ELECTRICAL SUBMERSIBLE PUMP HANDBOOK
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SAFETY
Section 1

1.1 Switchboard Safety Tips
1.1 SWITCHBOARD SAFETY TIPS

Listed below are several safety tips that should be followed in addition to any local safety requirements. When working with switchboards always remember:

HIGH VOLTAGE CAN KILL!

1. Stand to the right side of a switchboard when starting or stopping a unit. The door can blow open in case of explosion.

2. If checking high voltages, make sure proper meters and safety gloves are being used.

3. Always check a switchboard for proper grounding.

4. If unusual or loud noises are coming from a switchboard, call a qualified electrician.

5. If arcing noises are present, wear proper safety gloves until source of arcing is located and fixed.

6. Leave voltages alone if untrained or nervous. Have a qualified electrician check a switchboard if necessary.
NORMAL OPERATIONS
Section 2

2.1 Monitoring and Reporting

2.2 Treating (Acid, Scale, Asphaltenes)

2.3 Equipment
MONITORING AND REPORTING

Monitoring is the key to efficient ESP operations. Listed below are some data to be monitored:

- Daily amp charts
- Unusual operating characteristics
- Fluid levels
- Casing and tubing pressure
- Gauges (tubing & casing)
- Tear-down reports
- Cause analyses

Daily Monitoring

Sufficient records should be kept to allow the engineer or foreman to get an overview of the pump’s operation and well performance. Any out of the ordinary operating characteristics should be noted in the well’s file. Amperage charts should be maintained and used as a daily monitoring procedure (see Trouble Shooting Amp Charts). Seven day or daily charts should be used. If electronic data gathering systems are used then a hard copy should be kept periodically so the entire pump life can be examined. Proper maintenance and calibration of the recording devices should also be done. Section 4.2 shows a Standard Operating Procedure used by Sacroc to monitor well performance.
Rangley Shuttle Valve

A second alternative is the shuttle valve developed in Rangely, Colorado, and is similar to a check valve. The main difference is when the ESP shuts down, the check valve drops, preventing fluid from flowing through the ESP, and exposes a side opening which allows the tubing and annulus to equalize. The side opening will allow chemicals to be pumped down the tubing, but not through the ESP. When the ESP is restarted the check valve rises and seals the side opening.
2.3 EQUIPMENT

The ESP system can be divided into subsurface and surface components. The major downhole components include an electric motor, seal section, multi-stage centrifugal pump with an intake and discharge, and power cable. Optional downhole equipment may include a bottomhole pressure/temperature sensor, check and drain valves, motor shroud, and a gas separator. The surface components include a junction box, switchboard, and transformers. A typical ESP installation is shown in Figure A. A description of each component is given below, beginning downhole and moving up the well.

Subsurface Equipment

Motor

ESP motors are two-pole, three-phase, squirrel cage induction motors which operate at a nominal speed of 3500 rpm at 60 Hz. Voltages range from 480 to 4,125 volts, while amperages range from 14 to 143 amps. Horsepower is increased by increasing motor length for a given diameter size or motor series. Large horsepower requirements usually require two or more motors, commonly referred to as tandem motors.

Motors are filled with a nonconductive oil with a high dielectric strength which provides lubrication for bearings and good thermal conductivity. Produced fluid moving past the outside of the motor carries heat away, cooling the motor (minimum recommended fluid velocity is 1 ft/sec). If the fluid velocity is not sufficient to cool the motor, or if the motor is located below the perforations, a shroud should be placed around the motor.

Seal, Protector, Equalizer

The seal section (also known as a protector or equalizer) is located between the motor and fluid intake of the pump. The seal serves five main functions:
entrained in the cable to escape to the atmosphere before reaching the switchboard. The junction box also provides easily accessible test points for electrically checking downhole equipment. (To be used with pack-off type subpump hangar. Not necessary with EFT (Electronic Feed Through) hangar.

Switchboard

Switchboards (motor controllers) consist of a motor starter, relays for overload and underload protection, a circuit breaker, time delay relays, and a recording ammeter. The switchboard also features a lighted display so that a pump's operating condition can be seen from a distance.

Overload and underload relays protect the motor from drawing excessive amperage and insufficient amperage, respectively. A system does not automatically restart if it goes down on overload. Time delays are used to allow enough time to pass after a shutdown before a restart attempt is made; the time delay should be long enough to allow fluid in the tubing to equalize with the annular fluid. Time delays are also used with external control devices, such as tank level controls or line pressure switches. Excessive cycling is not recommended due to the high amperage occurring at start-up.

The ammeter records the amperage drawn by the motor on a 24-hour or 7-day amp chart. Amp charts are a vital means of ESP diagnostics. They give indications of power fluctuations, gas locking, pump-off, false starts, cycling, undercurrent loads, overload, debris, and normal conditions (see Trouble Shooting Amp Charts).

Variable Speed Drive (Optional)

ESPs are relatively inflexible in their production range when operated at a fixed frequency. Variable speed drives (VSDs) allow an operator to vary the frequency, and thus the flow rate, to better match well conditions. However, VSDs have high initial and maintenance costs. Most ESP companies rent VSD's for testing.


TREATING (ACID, SCALE)

Treating Partially Plugged ESPs:

Occasionally, ESPs become partially plugged with scale, wax or asphaltenes, reducing pump performance and increasing lifting cost. Suggested treating is as follows.

Wax

Wax can build up in the upper section of the production tubing as in a rod pump well. These problems can often be remedied by hot oiling or hot watering down the tubing or down the annulus through the pump. The following is a key point to consider:

Pump hot oil or water down the tubing if possible. Excessively hot fluids down the annulus could exceed the ESP cable temperature rating.

Scale

If well bore scale problems are present in your field, you will likely have scale build up in your ESP. Frequently you can treat the pump for scale by pumping the recommended acid for your type of scale through the pump. The following are some points to consider:

Try to pump the acid down the tubing instead of the annulus. This offers better control over the treatment and the acid will not contact the armored cable.

Corrosion inhibitors can be added to acid treatments to protect the steel armor around the cable. (Be careful! Corrosion inhibitors can cause emulsions that could be damaging to the formation.) Not to mention formation plugging from fines released from scale.
Asphaltenes

If you diagnose an asphaltene problem, aromatic solvents (such as xylene and toluene) must be used to disperse the asphaltenes, breaking them up so they can be removed. Chemical manufacturers have additives to help improve solvent performance. Be sure to check with the cable manufacturer before pumping solvents to be sure what affect they will have on elastomers (rubber material) in the cable and pump.

If asphaltenes are suspected a wireline knife can be used to cut material loose in the tubing. This material can be analyzed. If it proves to be asphaltenes, the proper treatment can be applied before the pump becomes irreversibly plugged.

Hot Oil

If a check valve exists above the ESP, the hot oil must be pumped down the annulus. Otherwise, the hot oil can be pumped down the tubing. It is more desirable to pump down the tubing in order to prevent exposing the cable to the hot oil. Cable may be damaged if the temperature of the oil exceeds the cable's temperature rating. Good rules of thumb are:

When pumping down the tubing, use two tubing volumes at 80% to 100% of the formation temperature.

When pumping down the annulus, use one and a half annular volumes at 80% to 100% of the formation temperature.

Hot Watering

The procedure for hot watering is the same as hot oiling except produced water is used. The advantage of using water is that it holds heat longer than oil, thereby requiring less volume and lower temperatures.

Hot watering will frequently have better results than hot oiling. Concerns about scaling, corrosion, bacteria, formation damage, and emulsion problems can be overcome by using
appropriate chemical additives. Rules of thumb for hot water injection are the same as for hot oiling.

Acid Selection

The type of scale present will determine the type of acid required. All large acid supply companies will analyze a produced water sample from the well to predict the type of scale present. Once the type of acid and corrosion inhibitors are selected, the volume and strength of acid required can be determined by the quantity of scale present. Good rules of thumb are:

Use a 5% solution of appropriate acid with good corrosion inhibition additives.

Use 2 bbls/1000 feet of tubing.

Always use a larger volume and weaker solution, rather than a smaller volume and stronger solution, because the bottom portion of the cable and some cable bands will unavoidably come in contact with the acid. If the acid is weaker the corrosive effects are lessened.

Treating

The acidizing procedure for a seized ESP involves a lined pressure truck with a lined or nonreactive pump. The acid should be thoroughly mixed prior to pumping down the tubing. A suggested acid procedure is as follows:
Description | Volume | Rate (bbls/min)
--- | --- | ---
1. Pump until acid is above the ESP. The first ¼ tubing volume of acid is used up, or spent, as it dissolves scale from the tubing. | 1 tubing volume of acid | 1
2. Pump the ¼ tubing volume of spent acid into the annulus and the next ¼ tubing volume of acid into the ESP. | ¼ tubing volume of acid | ½
3. Allow a 15 minute soak time for the acid to work. |  | 
4. Pump a fresh, unspent ¼ tubing volume of acid into the ESP. | ¼ tubing volume of acid | ½
5. Let soak approximately six hours. |  | 
6. Turn on the ESP and produce the spent acid down the flowline. |  | ½

The final ¼ tubing volume of acid is not pumped through the ESP because it will be diluted by the fluid used to displace the acid (usually water).

Acidizing Asphaltenes

Asphaltic crudes are sensitive to the presence of ferric iron during acidizing operations. The iron acts to crosslink the asphaltenene molecules, forming added-oil sludges. Iron
The asphaltene removal procedure for a seized ESP involves a pressure truck with a pump containing teflon seals. The solvent is thoroughly mixed prior to pumping. It is then pumped down the tubing. A typical asphaltene removal program is as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Volume</th>
<th>Rate (bbls/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pump until solvent is above the ESP. The first ( \frac{1}{4} ) tubing volume of solvent is used up, or spent, as it removes asphaltene from the tubing</td>
<td>1 tubing volume of solvent</td>
<td>1</td>
</tr>
<tr>
<td>2. Pump the ( \frac{1}{4} ) tubing volume of spent solvent into the annulus and the next ( \frac{1}{4} ) tubing volume of solvent into the ESP.</td>
<td>( \frac{1}{2} ) tubing volume of solvent</td>
<td>( \frac{1}{2} )</td>
</tr>
<tr>
<td>3. Allow a 15 minute soak time for the solvent to work.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Pump a fresh, unspent ( \frac{1}{4} ) tubing volume of solvent into the ESP.</td>
<td>( \frac{1}{4} ) tubing volume of solvent</td>
<td>( \frac{1}{4} )</td>
</tr>
<tr>
<td>5. Let soak approximately six hours.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Turn on the ESP and produce the spent solvent down the flowline.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sequestering agents are ineffective at preventing acid-oil sludging since the sludges are formed before the sequestering agents function. These sludges can best be controlled by a preflush of aromatic solvent/asphaltene dispersant which removes any existing asphaltene deposits plus acts as a spacer between the acid and oil. The aromatic will also clean the tubing and ESP, improving the effectiveness of the acid.

Most miscible flooding operations will have asphaltene deposition in the well during initial stages of gas breakthrough. A good rule of thumb for treatment volumes is 1 bbl/1000 feet of tubing of aromatic solvent/asphaltene dispersant as a preflush to the acid.

**Solvent-Rubber Reaction**

Solvent is usually pumped down the tubing and rarely down the annulus. If solvent is pumped down the annulus at full strength, it will come in contact with the cable and destroy the integrity of its fluid jacket. Most fluid jackets are nitrile-based and most solvents will swell nitrile 25 to 50%. If this happens the cable armor may burst and/or an electrical short will occur.

Check with the ESP manufacturer before pumping any solvents through an ESP. Some manufacturers use nitrile bushings in the pump, and these will swell and seize the ESP if they are contacted by a solvent.

**Solvent Selection**

The two most common and effective aromatic solvents are xylene and toluene. Both are equally effective at repetizing asphaltenes. The various chemical manufacturers have surfactants and dispersants which will improve the performance of these aromatic solvents. Chemical companies will test a sample of asphaltene and determine which is the best formula for the sample given. This is usually done quickly, but the testing is extremely biased. For complete, unbiased testing, send a sample to COFRC. The testing time is longer but the recommendations will be nonbiased.
The final ¼ tubing volume of solvent is not pumped through the ESP because it will be diluted by the fluid used to displace the solvent (usually oil).

The volume of solvent will be determined by the quantity of asphaltene present. A good rule of thumb is to use 2 bbls/1000 feet of tubing.

If the tubing or ESP is plugged solid and pumping down the tubing is impossible, a coiled tubing unit can be used to clear the plug in the tubing and/or squeeze solvent through the ESP. Plugging can be avoided by implementing the monitoring program described below.

Reducing Treatment Costs

Minor design and operational modifications will result in less downtime and reduced overall treatment costs.

Check Valve vs. No Check Valve

Check valves are the most common method of preventing fluid from passing through the pump. The advantages are that check valves are inexpensive, prevent sand or particles in the fluid from plugging pump during shutdown, allow immediate restarting, and immediate production upon restarting. The major disadvantage is that check valves do not allow circulation down the tubing; reverse circulating down the annulus can be done instead.

Back Spin Relay

An alternative to a check valve is a backspin relay. A backspin relay is part of the motor controller. It monitors voltage generated by the motor after the ESP has been shut down. It will not allow the ESP to start until the motor has stopped spinning. The advantages are that it allows for pumping down the tubing and reduces the number of restrictions in the tubing string. The disadvantages are that start up is only possible after the tubing and annulus have equalized, and the device does not differentiate which direction the ESP is turning. In other words, the well could be slightly flowing and the ESP would not shut.
PUMP OFF

Problems

- Unit too large

Solutions

- Redesign system with smaller pump (current system too large)
- Stimulate well
FALSE STARTS

Problems

- Auto restart delay not of sufficient length to allow adequate fluid build-up.

Solutions

- Increase restart delay
- Redesign ESP
Transformers

Transformers are used to convert primary line voltage to motor voltage requirements. Three types of transformers used in conjunction with ESPs are: banks of three single-phase transformers, three-phase standard transformers, and three-phase auto transformers. The transformers are oil-filled and self-cooling. For offshore platforms where oil-filled transformers might be prohibited, dry type transformers are available. The transformers are equipped with taps to provide maximum flexibility in voltage output.
IDENTIFY PROBLEM
"TROUBLE SHOOTING"
Section 3

3.1 Trouble Shooting General
3.2 Trouble Shooting Amp Charts
3.3 Trouble Shooting Flow Charts
3.1 TROUBLE SHOOTING GENERAL

Check the switchboard's indicator lights to see if the unit is running. If down, check to see if it is down due to underload or overload.

2. Check the amp chart to see if any unusual lines or blips are present. For help in interpreting amp charts see Trouble Shooting Amp Charts.

3. Check the murphy switch or the external switches to see if they are controlling the switchboard.

4. If down due to an overload condition, call an electrician to check for a short downhole before attempting to restart.

5. Check primary fuses to see if they are open. These fuses will open when there is a surge of power on one leg.

6. Visually inspect transformer hookups.

7. Insure the electrician checks the unit downhole from the lowest point of connection.
## Trouble Shooting - Common Problems

### Problem #1: Unit will not start.

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<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
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</thead>
<tbody>
<tr>
<td>No voltage to switchboard</td>
<td>• Check fuses in switchboard and replace blown switchboard fuses.</td>
</tr>
<tr>
<td></td>
<td>• Check incoming voltage.</td>
</tr>
<tr>
<td></td>
<td>• Check primary fuses above transformer and replace blown fuses.</td>
</tr>
<tr>
<td></td>
<td>• Check transformer for open windings and replace if needed.</td>
</tr>
<tr>
<td></td>
<td>• Have power company check distribution system.</td>
</tr>
</tbody>
</table>
| No control voltage in switchboard | • Check incoming voltage.  
• Check all fuses in switchboard and replace blown fuses.  
• Check HOA contacts and overload contacts. Clean or replace if bad.  
• Check control power transformer.  
• Check overload reset by turning HOA switch off and then back to Auto.  
• Check remote wiring to shut switchboard down.  
• Check controller by temporarily bypassing. To bypass Reliatrol, jumper Reliatrol #11 to ground. To bypass Vortex, jumper Vortex #11 to ground. To bypass Centrigard, jumper P1 to ground. To bypass Redalert, jumper #11 to #1. In any of these cases, if the unit runs the controller is bad. |
| Low surface voltage | • Check voltages and correct if necessary. |
| Downhole | • Check phase-to-phase resistance for low ohm shorts reading and shorts to see if balanced. Check phase-to-phase ground resistance for high ohm reading (20+ meg ohm). Lower reading acceptable if VSD controller. |
## Problem #2: Unit shuts down due to undercurrent.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
</table>
| Low well productivity - pumped-off condition | • Check amperage downhole.  
  • Shoot fluid level. Pump water down backside if no fluid level is available. If there is fluid in the well, consider pump change. |
| Plugging of pump intake                 | • Check to see if pump is pumping fluid.  
  • Pump acid down tubing and through pump if tubing is open to pump discharge. (see Section 2, Treating)  
  • Pump acid down backside and spot around pump intake.  
  • Change out pump. Have the pump acidized and tested before sending for repair. This may avoid the unnecessary cost of repairing a scaled pump. |
<p>| Underload set too high                  | • Check amperage downhole on all three phases and compare with nameplate amperage of motor. Reset underload if it is above 80% of nameplate amperage. Do not go below 60% of motor amperage. |</p>
<table>
<thead>
<tr>
<th>Broken shaft in unit</th>
<th>• Compare downhole amperage with idle load amperage (typically 45-55% of nameplate amps). Reverse unit in switchboard by changing two downhole leads. Check amps again; they should be within ± 10% of first reading. Reverse leads again. Pump water down backside if available. Start unit again. If amperage is constant through this procedure, a broken shaft exists and the unit must be pulled.</th>
</tr>
</thead>
</table>
| Pump is gas locked  | • Pump water down backside to break gas lock.  
• Vent casing to flowline if possible.  
• Check setting depth to see if unit can be lowered closer to perforations.  
• Install shroud or gas separator. |
| Faulty remote controls to switchboard | • Check pressure control circuit or other auxiliary that could cause shutdown. |
| Flowline restrictions | • Check all valves to make sure they are open. Check pressure on wellhead and flowline. Check to see if pump is pumping fluid. |
### Problem #3: Unit is running but produces little or no fluid.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect rotation</td>
<td>• Reverse unit in switchboard by changing two downhole leads (electrician only).</td>
</tr>
<tr>
<td>Tubing leak</td>
<td>• Pressure test tubing. Check fluid level in well and check amperage of running unit. If high fluid level and normal amperage, suspect hole in tubing. Pull tubing to fix leak.</td>
</tr>
<tr>
<td>Plugging of pump intake</td>
<td>• Refer to Corrective Actions described under Problem #2.</td>
</tr>
<tr>
<td>Broken shaft in unit</td>
<td>• Refer to Corrective Actions described under Problem #2.</td>
</tr>
<tr>
<td>Low well productivity - pumped-off condition</td>
<td>• Refer to Corrective Actions described under Problem #2.</td>
</tr>
</tbody>
</table>

### Problem #4: Unit will not stay running due to high amperage.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low voltage</td>
<td>• Check incoming voltage to switchboard. Change taps on transformers if necessary.</td>
</tr>
<tr>
<td>Changed well amperage</td>
<td>• Check fluid at wellhead for sand or mud. Check on all three legs to determine if unit is balanced downhole. Check to see if water cut has increased causing higher horsepower requirements.</td>
</tr>
<tr>
<td>Holding coil in main contactor</td>
<td>• Check to make sure all coils are pulling in all three contactors. If one is not, the motor is single-phasing and causing high amperage. Replace bad coil.</td>
</tr>
</tbody>
</table>
Problem #5: Unit will not restart after underload shutdown.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timer motor or controller not functioning properly</td>
<td>• Check and replace timer motor or controller if necessary.</td>
</tr>
<tr>
<td>Control fuses blown</td>
<td>• Check fuses and replace if blown.</td>
</tr>
<tr>
<td>HOA switch defective or dirty</td>
<td>• Check HOA switch and clean or replace if bad.</td>
</tr>
<tr>
<td>External Murphy, or a pressure switch set in wrong position</td>
<td>• Check all external switches for operating levels and correct as necessary.</td>
</tr>
</tbody>
</table>

Problem #6: Unit will not shut down with HOA switch.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control relay stuck</td>
<td>• Pull one control fuse in 110 volt circuit. Do not open main contactor with unit running. Clean relay contacts.</td>
</tr>
<tr>
<td>Main contactor contacts welded together</td>
<td>• Have an electrician physically open contactor.</td>
</tr>
</tbody>
</table>

Problem #7: Unit will not shut down by underload or overload.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller shorted or jumpered out</td>
<td>• Remove jumper from controller. Pull 110 volt shorted or control fuses.</td>
</tr>
</tbody>
</table>
### Problem #8: Controller problems - excessive trips.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Possible Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undercurrent shutdown</td>
<td>• Check downhole amperage. If normal, adjust setting.</td>
</tr>
<tr>
<td>Remote controls have opened and shut unit down</td>
<td>• Check for open or closed contacts on remote circuits and clean or repair as necessary.</td>
</tr>
<tr>
<td>Unit starts but shuts down within 5 seconds</td>
<td>• Check remote contacts and clean or repair as necessary.</td>
</tr>
<tr>
<td></td>
<td>• Check for correct phasing on control power transformer. Change if necessary.</td>
</tr>
<tr>
<td></td>
<td>• Check CT phasing. Change 3-5-7 to controller if necessary.</td>
</tr>
<tr>
<td>Unit will not time-off</td>
<td>• Check remote circuits. Unit will not start in time-off if remote contacts are open.</td>
</tr>
<tr>
<td></td>
<td>• Underload is set too low. If underload is set past the lowest setting mark, timer sequence is not operational. Check CT ratio and adjust underload as needed.</td>
</tr>
</tbody>
</table>
Connects the drive shaft of the motor directly to the pump shaft.

2. Absorbs the axial thrust from the pump.
3. Protects the motor oil from contamination by the well fluid.
4. Allows pressure equalization between the well annulus pressure and the motor internal pressure.
5. Provides a reservoir for volume changes as the motor oil heats up and cools down.

Seals contain a labyrinth chamber with a blocking fluid between the well fluid and motor oil. The blocking fluid is commonly the same oil used in the motor. It may also be a high density fluid for special applications. Seals may also contain a positive elastomeric barrier, or BAG, in combination with a labyrinth chamber. Several operators have increased run lives using tandem seal sections as an added means of protection.

Gas Separators (optional)

Gas reduces the efficiency of ESPs; therefore, gas separators may be installed between the seal and pump to reduce the amount of free gas entering the pump. Both reverse flow and rotary separators are available with the latter being more efficient at gas separation. Some operators run tandem gas separators in high GOR wells to more effectively remove gas from the pump intake. Gas separators do not handle significant volumes of free gas efficiently.

Pump

The submersible pump is a multi-stage centrifugal pump; each stage consisting of a rotating impeller and a stationary diffuser, that produces a given amount of head for a given volume. Impellers may be either floating or fixed. Floating impellers, which are the most common, move axially along the shaft and are free-floating when the pump is operating within the recommended capacity range (see Figure B). However, if the pump is operating below (to the left of) the recommended capacity range, the impeller will be in a downthrust condition. Conversely, if the pump is operating above (to the right of) the recommended capacity range, the
FIGURE
impeller will be in an upthrust condition. Both downthrust and upthrust can cause excessive wear and can be detrimental to the pump.

Fixed Impellers

Fixed Impellers are directly connected to the pump shaft and cannot move axially. Although this saves impeller and diffuser wear, fixed impellers may allow for a high axial thrust to be developed which must be absorbed by the thrust bearing in the seal.

Impellers are classified as either radial flow or mixed flow type. For a given diameter pump, radial flow impellers will have higher head pressure but slightly lower rate capacity than mixed flow impellers.

Impellers may be made of different materials. The most common is a metal alloy called Ni-Resist which is composed mainly of iron and nickel. Other impellers are made of a plastic called Ryton. Ryton is advantageous in scaly or corrosive environments since scale does not form on the Ryton, and since corrosion does not affect plastic. Ni-Resist is better for deep wells, high temperatures, and abrasive fluids.

Check and Drain Valves (Optional Equipment)

A check valve, located two to three joints above the pump, prevents the pump from rotating in the reverse direction when the unit shuts down. This reverse rotation occurs when the fluid in the tubing falls back after the unit has stopped. An attempt to start the system while the pump is rotating backward could result in a twisted shaft. The check valve, if not plugged open by debris, will keep the fluid from falling, thus protecting the pump from reverse rotation.

A drain valve, located one joint above the check valve, prevents pulling a wet tubing string. Drain valves also allow circulation of the well when a check valve is run. Drain valves are not required unless a check valve is used.
Power Cable

Electric cable strapped to the tubing supplies power from the switchboard to the motor. The cable is made up of three copper conductors, either solid or multistrand. The conductors are individually insulated; various insulations are available depending on well fluids, temperature, and pressure. A jacket material surrounds the insulated conductors for protection against mechanical damage and the environment. A metal armor is wrapped around the jacket for further protection against mechanical damage. The metal armor also helps prevent swelling when gas or liquid permeates the jacket material at high pressures.

Cables are available in round or flat configurations and in various sizes. Flat cables are used where clearance between the unit and casing is small. The most common conductor sizes are No. 1 (largest), No. 2, No. 4, and No. 6 (smallest). General amperage ratings for the different cable sizes are:

- \#6 - up to 37 amps
- \#4 - 38-57 amps
- \#2 - 58-65 amps
- \#1 - 66+ amps

As a general rule, voltage drop within the installed length of cable, corrected for bottomhole temperature, should not exceed 30v/1000 ft.

Motor Flat Cable

A motor flat cable, connected to the top of the motor, is run along the length of the ESP system and spliced into the main power cable just above the pump. The motor flat is necessary due to the lack of clearance between the ESP and casing.

Surface Equipment

Junction Box

A vented junction box is located between the wellhead and switchboard. In high pressure wells, gas may permeate the cable and migrate to the surface. The junction box allows gas
UNIT DOES NOT START

UNIT ATTEMPTS TO START BUT GOES BACK DOWN

OVERLOAD LIGHT ILLUMINATED

CHECK OVERLOAD SETTING

RESTART IF NECESSARY

ATTEMPT TO RESTART

GO TO OTHER PAGE

UNIT RUNS

CALL FOR ASSISTANCE

UNIT DOES NOT ATTEMPT TO START

UNDERLOAD LIGHT ILLUMINATED

CHECK EXTERNAL CONTROLS: IS PRESSURES FLOAT CONTROL SWITCH

CHECK UNDERLOAD SETTINGS: RESTART AS NECESSARY

ATTEMPT TO RESTART, UNIT RUNS

GO TO OTHER PAGE

JUMPER CONTROLLER

CHECK CONTROL POWER ON CONTROL FUSE OF #1 VOLTAGE PRESENT 120V AC

CHECK CONTROL TRANSFORMER FUSES REPLACE IF NEEDED

CHECK CONTROL TRANSFORMER REPLACE IF NEEDED

CHECK M.O.A AND START SWITCH OPERATED REPLACE AS NEEDED

CONTROLLER "BYPASS" JUMPERS

VOXET

JUMPER TERMINALS 2 & 3 ON VOXET

KRAOTOS

JUMPER TERMINALS 2 & 3 ON KRAOTOS

REDALERT

JUMPER TERMINALS 1 & 2 ON REDALERT

CENTRIGARD

JUMPER TERMINALS P1 AND P2 ON TERMINAL BOARD 18 #1

ESP ELIMINATOR

JUMPER TERMINALS 2 & 2 ON ELIMINATOR
ANALYZE PROBLEM
Section 4

4.1 Equipment Testing
4.2 Standard Operating Procedure
When ESP equipment is pulled from a well its disposition may vary from running it back into a well, to sending it to the manufacturer to be rebuilt, to having it tested by a manufacturer or testing company. If the equipment was pulled for some reason other than a failure, a well site inspection may be adequate to determine whether it is suitable for rerunning. However, if the equipment is not going to be rerun immediately, or if there is doubt as to its condition, it is recommended that it be tested. Testing is an inexpensive means of determining the condition of used equipment. In the motor testing program, expensive repair costs can also be reduced as much as 90%. Sending equipment to be tested is of particular importance when equipment has been subjected to a hostile well environment (high water cut, CO₂, H₂S, etc.). The cleaning of equipment and preparation for storage that is included in the testing procedure, is as important, if not more so, than the testing itself. Pumps, in particular, left stored on the rack without flushing can "lock down" and become inoperable.

**Pump Testing**

Each section of a pump should be inspected for problems, such as a twisted shaft, hole in the housing, or any problem that would require it to be sent for repairs rather than testing.

2. The pump should be steam cleaned inside and out to remove paraffin and well fluids. Other chemical washes are also available to remove sulfate scale, gyp, paraffins, and asphaltenes.

3. HCl containing an inhibitor and dispersant should be pumped through the pump for a minimum of two hours, or until acid reaction is complete, if scale is present.

4. The pump should be flushed with clear water prior to testing.
5. The pump shaft is checked for play, extension, and that it turns easily. Failure to meet selected standards precludes the pump from future testing.

6. The pump may be tested at the speed that the pump manufacturer states on its published curves. The pressure, rate, torque, and revolutions per minute for this point are recorded. The back pressure is then increased incrementally until the final flow rate of zero is reached. Calculations are done to determine the percentage of deviation from the curve. The pump shaft is again turned by hand, and any signs of roughness are noted.

7. The pump’s housing is inspected with an ultrasonic meter to determine whether there is internal corrosion near the discharge end. Experience has proven that the discharge end of a pump is most vulnerable to erosion and corrosion. Many pumps have parted in this area resulting in costly fishing jobs.

8. After the final inspection, the pumps are prepared for storage by first flushing with glycol and then with oil. All couplings and shipping caps are replaced and the intake ports are plugged and taped.

9. A decision is made as to whether the pump passes or fails by comparing test results with the manufacturer’s curve.

**Motor Testing**

Remove pothead cap and take initial readings:

a. Check the phase-to-phase (lead-to-lead) resistance. It should be balanced among all leads.

b. Check the phase-to-ground (lead-to-housing) resistance. Typically, it should be more than 2000 megohms on a megohm meter with no pressure device.

c. Record all readings. Stop testing if motor is shorted.
TRoubLe SHootIng Ammeter CHArts

Analyzing ammeter charts is one of the best ways to diagnose a number of problems. Listed on the next few pages are examples of ammeter charts for various operating conditions. These charts are reprinted from the "Submersible Pump Handbook" with permission from Centrilift.

Comparing these amp charts to your amp chart may give an indication of the type of problem you have.
NORMAL

- Under normal conditions the ammeter should draw a smooth symmetrical curve near nameplate current. Spikes at start-up are normal.
POWER FLUCTUATIONS

Problems
- Fluctuation of Primary Power Supply (Start-up of large HP motors injection pumps etc.)

Solutions
- Investigate Power Fluctuations
- ID causes of fluctuations (Start-up of large HP motors injection pumps)
- Call power company
Clean motor

a. Steam clean body to within one foot of motor head. Do not steam head.

b. Solvent wash motor head and fill valve areas.

Physically inspect motor for unusual wear from running/pulling and operations: wear on rub buttons and housing rubs; general corrosion; and wear on bolts and bolt holes are some items of concern.

The motor oil should be drained and checked for bronze content (Indicator of bearing wear), water content, varnish/epoxy content, and melted babbit content (silver in oil). All bolt holes and pothead cap 0-rings should be checked for damage. The lead washers on fill valves should always be replaced. The motor should be flushed from top down while turning rotor stack occasionally. Check oil during flush for obvious indicators of motor problems. Flush the oil unit the discharge is clear. Dielectric strength of the oil should be at least 25KV. Once flush is complete, cap motor while it is still full of oil.

The P.I. (leakage) of the motor should be calculated and have a greater value than 2.0. The hi-pot test should be run at a voltage which can be calculated by the following equation: 

\[ (NPV) \times 1.5 + 1.7 \times (NPV) = \text{Nameplate Voltage} \]

The phase-to-ground megohms from the hi-pot test should be greater than 5,000 megohms.

The spin test is performed by running the motor at Name Plate Voltage until the temperature reaches 100°F. The motor then coasts down after running. Coast time should be smooth and last 6 to 8 seconds. Spin testing should be performed for both the clockwise and counterclockwise directions.

If the motor does not meet the above criteria, it could possibly be salvaged by sending it through a “mini dryout.” This procedure involves placing the motor in an insulated compartment and applying DC current to the stator until the temperature reaches 250°F. While the motor is cooling it is
purged with nitrogen. After the dryout, the motor is retested as previously described. Replacement of the motor insulation block in the terminal head is recommended as part of any "mini dryout".
4.2 STANDARD OPERATING PROCEDURE

The following forms were generated by a SACROC Quality Action Team. It is currently used in SACROC as the Standard Operating Procedure for designing and redesigning submersible pumps.
GAS LOCKING

- Redesign pump
- Put on timer
- Choke production back
- Lower pump

Solutions
- Gas evolves in pump
- Lowering fluid level

Problems

GAS LOCKING
**WORKOVER ARTIFICIAL LIFT SELECTION**  
*Data Sheet - Initial Equipment Selection*

### I. Well Data
- **Well No.:**
- **Priority Area:**
- **Engineering Data:**
  - Added Pay: ___ ft
  - Isolated Pay: ___ ft
  - Net Change: ___

### TYPE OF WORKOVER
- **Recompletions**
- **Convert to Producer**
- **Water Shut-Off**
- **Return to Production**
- **Drill & Complete**
- **Other:**
- **Deepen:**

### II. Pre-WO Test Data
<table>
<thead>
<tr>
<th>Date</th>
<th>BO</th>
<th>BW</th>
<th>GV</th>
<th>CO2</th>
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</tbody>
</table>

### III. Pre-WO Fluid Levels
- **Date:**
- **FL:**
- **Casing Pressure & Comments:**

### IV. Down Hole Equipment
- **Date Run**
- **No. Stages X Size X Motor Size**
- **Mid-Range (BFPPD)**
- **Lift (Ft)**

### V. Comments: Briefly list major considerations for equipment selected:

### VI. Was equipment run the same as originally called for? (Y/N)

If no, give brief explanation:

---

**Engr:**  
**Date:**  
**Data WO Completed:**
## WORKOVER DATA

### VII. Post Workover Test Data

<table>
<thead>
<tr>
<th>DATE</th>
<th>BO</th>
<th>BW</th>
<th>GV</th>
<th>CO2%</th>
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</thead>
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</tbody>
</table>

### VIII. Post Workover Fluid Levels

<table>
<thead>
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<th>DATE</th>
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<th>CASING PRESS.</th>
<th>COMMENTS</th>
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</tbody>
</table>

### IX. Resize Data

<table>
<thead>
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<th>Equip. Pulled</th>
<th>Equip. Run</th>
<th>Reason</th>
<th>OS</th>
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</thead>
<tbody>
<tr>
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<td>Up/Dwn</td>
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</tbody>
</table>

### X. Comments:

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_______
DEVELOP SOLUTION
Section 5

5.1 Design

5.2 Decision Analysis Economics
Capital and operating costs, well conditions, reservoir performance, equipment and service performance, and ease of operating and maintaining the equipment are key considerations when designing an ESP.

An IBM PC computer program called ESPO (Electric Submersible Pump Optimization) is available from COFRC for ESP design. ESPO selects the most economic system for each manufacturer considering both capital cost and power cost. Although computer programs make the technical task of ESP design easier, they should not preclude your engineering judgment and experience. Contact W. H. (Bill) Ford at COFRC for more information about ESPO, or to obtain a copy of the program.
DECISION ANALYSIS ECONOMICS

Decision analysis can help you make the best economic artificial lift decision. Merek, which utilizes many tools of decision analysis, is a good program to base your economic decisions.

The foundation of good decisions is historical data. Please keep good records!
PULLING AND START-UP
Section 6

6.1 Installation/Pulling Procedures
6.2 Start-Up Procedures
PULLING AND START-UP
Section 6

INSTALLATION/PULLING PROCEDURES

Pre-Job Checklist

Listed in this section are tips that will hopefully lead to fewer failures. For complete running and pulling directions please consult API RP 11R.

Equipment Required
- Motor
- Seal Section
- Pump
- Cable Motor Flat
- Switchboard
- Round Power Cable
- Junction Box
- Transformers
- ESP Tubing Hanger with Tubing Head
- Tubing PUP (2'-6')

Optional Equipment
- Gas Separator
- Check Valve
- Drain Sub
- Motor Shroud
- Variable Speed Driver

Services Required
- Cable Reel (54" or larger)
- Cable Bands and Bander (Hand band with precut bands or power band with reel of stainless steel bands)
- Electrician (for disconnecting and connecting ESP and testing cable)
- Subpump Service Technician (on location for length of job)
- Chevron Representative (coordinate placement of equipment, timing of deliveries, and supervision of the installation).

DO NOT RUSH. Preplanning is an investment for success.

Wellbore Preparation

Run a bit and positive scraper set to drift diameter at least 100 feet below pump setting depth. A clean out trip below the
bottom perforation is recommended if cost effective. Note any past and present "tight spots".

If tight casing is suspect or the hole is deviated, run a stiff "Dummy" BHA to at least 100' below the pump setting depth. Note depths of tight spots. Look for unusual wear, gouges and marks on Dummy BHA.

**Equipment Handling**

When unloading ESP equipment, use a spreader bar with a chain attached near each end of the box. Never pick-up in the middle!

If the equipment is dropped, damaged, or appears already damaged, it should be checked by the service technician on location.

Note: Slightly more than 50% of all ESP failures in Chevron are cable failures, so special care must be taken in handling the cable.

The cable reel should be handled with an axle and spreader bar.

Never pick the cable reel up by the cable.

Never let any load be placed on the cable during loading, unloading, or storing.

Any rotation of the cable will cause damage.

**Pulling/Running Equipment**

Hold a safety meeting to discuss the scope of work to be performed. Note any special problems or concerns.

Suggested personnel on location:

- 2 Floor Hands
- Derrick Man
- 1 Operator
- 2 Cable Reelers (if by hand)
1 Service Technician
1 Chevron Supervisor

Handle equipment as recommended by the subpump technician.

**Cable Reeling/Banding/Running**

**Reeling**

1. Reel size should be 54" or larger.
2. Reel should be located 75-100' from service rig.
3. Cable guide on rig should be no more than 30' above ground.
4. Always have slack between the cable reel and guide wheel.
5. Always have the cable reel in the operator's line of sight.
6. Use cable stands to prevent cable from dragging through the dirt.

**Banding**

It is very important that the cable be run straight up the tubing.

2. Band squarely across the cable. Tubing band should be at right angles to the tubing with the cable vertical.
3. Band flat cable and flat guards straight up the side of the seal section and pump. Start immediately above the pothead with a section of flat guard which has the bottom end slightly tapered. Continue with the flat guard to just below the flat cable-round cable splice.
4. Stainless steel bands are recommended (0.025 x .75 (316SS)) as minimum. Where conditions warrant (hole deviations, doglegs, scale, etc..) larger bands (.035 x 1.25 (316ss)) should be used.

5. Cable band should slightly deform cable armor. A power bander should use about 125 psia.

6. Install two bands per 30' joint; one midway on the joint, and the other 18" above the collar. If using lead sheathed power cable, additional bands may be required in consideration of the cable weight.

7. STOP and contact a service technician if the cable is damaged.

8. Extra care should be taken in running cable into a well where an ESP has not been installed before.

Splices

Well conditions and field experience will dictate what type of splice is appropriate. Good splices are the key to reducing cable related failure. Quality control of the splicing procedures and materials determine the success of splice. The person making the splice has the greatest influence over it. Cleanliness of the tapes, cables, and the splicer's hands is a must. Tapes if used, must be smoothly wrapped and tight. The cable and conductors should not be manhandled or sharply bent during the splicing procedure. The job should not be rushed because the care and time taken here will be recovered in longer run times for your systems. Specific procedures and recommendations can be obtained from the Rangely office.

Running/Pulling Cable

1. Do not apply tension to the cable. This could elongate the cable and destroy the protective insulation. Avoid sharp edges and rubbing of the cable during running.

   Do not allow the tubing to rotate.
2. Check cable and motor every 2000' going in the hole (electrical continuity and insulation resistance checks).

3. Check the cable visually and electrically coming out of the hole.

4. STOP and have a service technician inspect the cable if the cable is broken, or the insulation or armor is damaged. (Remember: most cable failures result from mishandling.) (Note depth of damage to cable.)

5. Keep slips in good condition with sharp dies of non-rotating type. Be sure the swivel lock on the hook is latched and that the hook is not free to swivel.

6. Run and pull pump between 1000' and 2000' per hour. Never pull the cable from the reel.

7. All stops and starts should be as smooth as possible.

8. Always use lifting subs for raising or lowering ESP equipment.
6.2 START-UP PROCEDURES

Load tubing before start-up if possible.

2. Install proper amp chart.

3. Set overload amperage at 110-120 percent of motor nameplate amperage.

4. Set underload amperage at 80 percent of running amps.

5. Set time delay for a minimum of 30 minutes.

6. Check all valves between the wellhead and tank battery to insure they are in their proper position.

7. Set the selector switch to the "Hand" or "Auto" position and start the pump.

8. If pump fails to start, consult a service technician or electrician.

9. Make sure the load voltage is within 10 percent of the required surface voltage.

10. Once the amps have stabilized after start-up do the following:

   a. Observe the ammeter and flowline pressure during start-up. Low amperage and long pump-up time might indicate reverse rotation.

   b. Insure that the restart time delay is set for a minimum of 30 minutes.

   c. Install pressure gauge in tree and record pressure.

   d. Send a record of equipment to the well file.

   e. Check amp charts frequently and turn used charts in to supervisors when charts are changed.

11. Use 24-hour charts for first three days after ESP installation (may go to 7-day charts after).
GASSY

Problems
- Gas is being produced through the pump

Solutions
- Lower pump (use shroud if pump lower than lowest perl)
- Install gas separator
EXCESSIVE CYCLING

Problems
• Detrimental to ESP motors
• Too large a Unit
• Plugged TBG
• Tubing leak

Solutions
• Obtain a fluid level after shut-down
• Check for high TBG pressure
UNDERCURRENT LOAD

Problems
- No fluid in hole
- Failure of timing relay

Solutions
- Lower Undercurrent settings (by ESP specialist)
- Remedial acid.
UNDER CURRENT BELOW NO LOAD

Problems
- Unit oversized
- Under current set below idle amperage

Actions
- Shut well in
CONTROLS

Problems
- Controlled shut down
  (By tank level, etc.)

Actions
- Set auto start delay timer above thirty minutes
- Use HOA switch to delay start
- Check controls
OVERLOAD

Problems
- Increase in fluid viscosity, sand production, emulsions, or mechanical problems (lightning), motor overheat or worn equipment

Actions
- Have electrician check out unit
- Do not restart
DEBRIS

Problems
- Debris (scale, sand, muds)

Solutions
- Use clean workover fluids
- Clean well prior to ESP installation
- See treating
EXCESS RESTARTS

Problems
- Power problems

Solutions
- Have unit checked out by an electrician
- Do not restart
ERRATIC

Problems
- Mechanical failure (locked pump, burned motor, blown fuses)
- Change in surface pressures
- Change in specific gravity

Solutions
- Do not restart until unit is checked out.
The following two pages are flow charts generated by Chevron's Rangely, Colorado office to help in trouble shooting.