36.68 **Three 90% efficient secondary chilled water pumps operate in a parallel redundant N+1 configuration supplying a total of $1500gpm$ against $200ft$ of total dynamic head. In normal operation with all pumps running, the pumps have a speed of $900rpm$. When one pump fails, the remaining pumps increase speed to provide consistent uninterrupted flow to the cooling loads. During a pump failure, what brake horsepower is required to drive the two running pumps?**

A. $28hp$

B. $42hp$

C. $63hp$

D. $95hp$

Make a table to organize the information comparing the normal mode of operation to the failure mode described. The values in the table are per individual pump.

Normal	Failure
$Q_1 = 500gpm$	$Q_2 = 750gpm$
$h_{A,1} = 200ft$	$h_{A,2} = 200ft$
$n_1 = 900rpm$	n_2 ?
bhp_1 ?	bhp_2 ?

Look up the Pump Affinity Laws. Recall the relationship between volume flow rate and speed is linear. Therefore, a 50% increase in speed must be required to produce a 50% increase in the flow rate.

$$\frac{n_2}{n_1} = \frac{Q_2}{Q_1}$$

$$n_2 = n_1 \left(\frac{Q_2}{Q_1}\right) = (900rpm)\left(\frac{750gpm}{500gpm}\right) = 1350rpm$$

Brake horsepower changes with the cube of the speed. However, before applying another pump affinity law, first calculate the brake horsepower by finding the water horsepower, whp, which is determined by the flow rate and head added by the pump, then include the efficiency to account for the pumping losses. Assume the pump efficiency is constant over a range of speeds.

$$whp = \frac{Q_{[gpm]} h_{A[ft]}}{3960}$$

$$bhp = \frac{whp}{\eta_p} = \frac{Q_{[gpm]} h_{A[ft]}}{3960 \cdot \eta_p}$$

$$bhp_1 = \frac{(500)\,(200)}{(3960)\,(0.9)} = 28.06hp$$

Having defined the brake horsepower for the normal operating state, apply the affinity law relating power and speed to determine the *bhp* for the failure mode:

$$\frac{bhp_2}{bhp_1} = \left(\frac{n_2}{n_1}\right)^3$$

$$bhp_2 = bhp_1\left(\frac{n_2}{n_1}\right)^3 = (28.06hp)\left(\frac{1350rpm}{900rpm}\right)^3 = 94.7hp$$

Note the dramatic increase in power associated with a moderate increase in speed. This is one reason why energy savings can be readily achieved by running redundant pumps in parallel using variable speed drives.

Answer D