SPE

ESP Failures: Can We Talk the Same Language?

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Abstract

Several operators have recently launched a new industry-wide initiative focused on sharing failure information, operational practices and other pertinent data, in an effort to gain a better understanding of the various factors that affect ESP run life in any one application. Early on, the companies involved acknowledged that there were many challenges in such an effort, one of the main ones being how to achieve consistency in the data collected by several operators.

This paper presents an approach to establish consistent practices for collecting, tracking and sharing ESP run life and failure information. The approach is based on two key elements: (1) a general and common data set; and (2) a standard nomenclature for coding ESP failure information. The general data set contains basic information on operating conditions, ESP equipment, and the observed failures. While this data set is not overly detailed, in that the information is typically already collected by most operators and relatively easy to obtain, it is comprehensive enough so that meaningful analyses can be performed. The nomenclature standard builds on the International Standard ISO 14224[1] and on the API Recommended Practice (RP) 11S1[2]. Broad definitions and failure attributes follow the guidelines of ISO 14424, while nomenclature for components, parts and possible teardown observations follow the terminology suggested by API RP 11S1.

The paper also provides a review of the past practices in the industry, with regards to the types of data collected, and the main types of analysis performed with the data. Comments are included on difficult related issues, such as the tracking of used equipment and the treatment of running systems, when evaluating current operations or making future failure rate predictions.

It is hoped that the paper will encourage discussion on the topic, and help the industry share ESP run life data in a more consistent manner. The ultimate goals are to assist the industry improve ESP run life, expand the use of ESP's, and better realize the full potential of the ESP technology.

Introduction

Operators and vendors have long identified that having a failure tracking system in place is key to reducing failure rates of ESP systems[3-33]. Problems with system design, equipment specification, manufacturing, installation, and day-to-day operation can be identified and corrected, contributing to increased run lives, lower operating costs and increased profits. As a result, many operators and vendors have set up database systems to track ESP run life and failure information.

A review of existing tracking systems revealed that one of their main limitations is that they seldom integrate both failure information and a comprehensive set of influential factors, such as operational conditions during its in-service life, and equipment specifications. Most also tend to be field and/or operation specific, and typically lack sufficient breadth to assess ESP run life under different conditions.

These drawbacks impair one's ability to develop general relationships or correlations between types and frequency of failures, field/well conditions and equipment specifications. Without such correlations, run life predictions that are fed into a feasibility study are little more than educated guesses, adding significant uncertainty to a project's economic result. Furthermore, investigating the impact that a change in current practices might make on run life (i.e., conducting "what if" analyses) is also very difficult. For example, how would the run life be affected if we change our downhole assembly configuration (e.g., by including a rotary gas separator) or our equipment specification (e.g., by selecting different materials)? Generally, the information required for these types of assessments can not be readily obtained from existing tracking systems. As such, there is often little basis for making such critical decisions. Often, the only option is a "trial-and-error"

References and illustrations at end of paper.

approach, again with uncertain economic results. In many cases, such uncertainty has hindered the broader usage of ESP's.

Several operators have recently recognized that in order to get a better understanding of the factors affecting ESP run life, and reduce the uncertainty in predicting run life for new applications, one needs access to reliability information derived from as large and consistent a data set as possible. They have also recognized that such a large data set of ESP reliability data can only be achieved by pooling and sharing their individual data sets through a joint industry initiative.

Early on, the companies involved acknowledged that there were many challenges in such an effort, one of them being how to achieve consistency in the data collected by several operators scattered around the globe. This paper describes a common set of guidelines developed through this industry initiative to achieve such consistency. It includes two key elements: a general data set of quantitative and qualitative parameters, and a standard nomenclature for coding ESP failure information.

Brief Review of Existent Tracking Systems

The usage of failure tracking systems to monitor ESP run life has been reported by many authors[5, 8, 7 11, 12, 22, 24, 28, 29].

From the literature, and through discussions and communications with numerous operators and equipment vendors, it became apparent that most of the existing databases and tracking systems only track basic failure attributes (e.g., date of install and/or start-up, date of pull and/or failure, failed component, equipment manufacturer and model). It also became apparent that the structure of such databases very much depends on their initial purpose (e.g., while databases constructed by asset engineers are geared towards tracking specific equipment usage and inventory, databases constructed by field operators are geared towards failure analysis and production optimization). While many systems include in their records a "reason for pull", a "failure mode", or a "failure cause", there has been no standard with regards to such modes or causes[32]. Very few include well and operational information in the same tracking system. A system used by BP in the North Sea[11] is typical, in that it actually included two databases: a production database for storing daily production data, and a failure database to store ESP failure information.

The failure analyses performed with such systems are usually geared toward comparisons of failure frequency and Mean Time Between Failures (MTBF), and historical trending of run life. Comparative distributions of failures among the different components[12, 29], different equipment types and models[11, 28], or between different vendors, platforms and fields[24] have been presented. Historical trends have also been used to assess the evolution of ESP run life over time. Attempts have also been made at predicting failure frequencies in the future, by fitting statistical distributions to the historical data[24, 25, 28]. Both Brookbank[4] and Sawaryn[30, 31] have noted, however, that one has to be careful when interpreting historical trends of "run life". Different ways of estimating MTBF or Mean Time To Failure (MTTF) can lead to quite different results and conclusions. Sawaryn[30, 31] also noted the importance of including all ESP systems in the analysis, including running systems, so that systems with long run lives are properly taken into account (i.e., what is sometimes called right censored data analysis). Also, although perhaps not intuitively obvious, an increasing average MTBF does not necessarily mean improved reliability (e.g., early in the life of a field, the calculated MTBF may be increasing simply because the systems with longer run lives start to have an effect on the calculated average).

API's recommended practice (RP) on ESP teardowns[2], suggests a database structure for tracking ESP failures. The RP focuses on standardizing teardown forms and observations to facilitate data transfer between different databases. The RP also points out one of the major shortcomings of many ESP failure tracking systems: while "pertinent data regarding the well completion, production rate, and ESP equipment are valuable in determining the cause of a failure, unfortunately, these external databases are not usually shared".

Challenges of Sharing ESP Failure Information

As discussed, one of the main challenges in sharing ESP failure data (run time, teardown observations, etc.) and other pertinent information (operating conditions, equipment specification, etc.) through a common, industry-wide tracking system is to ensure data consistency. Several other operators and vendors in the industry have also stressed the importance of having a consistent approach for this type of data tracking system[33, 34]. In this initiative, data consistency would be promoted by defining both the parameters (quantitative and qualitative) that this common data set should consist of, as well as how these ESP failures would be described.

A common data set is essential for establishing meaningful relationships between the types of failures observed, the equipment used, the produced fluids, the operating practices, etc. While this common data set should be kept to a minimum (i.e., limited to parameters that (1) will have immediate or potential use in the analysis; and (2) are readily available from the existing tracking systems, databases and field records of most operators), it must be comprehensive enough so that meaningful analyses can be performed. Hence, defining this list of parameters is difficult because it must satisfy these two often-opposing objectives.

A common terminology and format for classifying the failures is also necessary; it ensures that all users have similar interpretations of a failure event, and that data collection and analyses are performed in a consistent manner. Establishing a common set of terminology is a challenge however, because failures are generally described in qualitative terms, strongly influenced by the experience and background of the observer. Interpretation of the failure tracking guidelines has accounted for the largest proportion of data quality problems in other similar failure data collection efforts[26].

General Data Set

For this industry initiative, the "minimum" data set shown in **Table 1** was developed. In addition to general information on the field and well, it also contains substantial information on each individual ESP installation, including:

- *Run-time information*: installation date, start date, failure date and pull date;
- *Installation, environment, operation and production data*: operator, fluid properties and rates, BS&W, wellhead and bottomhole temperature and pressure values, current, frequency, hours on production, number of restarts, etc. (for the time period which the ESP was in service, i.e., between the install and pull dates);

- *ESP equipment installed*: manufacturer, model, type, trim (e.g., coatings, elastomers and metallurgy), and, whenever possible, serial numbers, etc.; and
- *Failure information*: as per the standard failure nomenclature described below.

While this information is easily available to most operators, it may have to be pulled from a number of databases, such as production information systems, pull and install workover reports, equipment inventory databases, vendor teardown reports, etc.

ESP Failure Nomenclature Standard

ESP failure information is currently classified and recorded in a number of very different formats and codes. While most operators and vendors do have a standard set of codes used in their internal tracking systems, these "standards" are not common and widely accepted across the industry.

The proposed ESP Failure Nomenclature Standard attempts to establish a consistent terminology and structure for classifying, recording and storing the various attributes of an ESP failure. It is based on two other key industry guidelines: the API RP 11S1[2], "Recommended Practice for ESP Teardown Report"; and the ISO 14224, "Petroleum and Natural Gas Industries – Collection and Exchange of Reliability and Maintenance Data for Equipment" [1]. While the nomenclature for components, parts and many of the teardown observations follow the terminology suggested by the API RP 11S1, broad definitions for the failure attributes, and the overall structure for classifying and storing the information, follow the guidelines of the ISO 14424. Also note that the proposed standard only covers the downhole ESP equipment, as indicated in the boundary diagram of **Figure 1**.

Failure Definitions. In line with ISO 14224, the following failure definitions are used:

Failure: the termination of the ability of an item to perform a required function;

Failure Mode: the observed manner of failure;

Failed Item: any part, component, device, subsystem, functional unit, equipment or system that can be individually considered;

Failure Descriptor: the apparent, observed cause of failure (of a *Failed Item*); and

Failure Cause: the circumstances during design, manufacture or use which led to a failure.

Failure Mode. The *Failure Mode* is the main evidence of the downhole equipment failure. It is usually a result of an abnormal operating condition identified by the operator through surface instruments, a monitoring/control system, or a well test. A *Failure Mode* can be established once the operator has determined that the downhole equipment has "*Failed*". Usually, a pull is required to repair or substitute the downhole equipment. **Table 2** lists several possible *Failure Modes* for an ESP installation. Note that many operators track ESP *Failure Modes* under the broader designation of "Reason For Pull" which, in addition to ESP failures, includes numerous other workover reasons such as acid and zone recompletion operations.

Failed Items. As per the definition of *Failure* above, a *Failed Item* (i.e., either a main component, such as a pump or motor, or part of a component, such as an o-ring or shaft) has lost it ability to perform a certain function. In most cases, the item has been subject to inspection or shop tests and has failed to meet the required specifications. **Table 3** lists the main downhole ESP components, and many associated parts that may be deemed as *Failed Items*. Note that the list of parts included in **Table 3** is comparable to the list of parts presented in API RP 11S1, and discussed by Lea and Powers[16-20].

Failure Descriptors. A *Failure Descriptor* is an apparent or observed cause of failure of *Failed Items*. These observations are generally made as the ESP is pulled, during rig-site or shop tests, or during the teardown and inspection. They are the main symptoms, or observed signs of damage to the ESP components or their parts, that may have resulted in (or be the result of) the system failure. The "observation codes" described in API RP 11S1, Figure A-2, are essentially *Failure Descriptors* for the various parts of the ESP components. **Table 4** lists several possible *Failure Descriptors* for the main ESP components and associated parts. Note that some *Failure Descriptors* may not be applicable to some parts (e.g., a pump may not be "shorted").

Failure Cause. The *Failure Cause* is associated with the circumstances during design, manufacture or use, which have led to a failure. As noted in the ISO 14224, identification of the *Failure Cause* normally "requires some in-depth investigation, to uncover the underlying human or organizational factors that were influential in the failure of the system, component or part, and the technical explanation and sequence of events leading up to the observed mode, item and descriptors of the failure". **Table 5** lists several possible *Failure Causes* for an ESP system.

Applying the Nomenclature Standard. Most of the time, the various components of a failure record or event (i.e., mode, item, descriptors and cause) are lumped into one or two failure classes; for instance "reason for pull: low flow to surface due to plugging of the pump with asphaltene". In line with the proposed Standard, this failure record would be described as the following: *Failed Item*: pump; *Failure Mode*: low flow to surface; *Failure Descriptors*: plugged; and *Failure Cause*: reservoir or fluids.

Used Equipment

A difficult issue common to all ESP failure tracking systems is how to treat used equipment. After an ESP system is pulled, the components may be submitted to shop tests. If the components pass the required specifications, they may be deemed in a condition suitable for reuse.

Alternatively, operators and/or vendors may conclude that an ESP system or component has achieved a "reasonable", "acceptable" or "expected" run life and as such, may decide not to bother subjecting it to shop tests or to a teardown inspection. In these instances, the operator and/or vendor may decide that system or component should be scrapped, or be submitted to "refurbishment" or "repair".

For the purpose of this industry-wide data sharing initiative, components that have been pulled but are deemed suitable for reuse are not considered as *Failed Items* (but are flagged as "used"). On the other hand, components that were scrapped or sent to repair without any further inspection are still treated as *Failed Items*, because they have been classified as unsuitable for reuse (or not having the ability to perform their required function) in their current state.

Running Systems

Another often-controversial issue in ESP failure tracking and analysis efforts is if and how to consider systems that are currently running and systems pulled for reasons other than ESP failures. As pointed out by others[4, 30, 31], the problem of not including these systems in the analyses is that one would not account for potentially long run lives that would improve the statistics.

Figure 2 shows the trend of MTTF with time for a field of ESP wells, both with and without consideration of running systems. Note that, while one might conclude that run life is decreasing when running systems are not included in the analysis, one would likely make the opposite conclusion when running systems are included in the analysis. This becomes especially important when the number of ESP wells is changing, as illustrated in the example. In this industry initiative, participants are encouraged to track all ESP installations, including running systems.

Closure

While many operators and vendors have been tracking and analyzing ESP failures for several years, it's apparent that there have been, and continue to be, numerous approaches on how to structure these efforts. As such, when it comes to discussing ESP failures, we still find ourselves asking the question: "Can we talk the same language?" It is hoped that this paper will encourage discussion on the topic, and help the industry share ESP run life data in a more consistent manner.

It must also be noted that the proposed General Data Set and ESP Failure Nomenclature Standard are not absolute. Improvements continue to be made through feedback from the users, operators and vendors, and as experience is gained by working with the failure tracking system. The authors welcome any suggestions on how to improve the General Data Set, the ESP Failure Nomenclature Standard and the overall functionality of the tracking system.

Conclusions and Recommendations

1. Existing ESP failure tracking systems seldom integrate both failure information and a comprehensive set of influential factors, tend to be field and/or operation specific, and typically lack sufficient breadth to assess ESP run life under different conditions. As a result, it's often difficult to develop general relationships or correlations between ESP failures, field/well conditions and equipment specifications. Without such correlations, run life predictions used in feasibility studies and field optimization efforts are little more than educated guesses, adding significant uncertainty to a project's economic result;
2. In order to reduce the uncertainty in predicting run life, reliability information should be derived from as large and consistent a data set as possible. One of the main challenges facing this effort however, is how to achieve consistency in the wide range of data currently being tracked operators and vendors. Two key guidelines were presented to assist in this task: a common data set of quantitative and qualitative parameters, and a standard nomenclature for coding ESP failure information;
3. The common data set must be small (i.e., limited to parameters that will have immediate or potential use in the analysis and are readily available from the existing tracking systems, databases and field records), while comprehensive enough to enable meaningful analyses;
4. The proposed ESP Failure Nomenclature Standard is consistent with API RP 11S1 and ISO 14224. An ESP system failure is described by a failure mode, failed item(s), failure descriptor(s) and failure cause.

Nomenclature

ISO =International Organization for Standardization
API =American Petroleum Institute

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SI Metric Conversion Factors

ft	x	3.048*	E-01	=	m
in.	x	25.4*	E+00	=	mm
psi	x	6.894 757	E+00	=	kPa
bbl	x	1.589 873	E-01	=	m^3
gal	x	3.785 412	E-03	=	m^3
HP	x	7.456 999	E+02	=	watt

°API = $141.5/SG_{oil} - 131.5$

(where SG_{oil} = specific gravity of oil @60°C)

*Conversion factor is exact.

Goup	Data		Data Type	SI UNITS	US UNITS
Well Information	Well Name		Text		
	Wellhead Location		Text	Onshore, Platform, Subsea	
	Production Zone		Text		
	Completion Type		Text	Pef. Casing, Liner, Gravel pack, etc.	
	Reservoir(s) Name		Text		
	Reservoir Type		Text	Carbonate, Con. Sandstone, Uncon. Sandstone	
	Production Mechanism		Text	Primary, Water flood, CO2 flood, etc.	
	Casing Size		Number	mm / kg/m	inches / lb/ft
	Tubing Size		Number	mm / kg/m	inches / lb/ft
	Packer?		Binary	Yes, No	Yes, No
	Packer Depth (If Packer)		Number	mKB	ftKB
	Y-tool?		Binary	Yes, No	Yes, No
	Measured PSD (MD)		Number	mKB	ftKB
	Vertical PSD (TVD)		Number	mVD	ftVD
	Inclination at PSD		Number	°	°
	Max Dogleg		Number	°/30m	°/100 ft
Field Information	Asset Name		Text		
	Field Name		Text		
	Platform, Pad or Well Group		Text		
	Geographic Location		Text	Country / Province / Region	
	Field Type		Text	Onshore, Offshore	
Runtime Data (dates)	Production Period No.		Number		
	Date Installed		Date	mm/dd/yy	mm/dd/yy
	Date Started		Date	mm/dd/yy	mm/dd/yy
	Period Status		Text		
	Date Failed / Shutdown		Date	mm/dd/yy	mm/dd/yy
	Date Pulled		Date	mm/dd/yy	mm/dd/yy
	Actual Runtime		Number	Days	Days
Fluid Information	Oil Density		Number	°API	°API
	BHT		Number	° C	° F
	Bubble Point (Vapour) Pressure		Number	kPa	psi
Failure Information	ESP System Failed?		Binary	Yes, No	Yes, No
	Failure Mode: General		Text		
	Failure Mode: Specific		Text		
	Primary	Failed Item	Text		
		Failure Descriptor	Text		
	Secondary	Failed Item	Text		
		Failure Descriptor	Text		
	Failure Cause: General		Text		
	Failure Cause: Specific		Text		
	Failure Comments		Text		
Surface Equipment Data	Drive Manuf.		Text		
	Drive Type		Text		
	Power Quality		Text		
Downhole Equipment Data	PUMP(S)	Vendor	Text		
		Pump Type	Text	(e.g., GN3000, FS1150, RC5, TD-650)	
		Stages	Number	#Stages	#Stages
		Pump Trim	Text		
		Serial Number(s)	Text		
	SEAL/PROTECTOR(S)	Vendor	Text		
		Seal Type	Text		
		Seal Trim	Text		
		Serial Number(s)	Text		
	MOTOR(S)	Vendor	Text		
		Motor Type	Text	(e.g., 90-O, KME, etc.)	
		Motor Power	Number	kW	hp
		Motor Trim	Text		
		Serial Number(s)	Text		
	INTAKE / GAS SEPARATOR	Vendor	Text		
		Gas Sep. Type	Text		
		Intake / Gas Separator Trim	Text		
		Serial Number(s)	Text		
	CABLE	Vendor	Text		
		Cable Model/Size	Text		
		Cable Trim	Text		
		Serial Number(s)	Text		
		MLE Type	Text		
		Wellhead Penetrators	Text		
		Packer Penetrators	Text		
	DH Monitoring System Manuf.		Name		
	Equipment Comments		Text		
Operating and Production Data (period ave, or more detailed)	Total Flow Rate		Number	m^3/d	bpd
	Water Cut		Number	%	%
	Intake Pressure		Number	kPa	psi
	Free gas @ Pump Intake		Number	%	%
	Welhead Pressure (WHP)		Number	kPa	psi
	Casing Head Pressure (CHP)		Number	kPa	psi
	Static (or shutin) Pressure		Number	kPa	psi
	Gas-Oil Ratio (GOR)		Number	m^3/m^3	scf/sbl
	SandCut		Number	%	%
	Contaminents / Solids?		Text	Yes, No	Yes, No
	CO_2		Number	%	%
	H_2S		Number	%	%
	Frequency		Number	Hz	Hz
	Volts		Number	Volts	Volts
	Current		Number	Amps	Amps
	Number Restarts		Number		
Comments	Additional Comments (e.g.,		Text		

Table 1 General Data set.

General *Failure Mode*	Specific *Failure Mode*	Comments
• Flow	• No Flow to Surface • Low Flow to Surface	• As per well tests
• Electrical	• High Current • Low Current • High Voltage • Low Voltage • Low Insulation • Phase Unbalance • Short Circuit	• Relay Tripping • Fuse blows • As per electrical measurements at surface
• Downhole Instrumentation	• High Vibration • High Motor Winding Temperature • Low Motor Oil Dielectric Capacitance	• As per downhole instrumentation indications
• Other		
• Unknown		

Table 2 Failure Modes.

	Downhole ESP Components and Associated Parts					
Failed Item	**Pump**	**Intake and Gas-Separator**	**Seal**	**Motor**	**Cable**	**Other**
Parts	• Head • Base • Housing • Shaft • Coupling • Screen • Shaft support bearing • O-rings • Thrust washers • Diffusers • Impellers • Snap rings	• Head • Base/inlet • Housing • Shaft • Coupling • Radial bearings • Inducer section • Separation section/rotor • Snap rings	• Head • Base • Housing • Shaft • Coupling • Thrust bearing assembly • Bag-chamber assembly • Mechanical seals • Relief valves • Labyrinth chamber assembly • O-rings • Oil	• Head • Base • Housing • Shaft • Coupling • Thrust bearing assembly • Rotor bearing assembly • Stator • Pothead connector assembly • Rotors • Oil • O-rings	• Wellhead penetrator • Main Cable • Packer penetrator • Motor Lead Extension (MLE) • Splices	• Downhole Instrument

Table 3 Failed Items.

General ***Failure Descriptor***	Detailed ***Failure Descriptor***	**Comments**
• Mechanical Failure	• Leaking • Failed Pressure Test • Stuck (e.g., does not rotate) • Punctured • Ruptured, burst • Bent • Buckled • Dented • Broken (parted, sheared, torn) • Fractured, cracked, • Disconnected (loose) • Twisted • Collapsed • Faulty Clearance or Alignment	• Usually the result of force, pressure, or torque
• Material Failure	• Burn • Corroded (all types) • Worn • Eroded • Cracked • Swollen • Melted • Hardened • Brittle • Discolored • Overheated	• Usually related to the physical characteristics of the material such as colour, hardness, finish, etc.
• Electrical Failure	• Short circuit • Open circuit (disconnection, broken wire) • Faulty power (e.g., over voltage)	• Failures related to the supply and transmission of electrical power
• External Influence	• Plugged with scale • Plugged with paraffin • Plugged with asphaltene • Plugged with solids • Contaminated Fluid	• Failures caused by external events or substances, e.g., control, instrumentation, paraffin, asphaltene, scale, sand, iron sulfide
• Other		
• Unknown		

Table 4 Failure Descriptors.

General *Failure Cause*	Specific *Failure Cause*	Comments
• Design Related	• Improper equipment capacity • Improper material selection • Improper system configuration	• Inadequate pump flow or head capacity, motor power capacity, etc. • Improper equipment • Improper metallurgy
• Fabrication Related	• Manufacturing Problem • Improper Quality Control	• Failures related to inadequate fabrication
• Storage or Transportation Related	• Improper Storage • Improper Transportation	• Failures related to inadequate equipment handling
• Installation Related	• Assembly procedure • Installation procedure	• Failures related to inadequate installation
• Operation Related	• Operating procedure • Normal wear and tear	• Failures related to improper operating procedures or inadequate training
• Reservoir Related	• Reservoir Fluids • Reservoir Performance	• Unexpected reservoir conditions, leading to plugging by scale, paraffin asphaltene, sand, iron sulfide, etc. • Unexpected reservoir conditions, leading to lower/higher productivity, higher GOR or water cut
• Other		• Weather, war, terrorist attack, etc. • Failure of instrumentation or control
• Unknown		

Table 5 Failure Causes.

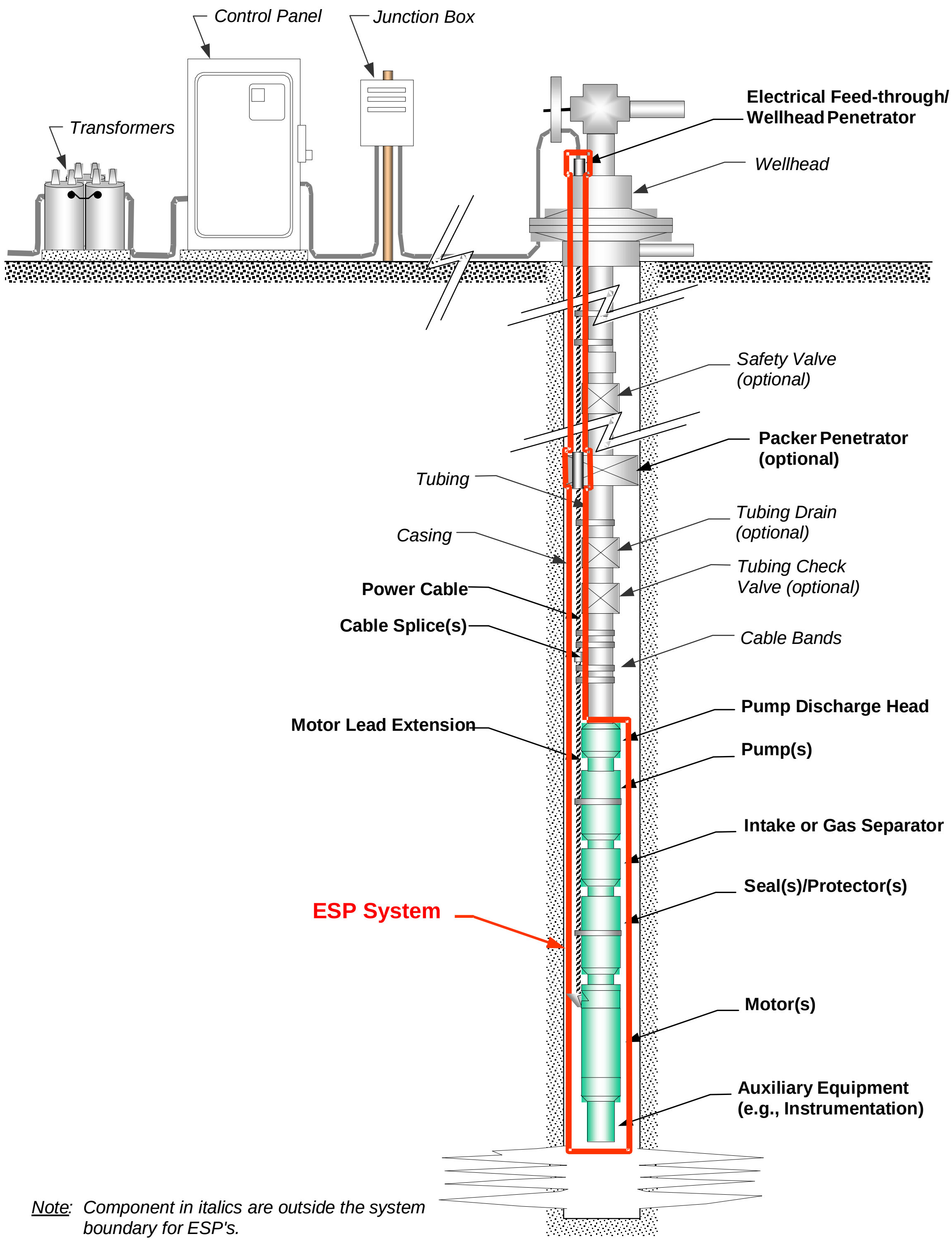

Figure 1 ESP System boundary.

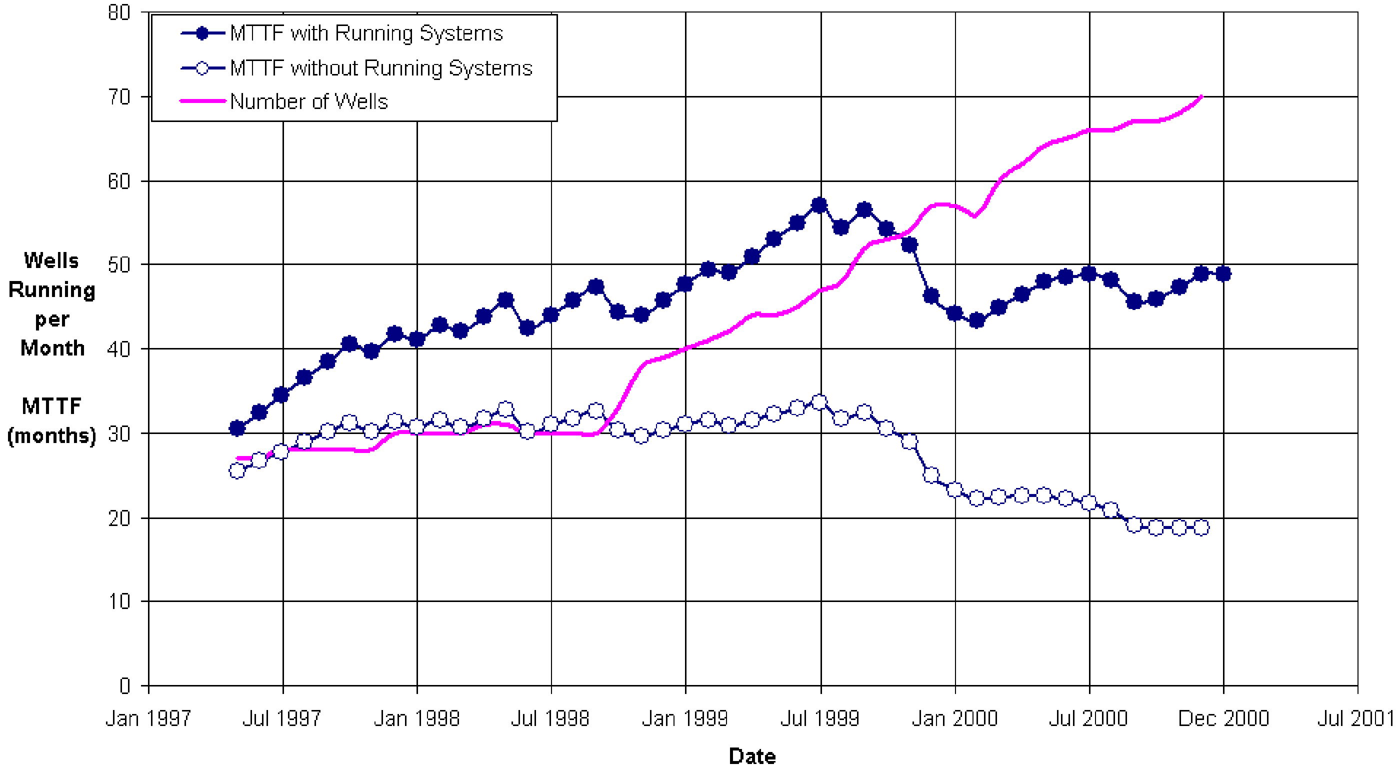

Figure 2 Example of estimated MTTF trends, with and without running systems.