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Head Determination and Pump Selection For A Water Treatment Plant In Villages Around Maiduguri, Borno State, Nigeria

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Abstract: *Water treatment plant uses pumps extensively for lifting from one level to another, for a small plant in a rural community the needed pump is selected for a total head of 9.221 m as calculated. This led to a selection of pump with flow rate of 0.0074 m/s (7.407 liters/s) and an output power of 1.894 kw(2.54 hp). The storage tank is design to cater for about 260,000 people and when the pump is shut there will be supply of about 3.7 hrs.*

Key words: *Total Head, pump, water treatment*

I. INTRODUCTION

Total head and flow are the main criteria that are used to compare one pump with another or to select a centrifugal pump for an application. In all water treatment plant pumps are used in transporting water from a low level to high level, hence the need to select a pump that can perform this function and also be able to overcome the friction within the piping system. Total head is related to the discharge pressure of the pump. For good reasons, pump manufacturers do not use discharge pressure as a criteria for pump selection. One of the reasons is that they do not know how you will use the pump. They do not know what flow rate you require and the flow rate of a centrifugal pump is not fixed. The discharge pressure depends on the pressure available on the suction side of the pump. If the source of water for the pump is below or above the pump suction, for the same flow rate you will get a different discharge pressure. Therefore to eliminate this problem, it is preferable to use the difference in pressure between the inlet and outlet of the pump. It is also known that the amount of pressure that a pump can produce will depend on the density of the fluid, for a salt water solution which is denser than pure water; the pressure will be higher for the same flow rate, so that a criteria that does not depend on density is very useful and it is called TOTAL HEAD, and it is defined as the difference in head between the inlet and outlet of the pump.

II. HEAD DETERMINATION

Consider, the raw water in the storage tank flowing under gravity to the cone shaped vortex mixer as shown in fig. 1 below.
Applying the energy equation (Bernoulli's equation), for an incompressible fluid flowing between points 1 and 2 as in fig. 1, we have

$$\frac{p_1}{pg} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{pg} + \frac{v_2^2}{2g} + z_2 + \sum hi \ldots\ldots\ldots\ldots(1)$$

For large surfaces, exposed to the atmosphere, p_1& p_2 are assumed to be at atmospheric pressure and also $v_1 \cong v_2$ thus, from equation1, $(z_1 - z_2) = \sum hi$……………………. (2)

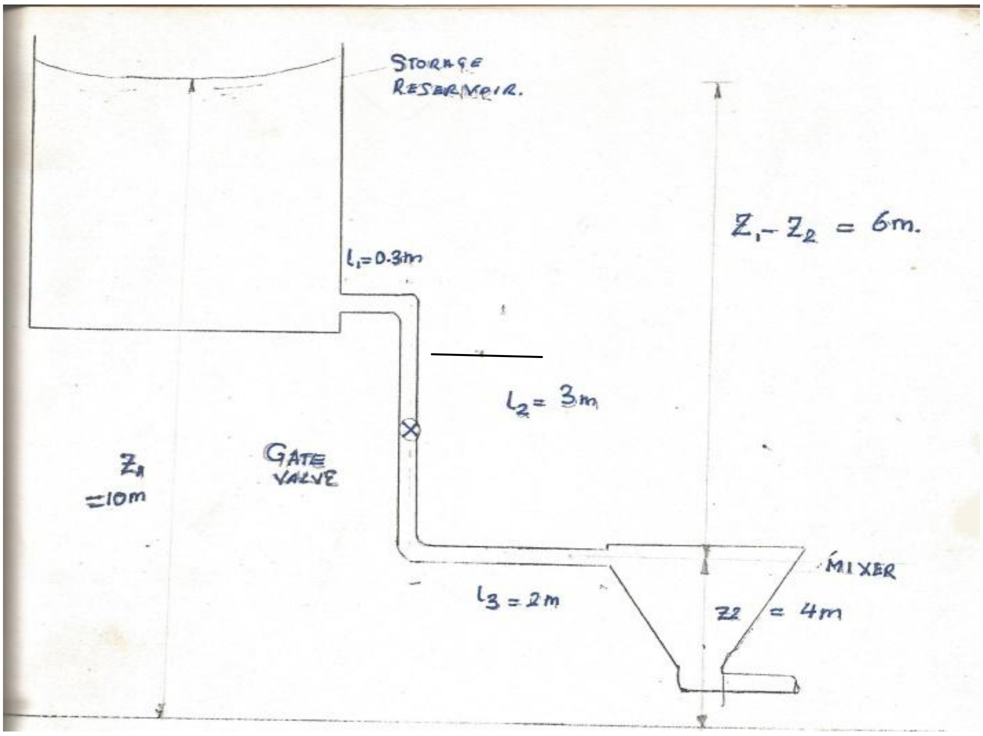

Figure 1: Total Head Determination

Where,
P_1= pressure of fluid at point (1) in N/m^2
P_2 = pressure of fluid at point (2) in N/m^2
V_1 = velocity of fluid at point (1) in m/s
V_2 = velocity of fluid at point (2) in m/s
ρ= density of fluid at that temperature in kg/m3
g= acceleration due to gravity in m/s^2
z_1= altitude above datum of fluid in tank (1) in m
z_2= altitude above datum of fluid in tank (2) in m
$\sum hi$ = summation of the losses of energy along the pipes in m
Thus, from figure 1 the height z_1 =9m, z_2=4m and the lengths l_1, l_2 and 1_3 = 300mm (0.3m), 3m and 2m respectively. The summation of the head loses is given by;

Thus, $\sum hi$= k_1 $v^2/2g$ $+\frac{FIQ^2}{3d^5}\frac{FI_1\ Q^2}{3d^2}$ $+k_2$ $v_2/2g$ + $\frac{FI_3\ Q^2}{3d^{25}}$ +
k_3 $v^2/2g$…………………. (3)

Where F= Friction coefficient in the Darcy back formula
Q= Discharge required in m^3/s ($0.003m^3/s$) (for the given purpose).
D= Pipe diameter in m.
v= mean velocity of fluid in pipeline in m/s
$K_{1, 2,3}$= shock loss coefficient. (k_1 = 0.5, k_2 = 0.025, k_3 = 1)

Hence,

$$\sum hi = \frac{fQ^2}{3d^5}(0.3 + 3+2) + v^2/2g(0.5 + 0.025 + 1)$$

$$= \frac{fQ^2}{3d^5}(5.3) + v^2/2g\ (1.525)…………….. (4)$$

For most mixers, the entry velocity should not be more than 1m/s, to facilitate proper mixing of the coagulant and water.

Thus, from the continuity equation,
$Q=a_1v_1=a_2v_2$ = constant …………… (5)
Where,
Q = discharge in m3/s (0.003 m3/s)
A = cross sectional area of pipe in m2
V = mean velocity of fluid in pipe in m/s (1.0m/s)
Hence, substituting values of Q and V in equation5;
0.003 = a x 1.00

Or, a = $\frac{0.003}{1}$

But Area, a = $\frac{\pi d^2}{4}$ …………………….. (6)

Where d = Diameter of pipe in m

Thus, $\frac{\pi d^2}{4}$ = 0.003

And $d^2 = \frac{4 \text{ x } 0.003}{\pi}$

Or

d = $\frac{\sqrt{0.012}}{\pi}$

The most economical pipe diameter closest to this is 60mm diameter pipe [8].

For most small treatment works, Galvanized iron pipes are mostly used, which has a roughness coefficient (e) of 0.15mm (Nikuradse-moody chart).

Thus, absolute roughness = 0.15mm,

Hence,

Relative roughness =$\frac{\text{Absolute roughness}}{\text{Diameter of pipe}} = \frac{e}{d}$ ……………….. (7)

Thus Relative roughness = $\frac{0.15\text{mm}}{60mm}$

Relative roughness = 0.0025

The Reynolds number for this flow is given by $N_R = \frac{vd}{v}$ ……. (8)

Where, NR = Reynolds Number

v = Velocity in pipeline in m/s

v= Kinetic viscosity in m^2/s

Thus,

For the water under consideration with a highest recorded temperature of 35°C, the kinetic viscosity at 35°C is 0.729 x 10^{-6} m^2/s (physical properties of water table)

Hence, from equation (8)

$N_R = \frac{1.0 \text{ x } 0.06}{0.779 \text{ x } 10}$ -6

= 82.30 x 10^3

The flow is seen to be laminar (Nikuradse-moody chart)thus; an approximation of the friction factor is obtained from the Nikuradse-moody chart, which is 0.024.

But a more accurate value is obtained by the use of Colebrook equation [8].

$\frac{1}{\sqrt{f}} = -2 \log_{10} [\frac{e/d}{3.57} + \frac{2.81}{R\sqrt{f}}]$ ……….. (9)

Thus, for f = 0.024,

$\frac{1}{\sqrt{f}} = -2\log_{10} [\frac{0.0025}{3.57} + \frac{2.81}{82.30 \text{ x } 10^3\sqrt{0.024}}]$.

Thus, $\frac{1}{\sqrt{f}}$ = 6.07

And $\frac{1}{\sqrt{0.024}}$ = 6.45

Hence a better approximation is obtained by assuming f = 0.02669,

Thus, $\frac{1}{\sqrt{f}} = -2\log_{10} [\frac{0.0025}{3.57} + \frac{2.81}{82.30 \text{ x } 10^3\sqrt{0.02669}}] = 6.08$

i.e.$\frac{1}{\sqrt{f}}$ = 6.08≅6.10

Thus, the friction factor for the pipes is 0.02669≅ 0.027

and the friction coefficient = $\frac{\text{friction factor}}{4}$ ……….. (10)

= $\frac{0.027}{4}$

i.e. f = 0.0068≅ 0.007

Thus, substituting values of f, Q, d and V in (4) we have

$\sum hi = \frac{0.007 \text{ x } (0.003)2 \text{ x } 5.30}{3 \text{ x } (0.060)^5} + \frac{1^2}{2 \text{ x } 9.81}$ x 1.525

= 0.143 + 0.078

$\sum hi$= 0.221m

Thus, the head loss in the pipe line is 0.221m the total dynamic head is given as; Total dynamic Head = Head loss + static Head ………. (11).

Total dynamic Head = 0.221m + 9m = 9.221m

Thus, it is advisable to raise the head to 10m, to compensate for unforeseen losses due to static head as a percentage should not be greater than 15% [9].

i.e. $\frac{\sum hi}{\text{Static Head (H)}}$ x 100≤15%...........(12)

Thus, for our purpose,

= $\frac{0.221}{10}$ x 100% = 2.21%

Which is less than 15%?

Thus if the pump is shut, there would be a 3.7hr, supply of the water from the storage tank. This will suffice for a rural community.

An overflow pipe should be fitted on the 2 x 4m side, which is a 20mm diameter galvanised steel pipe, 150mm long. Part it loners should be provided to stabilise flow, and improve the strength of the tank at the same time reducing bulging effects.

III. PUMP SELECTION

The volume of storage tank as determined in (5) is 40m^3. Thus assuming the time required to fill this tank is $1\frac{1}{2}$hr, the flow rate required of the pump to be selected as given by;

$$Q = \frac{V}{T} = \frac{40m^3}{1.5\text{hr}}$$

$$= \frac{40m^3}{1.5 \text{ x } 3600}$$

= 0.0074m3/s

= 7.407 litters/s

Hence selecting Q = 7.00 1iters/s and a 100mm diameter pipe, the pipe friction coefficient is found to be 0.618m per 100m (water friction loss chart), thus choosing a length of pipe of 100m from the pump to the storage tank (excluding the static head).

Friction head = $\frac{0.618}{100}$ x (100 + 10)

= 0.6798m

Thus, from total dynamic head = friction head + static head

= 0.6798 + 10 = 10.6798m

Also, the $\frac{\text{friction head}}{\text{static head}}$ x100% = $\frac{0.6798}{10}$ x 100

6.798% which is < 15%

The power required in kilowatt to pump the water to the storage tank is given by,

Power in kW = $\frac{\text{liter / second x metter head}}{\text{Efficiency}}$............. (13)

Kw = $\frac{Q\left(\frac{1}{s}\right)\text{x H (m)}}{\eta}$ .... (14)

Where η = hydraulic efficiency which for most practice purposes is taken to be 50%.Q and Hence as earlier defined.

Kw = $\frac{7 \text{ x } 10.6798}{50}$ = 1.495Kw

Power = 1.50Kw

Thus, power in horse power (hp) = $\frac{\text{power in Kw}}{0.746\text{ (Kw)}}$, where 1hp = 0.746Kw

Thus, Power (hp) = $\frac{1.50}{0.746}$

= 2.01hp

Hence, power required = 2.01hp (l.50Kw)

The actual power required = power required + derating due to temperature and altitude + derating due to aging.

i. **Derating due to temperature**:- there is a 1% reduction of power for every 2 . 8°C above 29°C [9]. Hence, for the temperature of 35°C, let(x) be the power due to the temperature increase, hence,

X = $\frac{\text{power required}}{1-\frac{(35-29)}{2.8}\text{ x }\frac{1}{100}}$

$X_{temp} = \frac{1.50}{0.98}$

X_{temp} = 1.533

Thus, power required due *to* temperature increase = 1.533 - 1.50

= 0.03kw

ii. Power reduction due to altitude;- there is a 3.5% reduction of power per 300m above 15Qm[9], the altitude range for Maiduguri area is 200-500m [11], thus a choice of 500m will be suitable. For' this altitude, let Y be the power required due to the increase in altitude hence,

$$Y_{alt} = \frac{\text{Power required}}{(1-\frac{500-150}{300}\text{ x }\frac{3.50}{100})}$$

$= \frac{1.5}{0.959}$

Y_{alt}= 1.564kw

Thus the power required due to increase in altitude = 1.564 - 1.50

= 0.064kw.

iii. Power required due to aging: 15-25% extra is allowed for failure in performance as the unit become older [9]. Hence choosing an increase of 20% factor of safety, we have;

Increase of power due to aging = $\frac{20}{100}$ x 1.5 = 0.3kw

Hence, the actual power required is:

Actual power = 1.5 + 0.03 + 0.064 + 0.3

= 1.894kw (2.54hp)

Let the pump be placed 1.50m above the surface of the water in well. The available net positive suction head,(NPSH) is given by

Available NPSH = P_1-H_s -V_p -F_s… (15)

Where, P_1 = Open pressure on liquid surface (m)

H_s= vertical height of pump suction above open surface in (m)

V_p = vapour pressure of liquid in (m)

F_s = suction entry and friction losses in (m)

The value F_s is practically taken to be 0.75m [9] at 35^{o}C and 500m altitude; V_p and P_1 are 0.625m and 7.04m (US standard atmosphere table).

Hence,

Available NPSH = 7.04 – 1.50 – 0.75

= 6.165m, 4.17m is taken been the maximum allowed for the pump suction intake.

Thus, from the graph of velocity VS flow, (choose of suction pump diameter chart) the bore of pipe recommended for such a suction arrangement is a 76mmdiameter pipe and the suction velocity corresponding to this flow rate and pipe diameter is 1.6m/s, which is necessary as the suction velocity should be less than 2.0m/s, to avoid cavitation.

Thus, the outlet point of the pump is to have a discharge of 71litres/s, ahead of 15m and a power of 2.5hp.For the suction arrangement, a suction pipe diameter of 76mm (3in), flexible reinforced rubber hose should be used, with a net positive suction head 4.17m as mentioned above.

Two 45° elbow joints are to be installed along the delivery line -due to changes in flow direction and the delivery line should also be fitted with the reinforced rubber hose for a length of 2m and be attached with a connector to facilitate easy removal.

IV. CONCLUSION

A Great cost reduction and improvement on the efficiency is obtained by the use of a well dug before the pump intake. This is another cost reduction, when we consider building of a raw water storage tank before the pump compared to this underground storage.

Lack of extension of electricity grid or it's instability in most rural communities, certain energy sources were considered before one was chosen for this purpose. Although Maiduguri area and most parts of Northern Nigeria have abundant solar and wind the choice of old fossil fuel type of energy source, to drive a pump was used.

The overhead tank was placed at a suitable head to produce the required flow and the choice of tank material and size all made to standard.

The mixer used for this design was adopted to ease the construction of separate mixing chamber, sophisticated mechanical or flash mixer used in high tech water treatment processes which require a great deal of power.

REFERENCES

[1] Smsrthurst G.: Basic Water Treatment 1997; Thomas Telford Ltd, London
[2] M. Fair, Gordon/C. Geyer, John/A. Okun, Daniel. Water andWaste water Engineering Vol.1, 1968, John Willey and Sons Inc
[3] James G. V.: Water Treatment. Lorch: Handbook of Water Purification 1981, McGraw-Hill (UK), (London; | New York :)
[4] M. Fair, Gordon/C. Geyer, John/A. Okun, Daniel; Water and Waste water Engineer Vol. 2, 1968, John Willey and Sons Inc.
[5] Mogarr, F: Water and Waste Water Utilization in Hot Climate
[6] Dunn, P.D.: Appropriate Technology 1978, MacMillan Press Ltd
[7] Ernest, F. B, Horace W. K, James E. L, C. Y. Wei; Handbook of Hydraulics 1996, McGraw-Hill
[8] Wilcork, Dennis: Water Engineering (March 1, 1996), McGraw-Hill Education; 7 editions
[9] Maria J. Ferrua, R. Paul Singh; Understanding the fluid dynamics of gastric digestion using
[10] Computational modeling, Procedia Food Science 1 (2011) 1465 – 1472, 11th International Congress on Engineering and Food ICEF11
[11] Regional Map of Borno State.