# Design and Optimization of Critical Dimension of Fire Fighting Nozzles through CAD

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***Abstract*—Many methods have been developed to extinguish fire. For major fire hazard problem, large amount of water is to be sprayed over the fire area to put it off.**

**Fire Fighting Nozzle is equipment generating the solid jet of water as well as diverging spray of water. This jet or spray is targeted towards the flashing spot of the fire to achieve the control over it. Water jet is used to control the fire from remote distance when the intensity of fire is much horrible. The jet coming out from the nozzle must have sufficient energy to extinguish the fire. The flow rate through the nozzle should be enough to extinguish the fire. Flow rate depends on the outlet area opening. This opening or gap is set by proper positioning of the components in whole assembly of Fire Nozzle.**

**Performance of nozzle depends upon the critical dimensions of annulus area through which jet of water is coming out. Handling of nozzle is uncomfortable for the fire fighter due to the back reaction. This paper deals with design of critical dimensions of the nozzle for better performance as well as keeping in view the reduction of reaction force.**

**This paper deals with the work carried out which includes the CAD modeling and obtaining velocity and pressure distribution for analysis of the Fire fighting Nozzle by applying the appropriate boundary conditions through computer aided analysis. Pressure and velocity distribution across the profile of the internal space of the nozzle is studied. By changing the geometry of the internal space, pressure and velocity profiles are modified to reduce the turbulence in order to achieve the objectives. Number of experiments have been conducted at the site to correlate the results of the computer-aided analysis.**

***Keywords*—Fire, Fire Fighting Nozzle, Flow Analysis, Flow Rate, Back Reaction.**

## I. INTRODUCTION

General functional requirements of the Fire Fighting Nozzle for optimum performance are as follows:

- Flow rate as per required
- Jet Throw (Reach) as required
- Reaction thrust as minimum as possible
- Jet pattern as smooth as possible

The paper includes the design of critical dimension of fire fighting nozzle which gives desired performance.

For the study, one type of the Fire Fighting Nozzle was selected with following specification.

TABLE 2: FUNCTIONAL REQUIRMENT

| *Specification* | |
|---|---|
| Type of Nozzle | Fixed Flow type |
| Inlet Pressure | 7 kgf/cm$^2$ |
| Flow Rate | 450 LPM |
| Jet Reach | 20 Meter (Minimum) |
| Nozzle Reaction | 15 kgf (Maximum) [4] |
| Jet pattern (In terms of Velocity distribution at outlet) | Uniformly Distributed |

Flow rate through Fire nozzle depends on the annulus opening area of fire nozzle. Different opening gives different flowrate at same inlet pressure. So, number of models have been prepared physically having different oulet area. The experiments have been conducted to measure the flow rate through all models.

CAD model of each model is prepared using SolidWorks 2004 software. Flow analysis of all CAD models has been carried out to obtain pressure and velocity profile through Cosmos Flow Works software.

Results of computerized analysis were compared with experiment observation and the critical dimension of best suitable model was selected.

## II. BASICS OF FIRE FIGHTING

*Fire Growth*

The energy liberated during combustion can radiate back on the fuel substance, where it causes pyrolysis and evaporation of the fuel. It can also aid further pyrolysis of the products in the gas phase. The heat liberated by the fire also causes the surrounding materials to warm up. The heat transfer is accomplished by three means, usually simultaneously: conduction, radiation and convection.

Three different fire phases can be distinguished namely the growth phase, the steady state phase and the decay phase. The early stage of a fire during which fuel and oxygen are virtually unlimited is the Growth Phase. This phase is characterized by an exponentially increasing heat release rate. The middle stage of a fire is the Steady State Phase. This phase is characterized by a heat release rate, which is relatively unchanging. Transition from the Growth Phase to the Steady State Phase can occur when fuel or oxygen supply begins to be limited. The final stage of a fire is the Decay Phase, which is characterized by a continuous deceleration in the heat release rate leading to fire extinguishment due to fuel or oxygen depletion.

*Flow Rates*

There have been several international research projects over the past 50 years that have attempted to produce an engineered solution to water flow-rate requirements for structural fire-fighting purposes. These studies have been generally based upon scientific data associated with heat release rates from compartment fires along with empirical research investigating actual flow-rates used by fire brigades when tackling fires in a wide range of occupancy types. Mr. P. Grimwood's[1] practical experience at that time would suggest that maximum flow of 200 LPM from a 12.5 mm nozzle; 450 LPM from a 20 mm nozzle and 700 LPM from a 25 mm nozzle on interior attack hose-lines were far more realistic than those suggested by the theoretical SRDB Codes, as used in the Lund research.[6,7]

*Effect of Parameters*

The design variables, which are to be optimized for the best performance of the fire nozzle, are as follows

- Discharge through nozzle (Output)
- Pattern of the flow coming out from the nozzle (Output)
- Maximum distance covered by the water jet (Output)
- Reaction force due to jet coming out from the nozzle (Output)

All these variables are affected by the following parameters

- Area between baffle and orifice
- Position of flow control valve
- Inlet water pressure
- Gripping of the nozzle
- Surface finish of the part which are in contact with water
- Turbulence at the inlet
- Temperature of the inlet water
- Atmospheric condition

- **Atmospheric condition** is not under control of human hand. However, by this consideration the design is so made that it can perform in worst weather also. The main affective condition is the wind speeds which affects the flow pattern as well as throw reach of the flow considerably. Again due to wind load the handling is much difficult which increases the back reaction force to fireman. As wind speed increases
  - Reach of Throw Decreases
  - Jet deflects in the direction of wind speed
  - Reaction thrust increases
- **Temperature of water** is also important for extinguishing the fire properly. As discussed earlier that the temperature of water used to extinguish the fire should be low enough to extinguish the fire. In general the temperature of water is kept in range $20^0$ to $25^0$ C for effective fire extinguishing. Hence the normal tap water or stored tank water at atmospheric temperature is widely used.
- **Turbulent at inlet** of the fire nozzle increases the losses due to eddies formation and raises the cavitations. Higher turbulence at the inlet, if not removed, causes the flow separation and damage the pattern of the flow coming out from the nozzle outlet. To reduce the inlet turbulence a long hose line (Approximately 15 to 25 meters) is to be used. Again to make the flow stream lined, one stream shaper is used.
- **Surface finish** of the parts, which are in direct contact with the water, also affect the performance of the nozzle. Poor surface finish increases the friction and losses. To avoid these losses the inner surfaces of the components, which are in contact with water, are highly super finished and black anodized.
- **Gripping of the nozzle** should be ergonomically designed so that it puts less thrust to the fire fighter. In general practice a fine pistol grip is to be provided. Still a major problem of smooth handling of nozzles is there in all nozzles.
- **Inlet pressure** of water is a very important parameter. In general all the fire lines are filled with continuous flow of water of approximately 100 psi (7 kgf/cm$^2$) pressure or more. So it is desired to design the nozzle, which can perform at this line pressure. It is obvious that as pressure increases, discharge increases but reaction thrust force also increases. Therefore, the nozzle is to be so designed that the discharge through the nozzle is as per requirement along with maximum possible reach and minimum reaction thrust force.
- **Position of flow control valve** affects the flow rate of the nozzle. Its position can be controlled by the flow control lever. At one extreme position of it, no water can flow through the nozzle i.e. nozzle is OFF. At the

other extreme position of it nozzle is running with maximum possible flow through it. Hence for the fine desired performance of the nozzle, care must be taken by the fire fighter during usage that the flow control lever should be in proper position.

- The most important parameter is **area between the baffle and orifice** through which the water is discharged in to the atmosphere. It is the minimum area of the nozzle geometry i.e. venacontracta which affects the flow rate of the nozzle as well the reaction thrust force and reach of the water jet. This area is to be defined exactly to have exact desirable performance of the nozzle.

This can be controlled at the manufacturing floor. In general practice this area is set by some experienced and skilled worker without any theoretical technical knowledge.

## III. Design of Nozzle

Flow rate through the nozzle is decided as per the requirements e.g. 450 LPM, 900 LPM, 1350 LPM etc. Based on this flow rate, the diameter of nozzle is calculated from the empirical equation 3.1[2].

$$Q = 0.667 d^2 \sqrt{p} \qquad \text{… (3.1)}$$

Where

Q = Flow rate, LPM

d = Nozzle Diameter, mm

p = Nozzle Pressure, kgf/cm$^2$.

Here'd' is the equivalent diameter as it is the case of jet spray nozzle which produces hollow jet.

This equation is based on the concept of flow through the orifice. The derivation is as follows.

$$Q = C_d a \sqrt{2gh} \qquad \text{… (3.2)}$$

where

Q = Flow rate in LPM

a = Area $= \frac{\pi}{4} d^2$ ; d = Diameter

g = gravity

h = pressure head.

Now pressure at the inlet of the orifice,

$$\rho gh = p \; ;$$

$$\therefore gh = \frac{p}{\rho}$$

Substituting it in to above equation 3.2

$$\therefore Q = C_d \times \frac{\pi}{4} \times d^2 \times \sqrt{\frac{2p}{\rho}}$$

$$\therefore Q = 1.110 \times C_d \times d^2 \times \sqrt{\frac{p}{\rho}}$$

But, in general coefficient of discharge $C_d$ = 0.6[3]

$$\therefore Q = 0.667 \times d^2 \times \sqrt{p}$$

This equation shows that as the inlet pressure increases, the flow rate increases. As diameter increases, the flow rate increases too.

According to this equation $Q \propto d^2$ and $Q \propto \sqrt{p}$ .

Therefore, d & p are the input parameter to determine the flow rate through the fire nozzle.

Reaction of Nozzle

As water jet discharges through the small opening of the fire nozzle, the thrust force is felt by the operator. This reaction thrust force is function of Flow through the nozzle and the nozzle inlet pressure. This can be clearly derived from the following empirical equation 3.3 [2].

$$F = 0.0505 Q \sqrt{p} \qquad \text{… (3.3)}$$

Where F reaction thrust in lbs Q Flow in GPM P Nozzle inlet pressure in PSI

Converting this empirical equation in to SI units, it yields [2]

$$F = 0.2237 Q \sqrt{p} \qquad \text{… (3.4)}$$

Where, F in N; Q in LPM & p in kgf/cm$^2$

## IV. Flow Analysis of Fire Fighting Nozle

*3D Model*

As the whole assembly of the fire Nozzle is much complicated, the simplified model of the nozzle is used for analysis as shown in figure 1. At the outlet of the nozzle, gap thickness is t. This gap thickness can be varied by changing the position of the baffle. The distance x indicate the relative position of the baffle. Hence by changing the x axially, t can be changed proportionally.

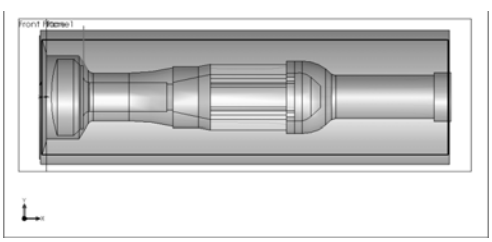

Fig. 1: Simplified model of Fire Fighting Nozzle for analysis

*Boundary Conditions*

Boundary conditions are the most important step of the analysis. Whole analysis and the effectiveness as well as accuracy of the results of analysis depend on the boundary conditions. At the inlet of the Nozzle, pressure is 7 kgf/cm$^2$ as per the performance requirement. And outlet pressure is atmospheric pressure. Figure shows the model with boundry condition.

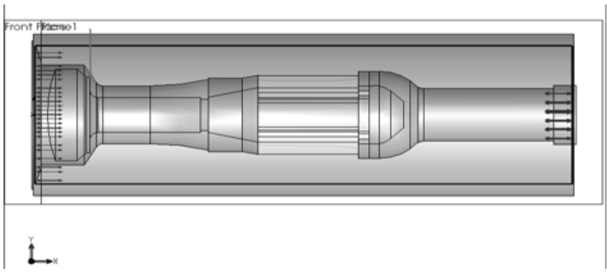

Fig. 2: Boundary Condition applied to model

*Meshing*

Meshing is the main important step in the flow analysis procedure. The fluid passage in the nozzle is meshed with elements as shown in figure. Each small element will be considered as control volume during analysis.

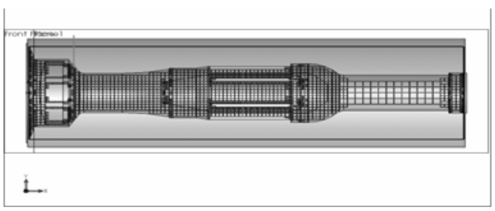

Fig. 3: Meshing of Flow Area.

*Results Plot*

After meshing and boundary condition, analysis can be started. At the successful completion of the analysis various results can be plotted as shown in figures. Figures show the pressure and velocity plots of one of the model.

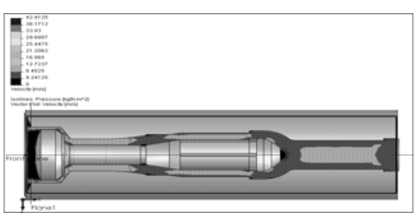

Fig. 4: Pressure plot

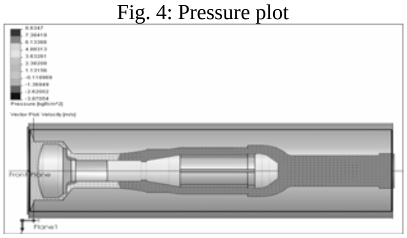

Fig. 5: Velocity Plot

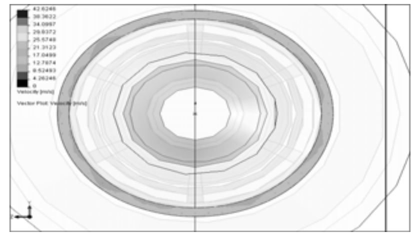

Fig. 6: Velocity plot at Outlet

## V. EXPERIMENTS

Setup consists following main parts, which are interconnected with each other.

- Water Sump (W)
- Pump (P)
- Hose Pipe Lines
- Pressure Gauge (Pr)
- Flow Meter (F)

Along with all these, one stopwatch is also needed to measure the time during the measurement of flow rate. The schematic layout of the arrangement of these components is as shown in the following figure.

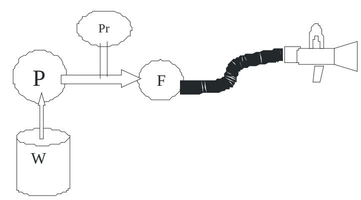


Fig. 7: Schematic layout of experimental setup.

*Followings are the Steps for Experiment*

Model of fire nozzle is prepared to perform an experiment on it. The annulus gap size for that model is properly maintained and recorded. The fire nozzle is attached to Hose line with the help of adaptor. Care is taken that the flow control valve is at fully open condition. Pump is stared to supply the water to the fire nozzle. Pressure is increased gradually in hose line up to 7 kgf/cm$^2$, which is the desired input pressure for fire nozzle best performance. Flow rate is measured through fire nozzle in LPM. Four readings of flow are recorded and then take of all is considered to avoid the error. The reaction force is felt physically by skilled standard fire man. A line is marked when the jet of the nozzle is touching the ground. Jet pattern coming out from nozzle is checked visually. Jet is converted in to spray & checked visually. Flow from the nozzle is stopped. The distance of marking line is measured which is recorded as jet reach. Nozzle is now removed from the adaptor of hose line. Change is made in the annulus gap appropriately and recorded again. And then whole process is repeated for this modified model. Table II shows the experimental observations.

## VI. Result and Discussion

Table III shows the comparison of flow rate of Experimental Observation and Flow Analysis results.

TABLE 3: COMPARISON OF RESULTS

| *Model* | *Flow Rate (LPM)* | | *% difference* |
|---|---|---|---|
| | *Experimental* | *Software* | |
| 1. | 320 | 310.830 | 2.87 |
| 2. | 392 | ----- | ---- |
| 3. | 440 | 403.000 | 8.41 |
| 4. | 488 | 449.440 | 7.90 |
| 5. | 528 | 493.206 | 6.59 |
| 6. | 578 | 534.018 | 7.61 |
| 7. | 612 | 578.006 | 5.55 |

Table III shows, as gap size increases, flow rate through nozzle also increases experimentally as well as through computer aided flow analysis. The % difference of results is minimum for model 1 i.e. 2.87% and maximum for model 3 i.e. 8.41%. But as per table I the standard specification shows that the selected nozzle type should have flow rate of 450 lpm. From table II, model 4 gives discharge of 488 lpm experimentally and 449.440 lpm analytically. So model 4 can be suitable for required application. All other design variables are calculated analytically and also observed experimentally. Table IV shows the detail specification of model 4.

TABLE 4: COMPARISON WITN STANDARD SPECIFICATION

| | *Standard Specification[2]* | *Specifications of proposed Model* | |
|---|---|---|---|
| Flow Rate | 435 to 460 LPM | 440 LPM | Accepted |
| Jet Reach | 20 Meter (Minimum) | 23 meter | Accepted |
| Nozzle Reaction | 15 kgf (Maximum)[4] | 13.7 kgf | Accepted |
| Jet pattern (In terms of Velocity distribution at outlet) | Uniformly Distributed | Uniformly Distributed (Refer fig 6) | Accepted |

Jet reach was measured at the time of experiment on the field. Nozzle reaction can be evaluated through cosmos flow work software.

## VII. Conclusion

It can be concluded that the model 4 is the best suitable model for the given specification of fire nozzle. The gap size to be kept 2.55 mm to achieve the desired flow rate.

The widely used fire-fighting nozzle of 450 LPM capacity is designed. Different models of fire nozzles are prepared using software and analyzed. The experimental verification is also carried out. It is found that the CAD results match with the Experimental Results and the error is less that 2.5%. Here it is verified that the required reach of minimum 20 meter is attained. The nozzle reaction is within range. The required jet pattern is attained.

## References

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