Electrical Submersible Pumps: On and Offshore Problems and Solutions

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Abstract

The following is an update to an earlier paper compiled and presented in April 1991 at the ESP roundtable held in Houston, Texas.

This paper contains referenced categories of problems that have been encountered in field operations and the solutions that have been found to the problems. The discussion for each problem/solution set is brief, but serves as an index to the particular reference, where more detail can be found. The discussion is restricted to field cases. Many excellent studies such as design techniques and recommended procedures are not covered since they are not in the context of a field study containing problems and solutions. Also, some field operational papers were not included if they presented identical information. This study was originally intended to be review of the field cases and a summary of various failures and their causes as a function of the conditions present. However, when beginning to review the papers in the literature, it became obvious that it is rare for a given paper to list detailed field conditions. In fact out of the fifty or so references examined here, only a few contained sufficient field condition data which would have allowed problems and solutions to be correlated to conditions. In addition to categorized and referenced problems and solutions, new innovations, products and operating techniques are presented.

Summary of Problems and Their Solutions

Beginning at the surface, equipment and associated problems and solutions to these problems mentioned in the 105 paper bibliographies of the field cases will be presented. Some of the solutions will appear to be very obvious or simple, but the appearance of the problem and solution will allow the user to reference the paper where it originated and to read in further depth on the subject.

A tabular format is used to present the problems and solutions provided in the case studies. It will be subdivided by whether it is a reservoir, completion, or equipment problem/solution category. In each category, the survey that will be given includes:

Ref: The reference number of the paper from the bibliography.

#ESP: The number of ESPs reported, in the paper, installed.

Yr: The year the paper was published.

Location: The geographical location of the field.

Problem: A short description of the problem.

Solution: A brief comment as to the solution(s) used.

Transformers					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
8	7	82	UK, Montrose	Transformers	Isolation transformers stopped problems due to running all ESPs off a common transformer.
15	610	83	Calif., THUMS	Overall	Isolation transformers for each unit.

The above is the format for the literature throughout the rest of the paper. hen searching the 50 papers, the above two comments indicate that problems have been solved by switching from 3-phase transformers to isolation transformers.

Switchboards					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
15	610	83	Calif., THUMS	Overall, controls	Went to solid state OL & UL controls.
21	3	85	Oklahoma	Control production	Use VSD, VSD soft start -helps if cycling on/off.
36	55	89	Canada, N. Kaybob	How to monitor?	Monitor installations with advanced motor controller.
42	37	90	Canada, B. Glen	Power supply quality	Control panels detect single phasing.
43	60	90	Canada, Mitsu	Pumping or flowing?	top pump if well can flow using pressure switch.

The information here is that solid state OL & UL controls are helpful, but this is state of the art for new purchases. Other comments on VSD, soft start, and single phase detection are presented.

New Variable Speed Drive for ESPs from Reda

Reda has developed a new variable speed drive (VSD) using the pulse width modulated (IPWM) concept for speed control as opposed to the more common SCR type of VSD. Figure 1 shows the IPWM, with diode bridge, reduction in line notching versus that of a six-step VSD which uses silicon controlled rectifiers (SCRs). The IPWM VSD is claimed to reduce low frequency harmonics (cogging) in the motor when compared to a 6 step SCR VSD. The Reda SPEEDSTAR VSD is fan cooled, uses a keyboard for start-up and adjustments, has a 255 event history for 10 days, and has a 15 minute interval for graphical and tabular current, speed and/or pressure. Apparently Reda has addressed the problem of line harmonics from PWM drives as discussed in I & C S, April, 1993 in and article entitled "Dealing with Line Harmonics from PWM Variable Speed Drives."

Electrical Problems					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
7	106	82	Canada, SS Hills	2/3's failures electrical	Established own cable shop...pay less for splices & cable repairs.
"	"	"	"	"	Locate cable shorts with TDR.
"	"	"	"	"	Established stringent cable testing requirements.
"	"	"	"	Wellhead electrical safety	Mandrels instead of packoffs for wellhead connections.
10	?	82	W. Texas	High horsepower electrical protection	Used multiple electrical protection systems...details are given.
13	1	83	UK, Piper	Electrical problems in general	Used grounded system...if fail, then unground...then continue to run if possible.
15	610	83	Calif., THUMS	Wellhead electrical problems	Use feedthrough mandrels, not packoff type.
16	10	84	Wyoming, Beaver Creek	Overall electrical system	Worked with power company, lightening protection added.
36	55	89	Canada, N. Kaybob	Electrical failures	Power filters, better power supply, reduced age of cable.
41	100	90	France	Cable failures	Established electrical tests.
42	37	90	Canada, Bonnie Glen	Electrical transients	Surge suppression filters for lightening.
42	37	90	Canada, Bonnie Glen	Wellhead electrical failures	Feed thru mandrel, no packoff.
43	60	90	Canada, Mitsue	Upper pigtails	Use of dielectric compound in connection to absorb moisture.
44	12	90	Calif., Bev. Hills	Cable Failures	Stricter electrical testing criteria.
52	35	91	Venezuela	Sharp voltage variations from generating station causing overheating of motor	Installed additional power generators to reduce amperage fluctuations.
64	?	93	Texas, West	Frequent problem with VSDs due to severe transient voltages	Installation of transient voltage surge suppressors.
67	215	93	Canada, Redwater	Power fluctuations; Significant differences between 2 utilities servicing the field	(1) Communication from utility before shut-downs. (2) Upgraded problem transmission lines. (3) Identified & repaired malfunctioning oil circuit recloser.

This topic brings up headings, some of which are covered in other topics to follow. The wellhead using a mandrel is preferred to using a pack-off. Electrical transients are controlled with filters and surge suppression devices. Better cable performance is obtained with more stringent testing. The TDR is mentioned as a field application tool.

Wellheads					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
7	106	82	Canada, SS Hills	Wellhead electrical safety	Mandrels instead of packoffs for wellhead connections.
15	610	83	Calif., THUMS	Wellhead electrical problems	Use feed thru mandrels, not packoff variety.
16	10	84	Wyoming Beaver Creek	Cable feed thru	Leave armor on cables where packed off thru wellhead.
28	3	87	Canada, SS Hills	Wellhead splice	Connector molded to cable...eliminate pigtail splice.
34	145	88	Abu Dhabi	Cable problems	Feed thru cable mandrels and pigtail splice system.
38	125	89	Canada, SS Hills	Wellhead connectors	(1) Packoff type deformed lead sheath, spliced on PPE near wellhead, leaked gas, high press blowout. (2) Mandrel with molded pigtails cracked & leaked gas. (3) Mandrel with attachable connectors successful after modification.
42	37	90	Canada, B.Glen	Wellhead electrical failures	Packer feedthrough mandrel, no packoff.
57	36	92	Alaska	Vent gas must be commingled with produced fluid stream at wellhead; Limited wellhouse space & high cost of valving/piping	Placed gas lift mandrel in tubing one joint below tree, where subsurface safety valve not required.

Several mentions were made of using the mandrel type wellheads instead of the packoff variety. Reference 38 discusses the packoff, mandrel, and the newer two-piece wellheads with a summary of the problems and solutions (if any) for the use of the three styles of wellheads.

Cable					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
3	96	79	Canada, SS Hills	Cable, doglegs	Used protectorlizers each joint.
"	"	"	"	Lead cable cracking	Trying new hi-temp cables.
4	154	79	Texas, Denver City	Cable problems	Polypropylene instead of polyethylene.
6	167	83	Sumatra	Cable problems, hi-temp	Buy cable with temp rating greater than well temp.
"	"	"	"	Cable handling problem	Procedures and training added...handling major problems.
"	"	"	"	Cable problems	Added own cable reconditioning facility.

"	"	"	"	Cable-gas expansion	Get cable with interstices initially filled.
7	106	82	Canada, SS Hills	2/3's failures elec	Own cable shop...pay less for splices and cable repairs.
"	"	"	"	"	Locate cable shorts with TDR.
"	"	"	"	"	Establish stringent cable testing requirements.
11	250	83	Canada, Judy Crk/Redwatr	Cable testing	Shop testing, not just meggaring at well site, is essential.
"	"	"	"	Cable problems	Use 36 in. instead of 24 in. sheave.
"	"	"	"	Cable testing	Tests more rigid (i.e., higher VDC level) as environment harsher.
"	"	"	"	Cable flexibility	Heat cable in shack when below freezing for flexibility.
12	12	84	UK, Beatrice	Cable fail-gas, heat	Increase pressure, lower rate, stimulate wells, set deeper.
15	610	83	Calif., THUMS	Cable problems	New specifications, downgrade cable as it ages, then use in less severe wells.
15	610	83	Calif., THUMS	Cable overall	Tailored length, terminated shop tested.
16	10	84	Wyoming, Beaver Creek	Cable feedthrough	Leave armor on cables where packed-off thru well head.
22	22	85	UK, Beatrice	Packer penetrator	Cable molded to top/bottom of the penetrator.
"	"	"	"	Cable protectors	All metal protectors better than rubber coated.
24		86	Florida, South	Cable problems	Use double armor cable & hi-temp lead solder splices.
25	98	86	Peru	Cable problems	Use lead cable, use 1-1/4 in. super bands, power spooler.
28	3	87	Canada, SS Lake	Splices fail, H2S	Use lead cable, X-ray splices, use lead sheath splices.
"	"	"	"	Cable, crush problems	Crush resistant cable with struts to stop deformation.
"	"	"	"	Wellhead splice	Connector molded to cable...eliminate pigtail splice.
32	268	88	Canada, Judy Crk/Redwater	Cable problems	From Polyethylene to lead cable.
"	"	"	"	Cable problems	Stricter cable testing.
34	145	88	Abu Dhabi	Cable problems	Feeder cable is not spliced in the field.
"	"	"	"	Cable problems	Use flat lead cable.
"	"	"	"	Cable problems	Feed thru cable mandrels and pigtail splice system.
36	55	89	Canada, N. Kaybob	Standard practice	Tandem seals, rotary separator, hi-temp oil, lead sheath cables, stainless armor mle.

"	"	"	"	Electrical failures	Power filters, better power supply, reduce age of cable.
39	15	89	UK, Montrose	Cable failures, gas	Evaluate cables...new cable better than others.
"	"	"	"	Cable-armor damage	Use stainless steel armor.
"	"	"	"	Cable protection	Cross coupling cable protectors applied.
39	15	89	UK, Montrose	Pothead failures	Use of new floating seal to allow for conductor movement.
41	100	90	France	Cable failures	Establish electrical tests.
"	"	"	"	Cable failures	Protectors used on deviated wells.
"	"	"	"	Power supply	Use hi-voltage motors (reduce cable power loss).
42	37	90	Canada, B. Glen	Cable failures	New cables.
43	60	90	Canada, Mitsue Gilwood	Splice failures	Use vulcanized splices, cable wet testing.
44	12	90	Calif., Bev. Hills	Cable, hot conds	Buy hi-temp options.
"	"	"	"	Cable damage	1-1/4 in. super bands for cables to band cables.
"			"	Cable failures	Use stricter electrical testing.
45	28	0	Several	Cable problems	Schedule reviews with manufacturers on problems.
45	28	0	Several	Cable problems	Monitor, use good practice, recognize problems.
51	7	1	Italy, offshore	Pothead & Hanger connector failures	Used 4KV dual insulation connectors.
53	5	92	UK, N. Sea	Failures due to penetrators	Improved protection of individual phase insulation within penetrator to avoid lead sheath/insulation cutting.
56	20	92	UK	Splice & Connector = 45% of failures	Detailed analysis with vendors. Carried out independent testing evaluation, with feedback to vendors.
57	36	92	Alaska	Pigtails & cable failures due to hot-oiling operations	Switch to EPDM/EPDM cable & pigtails. Lowered max hot oiling temperature from 230 to 150°F.
"	"	"	"	Cable failure due to pre-installation exposure to extreme cold	Switch to EPDM/EPDM cable. Store and run from heated spooling shed. Minimize cold exposure time.
58	95	92	Calif.	Galvanized armor corrosion - below fluid level	Ran stainless steel armored cable on bottom 2000 ft.
60	49	92	Canada, Judy Crk	Cable failures, gas & high temperature	Use newer technology cables with EPDM insulation and chemical

					barrier. Do not use nylon braid. Fatigue problems & more cost with lead sheath cables.
63	373	93	Colorado	Decompression cracking insulation due to CO, flood	Use an EPDM cable with chemical barrier.
66	138	93	Indonesia	'Blow out' of cable insulation, mainly in the fluid draw down area	Premium cable, elastomers can withstand 320 F.
67	215	93	Canada, Redwater	Shortrun failures due to rerunning used cable after repairing & Testing	Cable testing was not quantitative indicator of expected cable life, revised policy to run only 'new cable'.
68	11	93	Canada	To increase production by decreasing downtime	Redesigned electrical connector, improved splicing technique & cable testing spec.
94	?	93	Texas, West	Establish used cable evaluation criteria	Field specific testing/evaluation procedures for used cable have been successful.

Cable problems continue to be one of the most mentioned topics in the bibliography. The topics range from types of cables, protectorlizers, cable testing, owning a cable shop, using super bands, handling procedures, and splices. The comment on high voltage was listed as cable improvement, but although higher voltage reduces heating and power drop, additional voltage stress could tend to shorten life. Splices are broken out in a separate search below.

Time Domain Reflector					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
7	106	82	Canada, SS Hills	2/3's failures electric	Locate cable shorts with TDR.
24	?	86	Florida, South	Overall	Surveillance, use TDR, collect data, field levels, teardowns.

Only two references are identified that use the TDR to locate cable faults. It is recognized that specific papers have been given in the past on this subject. However, the above is what was found from this selection of field study reports. The TDR is a non-destructive method of cable fault detection.

Splices					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
3	96	79	Canada, SS Hills	Splice features	Went to molded splices.
7	106	82	Canada, SS Hills	Failures, electric	Own cable shop...pay for less for splices and cable repairs.
11	250	83	Canada, Judy Crk/Redwater	Splice problems	Molded splices are better than field splices.
22	22	85	UK, Beatrice	Splice features	Field splices better than factory

					molded connectors.
24		86	Florida, South	Cable problems	Use double armor cable & hi-temp lead solder splices.
"	"	"	"	Splices fail, H2S	Use lead cable, X-ray splices, use lead sheath splices.
"	"	"	"	Well head splice	Connector molded to cable...eliminate pigtail splice.
28	3	87	Canada, SS Lake	Splices bulky	Use short section smaller tubing near splice locations.
34	145	88	Abu Dhabi	Cable problems	Feeder cable is not spliced in the field.
"	"	"	"	Cable problems	Feed thru cable mandrels and pigtail splice system.
38	125	89	Canada, SS Hills	Wellhead connectors	Pkoff type deformed lead...must splice to PPE...leaked gas.
39	15	89	UK, Montrose	Splices at MLE	Larger gage wire, longer MLE, eliminate splice, #1 to motor.
"	"	"	"	Connector failures	Eliminate all connectors...use pigtail with vulcanized splice.
41	100	90	France	Splices	Lab test aging of splice materials.
43	60	90	Canada, Mitsue	Splice failures	Vulcanized splices, cable wet testing.
44	12	90	Calif., Bev. Hills	Splice failures	Hi-temp tapes, extra barrier tape, witness splices.
56	20	92	UK	Splices & Connectors = 45% of failures	Detailed analysis with vendors. Carried out independent testing evaluation, with feedback to vendors.

There is a general trend to prefer the vulcanized molded splices instead of the field splices although reference 22 reports that carefully made field splices are better than molded splices. Other quality control measures are taken such as X-rayed splices, and reference 44 mentions actually witnessing splices while they are made. Again, cables are a subject that is often mentioned in literature field cases.

Protectorlizers					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
3	1	79	Canada, SS Hills	Cable doglegs	Used protectorlizers each joint.
22	22	85	UK, Beatrice	Cable protectors	All metal protectors better than rubber coated.
39	15	89	UK, Montrose	Cable protection	Cross coupling cable protections applied.
41	100	90	France	Cable failures	Protectors used on deviated wells.
53	5	92	UK, N. Sea	Cable damage in tight, deviated completions	Detailed procedure on dressing casing/liner and use of protectorlizers.

Protectorlizers are used on deviated and/or severely doglegged wells. Reference 22 indicates a preference for all-metal protectorlizers. Reference 39 reports on use of a more robust protector for cables. Protectorlizers are generally considered for wells having roughly 3°-6° and greater dogleg severity.

Pumps					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
17	1000	84	Sumatra	Heating in pumps	Use only high temperature impellers.
19	98	85	Peru	Stock fewer points?	Use tandem and triple motors/pumps (remote area).
24	?	86	Florida, South	Pump problems	Size to mid-range, use high strength shafts.
25	98	86	Peru	Pump downthrust	Size to right of curves. Use full floater pumps (not BFL).
26	40	86	Calif., THUMS	Electrical mechanical failures	Pump tests showed should use all new rotating parts.
33	230	88	Canada, SS Hills/Nipisi	Test pumps - rerun	Test/rerun, 144 out of 225 pumps proved economical.
39	15	89	UK, Montrose	Sand pump wear	Use abrasion resistant pumps - inserts, new metallurgy.
43	60	90	Canada, Mitsue Gilwood	Shafts pumping out	Install heads/snap-rings to hold pump shafts.
47	?	90	Canada/Michigan	Gas interference	Tapered pumps and shrouds extend conventional methods of gas separation.
49	640	90	Calif., THUMS	Overall	New rotating components in all new pump.

Many important points are referenced back to the literature in the above list of problems/solutions. Some plastic impellers failed in high temperature use. One field advocates using tandem and triple pumps to reduce the stocking of equipment. One field finds better results sizing to the middle of the pump range while another (with sand) finds better results to the right of the pump design. For gas, the tapered concept is still used to advantage in one field. The testing and use of all new rotating parts has been very beneficial as reported in two papers. The abrasion resistant pumps are being used to advantage. One paper reports the problem of pumping out the pump shaft and the solution to this problem.

Seal Section, Protector, or Equalizer					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
8	7	82	UK, Montrose	Seal/Motor failures	Tandem seal sections increase run life.
10	?	82	W. Texas	Motor/Seal	Tandem seals have extended seal life to motor/pump life.

13	1	83	UK, Piper	Motor/Seal	Use tandem seal sections.
14	7	83	UK, Montrose	Motor/Seal	Use tandem seal sections.
17	1000	84	Sumatra	Motor/Seal	Use tandem seal sections.
24	?	86	Florida, South	Motor/Seal	Use tandem seal sections.
27	25	86	Canada, Nipisi Gilwood	Motor protection	Use tandem seal sections.
28		87	Canada, SS Lake	Water in seals	Use tandem seal sections.
32	268	88	Canada, Judy Crk/Redwater	Overall	Use tandem seal sections.
34	145	88	Abu Dhabi	Water in seals	Use tandem seal sections.
36	55	89	Canada, N. Kaybob	High temperature	No bag type seal sections.
"	"	"	"	High temperature	Babbitless thrust bearing in protectors.
41	100	90	France	Motor/Seals, water	Use tandem seal sections.
44	12	90	Calif., Bev. Hills	Motor/Seal	Use tandem seal sections.
49	640	90	Calif., THUMS	Motor/Seal	Use tandem seal sections.
52	35	91	Venezuela	Use of improper dielectric oil caused foaming & leakage into motor	Substituted oil meeting manufacturers specifications.
53	5	92	UK, N. Sea	Protector failures	Use modular protectors.
58	95	92	Calif.	Short motor life	Run multi-chamber seal sections with additional mechanical face seals.
60	9	2	Canada, Judy Crk	Premature thrust bearing failure	Install heavy duty thrust bearing for pumps over 60 hp.

For those holding to the belief that the use of tandem seal sections is still experimental, the above list should be evidence that it is actually the standard in many fields where problems with life have occurred. Also there is mention of bag failures, and the need for babbitless thrust bearings in high temperature environments.

Motors					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
3	96	79	Canada, SS Hills	Motor housing corrosion	Inhibitor for WC >20% weekly in annulus, high chlorides.
7	106	82	Canada, SS Hills	Gas, motor ULs	Conv. and rotary separators, shrouds, and inverted shrouds used.
8	7	82	UK, Montrose	Motor overheating	Oversizing motor, centralization, or shroud.
"	"	"	"	Run-in failures	Steel centralizers reduce pothead and motor failures.

9	26	82	Texas, Talco	Save motors, before major failure?	Pull when drop in rate indicates sand wear in the pump.
11	250	83	Canada, Judy Crk/Redwater	Pothead problems	Pressure test pothead at well after attachment to motor.
16	10	84	Wyoming, Beaver Creek	Poor performance of equipment	Use vendors equipment without brass & plastic in motors & seals.
17	1000	84	Sumatra	Motor heating	Derate motor by 25% when selecting.
"	"	"	"	Overall	Maintain motor (dry outs only) and pump shop.
24	?	86	Florida, South	Motors overheating	Derate motor HP by 25% (i.e., oversize motors).
27	25	86	Canada, Nipisi Gilwood	Test well, size ESP	Use motor/generator to vary speed and test new wells.
33	230	88	Canada, SS Hills Nipisi	Test motors - rerun	Test/rerun, 109 out of 117 motors proved economical.
34	145	88	Abu Dhabi	Corrosion	Chemical injection inhibitor line to bottom of motor.
36	55	89	Canada, N. Kaybob	How to monitor ESPs?	Monitor installations with advanced motor controller.
39	15	89	UK, Montrose	Splices at MLE	Larger gage wire, longer MLE, eliminate splice, #1 cable to motor.
41	100	90	France	Power supply	Use high voltage motors (reduce cable power loss).
42	37	90	Canada, B. Glen	Gas, motor UL	Downsized motors.
44	12	90	Calif., Bev. Hills	Motors in high temperature	Went to high temperature motor options.
"	"	"	"	Motors, seals	Use high density blocking fluid.
"	"	"	"	Motors in high temperature	
56	20	92	UK	Motor thrust bearing failures	Improved manufacturing quality.
57	36	92	Alaska	Motor failures - almost immediately in low bottom hole temperature application	Manufacture motors with additional radial bearing clearance.
58	95	92	Calif.	Short motor life	Oversized motors 5-15%.
59	400	92	Texas, Sacroc	Motor MTBF	Use IEEE/ANSI routine maintenance procedures to test ESP motors, perform electrical & mechanical tests, & change oil. Increased run times.
60	49	92	Canada, Judy Crk	Short motor life	Select motor with larger horsepower than generally recommended.
"	"	"	"	Decreasing motor run times with increasing	Alternate manufacturer.

				horsepower size	
67	215	93	Canada, Redwater	Higher failure rate with one vendor	Work with vendor to make design/manufacture improvement.
69	20	93	UK, N. Sea	400 day run life deteriorates to 180-350 days	Improve quality assurance in motor manufacturing & refurbishment.
72	?	94	?	Motor failure due to H2S burn in slots	Increase insulation thickness in stator, windings sealed with special epoxy, stainless stell replaced with Monel.
73	15	94	UK, N. Sea	Motor failure due to rotor/stator contact	Review a & make improvements to manufacture, design, & Installation.

The above search results for motors has the references to the use of tandem seal sections removed because the tandem seals usually had reference to the extension of motor lives. Other mentions are of the use of centralizers and derating for temperature problems. Reference 11 mentions how to test the pothead seal after it is plugged into the motor on the floor before running the equipment. Other items include downsizing in presence of gas. The important subject of testing and rerunning the motors after initial use.

New High Temperature Motors

High temperature motors for ESP applications may be needed when the following conditions exist:

- High bottom hole temperatures

- Low velocity past the motor caused by:

  a. setting in or below the perforations without a shroud

  b. low production wells

  c. large casings where shrouds cannot be used

- Steam flood injection projects

- Poor cooling due to high gas past the motor

For these type of conditions, both Reda and ODI have developed high temperature motors.

The Reda motor is called the Hotline motor containing a patented insulation system rated for 550°F internal motor temperature. Figure 3 from Reda shows the insulation life increase for their Hotline motor. The Reda and the ODI motor have been used in very hot steam flood wells in California.

The ODI motor concept uses double thick Kapton insulation and Aflas elastomer seals. Also it was used with a motor oil line from the surface which circulates motor oil into the motor and out through a check valve through the seal section where normally oil exits from hot oil expansion.

This maintains the oil dielectric strength, but does not provide additional cooling, as only about 1 gallon/day is used for injection.

ODI also has a feature for hot motors which is a recirculation pump. This pump, mounted below the seal section, directs a flow of wellbore fluids down the well towards the motor for the hot motor situations listed above.

Centrilift still provides motors with the epoxy injected around the stator wires. They point to the increased conduction of heat provided by the epoxy filled winding as an advantage in hot wells.

ESP Motors

ESPs can be utilized in a variety of conditions. These can include temperatures ranging from 80°F-400°F. The water cuts can range from 100% water to 100% oil. Flow rates, casing sizes and tubing sizes can range such that the velocity of fluid over the motor can vary significantly from a "rule of thumb" of 1 ft/sec.

The Reda 652 series motor is stated to be designed to maintain a high efficiency, power factor, and RPM over a range of variable ratings controlled by tailoring the hp, voltage and amperage to meet downhole requirements. As one example of several available from Reda, Figure 4 shows that the efficiency of the 562 motor is not significantly different from 65-95% motor load resulting in a high efficiency that is not a sharp function of motor load.

ODI offers a 55 and 70 series motor. Among features advertised are increased copper in winding, all steel stator design, enhanced oil circulation system, and a new rotor bearing assembly. They publish motor curves with the highest motor efficiency. The 55 series maximum efficiency is around 88% maximum efficiency and the 70 series maximum efficiency is 90%. They also show a broad range of flat efficiency relative to % motor loading, (see Figure 5 for the ODI 70 series motor performance).

Centrilift motors (375, 450, 544, 562 and 675) use a patented, elastomer "T" Ring on the radial support bearings to prevent rotation of the bearing and premature wear of the stator.

ESP Motors/PC Pumps

Two US companies are pursuing the development of an ESP motor driven PC pump. This type of pump was actually offered on the market in the past by ODI. The concept has certain advantages including the fact that rod/tubing wear, and tubing wind-up is eliminated. On the minus side, the motor must generally be geared down and the vibration from the PC pump may aggravate fluids invading the motor past vibrating seals. Further, any gearbox must also be sealed from wellbore liquids.

Reda is developing a motor which has a synchronous speed of 1800 rpm and Centrilift is considering a system with a 3600 rpm motor with a gearbox.

A Russian built pump system has an electric motor downhole driving a PC pump system. The PC pump system has two sections of rotor/stator. One section pumps down and the other section pumps up. The discharge is in the middle of the two sections. This puts any thrust in balance. The motor used is a 4 or 6 pole motor. Currently there are about 400 in use in Russia. The Connas Institute in Moscow designed this concept, although they have as yet not been exported. See Figure 6 for a schematic.

Pressure Instruments					
Ref	#ESP	Yr	Location	Problem	Solution
11	250	83	Canada, Judy Crk/Redwater	Design problems	Use VSDs (initially); obtain IPR, PVT, & other data; use pressure sensors.
12	12	84	UK, Beatrice	Pressure sensor	Pressure gage over packer (vented packer), no wire thru packer.
22	22	85	UK, Beatrice	Pressure measurement	Gage set above packer(vented), better than wire through.
23	5	86	Calif., Offshore	Well testing using ESP, offshore & heavy oil	Use of VSD & bottom hole pressure sensor to analyze reservoir performance and optimize well test procedures.
39	15	89	UK, Montrose	Accurate, reliable bhp	Use of downhole sensor intregal to ESP successful after changes.
40	30	89	Indonesia, Bima	Pump performance corrections for viscosity	Use downhole pressure sensor, establish correction procedure for pump head/performance.
75	2	94	UK, Wytch Farm	Monitoring ESP performance and operation	Utilized a downhole flowmeter (flow, pump intake & discharge pressure, & fluid temperature).
92	?	94	California, Offshore	Reliability of permanently installed downhole gauges	Modified the instrument wire splicing procedure.

Mention is made of using pressure instruments for unusual conditions, such as the presence of hi-viscosity crude (references 23 and 40). Other items include well testing to get the IPR for critical installations or where gas or other conditions make design difficult.

Downhole Sensors

For years, Centrilift and Reda have offered downhole pressure and at times combined temperature sensors to be installed at the base of the motor. The reliability of each system has come into question in the past. Reda has improved this option into a new tool using the Amerada capacitance sensor which produces a change in frequency output with a change in detected pressure. The signal is transmitted up the power cable. The tool has an option of sensing and transmitting the discharge pressure and fluid temperature. The pump discharge pressure sensor bolts directly to the top of the pump. The signal from this transducer is transmitted to the lower unit by a signal wire protected by a cable guard or a crush resistant stainless tube as shown schematically in Figure 7.

There are many benefits to being able to record simultaneously the intake and discharge pressure.

They are:

- The pump performance degradation with gas and viscosity can be recorded and checked back to industry correlations.

- Multiphase pressure drop in the tubing can be recorded in inclined wells with gas, and other fluid properties by using the discharge pressure. This can lead to multiphase flow prediction improvements.

- The pump and tubing performance can be separated and the correct values can be assigned to each component for diagnosis and later design improvements.

Phoenix Petroleum Services Limited offers a downhole sensor package which monitors:

- Intake pressure

- Discharge pressure

- Motor temperature

- Intake pressure and

- Current leakage

The Phoenix system transmits the multi-signal data up the power cable as well as to a surface unit for readout.

ODI offers a DHS-5000 for primarily intake pressure. It can be set up for discharge pressure in lieu of the intake pressure. Currently it is arranged for a downhole splice into the power cable. Current developments may allow the use of a toroidal coil around one of the motor leads.

Alnas, one of the Russian manufacturer's of ESP systems, offers a package that senses temperature, pressure and vibration as well. This data is also transmitted up the ESP cable. Currently there is no single criterion that says when vibration reaches a certain level, the unit should be pulled, but it does serve to see what changes in vibration occur during the equipment life. This could lead to experience to suggest a pull before severe vibration contributes to an avoidable motor failure.

Scale					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
3	8	79	Canada, SS Hills	CaCO, scale, plugging	Acidized, inhibitor squeezed, returns monitored.
13	1	83	UK, Piper	Sulfate scale	Inhibitor squeeze thru pump, inhibitors discussed.
15	610	83	Calif., THUMS	Barium sulfate scale from injection water. Calcium carbonate deposition.	For Barium sulfate 1000 gal 15% HCl followed by polyacrylate-phosphonate blend overflush thru Y-tool. Same method w/surfactant in acid for calcium carbonate scale.
30	?	88	UK, Piper	Barium, strontium, calcium sulfate scales. Pump plugging, motor overheating, disposal of radioactive scales.	Sulfate scale dissolver treatments rarely successful, poly-phosphonic acid inhibitor treatments used.
"	"	"	"	Carbonate scales	15% HCl treatments sufficient for

				($CaCO_3$)	carbonate scales.
34	145	88	Abu Dhabi, Mubarras	Inorganic scaling (calcium carbonate & calcium sulfate)	Use sodium chloride brine for kill fluid. Squeeze with scale control inhibitors (organophosphonates).
"	"	"	"	Organic scaling (asphaltenes).	Batch treatment with Xylene.
36	55	89	Canada	Iron sulphide (FeS_2) build-up on pump and separator	Changed from bronze bushings/sleeves to NiResist.
52	35	91	Venezuela	$CACO_3$ encrustations at wellhead & flowline	Inhibitor injection. Modified wellhead connections to reduce sudden pressure & temperature changes.
53	5	92	UK, N. Sea	Sulphate scale forming within pump causing motor overload	Bullheaded with dissolver and soaked 3 days. Long term - performed scale squeeze.
87	?	94	California, Offshore	Production sludge plugged pump stages	Procedure developed to treat wells resulting in longer runs.
88	630	94	California, Offshore	Scaling on low-volume stages (100-700 bpd)	Larger inlet opening on impeller reduced scaling tendencies.

Note that for scale, squeeze treatments through the pump are mentioned. Reference 36 reported that the presence of brass/bronze caused a scaling problem in the pump radial bushing areas. Reference 88 refers to special large impeller fluid passages for low volume stages that reportedly reduce scaling tendencies.

Sand					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
6	167	83	Sumatra	Sand causing production loss	Resize the pump or workover the well.
9	26	82	Texas, Taco	Sand production in 25% of wells	Reduce fluid production by backpressuring the ESP or recirculating some production until sand is stabilized.
9	26	82	Texas, Taco	Low production caused by pump wear (sand)	Monitor production and pull when rate drops, to prevent losing the motor too.
14	7	83	UK, Montrose	Wear in pump	Radial, mushroom stages give better life.
"	"	"	"	"	Rubber bushings are helpful.
15	610	83	Calif., THUMS	Wear in pump	Rubber bushings have helped.
"	"	"	"	"	Gravel packed inner liners.
18	21	84	N. Sea, Dutch Q-1 Block	Sand	Use open hole gravel pack completions.
39	15	89	UK, Montrose	Wear in pump	Use new abrasive resistant pumps, new metallurgy pump stage inserts.

44	12	90	Calif., Bev. Hills	Wear in pump	Scrape and bail before running ESP. Use abrasion resistant style pump.
48	21	90	Canada, Bellshill Lake	Wear in pump	Use of rubber bushings for radial stabilization very helpful.
"	"	"	"	"	Cartridge type sand screens installed in 3 wells, they plugged or disintegrated due to jetting action at perfs.
"	"	"	"	"	Used high density perforating (30 shots/m) and sand screens.
"	"	"	"	"	Use high density perforating, limit drawdown during first 2-8 weeks, continuous monitoring.
52	35	91	Venezuela	Motor overload heating and failure caused by pump wear	Monitoring program to watch motor AMPS. Perform preventative maintenance before high overloads occur.
"	"	"	"	ESP startup overload caused by settling of sand into pump during downtimes	Procedure to circulate well via pump intake to keep pump clear.
57	36	92	Alaska	Pump failure - due to sand plugging & abrasive wear	Incorporate bit & scraper trip, circulate surfactant & gel sweeps to remove solids prior to running ESP on new & replacement wells.
"	"	"	"	"	Tungsten Carbide inserts in pump appear to be providing some help, but not complete solution.
"	"	"	"	Reintroduction of produced sand into ESP during backflushing procedure for freeze protection.	Installed check valves.

Several references have indicated that sand can be controlled by controlling the fluid rate. Others mention using rubber bushings in the pump to improve run lives in several locations. One reference indicated that improved run life was realized from mushroom style stages, due to the increased downthrust area. More recently, however, abrasion resistant pumps, which incorporate hardened stage downthrust and radial materials, are discussed. Note: See the discussion following the section on pumps above considering new abrasion resistant pump designs.

Corrosion					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
1	?	77	Texas, Sacroc	CO_2 corrosion on O.D. of ESP and I.D. of tubing	Coat ESP w/ glass filled epoxy. Tubing ID coated w/ thin film epoxy modified resin.

3	96	79	Canada, SS Hills	Motor housing corrosion	For wells >20% water cut, corrosion inhibitor solution once a week batched down annulus & circulated in tubing.
10	?	82	Texas, El Capitan	Highly corrosive electrical field between ESP and casing	Solved by applying a 10-15 mil fiberglass reinforced air-dried polyester coating to motor and 30 mil coating to rest of ESP.
11	250	83	Canada, Judy Crk/Redwatr	Housing corrosion	Monel spray coating on ESP housings effective.
24	?	86	Florida, South	Housing corrosion (CO_2)	High chrome alloy housing used in place of monel coated carbon steel housing.
25	98	86	Peru, Amazon Basin	Housing corrosion (CO_2)	Use of high chrome alloy units and inhibitor treatment down annulus.
31	98	88	Peru, Amazon Basin	Housing corrosion (CO_2)	Conversion to ferritic housings, heads, & bases.
34	145	88	Abu Dhabi, Mubarras	Corrosion (CO_2) on bleeder & check valves	Changed bleeder & check material to stainless steel.
"	"	"	"	Corrosion (CO_2) on housing	Tried coated units w/ chemical injection line to bottom of motor.
"	"	"	"	Corrosion (CO_2) on housing	Final solution was ferritic units.
39	15	89	UK, Montrose	Corrosion (CO_2) on housing	Monel coating on motor and seal sections. Ferritic gas separator.
39	15	89	UK, Montrose	Corrosion (CO_2) on tubulars	Coated tubulars in highly corrosive wells. Chemical injection subs just above pump on less corrosive wells. Trials being made on scale/corrosion squeeze inhibition treatment.
48	21	90	Canada, Bellshill Lake	Corrosion (7% CO_2) on ESP housing	Monel coat all housings, 12 mil thick.
"	"	"	"	Corrosion (3% H_2S) on copper bearing alloys in pump	All internal copper bearing components replaced with NiResist material.
50	650	90	Texas, Sacroc	Housing corrosion (CO_2)	Flake coating (glass filled polyester) was moderately successful. Caused increase in motor burns. 316 SS flame sprayed coating tried. First at 6 mil thickness, then 12 mil, then 12 mil with air cured epoxy coating to fill coating porosity. Not durable due to scratching. Changed to ferritic metallurgy.
58	95	92	Calif.	Galvanized armor corrosion - below fluid	Ran stainless steel armored cable on bottom 2000 ft.

			level	
49	92	Canada, Judy Crk	Corrosion on gas separators causing premature failure	Install stainless steel impeller and additional bearing.
11	93	Canada	To increase production by decreasing downtime and optimizing applications	Upgrade pump components for mechanical and corrosive failures.
8	94	Canada	Pump failures due to corrosive solution mining fluids	(1) Change metallurgy on pump's fluid wetted components. (2) Choose metallurgy to prevent galvanic cells. (3) Vacuum fill motors & seals. (4) Use tandem seals with blocking fluid.

Housing coatings and inhibitors are mentioned frequently. The use of ferritic material to combat :on is mentioned as a final, successful solution in some papers. The SACROC papers from ›n (West Texas) are very good information sources because of the number of ESPs and the length :ation in a CO_2 environment.

Gas

#ESP	Yr	Location	Problem	Solution
154	79	Texas, Denver City	Gas separation	Complete with 7 in., not 5.5 in. csg to allow better gas separation.
167	83	Sumatra	Cable damage, elastomer expansion	Redesigned cable, filled the interstices between the conductors with impregnable synthetic compound.
106	82	Canada, SS Hills	Gas interference, motor underloading & pump gas locking	Where physically possible, conventional motor shrouds were used. Used inverted motor shrouds on 5 wells. Also successful w/ rotary gas separators.
7	82	UK, Montrose	High GOR causes sizing, design problems	Use of VSD helps, since gas creates design uncertainties.
"	"	"	Excessive free gas causes performance problems	The high downhole gas volumes were handled with either a rotary or static type separator.
12	84	UK, Beatrice	Gas related cable failure between pump and packer	Actions taken; restoration of reservoir pressure, lower rate ESPs, stimulate wells, and set pumps deeper.
7	83	UK, Montrose	Failures from rotary separator vibration	Now use reverse flow gas separator instead of rotary.
10	84	Wyoming, Beaver Creek	Gas interference	Used a VSD to maintain BHP to minimize interference. Installed gravity type gas separators.

20	411	85	China, Daqing	Failures due to gas	Use rotary gas separator, increased run lives.
27	25	86	Canada, Nipisi Gilwood	Gas interference	Used reverse flow or rotary gas separators.
32	268	88	Canada, Judy Crk/Redwater	Gas interference	Use rotary gas separators.
32	268	88	Canada, Judy Crk/Redwater	Gas interference, slugging	Operate the underload settings closer to operating amperage.
37	?	89	General	Optimizing production from low pressure wells	Use VSDs and rotary gas separators. Monitor amp charts to evaluate best production rate.
38	125	89	Canada, SS Hills	Wellhead connectors	Mandrel with molded pigtail cracked & leaked gas.
39	15	89	UK, Montrose	Gas related cable failures	Evaluate cables, new Kerite cable better than others.
42	37	90	Canada, B. Glen	Gas interference	Downsized motor hp to reduce shut-downs due to gas caused underloading.
"	"	"	"	"	Downsizing of the pump capacity to reduce gas coning & increase ESP operating efficiency.
"	"	"	"	"	Increased the number of pump stages to offset the pump head inefficiency due to gas.
"	"	"	"	"	Use of reverse flow gas separators on wells completed without a packer assembly.
43	60	90	Canada, Mitsue Gilwood	Seized pumps from swelling of rubber bushings	The elastomer in the bushing was changed from Buna-N to Viton.
44	12	90	Calif., Bev. Hills	Gas interference	Use a shroud and run the unit below perforations
"	"	"	"	"	In certain problem wells, overdesigning the pump by 20-30% worked.
"	"	"	"	"	Placed 50 psig back pressure on the annulus, smoothed out the motor amperage.
47	?	90	Canada & Michigan	Gas problems	Used tandem rotary gas separators, allowed operation in up to 80% free gas.
47	?	90	Canada & Michigan	Gas problems	Reverse flow and rotary gas separators have limitations. Tapered pumps, shrouds, and tandem rotary separators improve gas separation.
54	6	92	Congo	Gas interference due to need to run low BHP's	Use of VSDs allowed higher production rates.

"	"	"	"	"	Centrifugal gas separators allowed lower BHP and higher production.
55	?	92	Russia	High GLRs prevented use of ESPs	Utilized centrifugal gas separators successfully up to 82% free gas. Reduces time to bring well back on. Increased ESP run times.
57	36	92	Alaska	Pump gas locking	Corrected installation of motor shroud on gas separator. Shroud was plugging separator gas vents.
"	"	"	"	High radial wear on gas separator bushings	Installed Boron-diffusion coated sleeves & bushings.
61	?	92	Texas, South	Horizontal completion caused severe gas slugging	First: Tapered pump with separator & shroud lowered additional 700 ft. unsuccessful. Final: Shroud with dip tube & vented separator discharge.
65	?	93	China	Pump performance problems due to high GLR	Use tandem rotary gas separators where GLR >30%.
65	330	94	Wyoming	CO_2 flood resulted in high GLRs in producing wells, causing pump performance problems	Reliability problems w/rotary gas separators. Other experiments led to use of blender intake.
89	138	94	Canada, Swan Hills	High GOR with abrasive asphaltenes	Utilize rotary gas separator with tungsten carbide bearing system.
90	55	94	California, Offshore	ESP design for gassy, viscous crude	Since 1981, field specific ESP design procedures have been developed.
91	?	94	UK, S. England	Increased well productivity vs. higher GLR	Acquire quality downhole data to monitor and control ESP operation.

If the number of appearances in the literature shown in this study are an indication, then gas still gives the industry many problems. For the problem of free gas in the pump, the use of reverse flow and rotary gas separators is suggested as well as the use of shrouds. Tandem gas separators are also mentioned. Larger casing size is mentioned to help gas separation before it enters a separator or pump intake. Pump design is handled with overstaging or overdesign and tapered pumps. The use of VSDs to get good IPR data for design is mentioned. Cable swellage problems with gas are discussed with the need to get rid of insulation voids. The industry consortium TUALP (Tulsa University Artificial Lift Projects) is currently evaluating industry gas separator performance.

Viscosity					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
15	610	83	Calif., THUMS	Short runs due to 2000-3000 SSU emulsified fluid	Use of VSD, at reduced hertz, and oversized (hp) motor to correct cycling and erratic loading.
25	98	86	Peru, Amazon	Viscosity problems for	Derate motors 25% and annular

			Basin	<12o API & <50% water cut	injection of light blend oil.
40	30	89	Indonesia, Bima	Performance problems due to viscosity	Use downhole pressure sensor, establish correction procedure for pump head/performance.
60	49	92	Canada, Judy Crk	Gas Separators in asphaltene environment failing prematurely. Deposition causing vibration problems	Install additional bearing and move the exhaust port.
84	?	94	Venezuela	Producing wells w/5,000 - 20,000 SSU fluid	First: Use of dilutant injection to reduce viscosity tried but not successful. Second: Oversized pump & motor w/low efficiency reducing downhole viscosity.
88	630	94	California, Offshore	High losses in low volume (100-700 bpd) stages	Modified pump stages for larger inlet openings.
90	55	94	California, Offshore	ESP performance in gassy, viscous crude.	(1) Since 1981, field specific ESP design procedures have been developed. (2) Distributed Flow System (Injects H_2O below unit) tested on 9 wells, technical success but inefficient.

High viscosity is not mentioned much in the papers referenced here. VSDs help with the design, pressure sensors help with design, and one paper reports injection of light oil in the annulus to reduce the problem. Reference 90 discusses a patented system of water injection into ESP intakes.

High Temperature					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
3	96	79	Canada, SS Hills	Fatigue & cracking of lead sheath cable	Trying several new high temperature cables.
6	167	83	Sumatra	Cable damage due to high temperature deterioration	Used cable with temperature rating well above the ambient well temperature.
17	1000+	84	Sumatra	Short run times due to high temperature >300°F	Use impellers able to withstand a high temperature application.
"	"	"	"	"	Use of tandem protectors.
"	"	"	"	"	Set the unit as deep as possible to avoid thermal cycling.
"	"	"	"	"	Prevent the unit from operating under cycling conditions.
"	"	"	"	"	Use of a high temperature oil in the motor.
"	"	"	"	"	Derate the motor by 25%.

24	?	86	Florida, South	Cable short runs (3 months)	Replaced conventional cable splicing techniques with high temperature lead solder splicing.
36	55	89	Canada, N. Kaybob	ESP failures, deterioration of seal elastomeric bag, due to high temperature (240°F)	Changed to labyrinth type protectors.
"	"	"	"	ESP failures, seal chamber thrust bearings, due to high temperature (240°F)	Using babbitless thrust bearings in several severe wells.
44	12	90	Calif., Bev. Hills	ESP failures due to high temperature (200-250°F)	Went to high temperature motor options.
"	"	"	"	"	Used motor shrouds where motor cooling fluid velocity dictated.
"	"	"	"	High rate of cable failures due to high temperature (200-250°F)	Changed from purchasing low-priced cable to high temperature cable to match conditions.
44	12	90	Calif., Bev. Hills	Flat to round cable splice failures due to high temperature	Changed to high temperature tapes, added additional insulating and barrier layers, witnessed splices for better quality.
81	3	94	California	Operating in 400°F ambient	(1) Cable selection & elastomer application critical. (2) Modifications made to ESP equip. (3) Special electrical feed thrust required.
89	138	94	Canada, Swan Hills	Motor damage, rotor/stator rub	(1) Reduce diameter of rotors. (2) Set unit higher in csg (straighter section).

High temperature is mentioned to affect pump stages, cable, motors, bags in seal sections and cable splices. Several protective options are mentioned above. Note that the shrouds around motors are more important in the high temperature wells to increase the velocity past the motor to maximize cooling. Note: High temperature motors are discussed following the motor section above.

Miscellaneous - Overall

Ref	#ESP	Yr	Location	Problem	Solution
7	106	82	Canada, SS Hills	Overall problems	Automation: monitor start, stop, OL, UL, amps, & wellhead pressure.
"	"	"	"	"	Established running & pulling procedures.
11	250	83	Canada, Judy Crk/Redwater	Overall run life	Record keeping is first and most important step.
"	"	"	"	"	Running and pulling procedures

					specified exactly.
12	12	84	UK, Beatrice	Overall run life	Maintain the intake pressure above the bubble point if possible.
15	610	83	Calif., THUMS	Overall, controls	Went to solid state OL & UL controls.
"	"	"	"	Overall	Isolation transformers for each well.
"	"	"	"	"	Periodic review of problems, trends, etc.
"	"	"	"	Overall, cable	Tailored the length to the well, terminated with molded vulcanized, and shop tested.
16	10	84	Wyoming, Beaver Creek	Overall, electrical system	Worked with the power company and added lightning protection.
17	1000+	84	Sumatra	Overall	Established maintenance shop for repairing pumps and motors (dry outs only).
18	21	84	N. Sea, Dutch Q-1 Block	Overall	Use step-up isolation transformers to enhance run lives. Thorough failure analysis process.
24	?	86	Florida, South	Overall	Use of a TDR, well surveillance, collect data, check fluid levels, and monitor teardowns.
25	98	86	Peru, Amazon Basin	Overall	Use of a power trailer with VSD to test wells.
32	268	88	Canada, Judy Crk/Redwater	Overall	Use tandem seal sections.
"	"	"	"	"	Use backspin relays, no tubing check valves.
41	100	90	France	Overall	Training, generate data base of failures, operations.
49	640	90	Calif., THUMS	Overall	New rotating components in any new pump.
"	"	"	"	"	Manufacturers testing of all new pumps.
"	"	"	"		Third party spot testing of new pumps.
57	36	92	Alaska	Completion - must displace oil/water above check valve for freeze protection	Sliding sleeves unreliable in viscous crudes & deviated wells. Install gas lift mandrel with dummy valve above check. Remove dummy valve to freeze protect.
"	"	"	"	Completion - Government requirement to have fluid and vent gas comingled	Annular safety valves have been extremely unreliable. Commingle vent gas back into tubing with packer & gas lift valve/mandrel below subsurface safety valve.
62	1	94	Oklahoma	Project to reduce	Use coiled tubing to deploy ESP.

				installation/pulling costs	
67	215	93	Canada, Redwater	Reduced run times	Increased average from 48 to 78 months by using a more disciplined problem analysis approach.
75	2	94	UK, S. England	Start-up problems due to difficult/incomplete well clean-up	Utilize slow, controlled start-up with a VSD.
76	?	94	?	Equipment failure analysis	Utilization of Fault Tree Analysis provides systematic approach to analyzing equipment failures.
86	5	94	Oklahoma	Reduce water injection costs	(1) 4 vertical/1 horizontal saved $1+mm. (2) Installation provided somewhat transparent installation in high visibility area.
89	138	94	Canada, Swan Hills	Wear on ESP due to abrasive asphaltenes	(1) Modified bearing system in top of seal. (2) Tungsten Carbide bearing system in rotary gas separator.

Many categories are found in the search of "overall" where the overall category usually means some part of an overall plan undertaken to increase run life and the solutions mentioned above are just a part of the plan. Automation, running and pulling procedures, surveillance, and other topics are mentioned here.

Design					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
8	7	82	UK, Montrose	ESP sizing problems due to gas	Use of VSD helps since gas creates pump head design uncertainties.
11	250	83	Canada, Judy Crk/Redwater	Design problems	Obtaining accurate downhole data (IPR, PVT, etc.) is critical. The use of VSDs and downhole pressure sensors assists in getting this data.
40	30	89	Indonesia, Bima	Pump performance problems due to viscosity	Established head correction procedure for pump head/performance.
44	12	90	Calif., Bev. Hills	Design problems due to gas	Overdesign the pumps by 20-30%.
61	1	92	Texas, South	Horizontal completion caused severe swings in liquid/gas production	VSD provided flexibility in operational control
71	?	93	Yemen	Remote desert area, medium-to-heavy crude, high (130°F) surface ambients	(1) Use of parallel generators to power VSDs unsuccessful. (2) New style penetrator successful. (3) VSD in air-conditioned skid shacks.
75	2	94	UK, S. England	5,000 to 20,000 ft extended reach wells	Completion design details to alleviate long reach problems.

In these field papers, the use of the VSD is mentioned to help with the ESP design. Again there are not many field case histories which deal with design techniques. Long reach well problems are highlighted in Reference 75.

Power Consumption					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
7	106	82	Canada, SS Hills	600 volt spikes	Added surge suppressors to smooth power supply.
16	10	84	Wyoming, Beaver Creek	Overall electrical system	Worked with power company, added lightening protection.
19	98	85	Peru	Reduce start power	Use VSD soft start to reduce peak power needs.
41	100	90	France	Power supply	Use hi-voltage motors (reduce cable power loss).
42	37	90	Canada, B. Glen	Power supply quality	Control panels detect single phasing.
46	34	90	Canada, Redwater	ESP selection	Evaluate several vendors as well as power consumption.
70	?	93	Texas	Reduce electrical expenses	Electrical load shedding program.
93	28	94	Nevada	Increase ESP sub-station power factor from 0.81 to 0.90	Installed power factor correction capacitors.

Some of the "power" search papers mention power supply and some mention power savings Note the mention of the use of VSDs to reduce the needed peak power during start-up.

Run Life					
Ref	**#ESP**	**Yr**	**Location**	**Problem**	**Solution**
8	7	82	UK, Montrose	Seal/motor failures	Use of tandem seal sections increased run lives.
11	250	83	Canada, Judy Crk/Redwater	Short run lives	Recording keeping for performance evaluation is first and most important step.
"	"	"	"	"	Specified exactly the running and pulling procedures.
12	12	84	UK, Beatrice	Need to improve run lives	Keep pump intake pressure above bubble point if possible.
20	211	85	China, Daqing	Short run life due to gas	Use of rotary gas separators increased run lives.
53	5	92	UK, N. Sea	Short Runs	(1) Preparing guidelines/procedure manual. (2) Training operations staff on ESP design, installation, handling/storage, operation/trouble shooting, & failure analysis.

68	11	93	Canada	To increase production by decreasing downtime and optimizing applications	(1) Active participation in equip. disassemblies. (2) Improved sizing of ESPs. (3) Developed equip installation & handling procedure manual. Personnel training.
69	20	93	UK, N. Sea	400 day run life deteriorated to 180-350 days	(1) Established "ESP Daily Monitoring Database." Faster response to problems. (2) Established "ESP Failure Database." Analyzing failure trends. (3) Improve Q/A in motor manufacturing & refurbishment.
74	6	94	California	Short run lives in high temperature (<450°F) wells	(1) Extended runs due to designing for internal motor temperature instead of just BHP load. (2) Improved motor insulation systems.
77	56	94	UK, N. Sea	Evaluating field failure statistics to improve run life	(1) Document well installation procedures. (2) Improve operational procedures. (3) Improved QC/QA ESP manufacture. (4) Improve installation design & selection.
78	355	94	Canada	Does rerunning ESPs reduce run life?	Run life not significantly deteriorated although recommendation to continue short & long term monitoring to ensure success.
79	63	94	California, Offshore	Evaluate effect of used equipment on run life	Run life of used equipment = 225 days, new equipment = 334 days.
80	14	94	Texas, West	Reduce expenses by rerunning equipment	Economically successful.
82	300	94	U.S. Mid-Continent	Increase run life thru identification of pump types which are more reliable	Database analysis did allow guidance on better types of equipment.

Under this search topic, several miscellaneous topics are mentioned to assist in increasing run life. However, this is just the way the language was used in the papers. All of the previous topics can be considered ways of solving problems and increasing run lives.

Sweep Efficiency

Ref	#ESP	Yr	Location	Problem	Solution
5	?	79	India	Improve sweep efficiency	Install pump with 2-3 times normal well rate.
9	26	82	Texas, Talco	Increase sweep efficiency	Install hi-volume ESPs to produce liquids being swept.

The search subject of sweep brings up two papers where the ESPs are specifically used to generate high volume and increase sweep efficiency of a flood to produce the fluids as they pass the wells and not lose any possible production which a high volume system will produce.

Testing & Reusing Equipment

Testing and reusing ESP equipment began in about 1983 in earnest. One W. Texas company has been the pioneer (ESP Inc.) in establishing standards for testing and rerunning used equipment. Today pumps, motors protectors/seals/equalizers and gas separators are tested against established standards and rerun if the testing standards are met. In fact over 100,000 pieces of ESP equipment have been tested at one company with certain percentages put back into service. The following table is typical of the % of equipment tested that is returned to service:

Equipment Type	% Returned to Service
Pumps	~69%
Motors	~91%
Protectors/Seals/ Equalizers	~41%
Gas Separators	~46%

Although one company pioneered testing and re-use, it is common for manufacturers to offer a similar service in most instances. Currently ESP Inc. and others are working with vibration measurements to establish standards for acceptance and re-use. Although some data has been collected, no generally accepted standards are currently in existence.

Subsea ESP Completions for Deep Water/Horizontal Wells

Most subsea completed wells produce with no artificial lift or with the aid of gas lift. However, in some cases gas is not available. Also studies[95] of gas lift in horizontal wells is not efficient, which has to be due to the inefficient bypass of gas over liquid in horizontal well sections.

Currently two fields are being considered to be developed with ESPs using subsea trees with wet mateable connectors.

One such development is planned for the Liuhaua field which is located in the S. China sea, about 120 miles (193 km) southwest of Hong Kong. This is a venture between Amoco Orient Petroleum and Nanhai East Oil Corporation. This development is planned to make use of a floating production system, subsea trees with ESPs, wet-mateable electrical power connectors and horizontal well completions.

Two main concerns for this development are: (1) the incorporation of an electrical cable feedthrough path in the tree design and (2) the need to simplify well workover procedures given the relatively high replacement frequency of the downhole ESP completion. This concerns led to plans to apply a "tubing spool" or "horizontal" tree design.[96] The major components of the subsea tree are a tubing spool, a tubing hanger and a tree cap.

The tubing spool contains a through-bore profile with side outlets for production, annulus and chemical injection lines. The tubing hanger is installed using a hydraulic running tool that provides orientation and activate the lock-down and seal mechanisms with the tubing spool. The tree cap is installed after removal of the tubing hanger running tool and BOP stack/drilling riser. The tree cap also provides a structural termination point for the in-water ESP power cable riser shown in Figure 8.[97]

Petrobras PROCAP 200095 is a group of 11 companies developing a system for ESP production from wells in 1000-2000 m water depth initially to be utilized in the Albarcora field. Different suppliers will supply electrical power connectors, ESP equipment, subsea and downhole power connectors, a diver assisted X-mas tree for the installation of the power connector, and other associated equipment. A schematic of the wellhead is shown in Figure 9.

Coiled Tubing Deployed Pumping Systems

The combination of the rising costs or workover rigs and their limited availability has made rigless completions an attractive economic alternative. The same economics driving rigless completions and the use of coil tubing for specialty applications like logging, cementing, perforating, etc., in deviated wells, make coil tubing deployment of ESPs a viable option where workover rig costs are high. Successful installation of ESPs using coiled tubing have been recorded in a number of installations.[98,99]

Coil tubing is a continuous length of tubing coiled on to a large reel transported by means of a portable control unit. Coil tubing is currently available in sizes ranging from 0.75 in. OD. (19.1 mm) to 3-1/2 in. OD. (88.9 mm) having yield strengths from 70,000 psi (483 MPa) to 100,000 psi (689 MPa). Deployment of ESPs using coil tubing is performed through a "working window" as shown in Figure 10. An injector feeds the tubing into the well while the power cable is banded to the tubing.

Coiled tubing design consideration includes:[98] (1) the availability of units in the local area, (2) the tensile strength of the tubing, (3) the relative expansion of the coiled tubing with respect to the power cable, (4) the anticipated fatigue of the tubing over the anticipated life of the well, (5) the burst capacity of the tubing at the pump discharge head, (6) the increased pressure loss in the tubing due to the slightly smaller ID of coil tubing having standard ODs, (7) the relative cost of the coiled tubing to that of a workover rig, and (8) the design of the working window. Generally, the working window only accommodates installation of the ESP and equipment and banding of the power cable. Installation is significantly different and an experienced ESP service technician having familiarity with coiled tubing installations is recommended.[99]

Cable Deployed Pumping Systems

The concept of cable deployed ESPs was first developed in the late 1960s. The technique deploys either one or two cables. The single cable system suspends the pump and motor from a single cable that acts both as support and a supply of electric power. The two cable systems employ one cable for support and another for electric power. The advantage of the latter is: the suspension cable is generally torque balanced wire rope (proven technology) and can be field spliced. Standard power cable can also be used in two cable applications with single or double armor, as the application dictates. Although single cable systems appear simpler, they generally require a controlled environment for splicing requiring considerable time, and historically suffer from chinking of the power cable core caused by different rates of thermal expansion between the outer support and inner power core.[99,100] This latter difficulty has been addressed by manufacturers but is yet to be proven in the field.[101,102]

Cable deployed ESP systems have a variety of advantages[98] over conventional tubing deployed systems. Rigless installation and service of ESPs makes cable deployment an attractive alternative, particularly in remote locations where rig costs and availability make the economics of running ESPs less attractive. Other advantages include: (1) installation speeds from 100-120 ft/min, (2) increased flow area in the production tubing to consider rates as high as 30,000 bpd, (3) minimal surface equipment which is proven technology, being a modification of standard coiled tubing injectors, (4) the installation system is generally modular and easily transportable, and (5) banding of the power cable is not required in single cable systems. Cable deployment ESPs is restricted to hole inclinations less than about 60°. A typical chart indicating the range depths, flow rates and hole deviations for applicability of coiled tubing and cable deployment of ESPs is shown in Figure 11.

The downhole equipment used in cable deployed systems differs slightly from conventional system in that an annular flow arrangement is used where the pump is located below the motor (known as an inverted pump assembly). The ESP is generally located in the production tubing by a landing nipple and a locking-module discharge head is added to the assembly between the pump and the motor.

Highly Deviated Wellbores

Several applications of ESPs in highly deviated wells have been reported in the literature.[103,104,105] Submersible pumps are commonly run both in the vertical and horizontal sections of the hole. A number of operational problems have been identified when running ESPs in horizontal hole sections. These are:

(1) ESP Bending: ESPs are long slender pieces of equipment subject to high bending stresses when forced around corners. As a rule of thumb, an assembled ESP with no special equipment could tolerate a dogleg severity of 3°/100 ft without permanent damage.[105] Doglegs as high as 12°/100°ft. are possible with special equipment.[100]

(2) Seal Section: The seal section contains shaft seals to prevent well fluid from entering the motor. Both elastomeric bladder and labyrinth path systems are commercially available. Labyrinth path systems, however, require gravity and differential density to operate effectively and thus should not be used in horizontal sections.[104]

(3) Drill Larger Holes: It is recommended that the well be drilled as large as economical. The extra clearance between the ESP and the casing reduces the magnitude of the bending stresses transferred to the ESP when installing.

(4) Liner Installation: The horizontal section of the well tends to act like a long 3-phase separator. Gas separates, collects along the length of the wellbore and can serge up the wellbore interrupting production. Installation of a liner increases the superficial velocity in the horizontal section minimizing slugging.

(5) Drill the hole down hill if possible to allow free escape of the gas. Holes inclined at greater than 90o have been shown to experience severe slugging.[104]

(6) Use of centralizers should be limited. Centralizers increase the bending when an ESP is passing through tight radii and should be used only if necessary.

(7) Conventional gas separators work in horizontal sections much the same as they do in vertical sections and are therefore recommended in gassy wells. In gassy horizontal wells, it is recommended that the pump be set in the vertical section of the hole and a dip tube inserted into the horizontal section where possible (see Figure 12).[104]

Summary

In summary, many topics are brought in under various subheadings and give the reader some idea of what the problems are and what the solutions were. Very little detail is given here, but the reader can easily reference the appropriate papers for a more comprehensive discussion. This study may be incomplete and apologies are given for any pertinent field studies omitted. However, in spite of many possible shortcomings, it is hoped this presentation will be a help for the reader who is interested in solving a particular problem and would like a direction on where to read about similar problems and their possible solutions.

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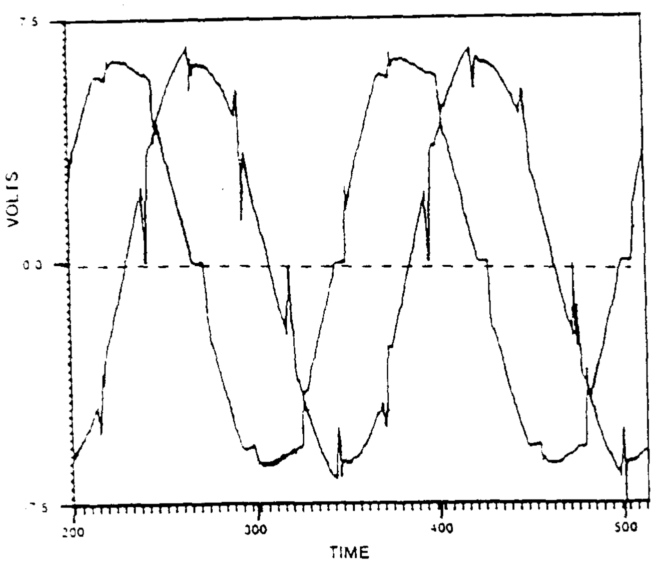

Figure 1 - Line Notching Comparison (Reda IPWM)

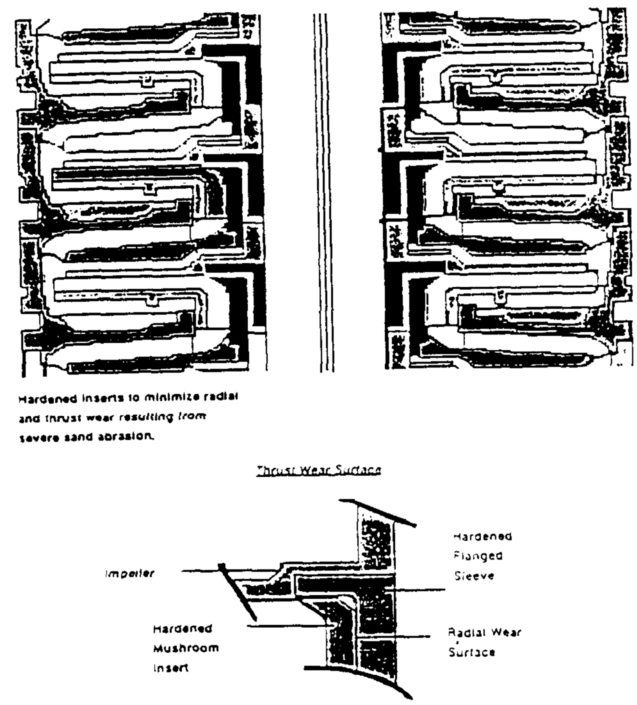

Figure 2 - Centrilift Sand Handler

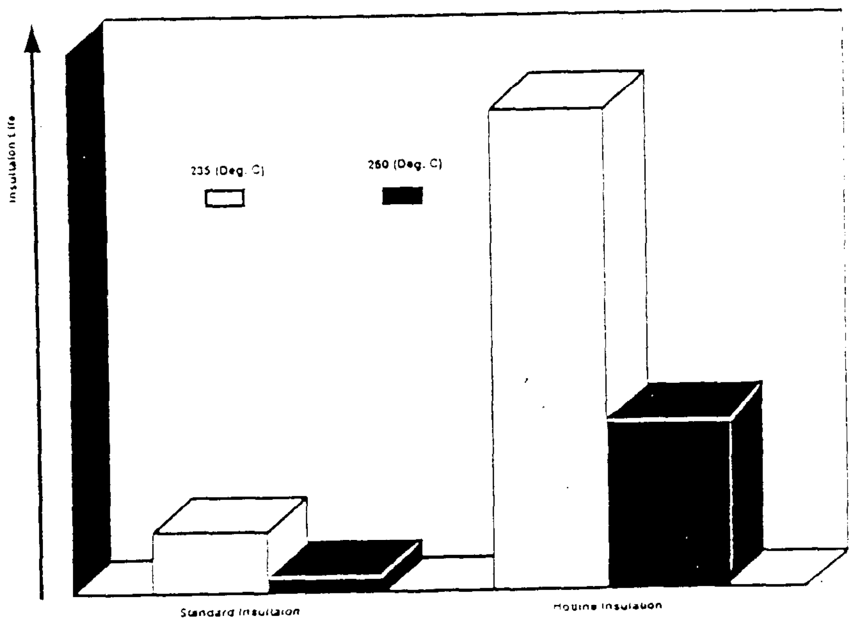

Figure 3 - Insulation Life Comparison

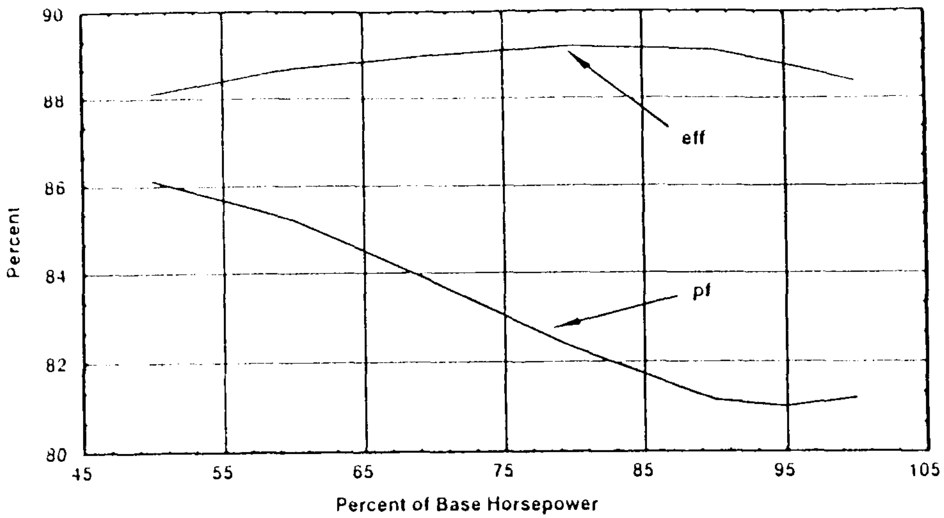

Figure 4 - Reda 562 Motor Efficiency Curve

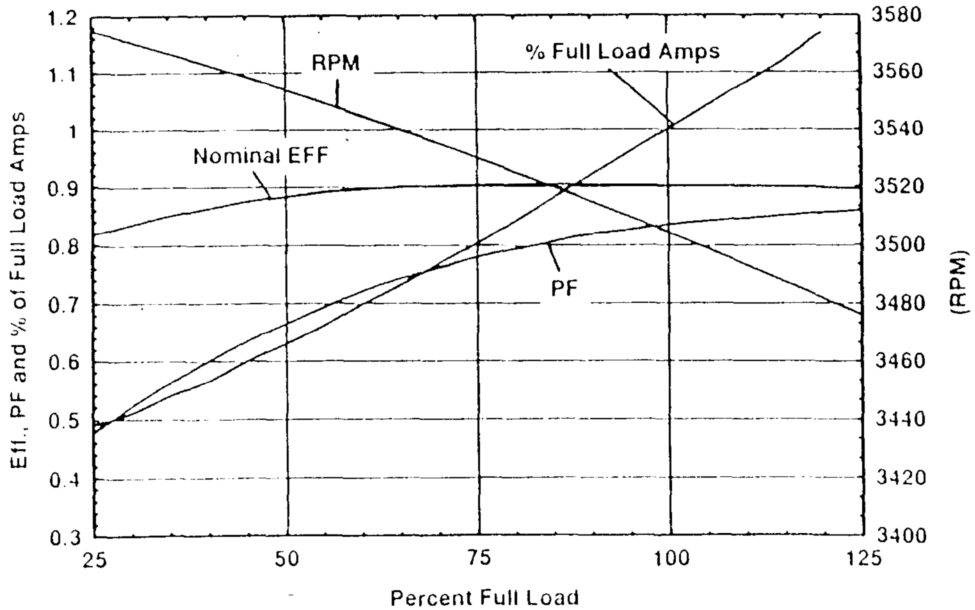

Figure 5 - ODI 70 Series Hi Performance Motor

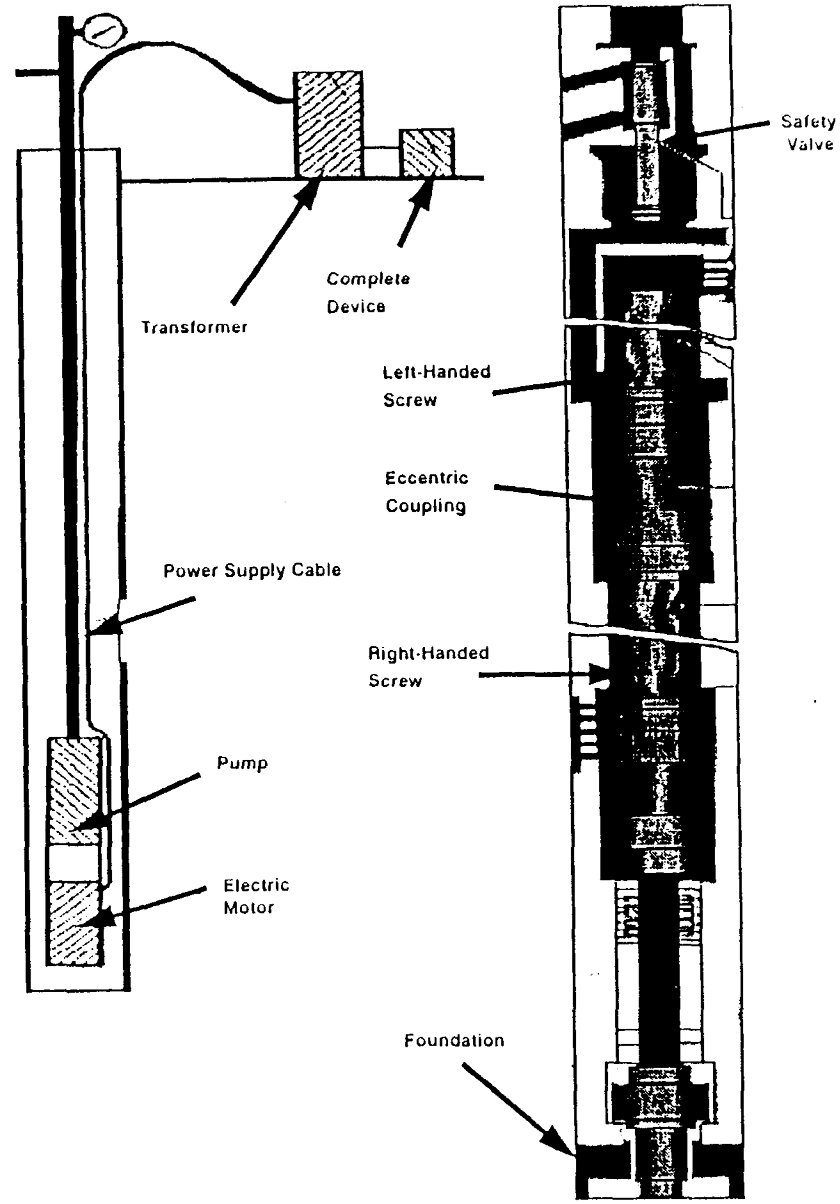

Figure 6 - Russian Built Dual PCP Pump

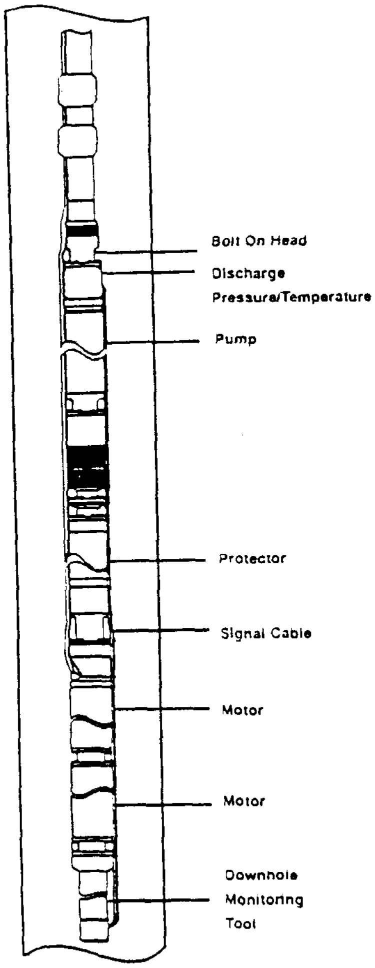

Figure 7 - Downhole Monitoring Tool

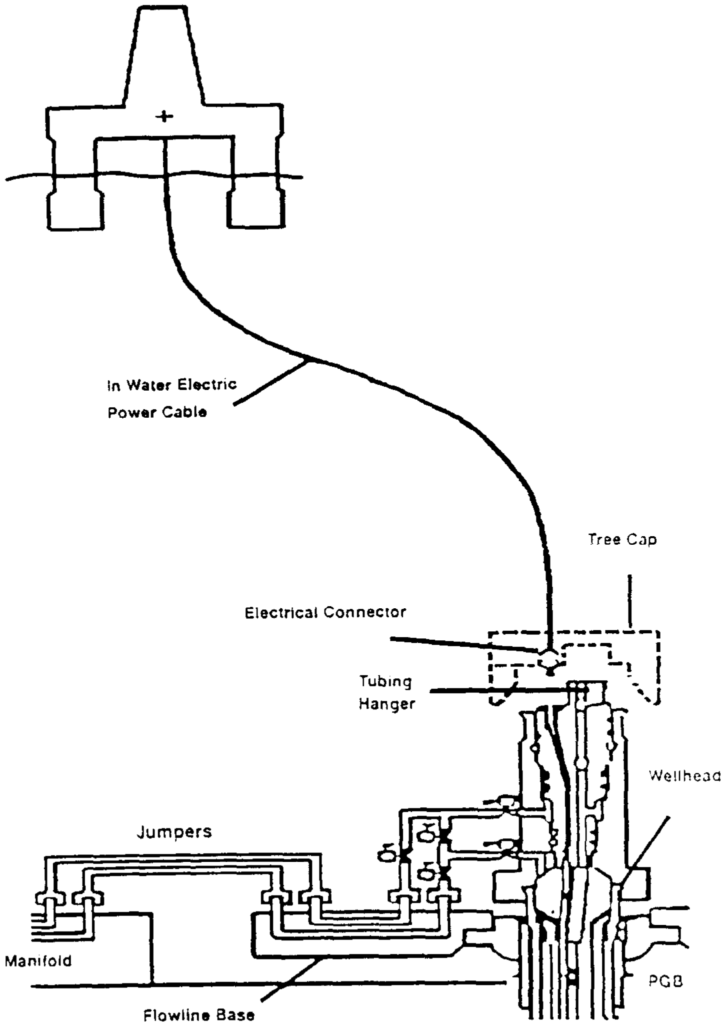

Figure 8 - Tubing Hanger/Tree Cap Interface with ESP Power Cable

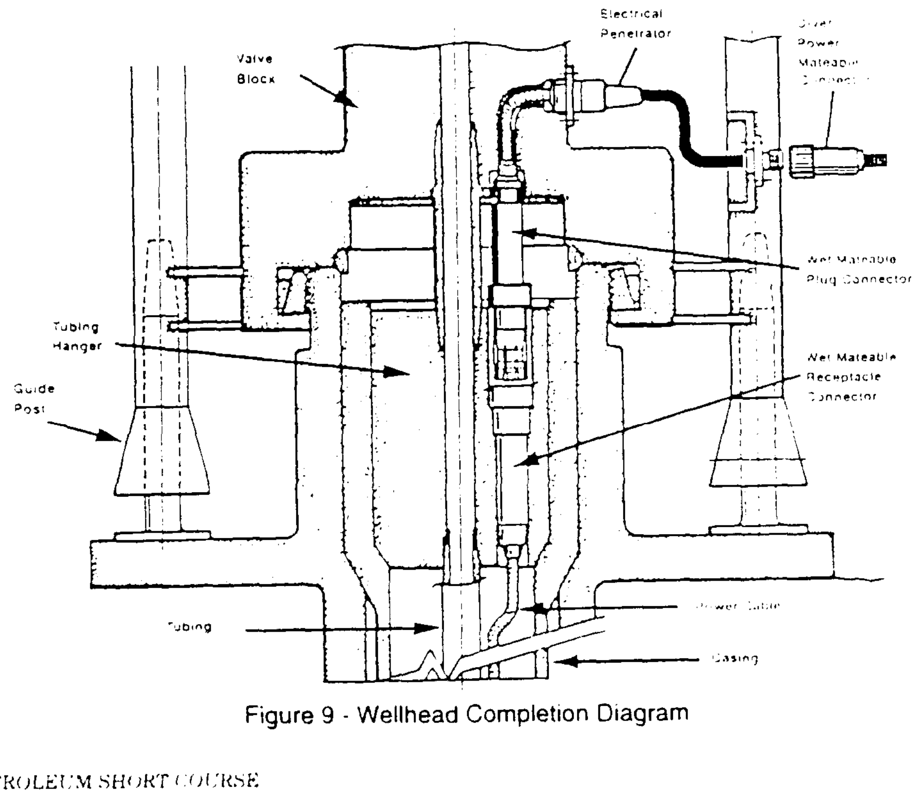

Figure 9 - Wellhead Completion Diagram

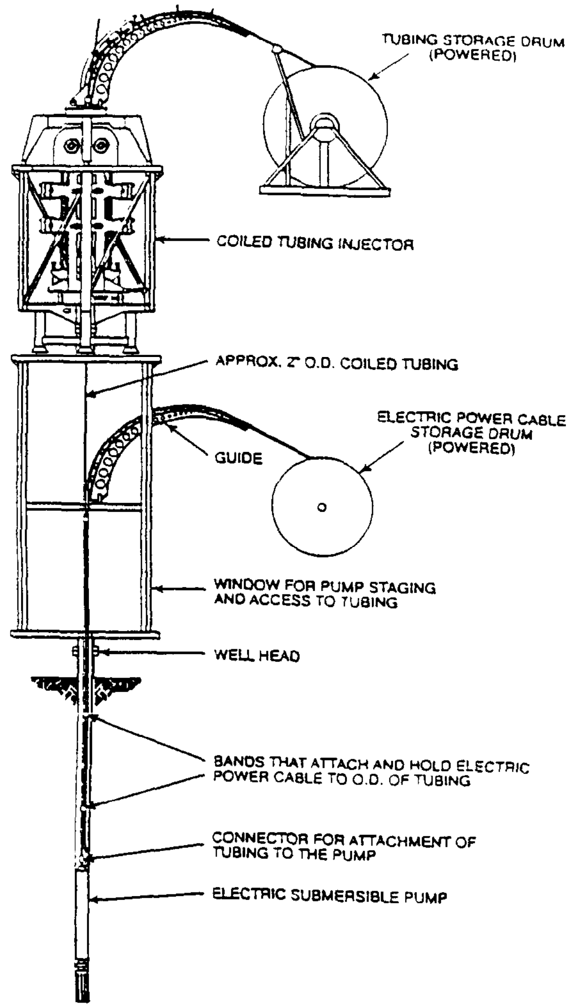

Figure 10 - Coiled Tubing/Cable Deployed ESP

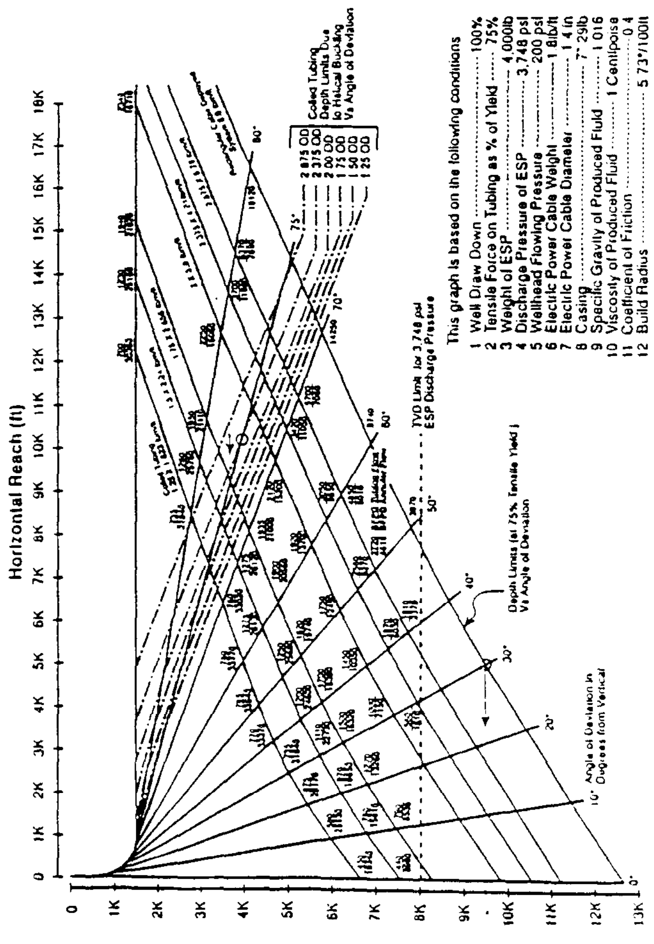

Figure 11 - Maximum Depths and Flow Rates for a Family of ESP Completions

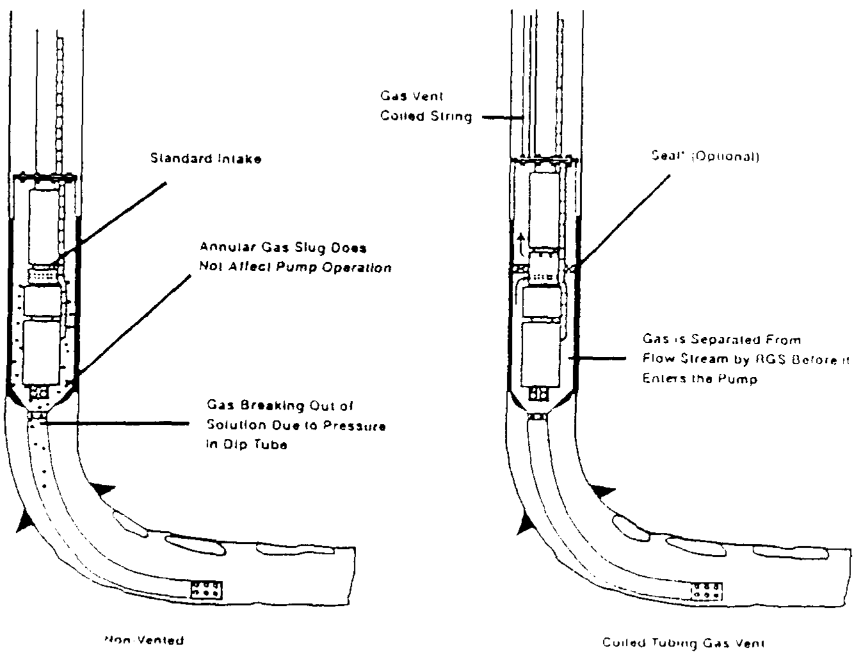

Figure 12 - ESP Dip Tube Design for Horizontal Wells