



Electrical Submersible Pumping (ESP) Systems

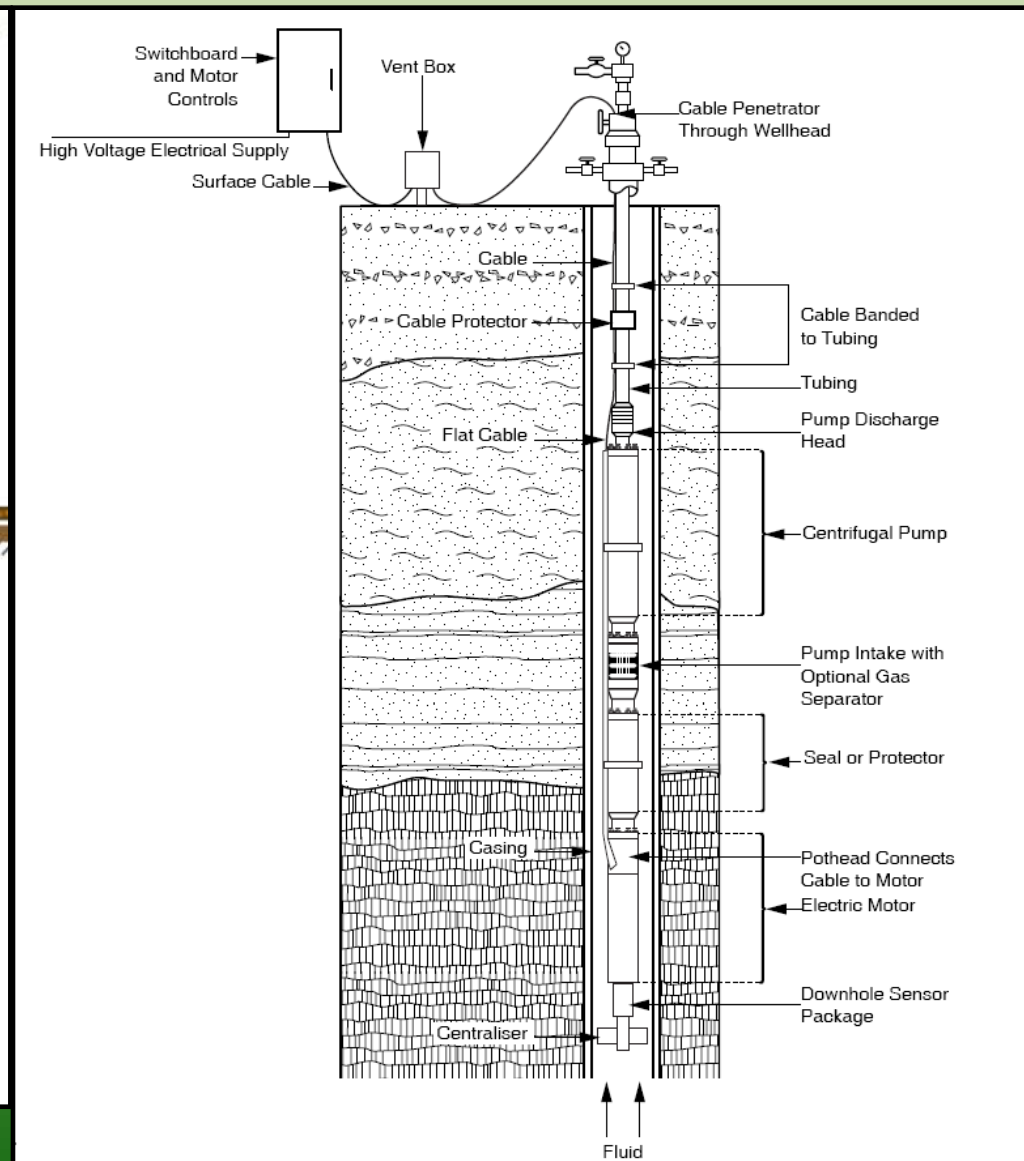
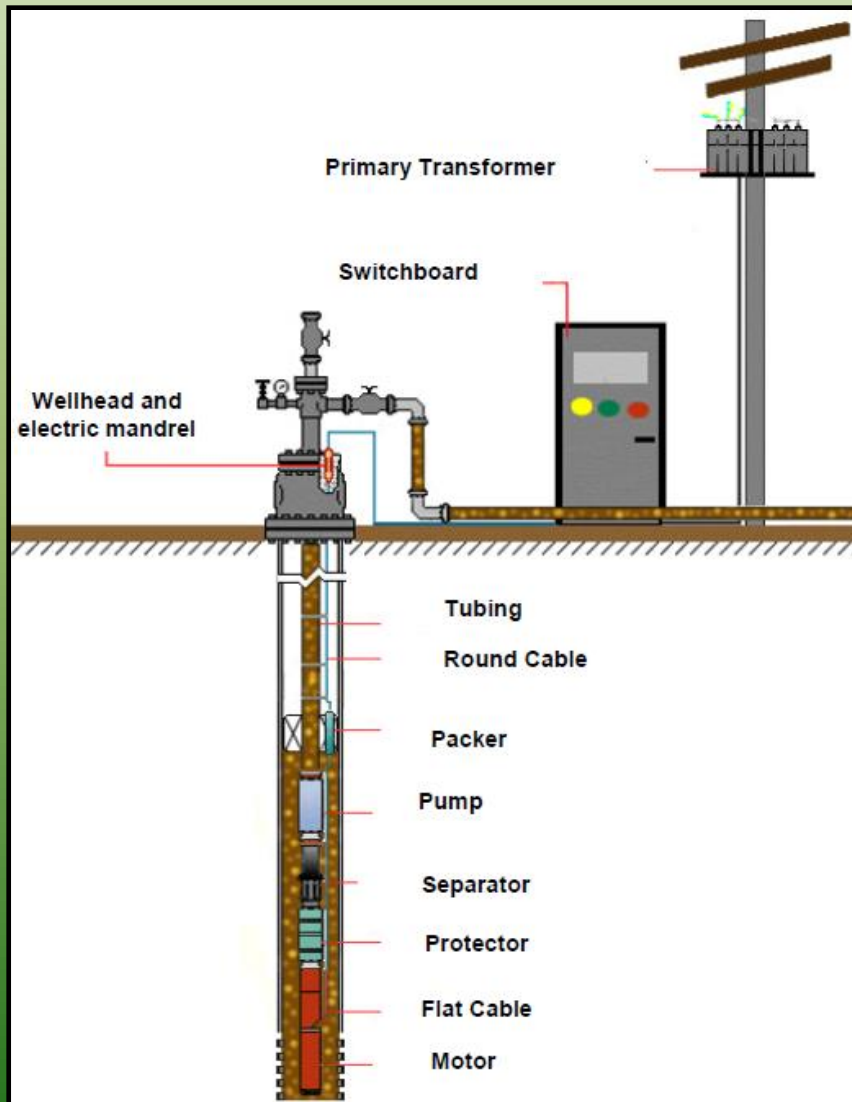
By

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Lecture Outline

- Components and Operating Mechanism
 - Downhole Equipment
 - Surface Equipment
 - Gas Separators
- Installation Design
- Class Examples
- Operational Notes
- Summary

Overview of ESP



ESP Service Providers

- Schlumberger-REDA
- Centrilift – Baker Hughes
- Weatherford
- Wood Group ESP
- ALNAS (Russia)

ESP SYSTEM

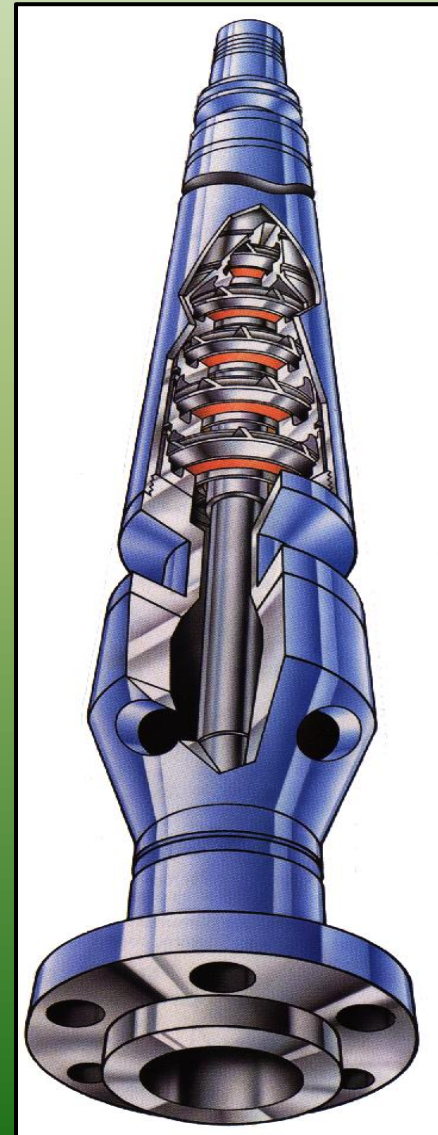
ESP system can be divided into surface components and downhole components. These components are listed below;

Surface Components:

- Transformers
- Motor controller Switchboard of Variable Speed Drive (VSD) or Soft Start
- Junction Box
- Cable Venting box
- Wellhead

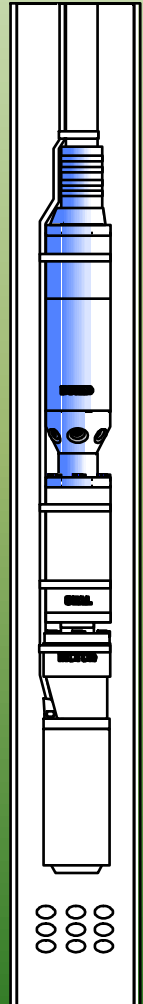
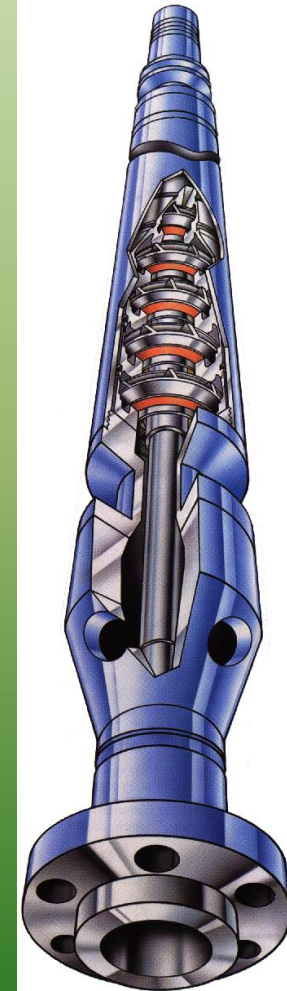
Downhole Components:

- Cable
- Cable Guard
- Cable Clamps
- Pumps
- Gas Separator
- Seal Section
- Motor
- Sensor- Data Acquisition Instrumentation
- Drain Valve
- Check Valve



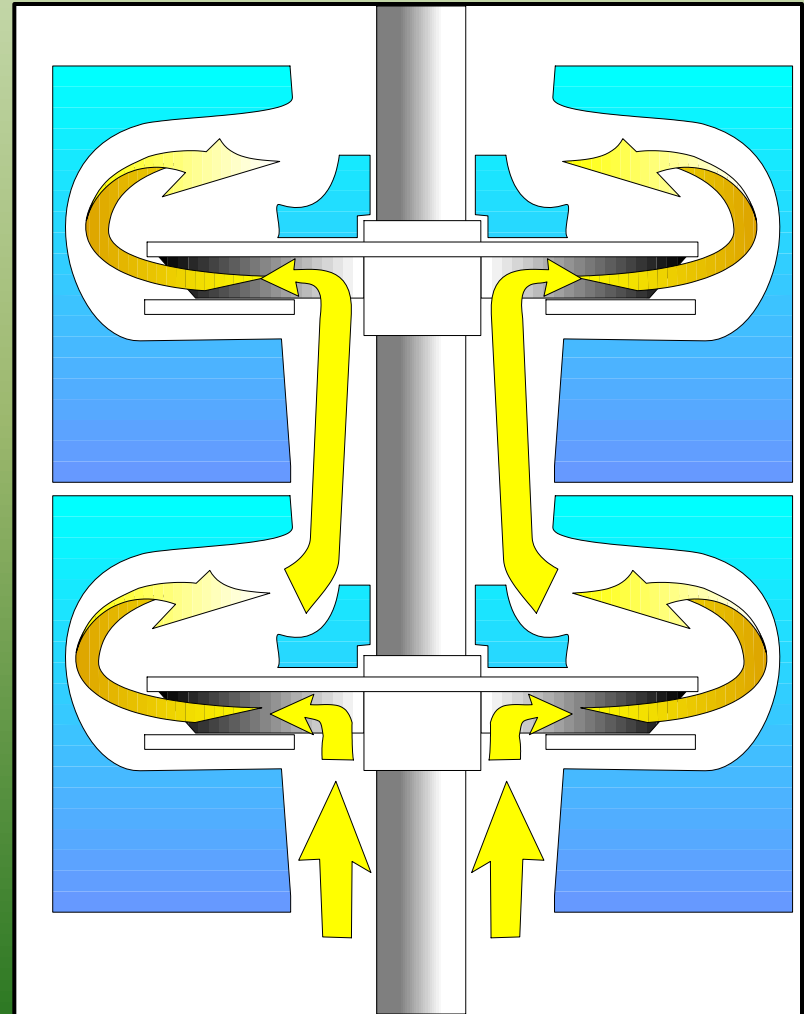
Downhole Centrifugal Pump

- Centrifugal pump is so named because the head added to fluid is due largely to centrifugal effects
- Characterized by:
 - Small diameter
 - Large quantity of stages
 - High design loads



Pump Stage

- Fluid enters impeller through 'eye' near shaft and exits impeller on outer diameter (OD)
- Diffuser (in blue) redirects fluid into next impeller



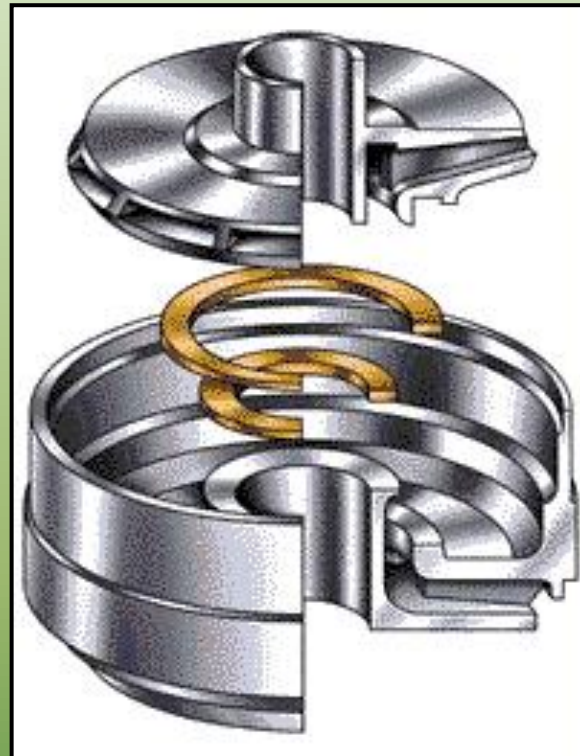
Pump Impeller



Impeller in Diffuser = A Pump 'Stage'



**Mixed Flow
Stage**

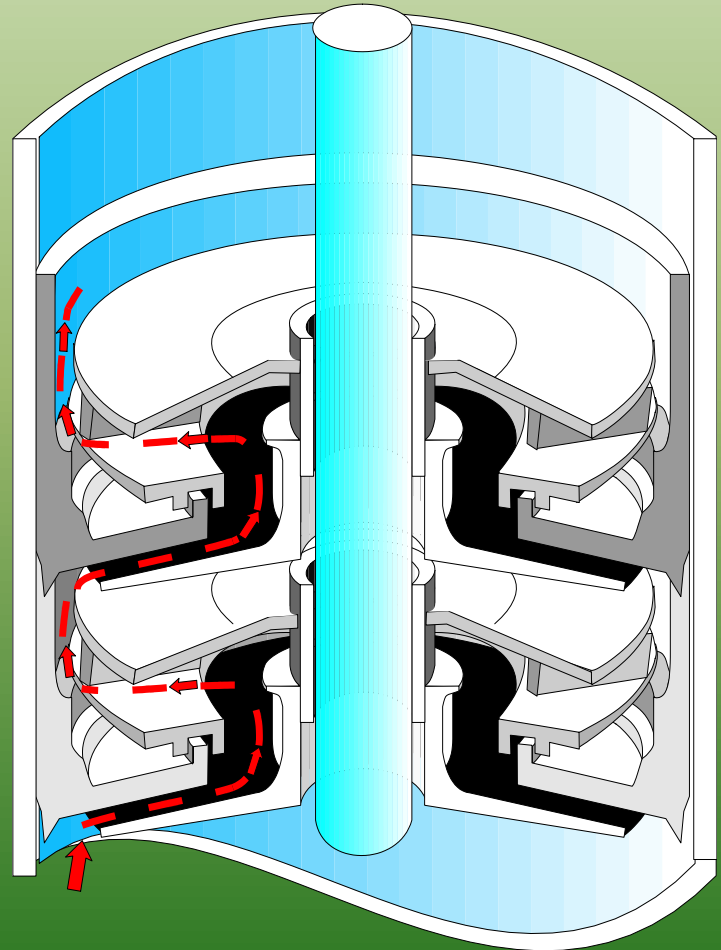


**Radial Flow
Stage**



Pump Stage

- Cut-away view of two impellers and diffusers
- By stacking impellers and diffusers (multi-staging), desired lift (TDH-Total Dynamic Head) is achieved



Gas Separators

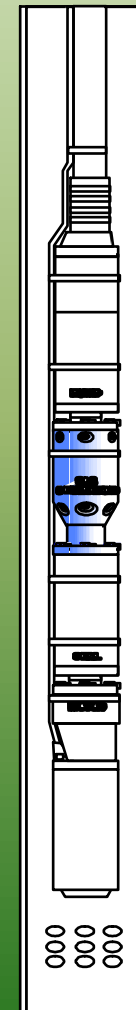
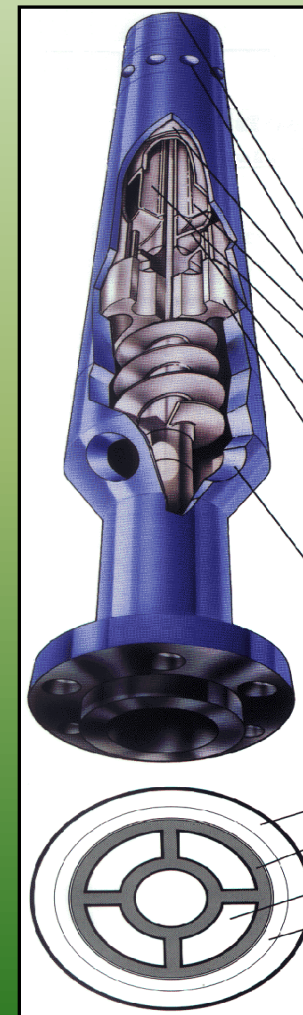
- Used in applications where free gas causes interference with pump performance
- Units separate some of free gas from fluid stream entering pump to improve pump's performance

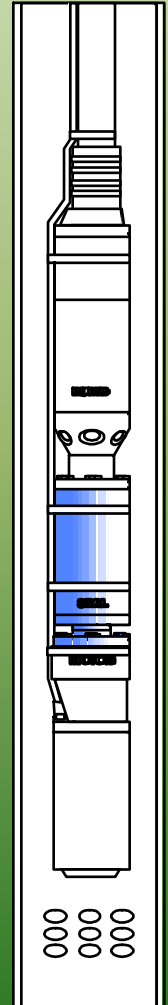


Homogenizer



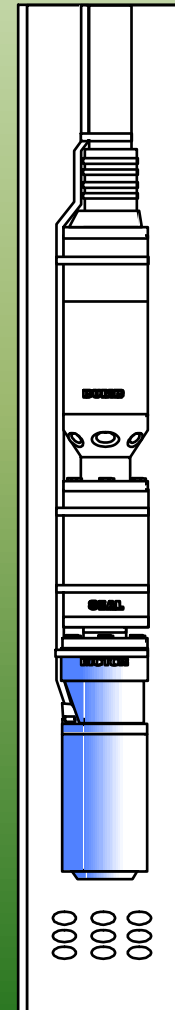
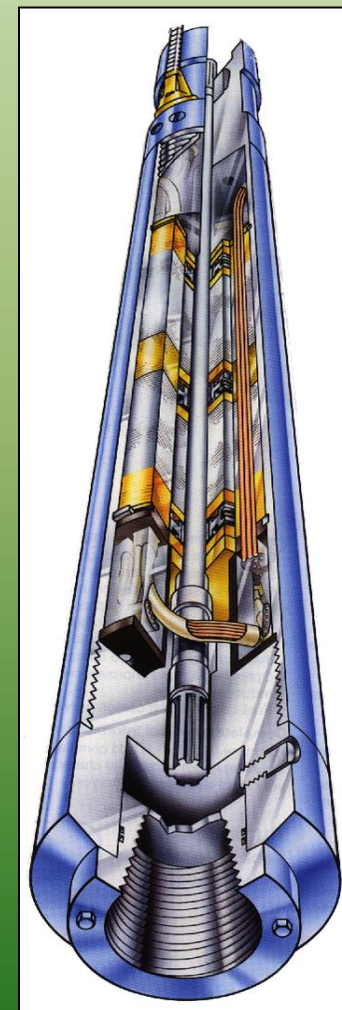
Separators



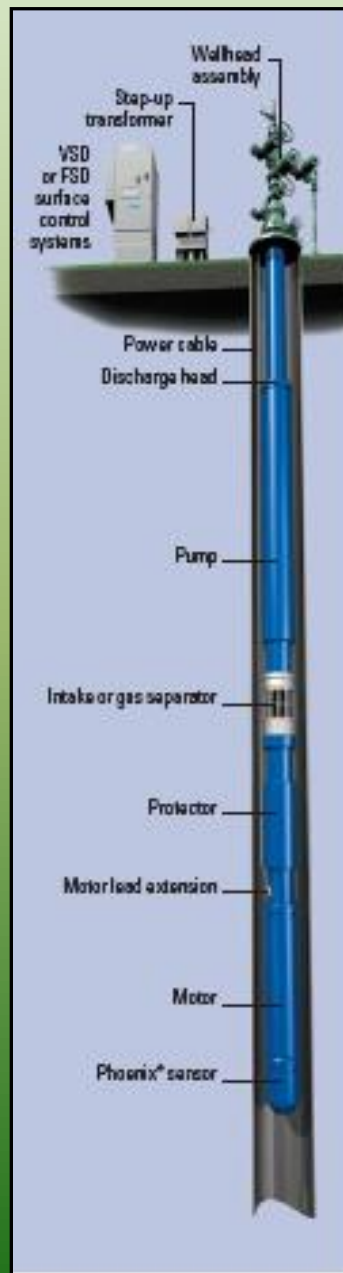
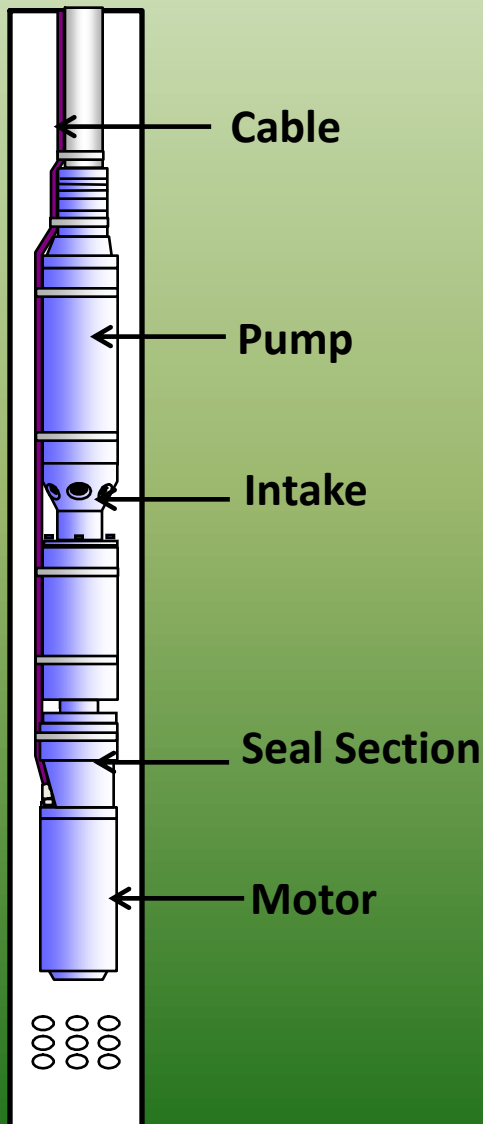


Submersible Motor

- Motor is filled with oil
- It is a two-pole, three phase, 3,600 rpm (revolutions per minute) design
- Motor components are designed to withstand up to 500°F temperatures

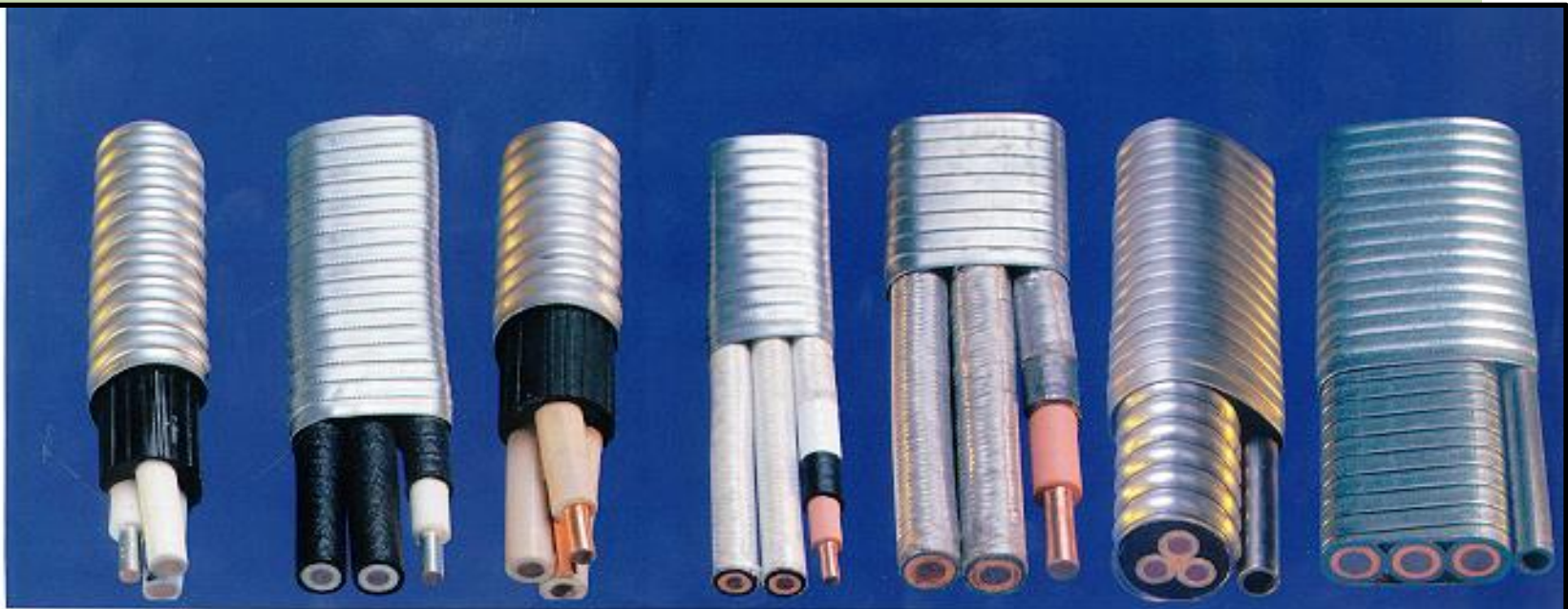


Downhole Components



Sensor can also be added to the pump below the motor to acquire data like downhole pressure, temperature, and vibration, these supply pump monitoring data.

Electric Power Cable



There are different types of cables available in the industry. These include;

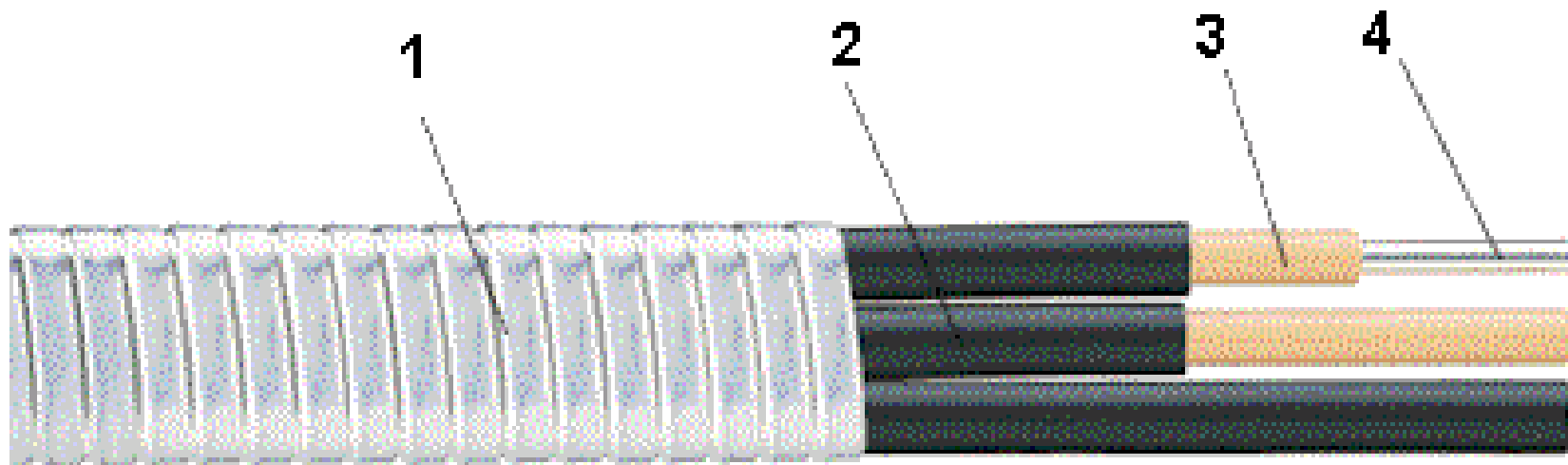
- Round Cables
- Flat Cables
- Number of conductors also varies from 1,2,4 etc...depending on company

Cables also vary depending on the type of insulation based on the working environment, there are special cable insulation for corrosive fluids and severe environments.

Parts of a Pump's Electrical Cable

FLAT CABLE

- 1 - Armor: Galvanized Steel
- 2 - Jacket: Electrical Grade Thermoplastic Insulation
- 3 - Insulation: High Dielectric Thermoplastic Insulation
- 4 - Conductor: Soft Drawn Tin Coated Copper (SDTC)



CTT Flat

Surface Equipment: Transformer

The transformer is a device that transforms the voltage of an electrical system. For example a transformer that converts 7200 volts to 480 volts. This is accomplished by two sets of coils wrapped around an iron core in the transformer. In this case the transformation ratio is 7200/480. Transformers are rated in KVA capacity. This depends on the voltage and the current the transformer can handle.

$$KVA = KV * A$$

KV = Voltage in Kilovolts

A= Current in Amperes



Power and control Skids

Surface Equipment: Motor Controllers

Motor Controllers;

- Fixed Speed Controller
- Variable Speed Controller



EQUIPMENT SIZING AND DESIGN

ESP Design Considerations

ESP Design

Wells with Low GOR and High Water Cut

Wells with High GOR

Wells Producing Viscous Fluids

Variable Speed Design

Design Guidelines

Steps Based Design

STEP	Design Task	Description
1	Basic Data	Collect and analyze all well data to be used
2	Well Production Capacity	Determine the production capacity and depth
3	Fluid Volume Calculations	Calculate all fluid volumes at pump intake pressure
4	Total Dynamic Head (TDH)	Determine the pump's discharge requirements
5	Pump Type	Select pump that has highest efficiency based on desired flow rate
6	Optimum Size of Components	Select optimal size of pump, motor, seal section and check the limitations if any
7	Electric Cable	Select correct type and size of cable based on well
8	Accessory and Optional Equipment	Select motor controller, transformer, tubing head and other optional equipment
9	Variable Speed Pumping System	For additional operational flexibility, select the variable speed submersible pumping system

STEP 1: Basic Data

The first step in an ESP design is to collect and verify the reliability of all data that will be used in the design. The following is a listing of the data required.

Well Data: Casing size and weight, Tubing size, type and thread, Perforated or open hole, Pump setting depth (measured and vertical), Deviation survey

Production Data: Wellhead casing pressure, Wellhead tubing pressure, Present production rate, Production fluid level/Pump intake pressure, Static fluid level/Static Bottom hole pressure, Datum point, Bottom-hole temperature, Desired production rate, Gas-oil ration, Water cut.

Well Fluid Conditions: Specific gravity of water, Oil API or specific gravity, Specific gravity of gas, Bubble-point pressure of gas, Viscosity of oil, PVT data.

Power Sources: Available primary voltage, Frequency, Power source capabilities

Possible Problems: Sand, Deposition, Corrosion, Paraffin, Emulsion, Gas, Temperature

STEP 2: Well Production Capacity

The Inflow Performance Relationship (IPR) or the Productivity Index (PI) of the well depending on the pressure regime should be integrated with the Vertical Lift Performance (VLP) Curve to determine the productive capacity of the well which would be used in the ESP design.

STEP 3: Fluid Volumes Calculation

The accurate calculation of fluid volumes and type at the pump intake is very important in pump design. The presence and volume of free gas at the pump intake must be taken into consideration. The presence of free gas may considerably decrease the required discharge pressure, hence there may be a need to use a gas separator at the pump intake to achieve maximum system efficiency. Ideally, if the gas remains in solution, the pump behaves normally, however as gas to liquid ratio increases beyond the critical value of between 10-15%, the pump efficiency decreases and lower pump head is produced.

Hence, the percent free gas must be calculated so that the right gas separator technique/device can be chosen and integrated in the ESP design.

STEP 3: Fluid Volumes Calculation-B

The free gas volume is calculate from the following equations/correlations, if PVT values are not available.

a. **Solution Gas Oil Ratio (Dissolved Gas Oil Ratio)**

Using Standing's correlation (any suitable correlation can be used);

$$R_s = \gamma_g * \left[\frac{P_b}{18} * \frac{10^{0.0125*API}}{10^{0.00091*T}} \right]^{1.20482}$$

Where,

γ_g = Specific gas gravity

P_b = Bubble Point pressure (psi)

T = Bottom-hole Temperature $^{\circ}\text{F}$

b. **Gas Volume Factor**

$$B_g = 5.04 \frac{zT}{p}$$

Z = Gas compressibility factor

T = Bottom hole temperature, $^{\circ}\text{R}$

P = Pressure, psi

B_g = Gas volume factor, bbls/STD

STEP 3: Fluid Volumes Calculation-C

C. Oil Formation Volume Factor, B_o

$$B_o = 0.972 + 0.000147 * \left[R_s * \left(\frac{\gamma_g}{\gamma_o} \right)^{0.5} + 1.25 * T \right]^{1.175}$$

Where,

B_o = Oil formation Volume Factor

R_s = Solution Gas Oil Ratio (SCF/STB)

γ_g = Gas Specific gravity (Relative to Air)

γ_o = Oil Specific Gravity (Relative to water)

d. Total Volume of Fluids

$$Total\ Gas = \frac{Producing\ GOR * BOPD}{1000} = MCF$$

$$Solution\ Gas = \frac{R_s * BOPD}{1000} = MCF$$

$$Free\ gas = Total\ Gas - Solution\ gas$$

STEP 3: Fluid Volumes Calculation-D

Volume of Oil @ Pump Intake, $V_o = BOPD * B_o$

Volume of gas @ the Pump Intake, $V_g = \text{Free gas} * B_g$

Volume of water @ Pump Intake, $V_w = BWPD * B_w$

Total Fluid Volume, $V_T = V_g + V_o + V_w$

Percentage of free gas to total volumme,

$$\% \text{ Free gas} = \frac{V_g}{V_T}$$

This is the amount of gas at the pump intake, the critical % is between 10-15 %, above, a solution to the gas volume must be included in the design (gas separator)

STEP 4: Total Dynamic Head (TDH)

Next, the total dynamic head (TDH) required to pump the desired capacity is determined. The total dynamic head is the height in feet of fluid being pumped.

TDH = Net well lift (dynamic lift) + Tubing Friction Loss + Wellhead Discharge

$$TDH = H_d + F_t + P_d$$

Where,

H_d = Vertical Distance in feet between the wellhead and estimated producing fluid level at the expected capacity

F_t = The head required to overcome friction loss in the tubing measured in ft

P_d = The head required to overcome friction in the surface pipe, valves and fittings and to overcome elevation changes between wellhead and tank battery. It is converted from pressure to head

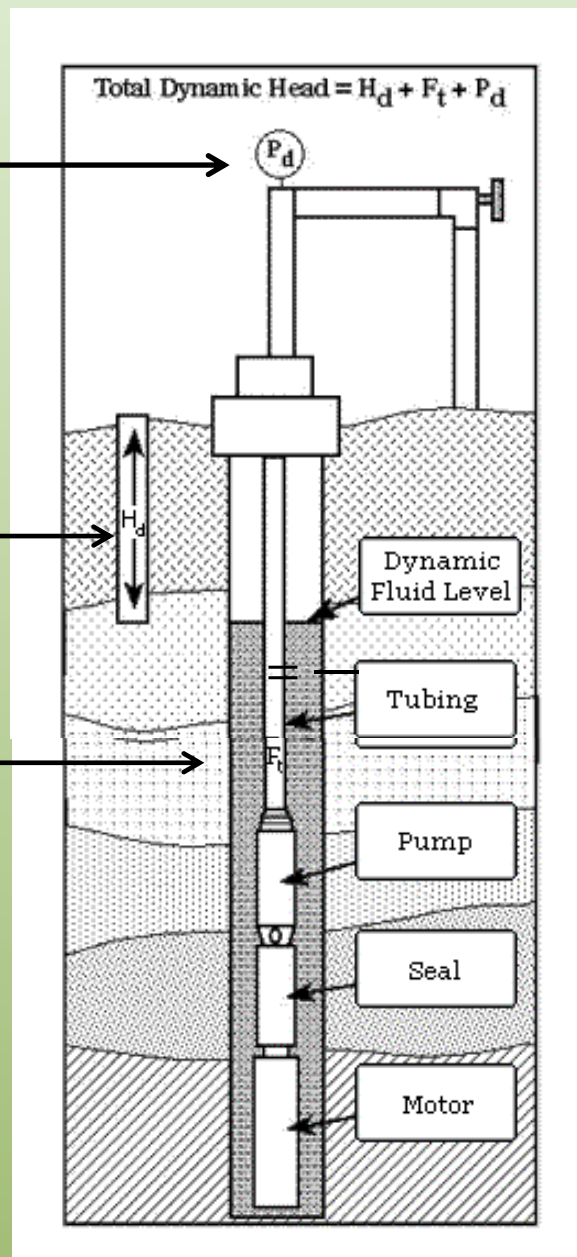
$$P_d = \frac{\text{psi} * 2.31 \text{ ft/psi}}{\text{specific gravity}} \quad \text{or} \quad P_d = \frac{\text{psi}}{0.433 \frac{\text{psi}}{\text{ft}} * \text{specific gravity}}$$

P_d

H_d

F_t

$$TDH = H_d + F_t + P_d$$



Total Dynamic Head

STEP 5: Pump Type Selection-A

Once the TDH has been calculated, its time to select a Pump. The pump type is selected from the **ESP Catalogue of the Service Company** you are interested in buying the pump from. ESP providers have tables that gives engineering information about pumps and also Pump Performance Curves that shows how pump performs at given conditions when tested with water.

Tabulated Engineering data on pumps include (**this may vary with companies**);

- Suitable Casing Size for Pump
- Weight of Casing
- Stage Type (Radial or Mixed)
- Best Efficiency Producing (BEP) rate
- Motor, Seal Section and Pump
- Operating Range (60 Hz or 50 Hz) depending on local voltage

The Pump Performance Curve is a plot of production volume per stage against;

- Pump Head
- Break Horsepower
- Efficiency

It also shows the recommended operating range

An Example Pump Performance Curve

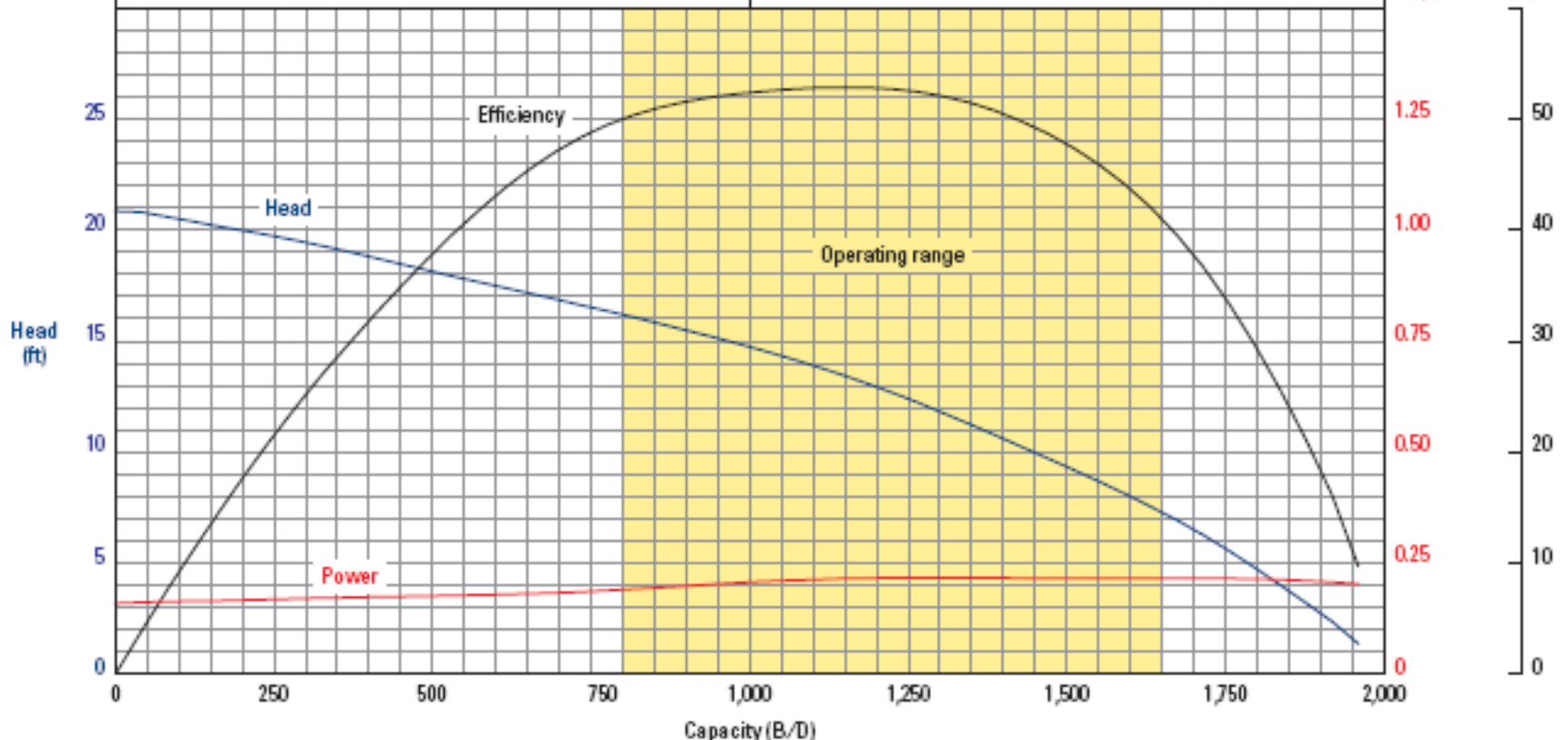
REDA ESP (Schlumberger)

REDA* ESP

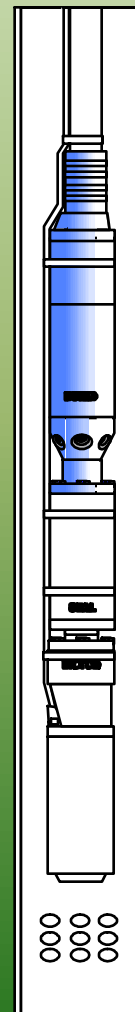
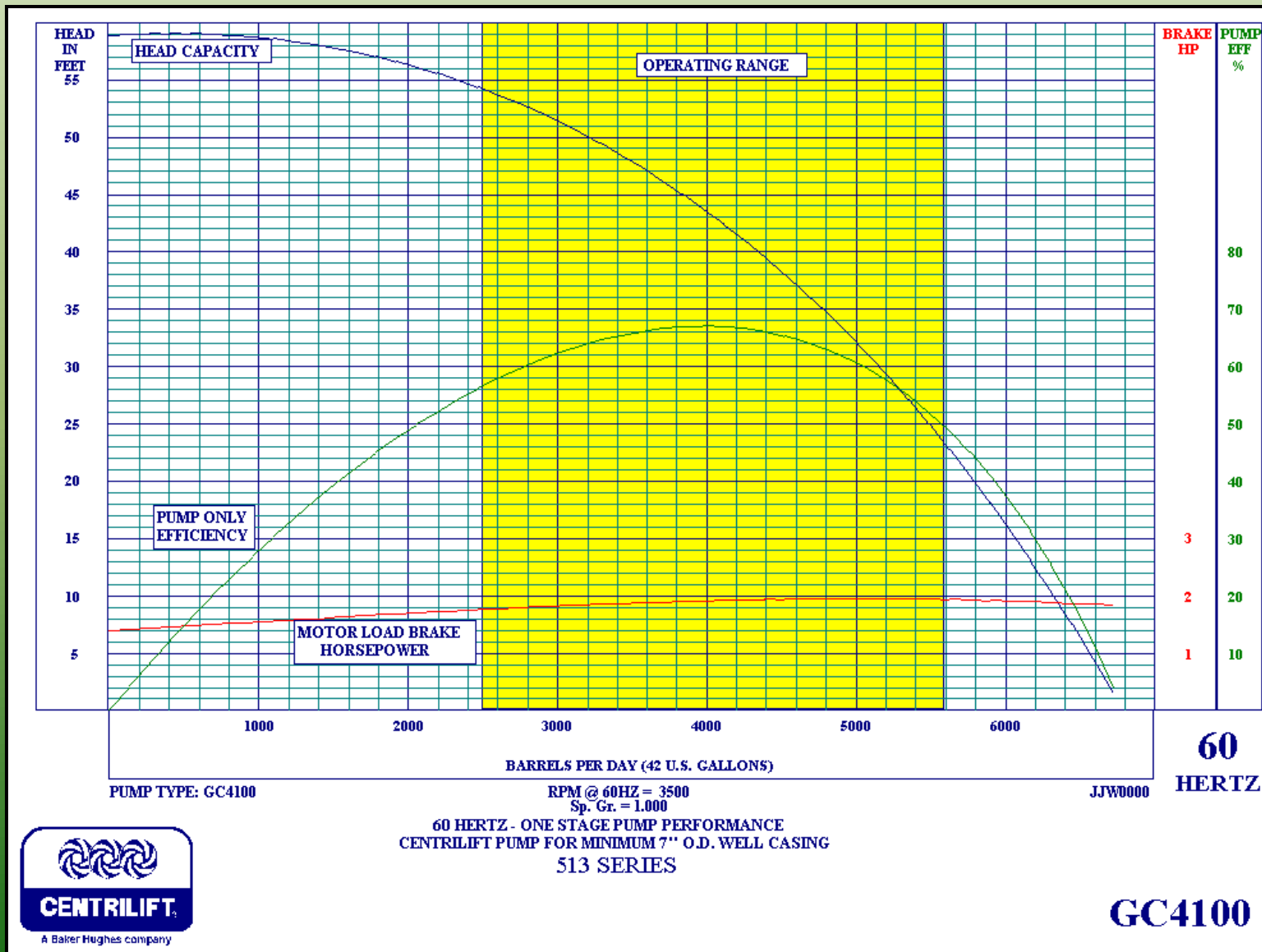
AN1200 Pump Performance Curve
Curve computed for one stage in fluid of 1.00 sg.

60 Hz, 3,500 rpm

Optimum operating range	800–1,650 B/D	Shaft brake-power limit	Standard	94 hp
Nominal housing diameter	3.38 in.		High strength	150 hp
Shaft diameter	0.625 in.	Housing burst-pressure limit	Standard	Not applicable
Shaft cross-sectional area	0.307 in. ²		Buttress	6,000 psi
Min. casing size	4.500 in.		Welded	6,000 psi



Typical Pump Performance Curve Centrilift (Baker Hughes)



STEP 5: Pump Type Selection-B

Notes on Pump Selection:

- Larger diameter pumps and motor are less expensive and they operate at higher efficiencies.
- Select the highest efficient pump that will fit in the casing
- If the well's production capacity is not accurately known, choose a pump with a steep characteristic curve.
- If desired volume falls at a point where two pumps have approximately the same efficiency, choose the pump type which requires the greater number of stages.
- If gas is present in the produced fluid, a gas separator may be required to achieve efficient operation.
- In wells with viscous fluids or emulsions, some pump corrections may be necessary to ensure more efficient operation, hence, working with a service company personnel will be expedient.

STEP 5: Pump Type Selection-C

Notes on Pump Selection:

In most cases there will be two or three pumps that meet the volume and diameter requirements. A comparison of efficiencies, expected production changes and actual pump efficiencies are used to select the optimum pump.

Other considerations are;

- Availability of pump in customer inventory
- Delivery Equipment

STEP 6: Optimum Size of Components-A

ESP components are usually designed and build in a number of different sizes, hence the components can be assembled in a variety of combinations. These combinations must be carefully determined to operate the pump at the optimal production rate, material strength and temperature limits based on the Company's catalogue.

Engineering considerations for sizing pump's components include;

- Maximum Loading Limits
- Maximum Diameter of Unit
- Velocity of fluid passing a motor (this affects rate of pump cooling, a velocity of 1 ft/s is recommended, if not achievable a motor jacket may be required to increase the velocity).
- Shaft horse power (HP) limitations at various frequencies

STEP 6: Optimum Size of Components-B

a. Optimum Selection of Pump

From the Performance Curve of the selected pump type, determine the number of stages required to produce the anticipated capacity based on the calculated dynamic head (TDH). Note that the performance curves are **single stage** pump characteristic curves, hence the total stages required is determined from;

$$\text{Total Stages Required} = \frac{\text{Total Dynamic Head}}{\text{Head per stage}}$$

b. Housing Pressure Limit

Maximum housing pressure will occur at pump shut in, when the maximum lift per stage is available. Worst case is when the pump is pumping against a closed valve.

$$MHP = SIH_{60} * \text{Stages} * \text{Mixture gradient} * (Hz/60)^2$$

MHP: Maximum Housing Pressure

SIH: Shut-in head per stage @ 60Hz.

Stages: Number of pump stages

Hz: Operating Frequency

STEP 6: Optimum Size of Components-C

C. Optimum Selection of Motor

The optimum motor is selected by first determining the brake horsepower required per stage by the pump. This value is also gotten from performance curve. Therefore, brake horsepower (BHP) required to drive a pump is then calculated from;

$$BHP = Total\ Stages * BHP\ per\ stage * Specific\ gravity$$

STEP 6: Optimum Size of Components-C

d. Optimum Selection of the Seal Section

Refer to company catalogue for recommendations based on pump type and well environment.

e. Optimum Selection of Gas Separator

Refer to company catalogue for recommendations based on pump type and well environment. Make the necessary adjustments in horsepower requirements and housing length.

Note: More power will be needed by the motor to drive an added gas separator, this must be added on when selecting the motor, if a gas separator would be needed in the pump.

STEP 7: Electrical Cable-A

Electric cable to be used is selected based on the evaluation of the following parameters:

Cable Size

Cable size is dependent on voltage drop, amperage and available space between casing and collars. Company catalogues have to be consulted for these values. However, it is recommended that the voltage drop should be less than 30 volts/1000 ft or less than 15% of motor nameplate voltage. This is to ensure that adequate voltage is available to operate the motor downhole.

Cable Type

This is based primarily on the fluid conditions, bottom-hole temperature and annular space limitations. Use flat cable for limited space installations.

STEP 7: Electrical Cable-B

Cable Length

Total cable length should be at least 100ft more than the measured pump setting depth in order to have sufficient lengths for surface connections. Make surface connections a safe distance from the well head.

Cable Venting

As a safety precaution, it is necessary to vent gas from the cable prior to the motor controller to avoid explosive conditions. A cable venting box should be used for this purpose.

Example Electrical Cable Specification-A

Oil Well Cable

Model	Max T deg.F	Min T deg.F	Flat Round	Insulation	Jacket	Application
CTT	190	-40	F	Thermo- plastic	Thermo- plastic	Shallow wells, Water wells, Low CO ₂ Light ends
CPN	205	-30	F/R	Poly- propylene	Nitrile	General
CPL	225	-40	F	Poly- propylene	Lead	Gassy Wells, High CO ₂ H ₂ S
CEN	280	-30	F/R	EPDM w/Tape	Nitrile	Low to Moderate Gassy Conditions
CEE	400	-60	F/R	EPDM	EPDM w/ Tape, Braid	Moderate Gassy
CEB	300 or 400		R	EPDM w/ Extruded Fluro- polymer	EPDM	Gassy Wells
CEL	450	-40	F/R	EPDM	Lead w/ Bedding Tape	Hot Gassy Wells

Example Electrical Cable Specification-B

Centriline CTT Flat -40°F (-40°C) to 190°F (88°C) Specifications

Part No.	KV Rating	Cond Size	Conductor Diameter		Insulation Diameter		Jacket Diameter		Overall Dimension		Weight Per	
			Inch	mm	Inch	mm	Inch	mm	Inch	mm	Lb/Ft	Kg/M
76574	3	6-1	0.162	4.11	0.288	7.32	0.394	10.01	0.514 × 1.272	13.06 × 32.31	0.71	1.06
76560	3	4-1	0.204	5.18	0.330	8.38	0.436	11.07	0.556 × 1.398	14.12 × 35.51	0.90	1.34
76572	3	2-1	0.258	6.55	0.384	9.75	0.490	12.45	0.610 × 1.560	15.49 × 39.62	1.20	1.79
76573	3	1-1	0.289	7.34	0.415	10.54	0.521	13.23	0.641 × 1.654	16.28 × 42.01	1.39	2.06

- 1 inch = 25.40 millimeters
- 1 pound per foot = 1.488 kilograms per meter
- All finished dimensions are nominal, + 0.040" tolerance.
- Weight is + 8% tolerance.
- Materials and specifications are subject to change without notice.
- Stranded conductors will be supplied on request.
- Flat cable construction has 0.020" thickness, galvanized steel armor.

STEP 8: Accessories and Other Equipment

a. **Downhole Accessories**

Cable Bands, Cable guard

Swaged nipple

Check Valve

Drain Valve

b. **Motor Controllers**

c. **Transformers**

The type of transformer selected depends on the size of the primary power system and the required secondary voltage.

d. **Wellhead and Accessories**

Select wellhead on the basis of casing size, tubing size, maximum recommended load, surface pressure and maximum setting depth.

e. **Surface Cable**

f. **Service Equipment** like cable reels, shipping cases etc.

g. **Optional Equipment**

- Bottom-hole pressure sensing device- For continuous measurement of bottom hole pressure
- Automatic Well Monitoring - This can be used for remote monitoring of wells.

STEP 9: Variable Speed Submersible Pumping (VSSP)

The ESP system can be modified to include an Electrospeed variable frequency controller so that it operates over a much broader range of capacity, head and efficiency. The speed of an ESP motor is proportional to its frequency of the electrical power supply. Thus by adjusting the frequency, the speed can be adjusted, this is the purpose of the variable speed system.

This system offers potential for boosting production, reducing downtime, and increasing profit. Also it can be used to extend the range of a submersible pump.

Also, if the production capacity of a well is not precisely known a variable speed controller can be selected for an estimated range of and adjusted for the desired production level once more data is available.



Design Class Examples

Question 1

Given the following data:

Lift required: 6200 ft

Rate: 2300 bpd

Fluid SG: 1.0

Operating Frequency: 60 Hz

Find:

- The number of Stages required
- The minimum motor horsepower required
- The pump efficiency

Question 2

Given the following data:

Pump Depth: 7500 ft

Tubing Pressure: 150 psig

Pump Intake Pressure (PIP): 275 psig

Rate: 3000 bpd

Mixture Gradient: 0.42 psi/ft

Tubing : 2 7/8 in. OD (New)

Calculate:

- The Total Dynamic Head (TDH)

Question 3

Given:

Casing: 7in., 26 lb/ft

TDH: 7427 ft

Casing Drift Diameter: 6.151 in.

Rate: 2500 bpd

Operating Frequency: 60 Hz

Find the largest diameter pump that will fit in the casing.

Design Example 4

Question: Select a suitable Submersible Pumping System for the following well and production data.

Well Data

Casing: 7in. OD., 23 lbs/ft

Tubing: 2 7/8 in. OD., External Upset 8 Round Thread (new)

Perforations: 5300-5400 ft

Pump Setting Depth: 5200 ft (measured and vertical)

Production Data

Wellhead Tubing Pressure: 150 psi

Test Rate: 900 bpd

Datum Point: 5350 ft

Test Pressure: 985 psi

Static bottom Hole Pressure: 1650 psi

Bottom-hole Temperature: 180 °F

Gas oil Ratio- Not Available

Water Cut: 90%

Desired Production Rate: 2000 bpd (stock Tank)

Well Fluid Conditions

Water SG: 1.02

Oil API: 30° (0.876)

Gas SG: Not Available

Bubble Point Pressure : Not Available

Viscosity of Oil: Not Available

Power Sources

Available Primary Voltage: 7200/12470 volts

Frequency: 60 Hz

Power Source Capability: Stable System

Possible Problems

None

Design Example 5

Question: Select a suitable Submersible Pumping System for the following well and production data.

Well Data

Casing: 5 ½ in. OD., 17 lbs/ft

Tubing: 2 3/8 in. OD., External Upset 8 Round Thread (new)

Perforations: 5500-6000 ft

Pump Setting Depth: 5000 ft (measured and vertical)

Production Data

Desired Production: 1000 bpd (Stock Tank)

Pump Intake Pressure @ 1000 bpd: 850 psi

Water Cut: 65%

Wellhead Pressure: 120 psi

Producing GOR: 430 scf/stb

Bottom-hole Temperature: 165 °F

Well Fluid Conditions

Water SG: 1.08

Oil API: 35° (0.85)

Gas SG: 0.65

Bubble Point Pressure : 2000 psi

Viscosity of Oil: Not Available

Power Sources

Available Primary Voltage: 7200/12470 volts

Frequency: 60 Hz

Power Source Capability: Stable System

Possible Problems

Gas

Design Example 6

Select the right pump for the data given below:

Casing: 7 in., 26 lb/fts

Tubing: 2 3/8 4.7 #/ft (ID=1.996 in.)

$SG_O = 0.865$ (32° API)

$SG_W = 1.04$

$SG_g = 0.8$

$Q_{O\ SC} = 150$ STB/D

$Q_{g\ SC} = 450$ STB/D

GOR: 225 SCF/STB

Bubble Point Pressure: 550 psi

BHT: 145 °F

Tubing Pressure: 100 psi

Casing Pressure: 100 psi

Top Perforation: 6000 ft

Pump depth: 5500 ft

Summary

- ESP system have been introduced and the operational mechanism explained in details.
- The design methodology, equations and steps were presented.
- Design examples were also shown and demonstrated in class.

References

- WG Wood Group “Basic ESP Sizing Manual”, 2007
- Baker Hughes, Centrilift, “Handbook for Electrical Submersible Pumping System”, 1997.
- Schlumberger REDA Electric Submersible Pump Technology, ESP Catalogue, 2006



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