target separation and liquid layer thickness at the given jet Reynolds number. It can be seen that the amount of splattered fraction of the incoming liquid jet increases by increasing the nozzle to target separation, also as the water layer thickness increases the amount of liquid jet splatter fraction decreases. Furthermore, when the splatter fraction profile is measured at larger nozzle diameter of 8 mm, its basic shape changes; the liquid jet splattered fraction increases by increasing the nozzle diameter for same jet Reynolds number. Both measurements and observations study illustrate that the actual splattering occurs within a certain radial region around the point of impact; beyond this region, splattering no longer occurs, as confirmed in References 20 and 21. Hence, as observed, a wider splattering radial region can be seen as the nozzle to target separation as well as nozzle diameter increases and consequently increases the liquid jet-splattering fraction. In addition, as the liquid layer thickness increases, the radial region of splattering markedly decreases.

This decay in the splattering region area is the probable cause of the decrease of the liquid jet splattering during the impingement with liquid layer. Furthermore, larger water layer thickness highly absorbs a great deal of the initial kinetic energy of the incoming liquid jet, which is consequently lost to deformation and turbulent energy at the point of impact.

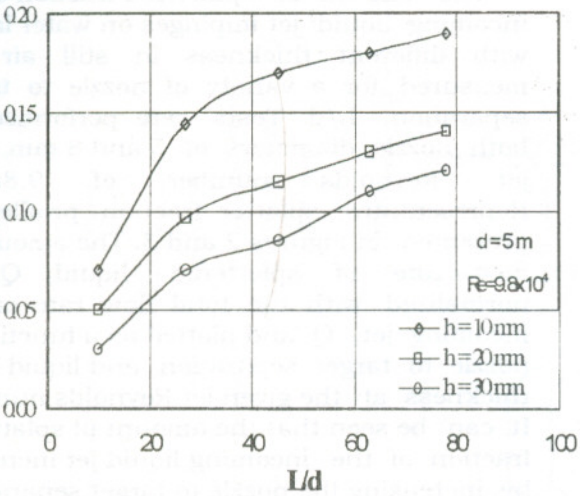

Figure 2 Relationship between splatter fraction of the incoming jet impacts on water layer with various thickness and nozzle to target separation

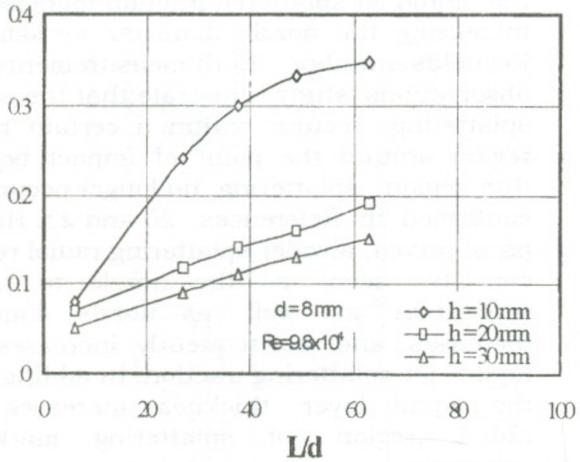

Figure 3 Relationship between splatter fraction of the incoming jet impacts on water layer with various thickness and nozzle to target separation.

This decay in the splattering region area is the probable cause of the decrease of the liquid jet splattering during the impingement with liquid layer. Furthermore, larger water layer thickness highly absorbs a great deal of the initial kinetic energy of the incoming liquid jet, which is consequently lost to deformation and turbulent energy at the point of impact.

This section, describes the experimental tests with the liquid jet impinges on a stationary and rotating flat gelatin layer with various thicknesses. The gelatin layer was rotating about an axis perpendicular to its plane with various uniform rotation speeds. For the data shown in Figure 4, the amount of splattered fraction of the incoming liquid jet impinges on a 5 mm thick stationary gelatin layer in still air was measured for a variety of nozzle to target separations, L/d, and jet Reynolds numbers, Re. The nozzle diameter for these tests and the gelatin layer diameter were held constant at 5 mm and 500 mm respectively. Clearly, it can be noticed that splattered fraction of the incoming liquid jet increases during the impingement with the 5 mm thick gelatin layer by increasing the nozzle to target separation. Also, increasing the jet Reynolds number, for the same nozzle diameter, increases the amount of splatter fraction.

Figure 5 shows the splatter fraction of liquid jet impacts from a 5 mm nozzle diameter onto a 10 mm thick stationary gelatin layer for various nozzle to target separations and jet Reynolds numbers. When the splatter fraction profile is measured for liquid jet impacts on larger gelatin layer, 20 mm thick, a pronounced increase of splatter fraction can be seen as the nozzle to target separation and jet Reynolds number are increased, as seen in Figure 6. Splattering of as much as 50 percent of the incoming liquid jet impact on 20 mm thick gelatin layer is observed at nozzle diameter of 5 mm, jet Reynolds number of 9.8×10^4 and a nozzle to target separation range of $10 \le L/d \le 78$.

In the data obtained for this set of experiments, it is interesting to notice that, a gelatin layer thickness increases from 5 to 20 mm produces roughly about 30 percent increase in the splatter fraction, holding other variables constant.

The effect of jet angle variation on the splattering fraction of the incoming liquid jet impinging on a 10 mm thick stationary gelatin layer for various L/d at Reynolds number 9.8×10^4 and nozzle diameter of 5 mm is shown in Figure 7. In this figure, zero jet angle represents the case of the liquid jet that impinges with its axis perpendicular to target plane. The splattered fraction decreases by increasing the liquid jet angle.

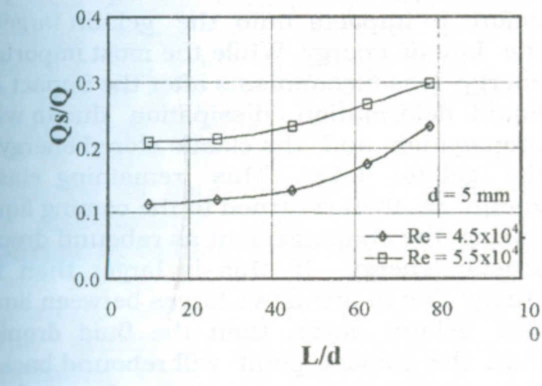

Figure 4 Relationship between splatter fraction of the incoming jet impacts on 5 mm thick fixed gelatin layer and nozzle to target separation.

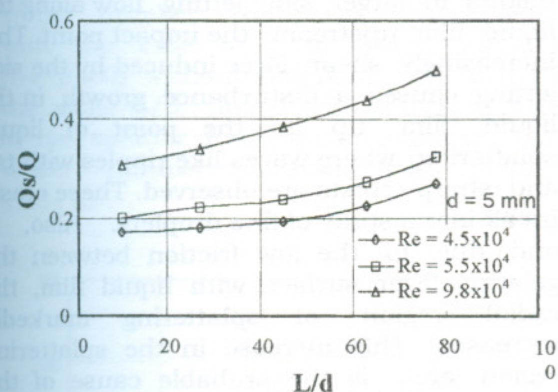

Figure 5 Relationship between splatter fraction of the incoming jet impacts on 10 mm thick fixed gelatin layer and nozzle to target separation.

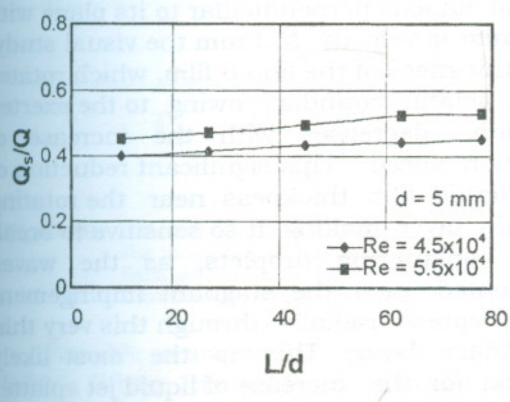

Figure 6 Relationship between splatter fraction of the incoming jet impacts on 20 mm thick fixed gelatin layer and nozzle to target separation.

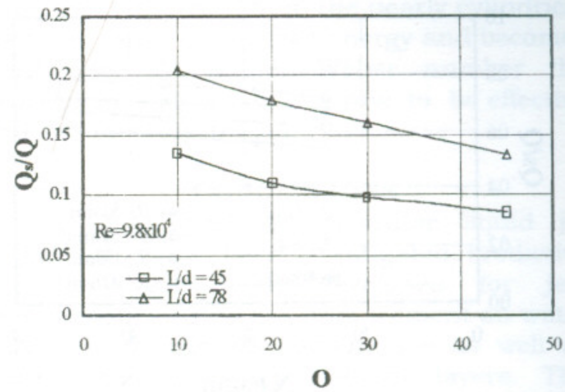

Figure 7 Relationship between splatter fraction of the incoming jet impacts on 10 mm thick fixed gelatin layer and jet angle.

The amount of splattered fraction of the incoming liquid jet impinging on the 10 mm thick rotating flat gelatin layer was measured in still air for a variety of rotating speeds, outward radial impact position, R, jet Reynolds numbers and nozzle to target separations. Tests were performed for nozzle diameter of 5 mm. Representative splatter fraction profiles are presented in Figures 8 and 9. It can be seen that the liquid jet splattered fraction increases with the increasing of rotating gelatin layer speed. In the data set for L/d=45, increases the gelatin layer rotation speed from 13 to 36 r.p.m. produces roughly about 5 percent increase in the splatter fraction.

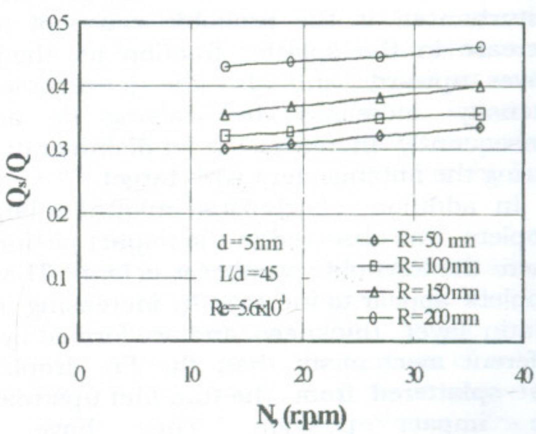

Figure 8 Relationship between splatter fraction of the incoming jet impacts on 10 mm thick rotating gelatin layer and rotating speed.

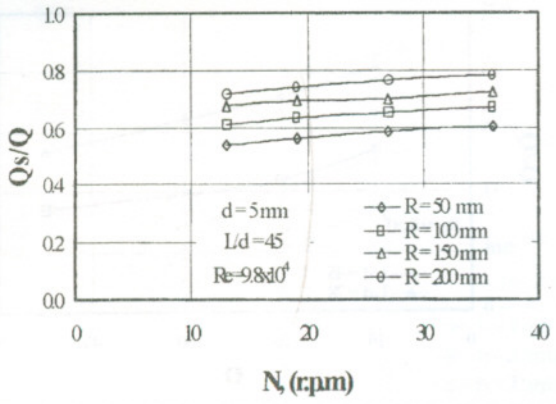

Figure 9 Relationship between splatter fraction of the incoming jet impacts on 10 mm thick rotating gelatin layer and rotating speed.

Furthermore, shifting the jet impingement location from the gelatin layer center outwards in the radial direction from R=50 to R=200 mm causes raising in the amount of the liquid jet splattering fraction by about 20 percent.

Possible explanation for these trends are provided in terms of some recent measurements of the amplitude of turbulent liquid jet surface disturbances by Bhunia *et al.* [4]. The splattering of an incoming liquid jet depends strongly upon the disturbances present on the incoming jet surface before it reaches the target. These initial jet disturbances are sharply grew as L/d and jet Reynolds number increases. This growth of disturbances is the probable cause of the increase in the splatter fraction as the jet moves upwards and also the jet turbulent intensity increases by raising Re and consequently increases the jet disintegration during the impingement with target.

In addition, a fairly large amount of large droplets was observed in the impact position when the Reynolds number was large. These droplets appear to increase by increasing the gelatin layer thickness, and are formed by a different mechanism than the fine droplets that splattered from the thin film upstream the impact position. They have a contribution to the total liquid jet splattering amount. This first splattering mechanism can be explained in terms of the concept that the energy available to the liquid jet just before it impacts onto the gelatin target is the kinetic energy. While the most important energy loss mechanisms after the impact are liquid deformation, dissipation due to wave propagation and the elastic stored energy in the gelatin layer. This remaining elastic energy is then returned to the coming liquid during the impingement as rebound droplet kinetic energy. If this is larger than the energy due to attractive forces between liquid and gelatin layer, then the fluid droplets from the impact point will rebound back to the atmosphere, especially for a large Reynolds number.

Furthermore, liquid friction with the gelatin surface will be generally lower than with solid surface targets, which should results in larger side jetting flow along the liquid film upstream the impact point. This increasingly shear force induced by the side jetting causes a disturbance growth in the liquid film up to the point of liquid splattering, where waves like ripples with tall and sharp crests are observed. These crests break into a spray of fine droplets. Also, and due to the low friction between the gelatin layer surface with liquid film, the radial region of splattering markedly increases. This increase in the splattering region area is the probable cause of the increase of the liquid jet splattering during the impingement with gelatin layers.

By considering the case of liquid jet impinging on a gelatin layer which rotates about an axis perpendicular to its plane with a uniform velocity, N. From the visual study, the thickness of the liquid film, which rotates with gelatin boundary owing to the exerted friction, decreases with the increase of rotation speed. This significant reduction of the liquid film thickness near the rotating gelatin layer making it so sensitive to break into splattering droplets, as the waves originated near the stagnant impingement point spread radially through this very thin boundary layer. This is the most likely reason for the increase of liquid jet splatter fraction during the impingement with rotating gelatin target. Another interesting fact can be seen, an increase in N from 13 to 36 r.p.m. produces an increase in splatter fraction roughly 5 percent with jet impact on rotating gelatin layer. However, more than doubled this value of splatter fraction 10 to 20 percent is noticed with jet impact on a rotating solid surface, [18].

To study the effect of surface tension variation on liquid jet splattering, solutions of approximately 0.25, 0.5, 0.75 and 1 percent by volume of detergent in water were used. The surface tension of the solution was measured before each run of the experiment. The density of the solutions was also measured. Figure 10 shows the amount of splatter fraction of the incoming jet impinging on a 10 mm thick gelatin layer against various jet Weber number. At any given nozzle to target separation, the splatter fraction increases by increasing the jet Weber number. Comparing these results with the case of pure water liquid jet (We=8400) without detergent in Fig. (5), for the same L/d, an extra 35 percent increase of the splatter fraction can be noticed as jet Weber number increases from 8400 to 2.35×10^4.

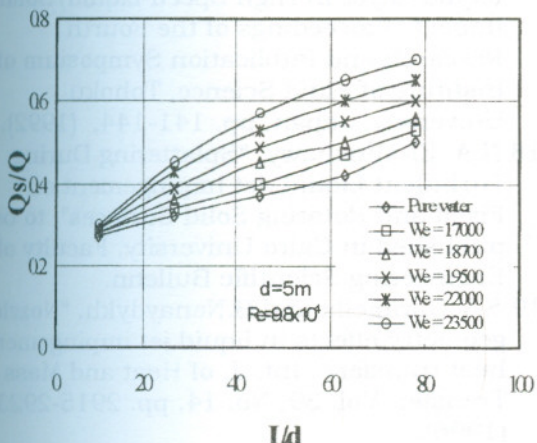

Figure 10 Relationship between splatter fraction of the incoming jet impacts on 10 mm thick fixed gelatin layer for various Weber number and nozzle to target separation

Possible reasons for this behavior are as follow. When the solution of liquid jet exits the nozzle, a new free surface is formed due to the present of detergent. As detergent molecules tends to diffuse in the bulk of the liquid and consequently alter the liquid surface tension. Thus, the nearly cylindrical jet can give up surface energy and becomes unstable. At higher Weber number the turbulent disturbances grow to be effective for breaking up the jet.

CONCLUSIONS

A fully turbulent circular liquid jet splattering has been investigated. Predictive results have been developed for jets splattering during the impingement on water layer with various thicknesses as well as fixed and rotating gelatin layers. The following conclusions can be drawn from the results obtained:

1. The splattering of an impinging liquid jet depends strongly upon the disturbances present on the incoming jet when it reaches the target. These initial disturbances are sharply amplified when the liquid flows into the thin liquid film surrounding the point of impact, and their magnitude determines both whether or not the jet splatters and the magnitude of the actual splattering. The disturbances undergo substantial distortion upon entering the liquid sheet.
2. Splattering occurs within a radial region around the impact point, rather than being distributed at all radii in the liquid sheet upstream the impact point.
3. Splattering is found to depend strongly on jet Reynolds number, nozzle to target separation, outward radial position and slightly on jet angle and rotation speed.
4. The data show clearly that the presence of detergent does alter the liquid jet surface tension, density and splattering characteristics. Consequently the splatter fraction increases by increasing the liquid jet Weber number.
5. The target surface condition, type and thickness appear to play a significant role in determining the amount of liquid jet splattering fraction. An elastic gelatin layer can enhance the amount of splatter fraction as its thickness increases. In contrast, the jet splatter fraction decreases sharply by increasing the impacted liquid layer thickness.

REFERENCES

1. M. Errico, "A Study of the Interaction of Liquid Jets With Solid Surfaces" Ph.D. thesis, University of California, San Diego, (1986).
2. V. Lienhard, X. Liu and L. Gabour, "Splattering and Heat Transfer During Impingement of a Turbulent Liquid Jet" ASME Journal of heat transfer, Vol. 114, pp. 362-372, (1992).
3. D. Varela and V. Lienhard, "Development of Non-Linear Waves on a Non-Uniform Axisymmetric Film" Bulletin of American Physical Society, A18, Vol. 36, No. 10, pp. 99-105, (1991).
4. S. Bhunia and V. Lienhard, "Surface Disturbance Evolution and Splattering of Turbulent Liquid Jets" Heat transfer-Atlanta, AIChE Symposium Series, Vol. 89, No. 295, (1993).
5. T. Chen and J. Davis, "Disintegration of a Turbulent Water Jet", Journal of Hydraulics Division, Proceedings of ASCE, Vol. 1, pp. 175-206, (1964).
6. Y. Sakakibara and J. Iwamoto, "Experimental Studies on Supersonic Jet", Journal of Trans. of JSME(B), Vol. 60, No. 572, pp. 41-46, (1994).
7. S. Kitamura and J. Iwamoto, "Numerical Analysis of Supersonic Impinging Jet", Int. congress on fluid dynamics & propulsion, Cairo, Egypt, pp. 486-494, (1996).
8. T. Obara, N. Bourne and J. Field, "Liquid-jet Impact on Liquid and solid Surfaces" Proceedings of the 8th International Conference on Erosion by liquid and solid impact, Cambridge, England, pp. 388-394, (1995).
9. J. Tilton and C. Farley, "Predicting Jet Breakup and Aerosol Formation During the Accidental Release of Pressurized Hydrogen Fluoride " Plant Oper. Prog. Vol. 9, No. 2, pp. 120-124, (1990).
10. G. Keating, T. McKone and J. Gillett, "Measured and Estimated Air Concentration of Chloroform in Showers: Effects of Water Temperature and Aerosols" Atmospheric Environment, Vol. 31, No. 2, pp. 123-130, (1997).
11. E.P. Bowden and J.E. Field, "The Brittle Fracture Solids by Liquid impact, by Solid Impact and by Shock", Proceedings of the Royal Society of London, Series A, Vol. 282, pp. 331-352, (1964).
12. H.M. Clark and L.C. Burmeister, "The Influence of the Squeeze Film on Particle Impact Velocities in Erosion" Int. Journal of Impact Engineering, Vol. 12, pp. 415-426, (1992).
13. B.M. Troyanovski, "Turbines for Nuclear Power Stations" Energia, Moskva, Vol. 23, pp. 46-51, (1973).
14. J.H. Brunton, "Erosion by Liquid Shock" Proceedings of the second Int. Conf. on Rain Erosion and associated Phenomena, RAE, Farnborough, England, (1967).
15. M.B. Lesser and J.E. Field, "The Impact of Compressible Liquids", Annual Review of Fluid Mechanics, Vol. 15, pp. 97-122, (1983).
16. J.E Field, M.B., Lesser and J.P. Dear, "Two Dimensional Liquid Wedge Impact and its Relevance to Liquid Drop Impact", Proceedings of the Royal Society of London, Series A, Vol. 401, pp. 225-249, (1985).
17. H.H. Shi and J.E. Field, "The Role of Liquid Layer in High Speed Liquid/Solid Impact "Proceedings of the Fourth Research and Publication Symposium of Institute of Fluid Science, Tohoku University, Japan, pp. 141-144, (1992).
18. N.A. El-Minshawy, "Splattering During Turbulent Liquid Jet Impingement on Fixed and Rotating Solid Surfaces", to be published in Cairo University, Faculty of Engineering Scientific Bulletin.
19. S.V.Garimella and B.Nenaydykh, "Nozzle geometry effects in liquid jet impingement heat transfer" , Int. J. of Heat and Mass Transfer, Vol. 39, No. 14, pp. 2915-2923, (1996).
20. X. Liu,V.J., Lienhard and J.S. Lombara, "Connective heat Transfer by Impingement of Circular Liquid Jets" ASME Journal of Heat Transfer", Vol. 113, pp. 571-582, (1991).
21. J.H. Lienhard, X. Liu and L.A. Gabour, "Splattering and Heat Transfer During Impingement of a Turbulent Liquid Jet", Trans. ASME Journal of Heat Transfer, Vol. 114, pp. 362-372, (1992).

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حساب كمية الايروسول المنفصل اثناء اصطدام منفوث سائل بالاسطح السائلة والمرنة

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ملخص البحث

فى هذا البحث تم اجراء التجارب المعملية التى بينت التأثير الكبير لكل من نسبة المسافة من مخرج المنفوث حتى الهدف المصدوم الى قطر المنفوث، رقم رينولدز، قطر المنفوث، زاوية ميل المنفوث، وايضا رقم ويبر على كمية الايروسول المنفصل من المنفوث السائل اثناء الاصطدام بالاسطح السائلة والمرنة الثابتة والدوارة. وضحت الدراسة ايضا الدور المهم لنوع السطح المصدوم وسرعة دورانه وسمكه على نسبة الايروسول المنفصل اثناء الاصطدام. ووجد انه كلما زاد سمك السطح السائل المصدوم قلت نسبة الايروسول المنفصل وعلى العكس زادت كمية الايروسول المنفصل بالاسطح المرنة كلما زاد سمكها.