# Total Dynamic Head Determination Model for Submersible Pumps Installation

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## Abstract

*In Nigeria, the rate at which borehole drilling is extensively adopted is very high both at rural and urban areas. Total dynamic head is the major factor that determines the optimal performances of submersible pumps. If the total head on the system increased, the volume of the discharge will be reduced proportionally until its stops. The factors considered during the model development are: pumping level, vertical rise, friction losses via: insert coupling, threaded adapter(plastic to thread), 90°standard elbow, Standard Tee(Flow Through Run), Standard Tee(Flow Through Side), Gate valve and Swing Check Valve, total length of the pipe, fittings equivalent of pipe, number of same fittings, and friction loss of head per 100feet (30.48 m)of pipe. In order to validate the model, data was collected from Osun State "Rural Water and Environmental Sanitation Agencies" (RUWESA). The data were used to compute: the pumping level, vertical rise and the friction loss. The summation of these three parameters gave the value the Total Dynamic Head (TDH) to be 737.31ft or 224.88m for this case study. Total dynamic head calculation will help to minimize and eradicate replacement or repair of pumps which can also maximise profit or minimize cost of production for industrial purposes and for domestic use purposes. TDH couple with flow rate either Gallon Per Minute(GPM) or Gallon Per Hour(GPH) will help to select adequate pump in horsepower from the performance curves graph of the pump manufacturer.*

**Keywords:**Submersible pump, Total Dynamic Head(TDH), Friction losses, Dynamic water level, pumping level, vertical rise, pipe length, fittings equivalent in feet or meter

## *Introduction*

**I**n Nigeria, the rate at which bore hole drilling is extensively adopted is high both at rural and urban area. Global competition has dramatically increased the need of companies to produce high quality competitively priced products both quickly and efficiently (Ranja*et al.*, 2012).

Each pump can operate only at a max flow rate for acertain Total dynamic Head(TDH).Even an expert manufacturer may not be able to produce a pump rendering satisfactory service if thehydraulic parameters specified by him do not meet the conditions required in the system in which the pump is supposed to operate. One of the major reasons for deterioration in such performance is the lack of proper care in system analysis and estimation of flow requirements and more importantly, actual head on pump.

Pumps move water from wells or surface sources. It is important to analyse the system properly in order to make it as efficient and economical as possible while still meeting the watering requirements(Jenkins, 2013a).

Total dynamic head (TDH) is the total "equivalent" vertical distance that the pump must move the water, or the pressure the pump must overcome to move the water to a certain height. Water pressure is expressed in pounds per square inch (psi) and is defined as the force caused by the weight of water in a column of a certain height, also known as "head." Head is a term relating feet of water in a column that exerts a certain pressure; for example, a column of water 10 ft (30.48 m) high would exert 10 ft (30.48 m) of head, or 4.3 psi (pressure). Knowing head, you can determine pressure and vice versa. Head is important to determine how hard the pump must work to move water from the source to a discharge point (i.e., to overcome the equivalent pressure of that water). Static head is a major part of TDH and refers to the total vertical lift (distance) from the water level in the well to the discharge level. Static head is composed of the water depth in the well at its lowest seasonal and draw-down levels plus the elevation from the water surface to the discharge point(Jerkins,2013b).

The amount of water that a solar pumping system will deliver over a given period of time (usually measured in gallons per minute (GPM) or gallonsper hour (GPH)) depends upon the pressure against which the pump has to work. The system pressure is largely determined by the total vertical pumping distance (the vertical distance between the water source and the watering tank) referred to simply as elevation head. It is roughly equal to an increase of 1 PSI (Pound per Square Inch) for every 2.31 feet (0.704 m)of elevation head. Simply put, as the vertical pumping distance increases, the amount of water pumped over a given period of time decreases. When system friction losses and discharge Pressure requirements (if any) are added to elevation head, the total system head can be determined. Pump manufacturers publish information that describes how each pump will perform under varying operating conditions (Buschermohle and Burns, 2009).

According to National Exploration, Wells and Pumps, size of the pump matters because it determines well diameter not the other way round. This means that before selecting a well, a pump must also be put into consideration during sizing a well.

Different types of coupling are used for water pumping purposes depending on the type of application and the water demand. Various types of pumps and motors are available for water pumping application depending on the daily water requirement, the pumping head, the suction head (for surface mounted units), and the water resource ( Foster and Ellis, 2003).

Pump performance specifications, if not matched with site operating conditions, lead to consequences that affect safety, reliability, capital costs, operational costs, etc. on actual usage. Entire range of operating conditions and the limitations imposed by the site must be duly considered before concluding on selection. The pump's ability to meet the discharge criteria is related to the pump's performance characteristics and the suction conditions imposed upon it(Bhambure, 2005).

The amount of water available from any water source is estimated using standard methods such as weir notch (for surface water) or driller's test pumping (for boreholes). At the time of drilling, drillers test the pump or bail the well before operating the pump. During test pumping, the pump in the well should operate for about 48 hours at peak water demand while the "drawdown" is measured. The minimum water level where the water can drop in the well is referred to as the "dynamic water level." The water level cannot drop below this point, even after long hours of pumping. The distance from the static water level, which is the water level before pumping is started minus the dynamic water level, is called the drawdown. Checking these factors during test pumping allows the total pumping head to be measured, which results indesign of the most suitable size and type of pump. After initial drilling, the water flow should be checked every 3–5 years to see if the well needs cleaning. The water level in the well is measured with a special type of cable that has an electrode at the end and a measuring scale in centimeters and feet. When the cable is lowered slowly into the well and the electrode touches the water surface, a signal light will illuminate on the top of the cable, registering that position. In this manner, both the static and dynamic water levels can be measured, from which the drawdown can be calculated. For routine use, a permanent water level indicator can be installed with the pump(Foster and Ellis, 2003)

Centrifugal (rotodynamic) pumps. These pumps are designed for a fixed head,meaning their efficiency decreases when the pumping head deviates from thedesign point. Unlike volumetric pumps, a significant decrease in a rotodynamicpump's power supply can cause it to fail at delivering water from a boreholebecause its vertical lifting capability is directly proportional to the power input.

The best type of equipment for a particular pumping application depends on the daily water requirement, pumping head, suction head (for surface mounted pump-sets), and the water source. Generally, positive displacement pumps are best for low flows (less than 15m³/d) and high pumping heads (30–150 meters). Submersible centrifugal pumps are bestfor high flow rates (25–100 m³/d) and medium heads (10–30 meters).( Foster, and Ellis., 2003)

Once the total gallons/day/animal figure is calculated and any extra water requirements are entered, values are summed to yield the total daily water requirement in gallons/day. A multiplier may be added that can provide an extra water cushion, offset evaporation losses, or refill the storage tank. Household water use demand is variable and depends on climate, usages, and other factors, but is typically around 75 gallons/person/day for drinking, cooking, and bathing(Jenkins, 2013a).

The friction loss in pipes depends on the diameter and pressure the pipe, as well as the amount and type of fittings used in the system. For example, friction losses in 90° elbows are higher than those experienced in “Y” connections (Foster and Ellis, 2003).

This paper was fully stressing the friction losses by fittings which must be put into consideration when calculating total dynamic head of submersible pumps.

## Methodology

Factors that helped in model development of Total Dynamic Head(TDH) were identified. These factors were:- vertical rise, pumping level, static water level, drawn down, dynamic water level, pump depth, well depth, friction losses due to (insert coupling), threaded adapter(plastic to thread), 90° standard elbow, standard Tee(flow through Run), standard Tee(flow through Side), Gate valve and swing check valve.The Schematic drawing of this study is as shown is Fig 1.

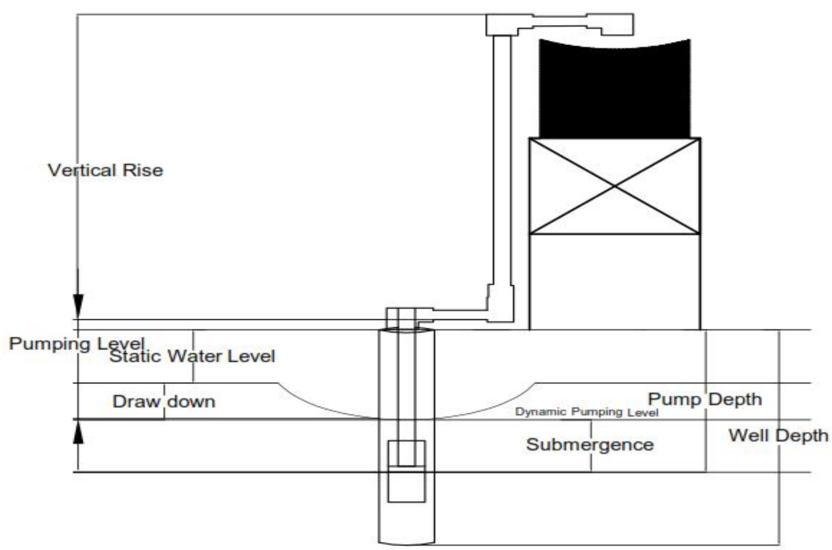



**Fig 1: Schematic drawing of Total Dynamic Head(TDH) of a submersible pump**

**Nomenclature**

| Symbol | | Meaning | Units |
|---|---|---|---|
| Let | $P_l$= | Pumping level | (ft) or m |
| | $V_r$ = | Vertical Rise | (ft) or m |
| | $F_l$= | Friction loss | (ft) or m |
| | $L_t$= | Total length of pipe | (ft) or m |
| | $f_e$= | Fittings equivalent of pipe | (ft) or m |
| | $n_f$= | Number of same fittings | |
| | $F_h$= | Friction loss of head per 100feet of pipe or 30.48m of pipe | |

## Model Development

The models developed in this study are used to compute for: frictional loss, total dynamic head while the vertical rise as well as the pump level are given;

Determination of Friction Loss in feet

$$F_l = [L_t + \sum(n_f . f_e)] \times F_h \times 100^{-1} \quad \text{--- (1)}$$

And similarly in meters,

$$F_l = [L_t + \sum(n_f . f_e)] \times F_h \times 30.48^{-1} \quad \text{--- (2)}$$

While the vertical rise ($V_r$) and the Pump level are given then.

Total Dynamic Head (TDH) in feet

$$\text{TDH} = P_l + V_r + [L_t + \sum(n_f . f_e)] \times F_h \times 100^{-1} \quad \text{--- (3)}$$

In summary, the Total Dynamic Head (TDH), TDH = $P_l + V_r + F_l$ --- (4)

## Model Application

Data was collected from a case study at Osun State "Rural Water and Environmental Sanitation Agencies" (RUWESA) to validate the developed model. This data is stated in Table 1

**Table 1: Data Collected for the Model's Validation**

| S/No | Parameters | Acronyms | Value ft(m) |
|---|---|---|---|
| 1 | Pump Level | $P_l$ | 520ft (158.50m) |
| 2 | Vertical Rise | $V_r$ | 200.5ft (61.11m) |
| 3 | Total Length of Pipe in the system | $L_t$ | 922ft (281.03m) |
| 4 | Number of same fittings in the system | $n_f$ | 4 fittings |
| 5 | Fittings equivalent in feet of pipe which has standard value in feet | $f_e$ | 3 feet (0.91m) |
| 6 | Frictional Loss | $F_h$ | 1.8ft(0.55m) |

## *Results and Discussions*

Application of Equation (3) by substituting the values in Table 1 gave a value of 737.31feet(224.88 m)
TDH = $P_l + V_r + [L_t + \sum(n_f . f_e)] \times F_h$= 737.31ft or 224.88 m
The frictional loss $F_h$ table used in this model development are as shown in Table 2 and 3.

**Table 2: Friction Loss in Equivalent Number of Feet of Straight Pipe**

| TYPE OF FITTING AND APPLICATION | PIPE AND FITTING | NOMINAL SIZE OF FITTING AND PIPE | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1/2" | 3/4" | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" |
| | | EQUIVALENT LENGTH OF PIPE(IN FEET) | | | | | | |
| Insert Coupling | Plastic | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Threaded Adapter (Plastic to Thread) | Plastic | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 90° Standard Elbow | Steel | 2 | 2 | 3 | 4 | 4 | 5 | 6 |
| | Plastic | 2 | 2 | 3 | 4 | 4 | 5 | 6 |
| Standard Tee (Flow Through Run) | Steel | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| | Plastic | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| Standard Tee (Flow Through Side) | Steel | 4 | 5 | 6 | 7 | 8 | 11 | 13 |
| | Plastic | 4 | 5 | 6 | 7 | 8 | 11 | 13 |
| Gate Valve[1] | Steel | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Swing Check Valve[1] | Steel | 5 | 7 | 9 | 12 | 13 | 17 | 21 |

Source: (N E W P, 2013)

**Table 3: Frictional Loss in feet of Head Per 100 feet (30.48 m) of Pipe**

| | | 1/2" | 3/4" | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 4" |
|---|---|---|---|---|---|---|---|---|---|---|
| GPM | GPH | ID 0.622" | ID 0.824" | ID 1.049" | ID 1.380" | ID 1.610" | ID 2.067" | ID 2.469" | ID 3.068" | ID 4.026" |
| 2 | 120 | 4.1 | | | | | | | | |
| 3 | 180 | 8.7 | 2.2 | | | | | | | |
| 4 | 240 | 14.8 | 3.7 | | | | | | | |
| 5 | 300 | 22.2 | 5.7 | 1.8 | | | | | | |
| 6 | 360 | 31.2 | 8 | 2.5 | | | | | | |
| 7 | 420 | 41.5 | 10.6 | 3.3 | | | | | | |
| 8 | 480 | 53 | 13.5 | 4.2 | | | | | | |
| 9 | 540 | 66 | 16.8 | 5.2 | | | | | | |
| 10 | 600 | 80.5 | 20.4 | 6.3 | 1.7 | | | | | |
| 12 | 720 | | 28.6 | 8.9 | 2.3 | 1.1 | | | | |
| 14 | 840 | | 38 | 11.8 | 3.1 | 1.4 | | | | |
| 16 | 960 | | 48.6 | 15.1 | 4 | 1.9 | | | | |
| 20 | 1,200 | | 60.5 | 22.8 | 6 | 2.8 | | | | |
| 25 | 1,500 | | | 38.7 | 9.1 | 4.3 | 1.3 | | | |
| 30 | 1,800 | | | | 12.7 | 6 | 1.8 | | | |
| 35 | 2,100 | | | | 16.9 | 8 | 2.4 | | | |
| 40 | 2,400 | | | | 21.6 | 10.2 | 3 | 1.1 | | |
| 45 | 2,700 | | | | 28 | 12.5 | 3.8 | 1.4 | | |
| 50 | 3,000 | | | | | 15.4 | 4.6 | 1.7 | | |
| 60 | 3,600 | | | | | 21.6 | 6.4 | 2.3 | | |
| 70 | 4,200 | | | | | 28.7 | 8.5 | 3 | 1.2 | |
| 80 | 4,800 | | | | | 36.8 | 10.9 | 3.8 | 1.4 | |
| 90 | 5,400 | | | | | 45.7 | 13.6 | 4.8 | 1.8 | |
| 100 | 6,000 | | | | | 56.6 | 16.5 | 5.7 | 2.2 | |
| 120 | 7,200 | | | | | | 23.1 | 8 | 3 | |
| 140 | 8,400 | | | | | | 30.6 | 10.5 | 4 | 1.1 |
| 160 | 9,600 | | | | | | 39.3 | 13.4 | 5 | 1.4 |
| 200 | 12,000 | | | | | | 66.3 | 20.1 | 7.6 | 2.1 |
| 260 | 15,600 | | | | | | | 32.4 | 12.2 | 3.4 |
| 300 | 18,000 | | | | | | | 42.1 | 15.8 | 4.4 |

Source: (N E W P, 2013)

## Pump Requirements for Procurement

### Sizing the System

The type of information you will need to supply to the vendor to have your system designed or to solicit a price quote includes:

(a) The maximum number of gallons of water needed daily for each month of the year.
(b) Description of water source.
(c) Total vertical distance that water is to be pumped, as measured from the lowest level from thewater source to the highest level of the watering tank, including the pipe outlet.
(d) Quality of water. Is it clear, silty, high in mineral content or does it contain a lot of algae growth?(Morris and Lynne, 2002).

Before this model was effectively utilized, the followings were duly observed.

### Guides before Installation

Before beginning installation, the following checks should be made. They are all critical for the proper installation of this submersible pump.

(a) Condition of the Well: If the pump is to be installed in a new well, the well should be fully developed and bailed or blown free of cuttings and sand. The stainless steel construction of the Grundfos submersible make it resistant to abrasion; however, no pump, made of any material,can forever withstand the destructive wear that occurs when constantly pumping sandy water. If this pump is used to replace an oil-filled submersible or oil-lubricated line-shaft turbine in an existing well, the well must be blown or bailed clear of oil.
Determine the maximum depth of the well, and the draw- down level at the pump's maximum capacity. Pump selection and setting depth should be based on this data. The inside diameter of the well casingshould be checked to ensure that it is not smaller than the size of the pump and motor.

(b) Condition of the Water: Submersible pumps are designed for pumping clear and cold water that is free of air and gases. Decreased pump performance and life expectancy can occur if the water is not cold and clear or contains air and gases.Maximum water temperature should not exceed102°F. Special consideration must be given to the pump and motor if it is to be used to pump water above 102°F. The Grundfos stainless steel submersible is highly resistant to the normal corrosive environment found in some water wells. If water well tests determine the water has an excessive or unusual corrosive quality, or exceeds 102°F, contact your Grundfos representative for information concerning specially designed pumps for these applications.

(c) Installation Depth:A check should be made to ensure that the installation depth of the pump will always be at leastthree feet below the maximum draw-down level of the well. For flow rates exceeding 100gpm, the NPSH may have to be considered. Refer to NPSH curves in the technical brochure. The bottom of the motor should never be installed lower than the top of the well screen or within five feet of the well bottom. If the pump is to be installed in a lake, pond, tank or large diameter well, the water velocity passing over the motor must be sufficient to ensure proper motor cooling.

(d) Electrical Supply: The motor voltage, phase and frequency indicated on the motor name plate should be checked against the actual electrical supply(Grundfos, 2000).

Below the casing and in line with aquifer is another casing with fine slots. This is the well screen, where the slots allow the water to enter the well. It holds back sand larger particles trying to enter the well.

There are some pumps that permit some mg/l of sand content while some didn’t. For example, Grundfos pumps permit a sand content of no more than 50mg/l, the pump efficiency and the lift time will remain accepted for up to 25000-35000 duty hours, equal to approx four years of operations for eight hours a day. And moreover if the well water has a sand content higher than 50mg/l, a special pump and motor is available on request. Before the well can be put into operation, it must be developed. A new well will always produce some sand and silt in the beginning and well development is the process of pumping a new well free from sand and silt. It is done by pumping with a very high flow which draws the particles in the aquifer into the filter of the well. This slowly makes the filter more effective. Approximately one day of pumping, the well is normally pumped clean and is ready for normal operation.

The pump used for well development wear out relatively quickly because of the high sand content and it should therefore always be replaced with a new pump as soon as the well does not produce any more sand. The pump must always be installed above the screen area of the casing. In this way, you ensure that the water is forced past the motor, providing adequate motor cooling. If the pump cannot be installed above the screen filter, a cooling sleeve is always recommended to create the necessary flow along the motor for proper cooling.

When the pump is installed the draw down and dynamic water level must always be known. During operation, the water must never fall below the inlet of the pump. The risk of cavitation is normally very small with submersible pumps.

From eqn (ii), the eqn now gives the room for summation of all losses due to fittings as well as number of the same fittings in the system is also considered. That is, in a single system TDH calculation, is possible to have more than one 90° standard elbow, one swing-type check valve and one gate-type valve in the pipe line.

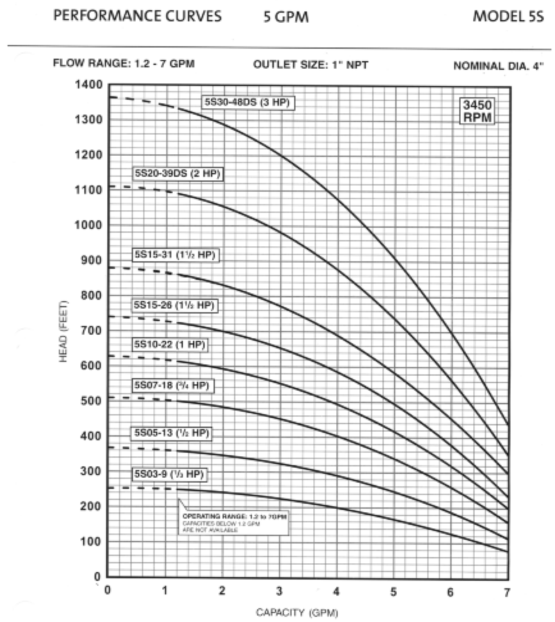
## *Conclusion*

The model developed will be a contributing tool for submersible pump installer and prospective users as it makes their calculation and estimation work easier with the help of computer software incorporated with this model.
The era of installer saying horsepower in selecting a pump should be off now, horsepower does not give adequate and appropriate solution in selecting pump, rather total dynamic head gives an installer appropriate calculation in selecting submersible pump.

With all these putting into consideration, installers would able to give installation warranties coupled with pump manufacturer warranties because adhering strictly to what the pump predicts, there won’t be overwork for the pump, there won’t be overheating as a result of neglecting loss in fittings which also counts during pumping and linear life span of the pump will also be guaranteed as stated by pump manufacturer. Also, total dynamic head calculation will also minimize and eradicate replacement or repair of pumps which can also maximise profit or minimise cost of production for industrial purposes and for domestic use purposes.

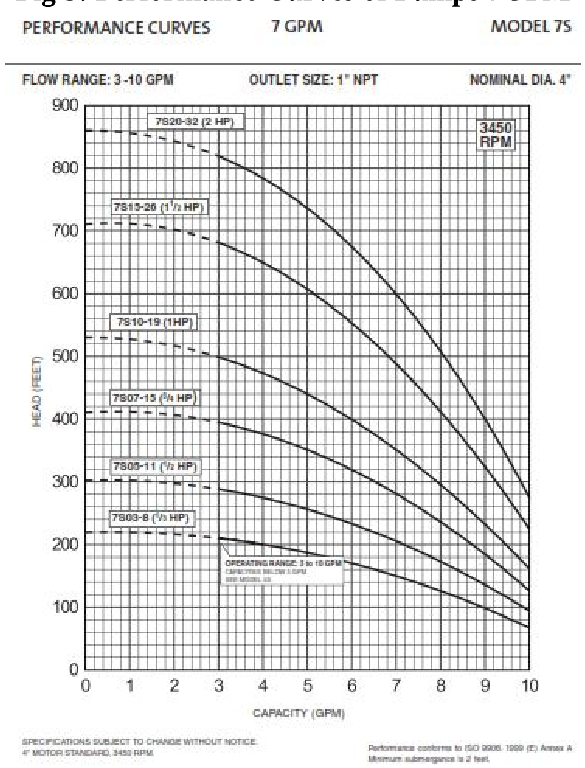
Lastly, total dynamic head coupled with flow rate in GPM or GPH will help to select adequate horsepower of pump from the performance curves graphs shown in Figures 2 and 3.

**Fig 2: Performance Curves of Pumps of 5GPM**




Source: (N E W P, 2013)

**Fig 3: Performance Curves of Pumps 7GPM**




Source: (N E W P, 2013)

### *Acknowledgement*

Thanks to the Management of Osun State Rural Water and Environmental Sanitation Agencies (RUWESA), Osogbo, Osun State, Nigeria especially Engr 'Bayo Adigun and Afolabi Oluwasola E. and all staffs at the Works & Maintenance Department of the Agencies for providing enabling environment, which is conducive in carrying out this study.

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