

*Full Length Research Paper*

# Hands-on model of sucker rod pumping facility for oil well production

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Often students of the petroleum engineering programs at the early stage of their studies in institutions of developing countries do not have easy access to the oil and gas industry facilities. Multinational petroleum companies come in with the state-of-the-arts technology, with expatriates who work and leave without technology transfer. Laboratory equipment is very costly to developing institutions of petroleum studies in developing nation. As such, different hands-on models have been developed to simulate different processes of the oil and gas industry in the laboratory. This model captioned "Golden Horse Head" Sucker Rod Pumping model is one of such hands-on models that has been constructed and successfully tested. This model is 88 cm in length, 52 cm wide and 56.5 cm high. It was made using very basic local materials to represent the actual field components, for the purpose of better understanding of how such systems operate. The materials are very affordable and less costly. The overall cost of the model is about 75,000FRS CFA, that is, about US\$150.0. This low cost of construction makes the model very affordable to developing institutions of petroleum studies. In this model, there was a reduction from the prime mover speed of 2000 rpm to the pumping speed of 38 rpm, giving a reduction ratio of 52.6:1. It has been tested with a multiphase fluid (water and oil (diesel) simulating crude oil) model, during which 75.4% oil and 97.7% of water were produced. Its functioning accurately simulates that of a practical oil field sucker rod pumping facility.

**Key words:** Developing countries, oil well, model, low-cost, Sucker-rod, pump unit.

## INTRODUCTION

Over the recent years, more and more petroleum reserves are discovered in developing nations, most of which are in Africa. The recent universities survey by Schlumberger Business Consulting and SPE International in 2012 (Schlumberger Business Consulting, 2014) shows that there is a big gap between demand and supply of graduates to the petroleum industry. This gap is

worse for Africa. Most often, oil and gas reserves in these developing nations are exploited by multinational petroleum companies. These companies come in with the state-of-the-arts technology, with expatriates who work and leave without technology transfer. To encourage the development of local content in this sector and reduce capital flight, the growth of institutions for

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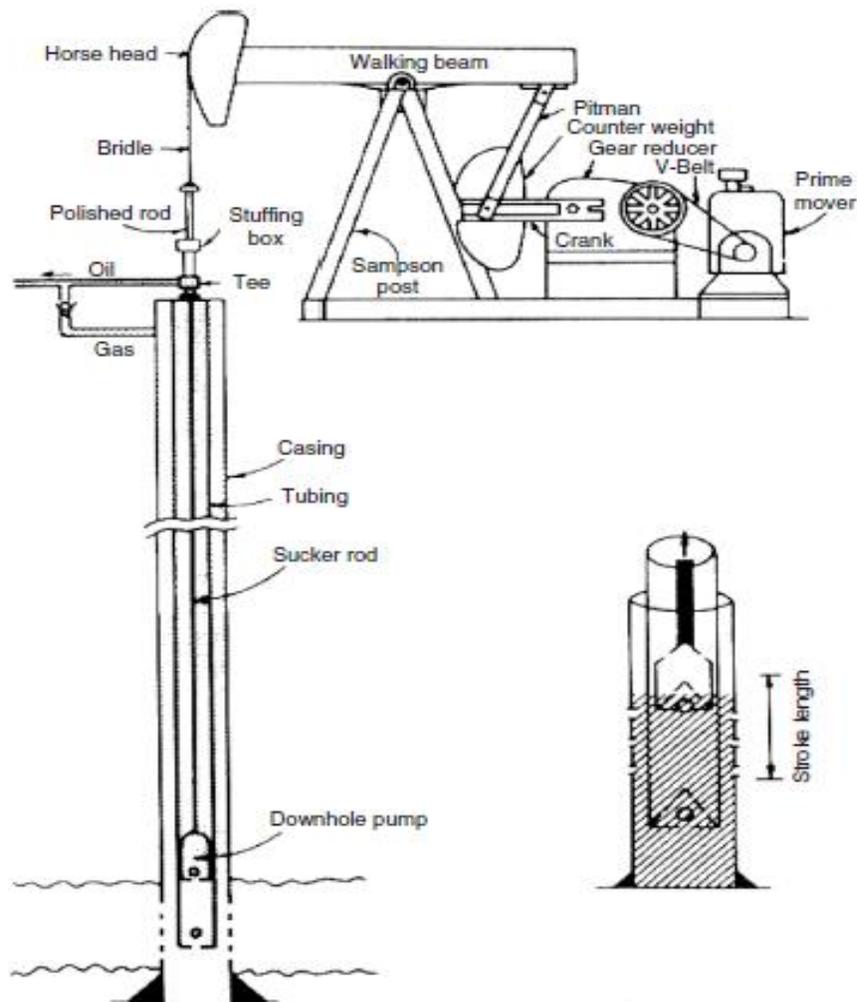


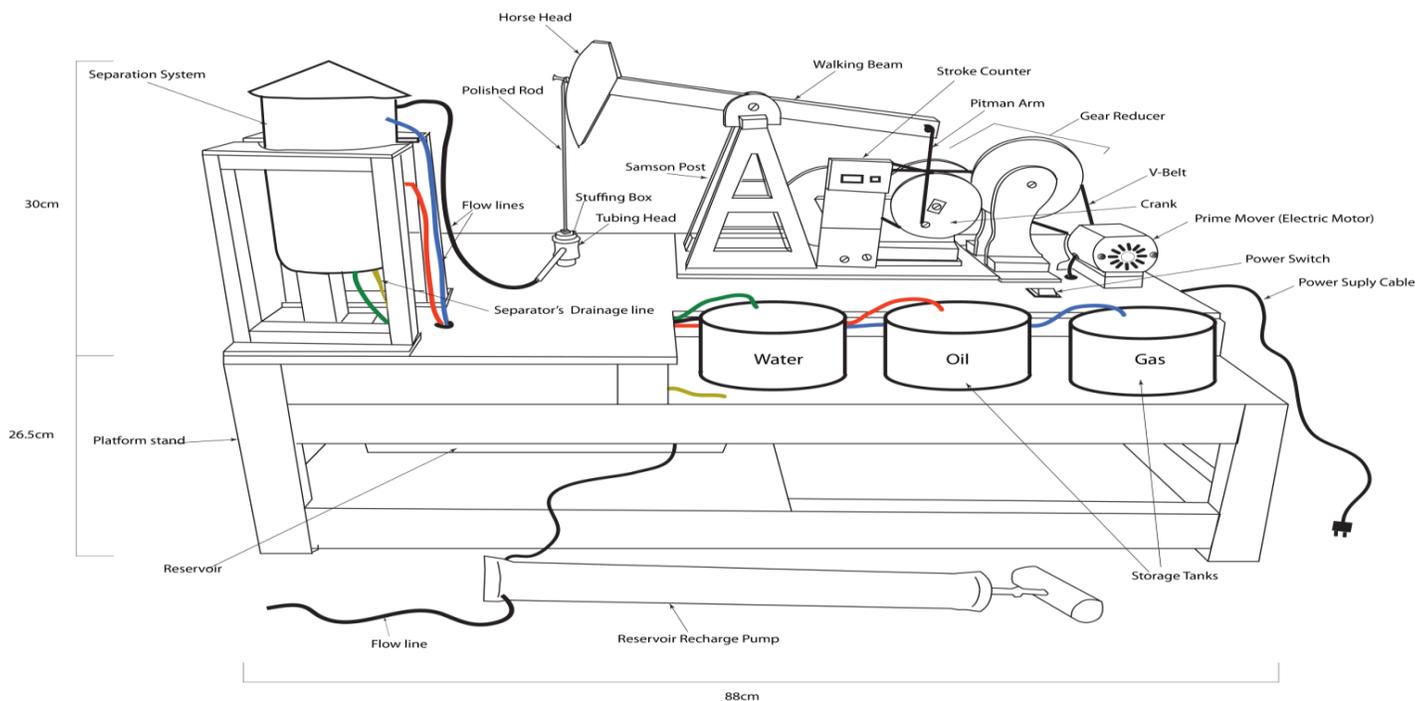
Figure 1. A schematic diagram of a sucker rod pumping system (Golan, 1991).

petroleum studies is highly encouraged, thus the strive for so many institutions of petroleum studies in these nations, particularly in Cameroon. The laboratory equipment required to run such institutions are often very expensive and not affordable by some of these developing institutions. It is therefore imperative that while looking for funds to equip these laboratories, hands-on models should be developed to assist in teaching some of the aspects of the oil and gas industry. Many books, technical articles, and industry standards have been published on the sucker-rod lift method and related technology (Economides et al., 1994; Guo et al., 2007; Golan, 1991). This work is aimed at developing a hands-on model of the sucker rod pumping unit using very basic materials to represent the actual field components. This will help improve a better understanding of how such systems operate in the field, and also inspire students to apply the basic knowledge acquired in class to think, create, make and innovate models in the petroleum sector.

## System description

### *Sucker rod pumping system*

Sucker rod pumping system is one of the oldest and most widely used production methods for oil wells. It is an artificial-lift pumping system which uses a surface power source to drive a down-hole pump assembly. Sucker rod pumping unit is classified under the positive displacement or reciprocating group of pumps. A sucker-rod pumping system is made up of several components, some of which operate aboveground and other parts of which operate inside the well as demonstrated on Figure 1 (Clegg, 2006; Takacs, 2003). The surface-pumping unit, which drives the underground pump, consists of a prime mover (usually an electric motor) and, normally, a beam fixed to a pivotal post. The post is called a Sampson post, and the beam is normally called a walking beam. A beam and crank assembly creates reciprocating motion in a sucker-rod string that connects to the down-hole pump



**Figure 2.** Schematic diagram of the complete setup of the “Golden Horse Head” sucker rod production facility.

assembly. The pump contains a plunger and valve assembly to convert the reciprocating motion to vertical fluid movement. The entire surface system is run by a prime mover, V-belt drives, and a gearbox with a crank mechanism on it (Gudmestad et al., 2001).

The relatively simple down-hole components and the ease of servicing surface power facilities render the rod pump a reliable artificial-lift system for a wide range of applications.

### **“Golden horse head” sucker rod model**

Similar to the sucker rod pumping system, the golden horse head model was constructed and is made up of surface and subsurface units as shown on Figure 2. The surface unit is made up of the following components: the prime mover (sewing machine - A555 model), linked to the gear reducer made of three sheaves of different sizes, linked together by V-belts and the Sampson post on which the walking beam is fixed. The walking beam is linked to the gear reducer through a crank-pitman mechanism. The other end of the walking beam has a horse head. This is linked to the subsurface unit through a sucker rod which in this model is again a spoke of a bicycle. The subsurface unit is made up of the subsurface pump, the casing and tubing inserted into the reservoir model attached to the base framework. The well head of the surface unit is linked to a vertical separator through a flow line. The separated fluids flow from the separator

into the respective storage tanks of oil and water. The complete setup is illustrated on Figure 2.

### **MATERIALS AND METHODS**

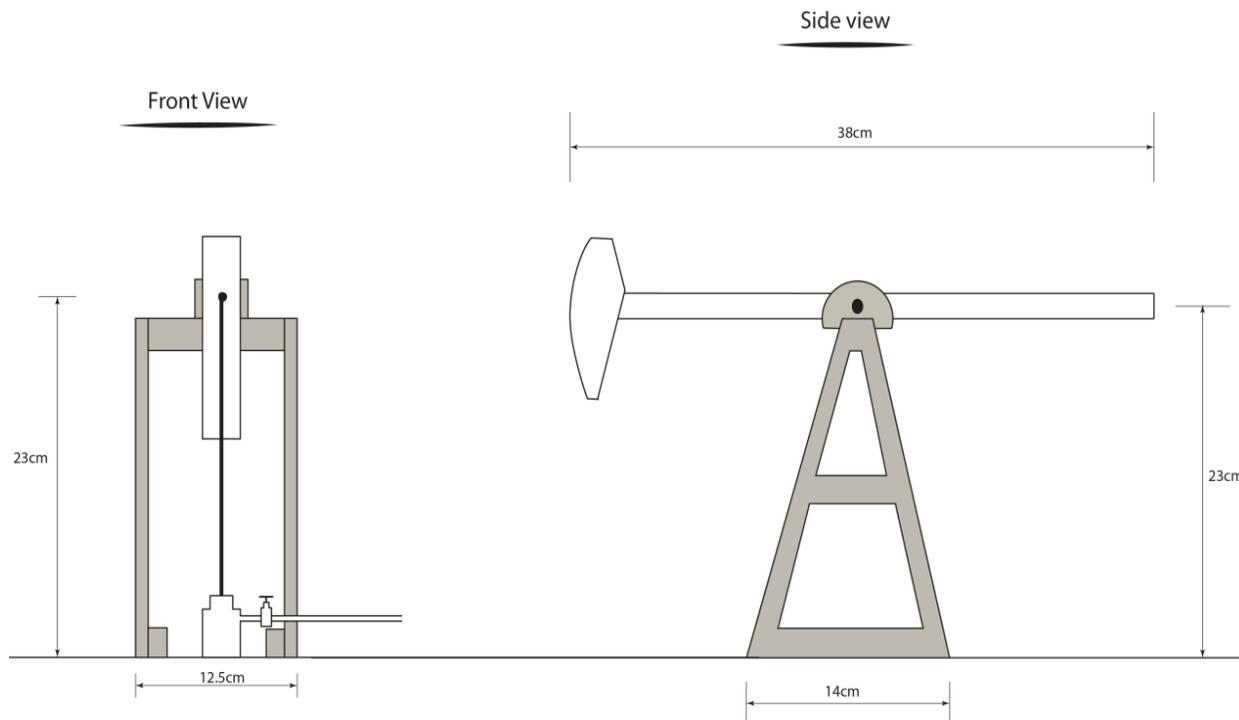
The materials used for constructing this model are mostly local materials that could be acquired in local technical shops. These include: Camwood; obeche wood; 8 mm plywood; 4 mm plywood; electric motor (Sewing machine model A555), bicycle spokes, elastic band and twine rope, pressure pipe (d25), polypropylene random copolymer (PPR) pipe (d20), bolts and nuts, rubber seals, galvanized socket and galvanized male plug, transparent flexible tubes (d4, d8 and d10), electrical power supply switch, analog counter, metal balls (d2, d4 and d6), pen casing, plastic containers (2 L and 3x1 L), metal plate (0.3 mm thick), nails, sand, grease, silicone sealant, ABRO epoxy steel, polyvinyl chloride (PVC) pipe (d40) and two PVC (d40) plugs, metal rod (d6), and paints (water based and oil based). The materials are very affordable and less costly. The overall cost of the model is about 75,000FRS CFA, that is, about US\$150.0.

### **Model construction**

This project was carried out in two phases: The desktop (preparation) study and practical phase. In the desktop phase, the system was drawn with all the dimensions stated. A list of materials, practical work methods and the budget were made.

### **Well production system**

Practically, the project started with the carving of the Sampson post (from the 8 mm plywood), then a horse head (from camwood) and



**Figure 3.** Sampson post and walking beam

walking beam (from obeche wood) that correspond to the size of the Sampson post were made. These three parts were coupled together as shown in Figure 3.

The wheels of the gear reducer were carved out from the 8 mm plywood, and the gear box was built up. These wheels were linked to each other by V-Belts (elastic band and twine ropes to prevent the elastic band V-belt from sagging) (Figure 4). The gear reducer reduced the speed of the prime mover from 2000 to 38 rpm. The gear reducer was then linked to the walking beam using a crank-pitman mechanism (a bicycle spoke connected to a small sheave). The prime mover (sewing machine motor model A555) was anchored behind the gear reducer and these two parts were linked using a V-Belt.

The base of the subsurface units which carry the reservoir was made with wood and the reservoir was made up of 9 L plastic container filled with pebbles, giving a reservoir model of 7.47 L bulk volume (Figure 5). The casing (d25 pressure pipe) and tubing (d20 Polypropylene Random Copolymer (PPR) pipe) with perforations and standing valve at the base were inserted into the reservoir model, which was then attached to the base framework. A plunger pump made from the barrel of a pen, coupled together with a traveling valve was attached to sucker rod (bicycle spoke) and inserted into the tubing as shown on Figure 6.

The down hole equipment (model reservoir-casing-tubing-plunger pump setup) was linked to the surface equipment by the help of a sucker rod (bicycle spoke). The complete setup is illustrated on Figures 2 and 9.

#### **Surface separation and storage system**

This system is made up of the separator and flow lines and fluid storage tanks. The separator is a three-phase separator, that is, separation of oil, water and gas (Figure 7). It is constructed using a 2 liters plastic container, a plaster ball partly fill with engine oil and

used as a float. The lower end of this tube is open while the upper end is closed with a breathing hole at the top. This tube is attached to wall inside the 2 L container. The float is connected to a valve system at the base of the container. This float and valve system allows water out of the container when water level reaches the maximum water mark and the valve closes when the water level drops a bit, thereby keeping the water level at a fairly constant level. Since the various liquids are being separated by gravity, oil which is usually on water, will leave the separator through an outlet just above the maximum water mark. The float is partly filled with engine oil to counterbalance the weight of the oil on top of water out of the tube containing the float. The drainage pipe at the base of the separator is used to manually empty the separator. The separated fluids drain into their respective storage tanks through flow lines made of plastic pipes. The storage tanks are 1.5 L plastic compact-disc-containers.

#### **Reservoir recharge pump**

This pump is made up of a PVC Ø40 mm pipe, 2 PVC Ø40 mm plugs, nuts, metal rod Ø6 mm with threaded ends, rubber seal, 2 valves and a wooden handle as shown on Figure 8. Its main use is to recharge fluids (oil and water) into the model reservoir.

#### **Strokes counting system**

The number of strokes made by the sucker rod was determined using an analog stroke counter recycled from an old radio set. This analog counter was connected to the crank-and-pitman mechanism by the help of an elastic band and a twine rope serving as a V-belt. Apart from the analog counter, there was no computer or electronic monitoring system to record experimental data since the main aim of the authors was to build a low-cost experimental model.

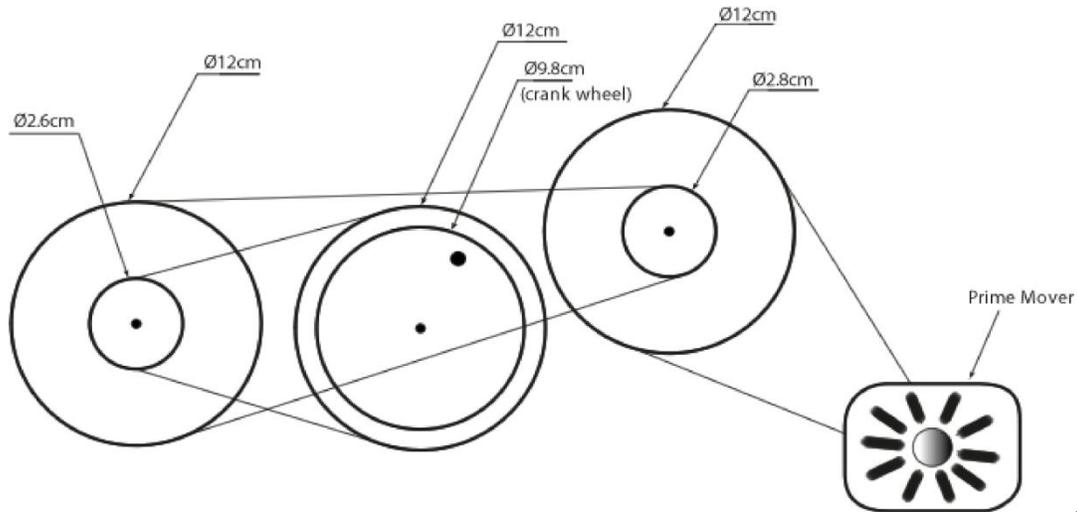


Figure 4. Gear reducer - prime mover connection.

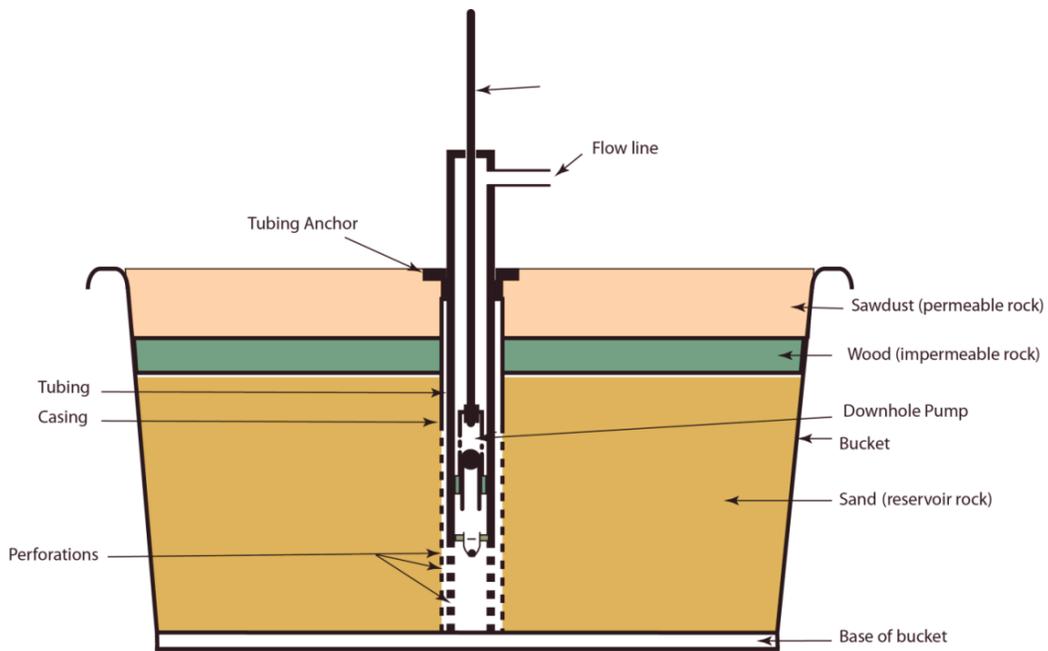


Figure 5. Schematic view of the model reservoir-casing-tubing-sucker rod pump.

**Experimental Investigation**

Testing of the model was in two phases. In the first phase, the reservoir was charged with a single phase reservoir fluid (water), with the help of the reservoir recharge pump (Figure 8). The whole model was inspected to make sure there were no leakages. The prime mover was switched on, and the water in the reservoir model was produced to the surface where the flow rate was determined using a measuring cylinder and a stop watch. The number of strokes was determined using an analog counter linked to the crank-pitman arm connection through a V-belt.

In the second phase of the experiment, the reservoir was charged with a two-phase fluid system (1.3 L of water and 1.3 L of

diesel). The diesel serves as a model of crude oil. After inspections to check for leakages, the prime mover was switched on to produce the multiphase fluid system. The multiphase fluid system was produced to the surface into the model separator (Figure 7) where gravity separation of the two phases took place. Water flew through its outlet into the water storage tank model (1.5 L plastic container), while the oil phase passed through the oil flow line into the model oil storage tank (1.5 L plastic container) as shown on Figures 2 and 9.

Prior to model testing, the bulk volume of the model reservoir was determined to be equal to 7.47 L. The total volume of water charged into the pore space of the reservoir was 2.6 L. In the second phase of the experiment, the volume of oil in place could be

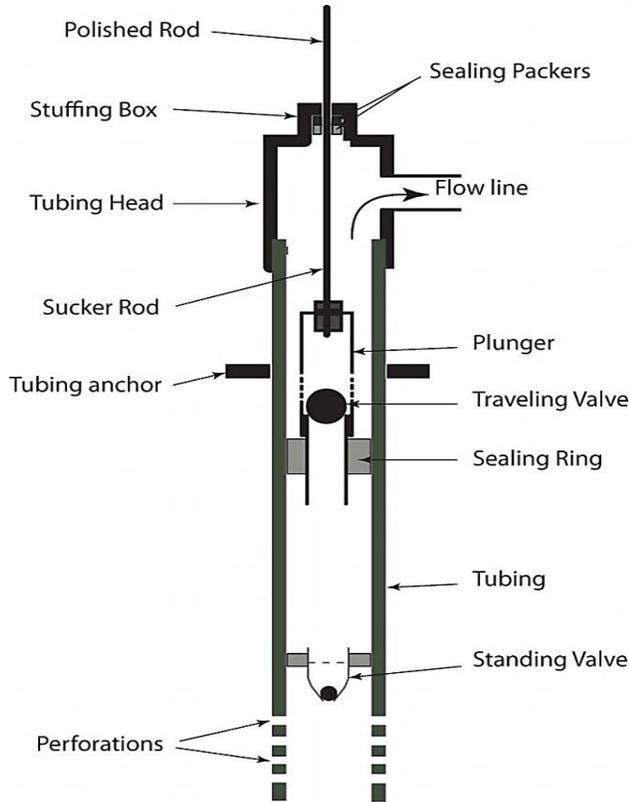


Figure 6. A schematic view of the down-hole plunger.

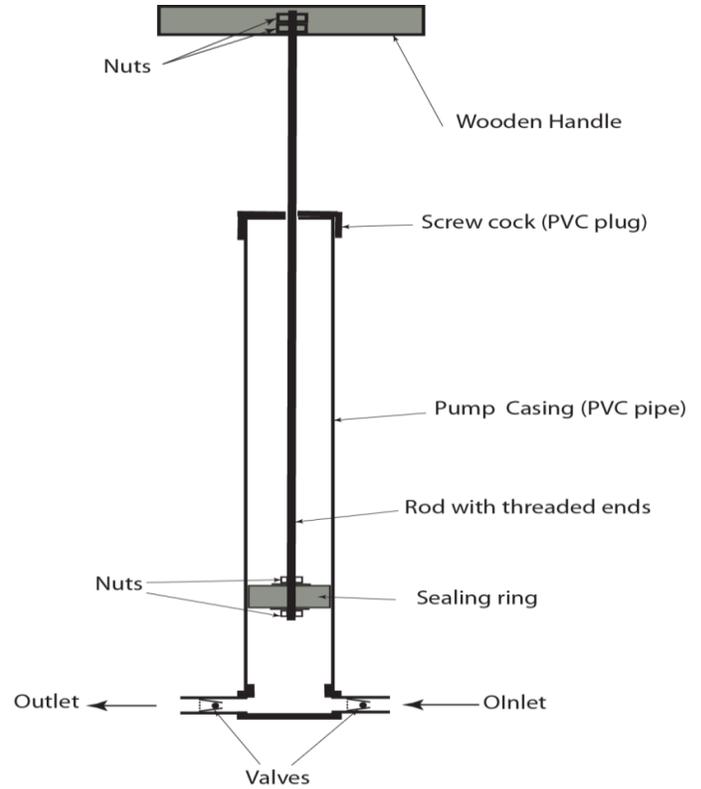


Figure 8. Reservoir recharge pump.

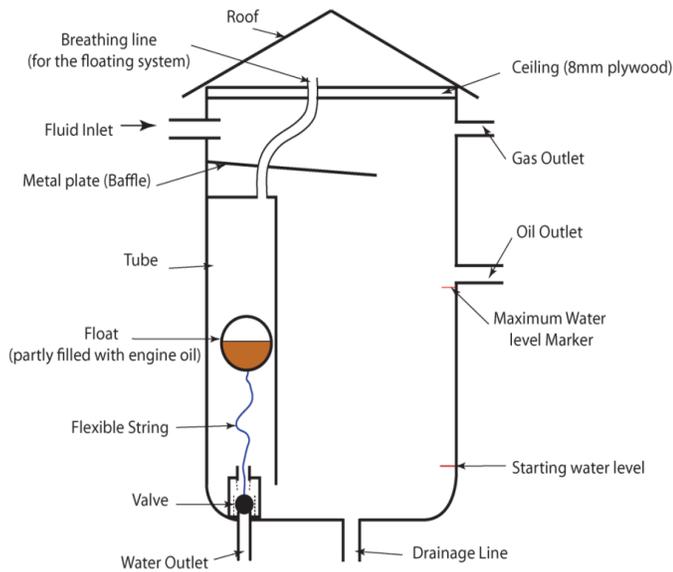


Figure 7. Vertical cross-section of the model separator.

estimated using the basic volumetric formula (Towler, 2002) given by:

$$N = Ah\phi(1 - S_{wi}) \quad (1)$$

Positive-displacement pump performance is evaluated based on the volume of fluid displaced, not the pressure increase generated by the pump, since the compression of the wellbore fluid in the pump will create enough pressure to displace the fluid in the tubing (Economides et al., 1994). The volumetric flow rate displaced by the rod pump is:

$$q = NE_v A_p S_p \quad (2)$$

The production rate of water,  $q_w$  during the first phase of testing was determined as follows:

$$q_w = \frac{V_{w,prod}}{t} \quad (3)$$

The residual water volume in the pore space was calculated:

$$V_{w,res.} = V_{w,t} - V_{w,prod.} \quad (4)$$

## RESULTS AND DISCUSSION

During the first phase of testing, 2.25 L of water were produced before the start of influx of air bubbles. This took place at 356 strokes. The number of strokes per minute was determined to be equal to 38 strokes/minute, and the volume of water produced per stroke was 0.007 L/stroke, giving a production capacity of 0.27 L per minute.

The production rate of water,  $q_w$  during the first phase of testing was determined to be equal to 0.27 L/min. The



**Figure 9.** Hands-on model of the “Golden Horse Head” Sucker Rod production facility.

**Table 1.** Summary of production data of the experiment.

Fluid	First phase		Second phase	
	% produced	% residual	% produced	% residual
Water	86.5	13.5	97.7	2.3
Oil	-	-	75.4	24.6
Total fluid	86.5	13.5	86.5	13.5

residual water volume in the pore space was calculated to be equal to 0.35 L.

During the second phase of production, 1.27 L of water and 0.98 L of diesel were produced. The bulk volume of liquid produced during phase was equal to 2.25 L and equal to the bulk volume produced during the first phase of the experiment. The residual water was 0.03 L and the residual oil was 0.32 L, giving a total residual liquid of 0.35 L. The water cut during the second phase of the experiment was determined to be 0.56.

The percentages of the fluids produced during both phases of the experiment were calculated and presented in Table 1.

Each component of a sucker rod pump has a unique name as well, which may seem difficult to understand unless someone is familiar with the machinery. The individual parts all serve as jointed links in a mechanical chain reaction that gradually transfers circular motion to a general up-and-down pumping motion (Hawk, 2014). The industry standards for pumping units have developed minimum requirements for the design and manufacture of the various structured components-the beams, shafting, hanger, brakes, horsehead, cranks, and bearings. These standardized structures are more widely known by the

respective designations as Conventional, Mark II™, Air balanced, and Reverse Mark™ (Guo et al., 2007). The conventional unit is probably the unit used most often. It is simple to install, has the widest range of sizes available, and usually has lower operating costs than other units. The golden horse head sucker rod model structure is of the conventional type. The materials used for the construction of the model are very affordable and less costly. The overall cost of the model is about 75,000FRS CFA, that is, about US\$150.0. The setup is easy to operate and can be installed in any laboratory for educational purposes so far there is power source to run the model.

The pumping unit is characterized by kinematic parameters such as the suspension point displacement, velocity and acceleration (Kong and Wu, 2013; Liu et al., 2011) and gear box torques (Takacs and Gabor, 2012). The golden horse head sucker rod model could be used not only for academic purposes, but also for research purposes to investigate the influence of these kinematic parameters on the sucker rod pumping unit performance.

There are 18 gear-reducer sizes currently included in API Spec. 11E (1994). The size range is from 723.1 to 412,168.67 N-m capacity. The gear reducer of the model

is made up of three (3) sheaves (grooved pulley wheels) that are linked together using twine ropes (V-belt). The sizes of the sheaves range from 2.6 to 12 cm.

Sucker-rod pumping units can be operated over a range of pumping speeds. It has been recognized that there is a need for a nominal pumping speed to rate the various gear reducers. Originally, the industry adopted a nominal speed of 20 spm. This assumed that the up and down stroke of a unit forms one complete stroke cycle. As *API Spec. 11E* has been revised over time, rating speed for the 456- and larger-sized reducers has been reduced because it was not practical to expect larger gearboxes to operate at 20 spm with longer stroke lengths and larger-sized structures. In actuality, industrial applications with these similar-sized reducers can be operated from 580 to 1,750 rpm (AGMA 422.03, 1998). The “golden horse head” model was operated at a steady speed of 38 spm which for such a small model is acceptable as compared to the reducers used in actual field applications.

Pumping units typically use single- or double-reduction gearing, with an approximate 30:1 speed reduction from the prime-mover to the pumping speed. The standards also include chain reducers that use sprockets and chains for transmitting the prime-mover speed through the structure to the rod string. In this model, there was a reduction from the prime mover speed of 2000 rpm to the pumping speed of 38 rpm, giving a reduction ratio of 52.6:1.

The sucker rod pump design typically removes about 20 L of fluid for every cycle of the pump, which equates to one barrel of oil or 159 L for roughly every eight pumping cycles (Hawk, 2014). In the USA alone about 441,500 wells belong in the stripper well category with production rates below 1.59 m<sup>3</sup>/day. The production capacities of rod pumping installations range from very low to high production rates. As lifting depth increases, a rapid drop in available production rate is observed. At any particular depth, different volumes can be lifted depending on the strength of the rod material used. Stronger materials grades allow greater tensile stresses in the string and thus permit higher liquid production rates (Takacs, 2003). During the first phase of testing the model, 2.25 L of water were produced before the start of influx of air bubbles, and the volume of water produced per stroke was 0.007 L/stroke, giving a production capacity of 0.27 L/min, equivalent to a daily production of 0.39 m<sup>3</sup>/day.

The high liquid production during both phases of the test is linked to the very high porosity and permeability of the reservoir model where the rock model was pebble instead of sandstone. The relatively high water production compared to oil production during the second phase of the experiment could be due to high water mobility compared to oil mobility (Ahmed, 2006). It could also be due to the fact that the casing model was perforated very close to the base of the reservoir model, that is, the water saturated zone. Uniform perforation of the casing within the pay zone would yield a higher oil

production.

Two principal categories of sucker-rod pumps are the tubing- pump and insert- or rod-pump (Gudmestad et al., 2001). In a tubing-pump, the working barrel is an integral part of the tubing string. It is connected to the bottom of the tubing and run to the desired depth with the tubing string. This construction allows using a barrel diameter slightly less than the tubing inside diameter. Below the barrel of the tubing pump, a seating nipple is mounted into which the standing valve can be locked. The downhole pump (Figure 6) designed for the golden horse head sucker rod pump model is of the tubing-pump type.

### Limitations

This hands-on model has the following limitations:

1. Apart from the analog counter, there was no computer or electronic monitoring system to record experimental data since the main aim of the authors was to build a low-cost experimental model.
2. There was relatively high water production compared to oil production during the second phase of the experiment. One of the limitations of the model that could contribute to this could be the fact that the casing model was perforated very close to the base of the reservoir model, that is, the water saturated zone. Uniform perforation of the casing within the pay zone would yield a higher oil production.
3. The model prime mover warms up when switched on for long. This could be resolved by applying a more durable prime mover.
4. At the present state, it is difficult to handle gas as a third phase. New measures have to be taken if gas has to be added as the third phase.

### Conclusion

This sucker rod pumping model captioned “Golden Horse Head” has been successfully conceived, constructed and tested. The materials are very affordable and less costly. The overall cost of the model is about 75,000FRS CFA, that is, about US\$150.0. This low cost of construction makes the model very affordable to institutions of petroleum studies in the developing countries. Its functioning accurately simulates that of a practical oil field sucker rod pumping facility. It has been tested with a multiphase fluid (oil, water and gas) model, and accurately simulates the actual sucker rod pumping facility in oil fields. The setup is easy to operate and can be installed in any laboratory for educational purposes so far there is the required power source to run the model. The golden horse head sucker rod experimental model could be used for academic purposes in laboratories of institutions of petroleum studies in developing countries to demonstrate the functioning of actual sucker rod

pumping facilities and to investigate kinematic parameters and gear box torques of sucker rod pumping unit. The model will go a long way to encourage students of the petroleum engineering sector to apply the concept of “learn, think, create, make and innovate” which is highly encouraged in developing countries hoping to emerge and contribute to the development of their oil and gas industries.

**Nomenclature:** **A**, cross sectional area (cm<sup>2</sup>); **d**, pipe diameter (mm); **E**, efficiency; **h**, height of reservoir model (cm); **N**, pump speed, (spm); initial reservoir volume of oil (cm<sup>3</sup>); **q**, volumetric flow rate (m<sup>3</sup>/day); **rpm**, revolutions per minute; **SBC**, Schlumberger Business Consulting; **S**, saturation, length (m); **SPE**, Society of Petroleum Engineers; **spm**, strokes per minute; **t**, time (mn); **V**, volume (m<sup>3</sup>); **∅**, porosity;

**Subscripts:** **n**, nominal; **p**, plunger; **r**, residual; **t**, total; **v**, volume; **w**, water;

### Conflict of Interest

The authors have not declared any conflict of interest.

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