

Artificial Lift Power Efficiency

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Introduction:

The purpose of artificial lift equipment is to do work by adding extra power to the produced fluid so that the fluid will flow to the surface. The power added lifts the produced fluid to the surface at a rate higher than the well power can provide. The power is added to the fluid by some type of downhole pump or gaslift. "Artificial Lift Efficiency" is a way to calculate how effective a particular type of lift equipment is in adding power to lift the fluid.

In the literature there are many definitions of artificial lift power efficiency, but there is not one particular accepted equation. Reference 1 lists and reviews a number of references, which provide a variety of expressions calculating artificial lift efficiency. Also this reference compares a number of ESP vs. Beam Pump wells with electrical or power efficiency. However, in the paper it is shown that the definition of efficiency that was used in that study is subject to some unexpected variations if the surface pressure or amount of gas produced through the tubing is varied. Because of this, the definitions of artificial lift efficiency are reviewed and a standard equation is recommended.

Artificial Lift Efficiency:

From an ESP stage curve, the output hp is calculated from the product of volumetric flowrate multiplied by the Δp across the total pump. This term ($Q \times \Delta p$) is often termed the hydraulic horsepower (HHP). Because of this, the total system efficiency is often calculated by dividing the hydraulic horsepower by the input power delivered to the well at the surface. The input power could be just the Kw input to the system and converted to appropriate units. The total system efficiency would be:

$$\eta = K \times Q \times \Delta p / K_w$$

where, K is an appropriate units conversion factor. This expression gives some unexpected results when surface pressure is varied. Because of this, the definition of efficiency is re-examined in this paper and an expression without the unexpected results is recommended.

Note that if compressible flow exists, then the term becomes more complex and the hydraulic horsepower becomes HHP,

$$\text{HHP, with compressible fluids} = \int_{p_{ip}}^{p_d} Q dp$$

where: p_d = pump discharge pressure

p_{ip} = pump intake pressure

The above term becomes complex if you consider gas in solution, gas out of solution , combinations of each during the pump cycle, etc. The equations in this paper will be for the case of fluids that are incompressible or slightly compressible.

ESP Efficiency:

The input to a single stage (or multiple stages) is determined by the BHP curve from a stage performance curve as shown below. Using the ESP stage curve, a point at any flow rate on any two curves can be used to calculate a point on any of the other two curves.

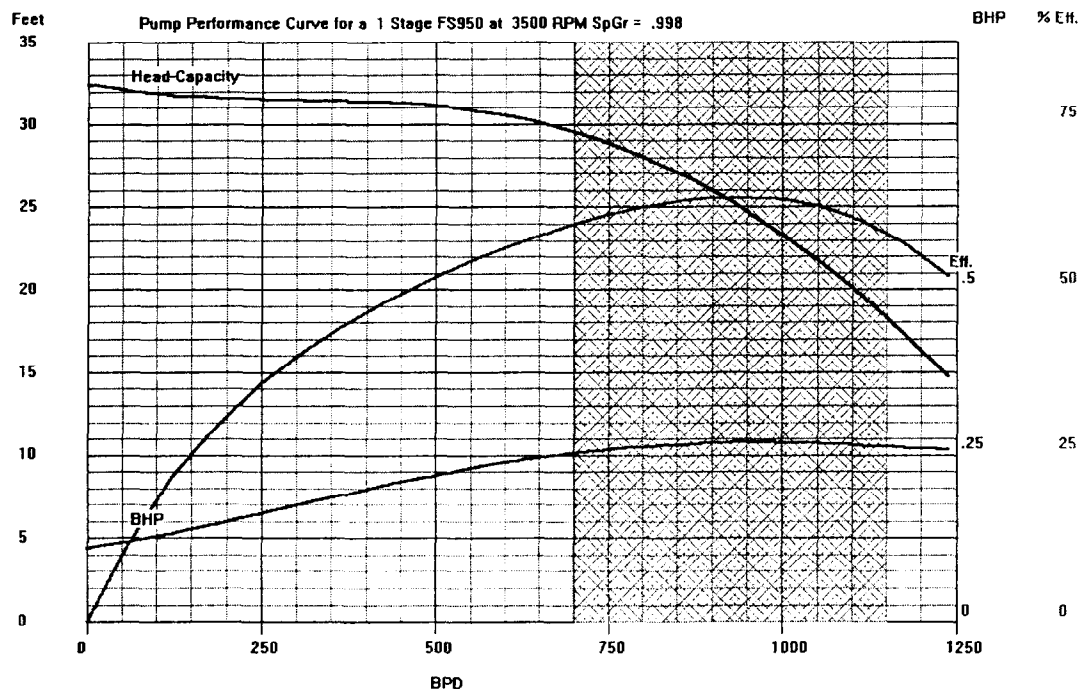
The relationship is :

$\eta_{\text{esp pump}} = (Q, \text{ bpd})(\text{Head, ft}) / (\text{BHP} \times 136986.3)$, where η is the efficiency of an individual stage.

Example: at 1000 bpd from below curve, the BHP is about .254 and the Head is about 23.2 ft. Calculate the efficiency:

$$\eta_{\text{esp pump}} = 1000 \times 23.2 / (.254 \times 136986.3) = .666 \text{ or } 66.6 \%$$

This value of efficiency can be approximately read from the below pump performance curve.



It should be noted, that the output HP of the stage is $H_p, \text{ out} = Q, \text{ bpd} \times \text{Head, Ft} \times \text{SG} \times 7.36 \times 10^{-6}$ where SG is specific gravity of fluid through the pump. The question that will be explored below is how should this output HP be used in calculating a "system" efficiency.

ESP Efficiency from the Surface Input to the Pump Output:

First consider the losses from the surface to the pump output.

The definition of this efficiency is:

$$\eta, \text{ surface input to pump output} = Q, \text{ bpd} \times \Delta p, \text{ pump} \times 1.7 \times 10^{-5} / (\text{Kw} / .746)$$

or:

$$\eta, \text{ surface input to pump output} = Q, \text{ bpd} \times \text{Head, pump} \times \text{SG} \times 7.368 \times 10^{-6} / (\text{Kw} / .746)$$

Where:

Kw/.746 is the electrical power being supplied to the system at the surface.

In terms of pressure, the blow equation converts pump head to pressure difference.

$$\Delta p, \text{ psi} = \text{Head, pump} \times \text{SG} \times .433$$

The efficiency from the surface input to the pump output can also be calculated as a product of efficiencies of individual components as in the following expression. Note, that the following expression calculates exactly the same result as the proceeding expressions:

$$\eta, \text{ surface input to pump output} = \eta_e \eta_c \eta_m \eta_p$$

Where above the efficiencies of the surface electrical equipment, η_e , the cable, η_c , the motor, η_m , and the pump, η_p , are multiplied together to get the total system efficiency. Other efficiencies with small losses could be interjected such as losses for gas separators, seal sections or protectors, or other components could be added here.

Example Calculation:

Design rate: 1000 bpd

Surface tubing pressure: 100 psi

$P_r = 900$ psi, $P_{wf} = \text{PIP} = 400$, $\text{PI} = 2.0$

Depth to pump, perforations, 5000 feet

Avg. well temperature, 100 F

Use water properties for simplicity, ($\text{SG} = 1.0$)

Tubing ID = 1.995", Friction factor for tubing = .03

Use proceeding pump curve for calculations:

Calculate velocity in tubing:

$$Q, \text{ ft/sec} = 1000 \times 5.615 / (24 \times 3600) = .0649$$

Calculate the area of the tubing cross section, sq. ft.

$$A = .0216$$

Calculate the velocity in the tubing, ft/sec

$$V = .0649 / .0216 = 3. \text{ Ft/sec}$$

Calculate (approximately) Pump discharge pressure = Pd

Pd = P_{tbg} + gravity effects + friction effects

$$= 100 + 5000 \times .433 + .433(.03)(5000 \times 12/1.995) \times (3^2)/(2 \times 32.2)$$

$$= 2319 \text{ psi}$$

$$\text{PIP} = 400 \text{ psi}$$

Calculate the total dynamic head:

$$\text{TDH} = (\text{Pd} - \text{PIP})/.433 = (2319 - 400)/.433 = 4432 \text{ ft}$$

From pump curve, read about 21.41 ft/stg and $\eta_p = 62.5\%$

$$\# \text{ stages} = 4432/21.41 = 207 \text{ stages}$$

Assume the motor selected has 1170 NPV and 38 NPA with $\eta_m = 82\%$

$$\text{BHP} = \# \text{stages} \times \text{BHP/stg} = 207 \times .265 = 55 \text{ BHP}$$

Calculate the cable loss, assuming a number 1 flat cable:

The $\Omega/1000$ ft from tables is 0.158×1.136 (temperature correction factor)

The cable loss in HP is

$$\text{Cable loss, hp} = 3.0 I^2 R / 746 = 3.0 \times 38^2 \times 1.136 \times .158 / 746 = 5.21 \text{ hp}$$

The output of the cable efficiency is the motor input so the cable efficiency is:

$$\begin{aligned} \eta_c &= \text{output/input} = \text{bhp}/\eta_m / (\text{bhp}/\eta_m + \text{cable loss}) = \\ &= (55/.82) / (55/.82 + 5.21) = 0.928 \end{aligned}$$

Assume the surface equipment electrical efficiency is :

$$\eta_e = .97$$

So calculating the efficiency from the surface input to the pump output:

$$\eta_{\text{surface to pump output}} = \eta_e \eta_c \eta_m \eta_p$$

$$= .97 \times .928 \times .82 \times .625 = .46 \text{ or } 46\% \text{ efficiency from surface input to the pump output.}$$

$$\begin{aligned} \text{The pump output hydraulic hp, HHP, is} &= Q, \text{ bpd} \times \text{Head, pump} \times \text{SG} \times 7.368 \times 10^{-6} \\ &= 1000 \times 4432 \times 1.0 \times 7.368 \times 10^{-6} = 32.62 \text{ hp} \end{aligned}$$

$$\text{The input at the surface is } K_w/.746 = 32.62/.46 = 70.9 \text{ hp}$$

Checking using the efficiency with the pressure increase across the pump:

$$\eta_{\text{surface to pump output}} = Q_{\text{bpd}} \times \Delta p_{\text{, pump}} \times 1.7 \times 10^{-5} / K_{\text{w}}/.746$$

$$= 1000 \times 1919 \times 1.7 \times 10^{-5} / 70.9 = 0.46 \text{ or } 46 \%$$

To calculate the η (surface input to pump output), then use the above formula where $\Delta p = (P_d - \text{PIP})$ and obtain P_d from a multiphase flow correlation considering gas through the pump or simplistically as in the above example (for high water production). The PIP, pump intake pressure, varies as a function of flow rate produced from the well. The PIP can be obtained by a well inflow performance calculation using the desired production rate and the PI or IPR of the well. The PI can be determined from a representative production volume test, static bottom hole pressure and a producing pump intake pressure. A fluid level shot can be used to determine the PIP, but an accurate PIP should include the effect of: 1) the casing pressure, 2) the gas pressure from the surface to the fluid level, and 3) the pressure increase across a fluid level to pump intake correcting for the gas content of the fluid level.

So for field measurements for efficiency of surface input power to pump output, use:

$$\eta_{\text{surface to pump output}} = Q_{\text{bpd}} \times \Delta p_{\text{, pump}} \times 1.7 \times 10^{-5} / (K_{\text{w}}/.746)$$

The above efficiency calculation methods were recommended and used in Reference 1 and the formula is unchanged from the reference. The calculated operating efficiency is correct for the ESP operating under the current configuration. However, as discussed in the beam pump section in this paper, there may be reasons for not using the above operating efficiency as the total system efficiency, but instead using a slightly different efficiency modified to change the output from pump output to surface output. The reasons are more evident as discussed in the beam pump output section.

ESP Efficiency from the Surface Input to the Pump and to the Surface of the Well:

The operating efficiency discussed above is used to calculate how efficient the ESP lift equipment is in transporting the surface power and delivering the power to the fluid by the pump. The expressions for this operating efficiency is:

$$\eta_{\text{surface input to pump output}} = \eta_e \eta_c \eta_m \eta_p$$

or:

$$\eta_{\text{surface input to pump output}} = Q_{\text{bpd}} \times \Delta p_{\text{, pump}} \times 1.7 \times 10^{-5} / K_{\text{w}}/.746$$

or:

$$\eta_{\text{surface input to pump output}} = Q_{\text{bpd}} \times \text{Head}_{\text{, pump}} \times \text{SG} \times 7.368 \times 10^{-6} / (K_{\text{w}}/.746)$$

The rate of production of fluid from the well results in a specific PIP. For the production rate to flow (be lifted) to the surface a specific P_d is required, based on operational requirements and the well bore configuration. The ESP artificial lift equipment uses power and increases the pressure at the intake, PIP, to the pump discharge pressure, P_d , needed for a given flow rate. How much power is used to provide the Δp results in the determination of operating efficiency. Since the ESP system provides the Δp the well needs to produce at the

specific production rate, then all of the above expressions are equivalent. However, as discussed in the beam pump section, this expression can have problems since increases in surface pressure results in additional pump work. This work is not used to produce fluid and should be viewed as work wasted to overcome the increase in tubing pressure. The calculation of system efficiency including the wasted work as pump output, can result in an increasing calculated η as the tubing pressure is increased especially when pumping with a beam pump system.

As shown in Figures 1 and 2, there are additional losses in the produced stream from the pump the surface. From the pump output, there is tubing friction that occurs from the pump to the surface and there is the surface tubing pressure that reduces production. Also there is gas that lightens the tubing gradient from a mixture of oil and water only. Operational requirements and well bore configurations can result in wasted work (i.e. separator/tubing pressure necessarily greater than zero or old rough tubing). First we conceptually remove the tubing friction and effects of surface pressure from the ideal production system. The useful work is determined from the hydraulic horsepower $Q \times \Delta p$ to be just the minimum amount of work required to lift the fluids to the surface without any surface tubing pressure or friction.

First calculate the Hp involved in the friction losses and to overcome surface tubing pressure.

$$\Delta p, \text{ friction} = .433(.03)(5000 \times 12/1.995) \times (3^2)/(2 \times 32.2) = 54.6 \text{ psi}$$

The Hp due to tubing friction is:

$$H_p, \text{ friction} = Q, \text{ bpd} \times \Delta p, \text{ friction} \times 1.7 \times 10^{-5} = 0.92$$

Since this occurs downstream of the pump, the η , friction = tubing output/tubing input or

$$\eta, \text{ friction} = (HHP - H_p, \text{ friction}) / HHP = (32.62 - 0.92) / 32.62 = 0.97$$

Next calculate the Hp due to overcoming the surface tubing pressure:

$$\begin{aligned} H_p, \text{ surface pressure} &= Q, \text{ bpd} \times \Delta p, \text{ surface pressure} \times 1.7 \times 10^{-5} \\ &= 1000 \times 100 \times 1.7 \times 10^{-5} = 1.7 \text{ hp} \end{aligned}$$

The efficiency (showing the drop in Hp due to the surface pressure) is:

$$\begin{aligned} \eta, \text{ surface pressure} &= (HHP - H_p, \text{ friction} - H_p, \text{ surface pressure}) / (HHP - H_p, \text{ surface pressure}) \\ &= (32.62 - .92 - 1.7) / (32.62 - 9.92) = 0.946 \end{aligned}$$

So now if we define the system efficiency from surface input of power, to down hole, and to the surface production of fluids,

$$\eta, \text{ system} = \eta_e \eta_c \eta_m \eta_p \eta_f \eta_{s.p.}$$

Theoretical value of ESP "system" efficiency

And for the problem illustrated above,

$$\eta_{\text{system}} = .97 \times .928 \times .82 \times .625 \times .97 \times .946 = .423 = 42.3 \%$$

Alternatively, this can also be calculated using the head formula, where the head is only to overcome the vertical gravity lift and not to include the effects of tubing friction or surface pressure. This becomes:

$$\eta_{\text{system}} = Q_{\text{bpd}} \times \text{Lift} \times SG \times 7.368 \times 10^{-6} / (Kw/.746),$$

Where again, Lift is the vertical fluids are lifted. In the above problem, the vertical distance the fluids are lifted is 5000 ft. However we have 400 psi at the intake which corresponds to $400/.433 = 923.78$ ft of fluid that does subtracts from the 5000 ft of fluid to be lifted. The system efficiency is:

$$\eta_{\text{system}} = (Q_{\text{bpd}}) \times (\text{Depth} - \text{PIP}/(.433 \times SG)) \times SG \times 7.368 \times 10^{-6} / (Kw/.746)$$

Use to measure "system" efficiency in the field--- good for any pumping system.

The calculation using the proceeding example is:

$$\eta_{\text{system}} = 1000 \times (5000 - 400/.433) \times 7.368 \times 10^{-6} / 70.9 = 42.3 \%$$

In the above equation the PIP term includes the benefit from the well's inflow performance and reduces the power required to lift the fluid. The SG is the SG of the produced fluids in the tubing, and includes the effect of gas produced through the pump and reduces the pump discharge pressure, Pd.

Calculation of the system efficiency including corrections for tubing pressure and tubing friction will now result in a lower η_{system} value with the above definition. Typically in the past the calculated η_{system} ignored the impact that operational requirements and the well bore configuration had on the hydraulic required to produce the fluid to the surface. With the changes proposed part of the hydraulic horsepower required to produce the fluid to the surface will be identified as wasted work. The η_{system} can also be expressed in terms of the ratio of minimum hydraulic Hp divided by input Hp:

$$\eta_{\text{system}} = \text{Hp (minimum hydraulic)} / \text{Hp (Input)}$$

Where:

$$\begin{aligned} \text{Hp (minimum hydraulic)} &= (Q_{\text{bpd}}) \times (\text{Depth} - \text{PIP}/(.433 \times SG)) \times SG \times 7.368 \times 10^{-6} \\ \text{Hp (Input)} &= Kw/.746 \end{aligned}$$

This form of the equation calculates the minimum hydraulic horsepower required to produce the fluid, treating the surface tubing pressure and tubing friction as losses the system. Note that this form of the equation is not specific to ESP operations and can be used to measure "system" efficiency for any pumping system. Although Gaslift is not discussed here it must be treated separately because of a need for a different expression to replace the hydraulic horsepower. This discussion will center only on the pumping methods of lift.

This "system" efficiency considers the liquid being brought to the surface and excludes work to overcome friction and surface pressure from the useful hydraulic hp (HHP) developed by the pump. This "system" efficiency is less than the previous definition of the pump output divided by the total input of Kw or HP input to the system. It is less because of the reduced definition of useful work from the pump. This definition of "system" efficiency has the correct trends and can be used to compare one system of artificial lift to another. If used for beam pumps it will decrease if surface pressure is increased and it will decrease if the friction of the tubing is increased. These are trends that should be expected from a system efficiency definition.

The efficiency of $HHP/(Kw/.746)$ including tubing friction and surface pressure is correct for the efficiency of what fraction of input surface power is output by the pump. However this pump output efficiency shows the non-intuitive effect of increasing efficiency with more surface pressure for, in particular, beam pumps. So the "system" efficiency is recommended for general use because of this surface pressure effect. This is discussed in the Beam Pump section. Note in Reference 1 the definition of efficiency was used as $(HHP/Kw/.746)$ and it gave a fair comparison between Beam and ESP efficiencies. However, now that it has been recognized that this form gives the unintended result of increasing efficiency with more surface pressure, it is recommended that the above "system" efficiency be used in the future.

Beam Pump Efficiency:

Typically beam pump systems have higher electrical or power efficiency compared to ESP's. Some of the component efficiencies are not as easily obtainable such as the motor and pump efficiencies of ESP's. At this point it is contended that many of the proceeding formulas developed in the ESP section can also be used for beam pumps.

In fact the following equations should be able to be used for any pumping system including beam pumps and ESP's. They depend on the input power be electrical or Kw/.746 being the input Hp:

$$\eta_{\text{surface input to pump output}} = Q_{\text{bpd}} \times \Delta p_{\text{pump}} \times 1.7 \times 10^{-5} / Kw/.746$$

$$\eta_{\text{system}} = (Q_{\text{bpd}}) \times (\text{Depth} - PIP / (.433 \times SG)) \times SG \times 7.368 \times 10^{-6} / (Kw/.746)$$

Use to measure "system" efficiency in the field--- good for any pumping system.

In Reference 1, the first of the proceeding equations was used to measure Beam Pump and ESP efficiencies. However, as mentioned, it has been since brought to our attention that with beam pumps, use of the proceeding equation involving the pump output and the Δp_{pump} will show increasing efficiency when the surface pressure is increased, especially when analyzing beam pumps. However, since effects of surface tubing pressure and tubing friction are taken out of the useful pump work in the system efficiency, then this definition will always show a decreasing efficiency with a beam pump system.

Similarly to the ESP section, a theoretical component efficiency for the Beam Pump System can be developed. The equation might take the form of:

$$\eta, \text{ beam system} = \eta_e \eta_m \eta_u \eta_r \eta_f \eta_{s.p.}$$

Where the terms are as in the ESP section except for the following definitions:

η_m –average cycle efficiency of the electrical motor. Measurement of many pumping unit/motor system's surface efficiencies have resulted in the following table of minimum recommended surface ($\eta_m \times \eta_u$) efficiency guidelines. Most beam pump Nema D motors have a full load efficiency of about 88 %. However during the loading and unloading of a beam pump motor over ranges of lower efficiency, the cycle efficiency of the motor is closer to the values displayed for the average motor efficiency for 30%-80% load.

Minimum Recommended Surface (Es) Guidelines

Motor HP - NEMA D	5	7.5	10	15	20	25	30	40	50	60
Motor Efficiency (30%-80%) Load	78	80	84	85	88	91	88	91	90	86
Minimum Surface Efficiency , $\eta_m \times \eta_u$	70	72	76	77	79	82	79	82	81	77

η_u – unit efficiency. The unit efficiency would include belts and sheaves, gearbox, and various bearings which give rise to losses. Typically the value of efficiency of a beam pump unit is 90% or greater as long as the gearbox is over 50% loaded.

η_r - rod efficiency. This is a complex term involving the loss from the polished rod to the pump caused by losses along the rods as they transmit power from the polished rods to the down hole pump. This term must be calculated by complex models such as the API method or use of a wave equation model that simulates the dynamics of the system and the rod dynamics and losses occurring along the rods. Typically fast pumping units have a low value of this term, perhaps as low as 70-80% and slow value of SPM result in a much high value of this term, as high as 95% perhaps. Rod/Tubing friction due to rod buckling, paraffin, and deviated well bores will result in rod efficiencies less than 70%.

To illustrate, first let's find a beam pump design for the following data repeated from the ESP section:

Example Calculation:

Design rate: 1000 bpd

Surface tubing pressure: 100 psi

Pr = 900 psi, Pwf = PIP = 400, PI = 2.0

Depth to pump, perforations, 5000 feet

Avg. well temperature, 100 F

Use water properties for simplicity.

Tubing ID = 1.995", Friction factor for tubing = .03

A marginal design for this data would be a 912-305-168 unit, an 86 rod string, a 2.25" pump, and a 75 hp motor with the system pumping at 11 SPM. The calculated input Kw would be 43 Kw and the input Hp to the motor would be 58.3 Hp. The output of the motor is calculated to be 46.9 Hp. The polished rod Hp is 44.3 and the power delivered to the downhole pump is 32.62 Hp. First calculate a system component efficiency using the below equation:

$$\eta, \text{ beam system (theoretical) } = \eta_e \eta_m \eta_u \eta_r \eta_f \eta_{s.p.}$$

Assume that the $\eta_e = 1.0$ unless there is a VSD or surface controller drawing power

$$\text{For this case } \eta_m = 46.9/58.3 = 80.44 \%$$

$$\text{For this case } \eta_u = 44.3/46.9 = 94.45 \%$$

$$\text{For this case } \eta_r = 32.62/44.3 = 73.63\%$$

From the ESP example, $\eta_f = .97$ (although this could be calculated differently for beam pump system, the same approximate value for the ESP system will be used here)

$$\text{From the ESP example, } \eta_{s.p} = .946$$

$$\eta, \text{ beam system (theoretical) } = 1.0 \times .8044 \times .9445 \times .7363 \times .97 \times .946 = 51.3$$

This is typical of a good beam pump system, although because of the relatively high SPM, it might be designed for even better for efficiency. Also rates in excess of 1000 bpd from this depth begin to approach the limits of beam pump operations due to high rod and unit loads.

Next calculate the same value using the “measured” data system efficiency: $\eta_{\text{system}} = 1000 \times (5000 - 400/.433) \times 7.368 \times 10^{-6} / 58.3 = 51.5 \%$. However, as far as field measurements would be concerned, all you would have to know is how to apply this last equation which includes the effects of the various components and their individual losses.

All that is needed to measure the “system” efficiency is a measure of the Kw input on a regular or time averaged basis, the production rate, and some knowledge of the intake pressure (hopefully from a fluid level shot).

Summary:

A “system” artificial power equation is developed. It is differentiated from an artificial lift efficiency developed by dividing the pump output by the system power input. The recommended efficiency excludes the work of the pump overcoming tubing friction and surface pressure as useful work. The recommended equation is:

$$\eta_{\text{system}} = (Q, \text{bpd}) \times (\text{Depth} \times \text{SG} - \text{PIP}/(.433)) \times 7.368 \times 10^{-6} / (\text{Kw}/.746)$$

Comments on above system efficiency equation:

1. It was developed from an expression for incompressible flow or flow with no gas.

2. If a well is pumped down to low pressures, and gas is separated up the casing, then only liquids with no gas will be produced through the pump and tubing.
3. If no gas is present in the tubing then the tubing SG can be approximated from:

$$\text{SG, tubing} = [(\% \text{ oil}) ((141.5)/(131.5 + \text{API})) + (\% \text{ water})(\text{SG, water})] / 100.$$

4. If a small amount of gas is present in the tubing, then to estimate the effects, the tubing gradient without friction effects would have to be calculated to estimate SG average for the tubing, and the total Q(bpd) through the pump would have to be calculated. This becomes more complex. If Pd and PIP are known/calculated, then the equation for the average tubing SG is: $\text{SG} = (\text{Pd} - \text{Ptbg}) / (.433 \times \text{Depth})$. The flow through the pump would be based on the volume of the in-situ oil, water and gas.
5. For larger amounts of gas, this equation would not be correct and a more complex equation involving integrals and other fluid property calculations would have to be considered. Since this paper is attempting to present a comparative efficiency equation that can be used for most beam pump wells and many ESP wells that produce with small amounts of dissolved in the fluids entering the pump, then the above simplified equation is suggested.
6. This form of the equation does show reduced efficiency as the tubing pressure is increased and as the tubing friction is higher.
7. Equations like this have been presented before (see Ref. 1), but it is not known if the purpose was to avoid expressions that show increasing efficiency as tubing pressure is increased or if it was just an approximation to efficiency using pump output as the total output.

Again the Q is the total volumetric flow of fluids through the pump and the SG reflects the flowing gravity gradient of the fluids. If severe gas interference is present, a more complicated form of the equation would be required to be exactly correct.

All that is needed to measure the "system" efficiency is a measure of the Kw input on a regular or time averaged basis, the production rate, and some knowledge of the intake pressure (hopefully from a fluid level shot).

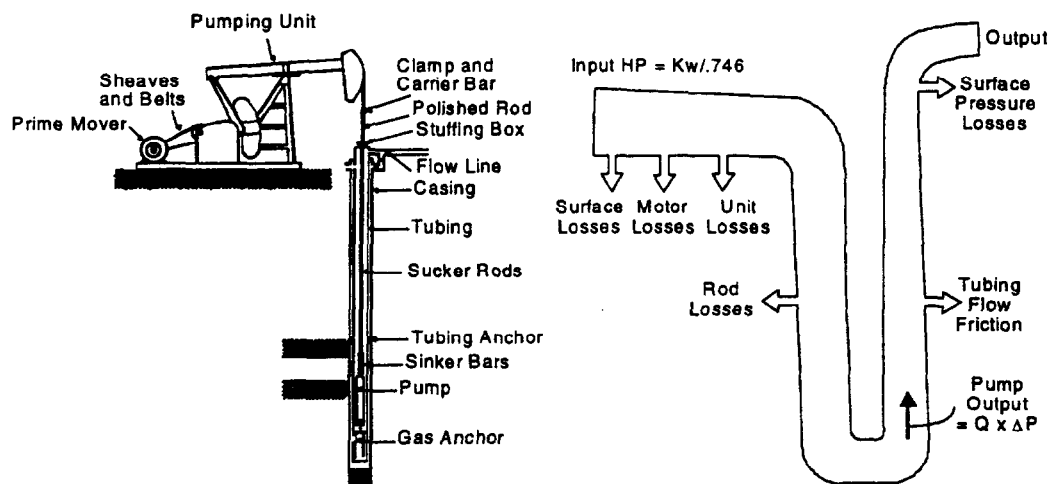
Improvements to efficiency can be made by lowering the surface pressure, reducing tubing friction, and reducing pumping component losses.

In the beam system, low pumping speeds used with a system that is not overloaded is a good objective to increase system power efficiency. This is typically achieved by using the longest stroke length up to point. Worn equipment or gas interference or over-pumping will result in low efficiencies. To reduce rod/tubing friction losses due to rod buckling on the down stroke, set the pump below the perforations when gas is present. Then the advantage of gas entering the tubing is not received, although the disadvantage of reduced problems in the downhole pump is usually more desirable. Motors that are too large are a secondary effect in lowering efficiency.

When using ESP's, design with the larger diameter equipment if it will fit into the casing. Tend towards use of the higher voltage motors and use of larger diameter power cable when economically acceptable. Lower the tubing pressure if low cost adjustments can be made and try to design such that only 2-3% friction is present in the tubing pressure drop. Use gas separators when possible and necessary, because pumps have low efficiencies when compressing gas. Always allow for gas venting of the casing for any pumping situation, whether beam pump, ESP, or another pumping system.

References:

1. Lea, J. F. & Minissale, J. D. , "Beam Pumps Surpass ESP Efficiency," Oil & Gas Journal, May 18, 1992.

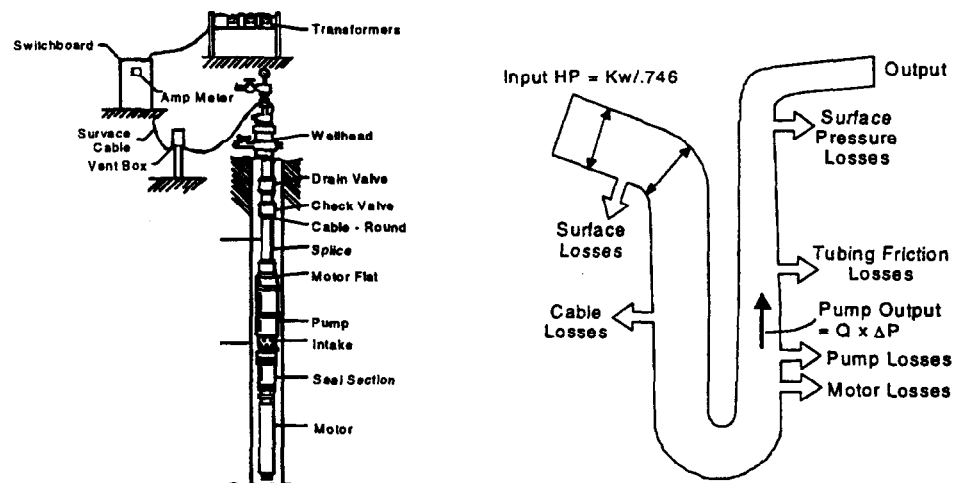


$$\eta_{\text{BEAM, system}} = \eta_{\text{surface}} \eta_{\text{motor}} \eta_{\text{unit}} \eta_{\text{rods}} \eta_{\text{tubing friction}} \eta_{\text{surface pressure}}$$

OR

$$\eta_{\text{system}} = \frac{(Q, \text{BPD}) (\text{Depth} - \text{PIP} / .433 \text{XSG}) (\text{SG}) (7.368 \text{E-}06)}{(Kw / 0.746)}$$

Figure 1 - Flow of Power in Beam Pump System



$$\eta_{\text{ESP, system}} = \eta_{\text{surface}} \eta_{\text{cable}} \eta_{\text{motor}} \eta_{\text{pump}} \eta_{\text{tubing friction}} \eta_{\text{surface pressure}}$$

OR

$$\eta_{\text{system}} = \frac{(Q, \text{BPD}) (\text{Depth} - \text{PIP} / .433 \text{XSG}) \text{SG} 7.368 \text{E-}06}{(Kw / 0.746)}$$

Figure 2 - Flow of Power in ESP System