During the hurry to reach a fire on time, a fireman mistakenly picked a nozzle whose diameter is the same as that of the hose. The length of the hose is 30 m. the diameter of is 8 cm and the roughness of the hose is 0.0008m. He has to deliver a jet of water to a height of 10 m above the ground. The water jet leaves the hose at an angle of 60° to the horizontal. Evaluate the minimum head to be developed by the pump that draws water from a reservoir (at the same level of the hose) maintained at atmospheric pressure.
His fellow fireman has later brought a reducing nozzle of 2.5 cm exit diameter and advised his friend to attach it to the exit of the hose, suggesting that this would significantly cut down the pump head requirement. You as an expert in fluid mechanics are entrusted to resolve this. Your opinion should be based on quantitative assessment of the situation. You can neglect minor losses for both the cases.

The velocity head at the nozzle exit determines the height the water jet reaches. The head developed by the pump is then obtained from the velocity head at the nozzle + the head lost in the hose.

The velocity ~~at~~ at the exit (and hence the velocity through the hose) can be determined by noting that, at the highest point, the vertical component of the velocity becomes zero, while the horizontal component remains unchanged at the nozzle exit value of $V_j \cos 60°$ or $V_j/2$.

Applying the energy eqn betn the nozzle exit and the highest point,

$$\frac{V_j^2}{2g} + \frac{p_{atm}}{\rho g} = \frac{(V_j/2)^2}{2g} + 10\,(m) + \frac{p_{atm}}{\rho g}$$

$$\Rightarrow \underline{V_j = 16.17 \text{ m/s}}.$$

The head loss in the pipe

$$h_l = f \frac{V^2}{2g} \cdot \frac{L}{D}$$

$$Re_D = \frac{10^3 \times 16.17 \times 0.08}{10^{-3}} = 1.294 \times 10^6$$

$$\frac{\epsilon}{D} = \frac{0.0008}{0.08} = 0.01 \quad \Rightarrow \quad f = 0.038$$

$\therefore h_L = 0.038 \times \dfrac{(16.17)^2}{2\times 9.81} \times \dfrac{30}{0.08} = \underline{\underline{189.9\,m.}}$

$\therefore$ A head of 189.9 m is lost within the hose.

Total head generated by the pump (apply B eqⁿ between the inlet & outlets of the pump and nozzle exit)

$$\frac{p_{atm}}{\rho g} \quad h_s = \frac{V_j^2}{2g} + h_L = \frac{(16.17)^2}{2\times 9.81} + 189.9$$

$\underline{h_s = 203.2\,m.}$ too high a value for throwing water to only 10 m.

If a nozzle of 2.5 cm exit diameter is used, the velocity read. in the hose is

$$V_h = 16.17 \times \left(\frac{2.5}{8}\right)^2 = 1.58\,m/s.$$

$$\text{Corresponding Re no.} = \frac{10^3 \times 1.58 \times 0.08}{10^{-3}} = 1.264\times 10^5.$$

$\Rightarrow f = 0.038$ (unchanged, since the flow is fully turbulent)

$$h_L = 0.038 \times \frac{(1.58)^2}{2\times 9.81} \times \frac{30}{0.08} = 1.81\,m..$$

Total head developed by the pump is now

$$h_s = \frac{V_j^2}{2g} + h_L = \frac{(16.17)^2}{2\times 9.81} + 1.81 = \underline{15.13\,m}.$$

$\therefore$ Pumping head requirement can be cut down considerably.

B eqⁿ has to be applied betⁿ the pump inlet and the nozzle exit, NOT betⁿ pump inlet & outlet as at the pump outlet the pr. is unknown.

[If the hose diameter itself is reduced to 2.5 cm; the hose Velocity will be same as jet velocity, but $Re_D = 4.04\times 10^5$.
$\frac{\epsilon}{D} = 0.032 \Rightarrow f = 0.059, \Rightarrow h_L = 943.53\,m$]