

## Root Causes for Failure of Electrical Submersible Pumping (ESP) Systems In West Kuwait

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### **Abstract:**

ESPs have been deployed in West Kuwait since mid eighties, where highly sour and corrosive fluids are being produced. As the ESP population in the area was quite low until late nineties, not much attention was given to ESP failure rate and failure causes. By December 2005, well count on ESPs in the area stood at 130, and with increasing ESP deployments, the controlling team started to exert extra efforts to improve ESP performance by initiating a study to identify the root causes of ESP failures in two West Kuwait fields.

This study reviewed 75 ESP failures in one field and another 28 failures in the second field on well by well basis for over five years period, from May 2000 to December 2005. Failures were analyzed using a four step approach and are categorized in four classes as under:

1. Application: In this step company supplied design input as well as lease contractor's design/sizing was reviewed.
2. Environment: This step involved review of actual well conditions and incoming power supply as against initial input.
3. Installation: This step looked into equipment handling at site, installation procedure, operation, monitoring, and trouble shooting as well as diagnostic ability of lease contractor's personnel.
4. ESP Equipment limitations.

Failure reasons for various ESP system components were identified and are being presented in this paper. Majority of failures were related to poor cable and motor lead extension (MLE) quality. Conclusions are based on detailed analysis conducted on well histories, well conditions variance as against those provided to vendor, ESP installation/pull reports and tear-down of failed equipment from each well. It is prudent to state here that identified failure causes are always subject to human bias. What one operator may tolerate in one situation might be reported as a failure in another.

In this case study, the authors have tried to determine probable reasons for ESP failures and made number of recommendations to improve ESP run life and thus enhance ESP performance against the identified failure root causes. The authors wish to share their experience and learning's with other ESP operators producing sour & corrosive fluids from similar field conditions.

## **Introduction:**

KOC started to operate ESP wells in May 2000 through ESP lease contract which covered 70 wells in field – “A”. In the year 2001, additional 205 ESP wells from various fields within the State of Kuwait were added to the second ESP lease contract scope of work. The frequency of ESP failure increases as ESP population increases and this is normal. Also, when ESPs are introduced in a new area/field, one should expect some infant mortality, thus increase in ESP failure rate. In field – “A” for example, the ESP failures in year 2000 was 3 out of 26 ESP installations but in year 2005 the ESP failures increased to 25 out of 136 ESP installations (see plot -1). For that reason, the strategy of ESP lease contracts account for the expected downtime and pump replacement cost in the case where ESP fails, thus it provides penalty/compensation options based on the root cause of failure which will challenge the ESP contractors to take all the steps that will increase the ESP run days.

To determine the root cause of failure, the ESP lease contract requires the contractor to provide an ESP dismantling facility in the State of Kuwait to handle the dismantling operation for every ESP failure that takes place before achieving the target run life, TRL (1,000 days). However, the determination of the root cause of failure sometimes is debatable especially when the root cause of failure is not clear.

During the life of the ESP lease contract, several ESP failures were dismantled and were studied. Certain corrective actions were taken based on the dismantling results to improve the subsequent ESP installation and to avoid another failure for similar reasons. This practice was productive and continuous improvement in the over all ESP run days (average ESP run life) was recorded. The average ESP run life in field – “A” for example improved from 99 days in year 2000 to 1,041 days in year 2005 (see plot -2).

We in KOC conducted a field study in April 2006 to identify the main ESP failures root causes in West Kuwait area for the period May 2000 and December 2005 and to make recommendations for enhancing ESP run life. This study reviewed 103 ESP failures in two oil fields (field – “A” and field – “B”) and 10 ESP failures in water producing wells in field-B. In general, 60% of the ESP failures (mature plus premature) were due to fault in the power cable and the Motor Lead Extension (MLE).

This paper is prepared to share our findings, conclusions and recommendations made in the said study with other MEALF participants. Although, the study included several fields, this paper focuses on field “A” case only which has maximum number of ESP installations...

## **ESP life cycle:**

1. ESP Design data: the ESP design data is prepared by KOC based on the full field model and strategy and it is submitted to the ESP contractor for ESP design.
2. ESP design/ ESP selection: the ESP contractor prepares the ESP design by using the ESP design software and selects the ESP equipment that will deliver the requested production with the best possible operating conditions of the ESP system. This design is discussed and approved by KOC.
3. ESP delivery to well site: the ESP contractor loads, transports, off loads the ESP equipment at desired well site safely under KOC supervision.

4. ESP assembly and installation: the ESP contractor assembles and installs the ESP under KOC supervision and KOC provides Work over Rig for the installation. Some ESP failures were attributed to the ESP installation process.
5. ESP operations and monitoring:
  - a. ESP commissioning test: a rate test is done for every ESP installation prior to release of the Work over Rig. The main purposes from this test are to validate the well productivity and to insure that the ESP is operating within the pump recommended range. Operating the ESP outside the pump recommended range will lead to premature ESP failure.
  - b. ESP protection setting: The ESP controller and the down hole multisensor controller are programmed in a manner to protect the ESP system from abnormal situations. By passing the protection parameters will harm the ESP system.
  - c. Daily monitoring: ESP contractor carries out ESP monitoring twice a day. The monitored data consists of: parameters of down hole sensor, parameters of down hole motor (voltage and amperage), flow line and well head pressures and Diesel fuel level for power generator units. These data are collected and reviewed on daily basis to avoid ESP tripping/failure.
  - d. ESP start up: compression and decompression of power cable will increase with the numerous starts/stops of the ESP system which may lead to ESP cable failure.
  - e. Well testing: regular well testing is conducted for the wells on ESP in order to optimize the well production and to protect the ESP from up thrust or down thrust condition.

### **ESP Failure Analysis:**

Two main questions arise when any ESP system fails:

- 1) Why did ESP failure occur?
- 2) How can we avoid the ESP failure in future?

This section addresses the first question in the light of the results obtained from the study conducted in field – “A” and the answer to the second question will be addressed under “Recommendations and actions taken to improve the ESP Run Life” section.

The ideal situation for any ESP system is to be in operation without interruption for the longest period. This situation will insure the maximum profits for the Oil Company by continuous production and less well work over. The ESP lease contractor would also gain due to the lower ESP replacement cost. However, this ideal situation does not exist in the real life and the ESP system is subject to interruptions by either external factors or internal factors or both. Internal factors like, electrical fault in the surface ESP components, electrical fault in the subsurface ESP components or mechanical fault in the subsurface ESP components. Examples for external factors are: power quality, surface production facility constraints and limitations, produced fluid quality, subsurface production tubing and production casing condition, human intervention and the like. Internal and external factors could combine together and result into interruptions to the ESP system when an internal control system (such as Over load, under load, Voltage Unbalance etc) activates as a results of external factor.

Interruption leads in most cases into either mechanical failure (such as broken shaft) or electrical failure (such as burnt motor or blown power cable) in the ESP system which is not desirable for parties, the Oil Company and the ESP contractor.

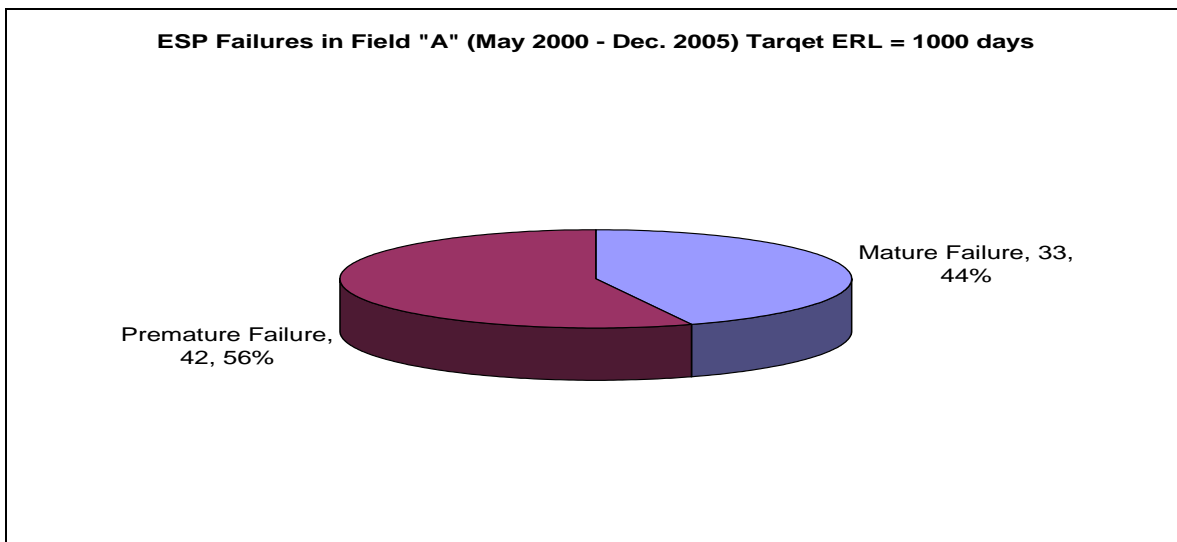
**Root causes of ESP Failures:**

During the period between May 2000 to Dec. 2005, 76 ESP failures were recorded in Field “A” in West Kuwait area. 75 units were pulled out and one unit was stuck in the well and declared as unrecoverable. 42 ESP failures out of the 75 failures were premature failures (less than 1,000 days run life). See plot – 3. The 42 ESP premature failures were studied and the root causes of the failure were classified – see plot - 4 - based on the following steps:

1. Application: This step covered company supplied design input to the contractor who will design/size the ESP system/equipment and obtain Company approval. No ESP failure in Field “A” was attributed to application reasons during the period of study.
2. Environment: This step involved review of actual well conditions and incoming power supply as against initial input. 15 ESP failures in Field “A” were due to harsh environmental reasons. Plot – 5 shows the details of the environmental related failures.
3. Installation: This step looked into equipment handling at site, installation procedure, operation, monitoring, and trouble shooting as well as diagnostic ability of lease contractor’s personnel. 2 ESP failures were recorded in Field “A” due to operating against closed valve at the surface. See plot – 4.
4. ESP Equipment limitations: ESP failures took place due to ESP equipment related reasons in Field “A” were 25 failures where 72% of them were due to cable elements. Plot – 6 describes the ESP failures due to ESP equipment limitations.

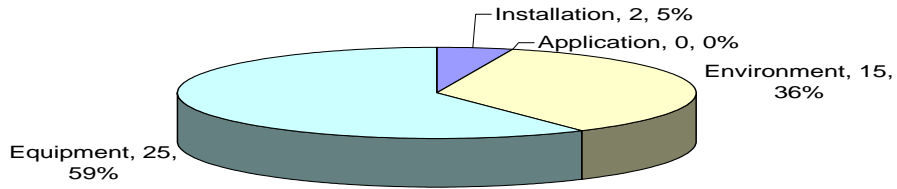
All analyzed failures are listed in table-1 below for the main ESP components. For each failure, all the observed root causes are also listed. For example, the power cable could be burnt, burst, cramped, blown at splice or washed out. The root causes for the cable burn could be corrosion, unstable power supply and frequent system starts/stops.

Although, casing/tubing is not a part of the ESP system, however, tubing or casing failure will usually result in failure of ESP components.



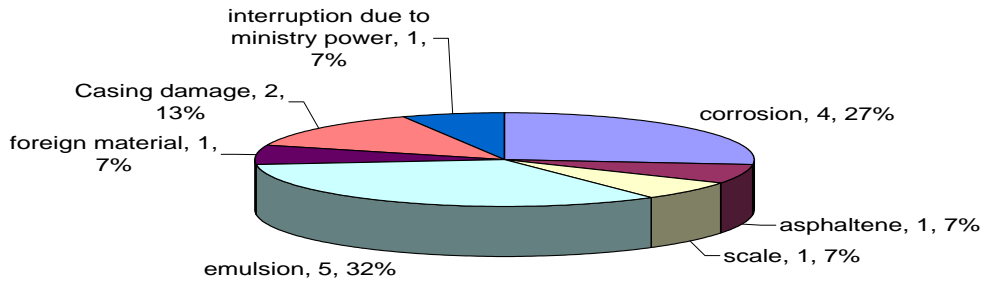
Plot – 3

**Analysis of ESP Premature Failures in Field - "A" (May 2000 - Dec. 2005)**



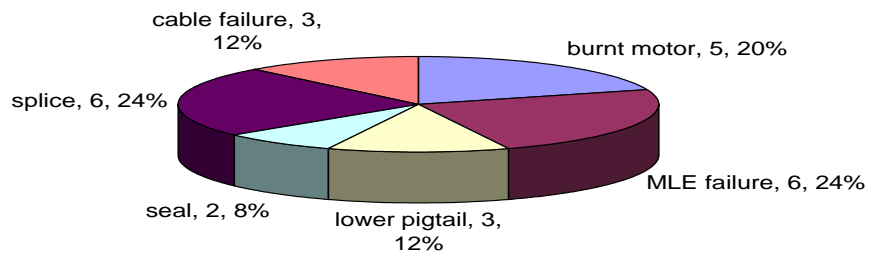
Plot - 4

**Premature ESP Failures due to environmental reasons in Field "A" (May 2000 - Dec. 2005)**



Plot - 5

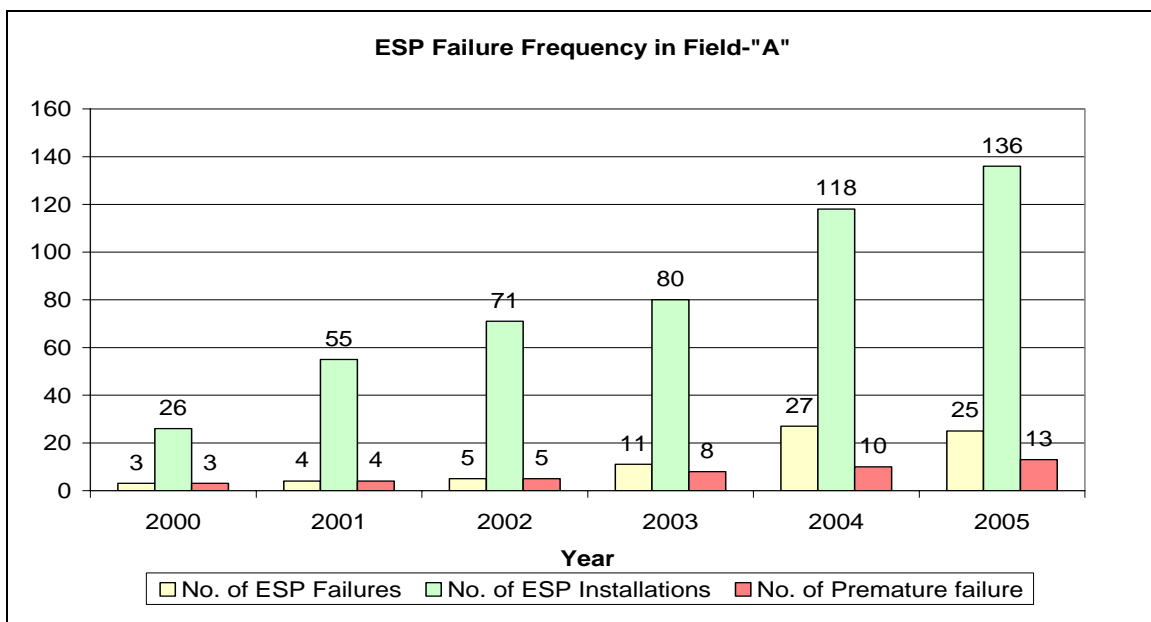
**Premature Failure related to ESP equipment in Field - "A" (May 2000 - Dec. 2005)**



Plot - 6

Components	Observed Failure	Mode	Root Cause/causes
Main Cable	Burnt/Burst	Electrical	1. Corrosion 2. Unstable Power 3. Frequent starts/stops
	Insulation Damaged	Electrical	Corrosion
	Cramped	Installation	Operation
	Washed Out	Erosion	1. Tubing Leak 2. Casing Leak
MLE	Burnt	Electrical	1. Corrosion 2. Unstable Power 3. Frequent starts/stops 4. Emulsion
Pr/temp Sensor	No reading	Electrical	1. Corrosion 2. Installation Damage
Seal	Shaft broken	Mechanical	1. Corrosion 2. Low strength
	Contaminated	Mechanical	1. Poor seal Quality
Motor	Burnt	Electrical	1. Unstable Power 2. Frequent starts/stops 3. Low cooling due to low rate/Viscous Fluid
Pump	Worn Out	Operation	1. Upthrust/downthrust operation
Pump/Motor shaft	Broken	Operation	1. Low strength shaft 2. Locked pump due to scale/asphaltene
Tubing/Casing	Parted tubing	Mechanical	1. Corrosion
	Leak	Mechanical	1. Corrosion

Table-1: Classifications of ESP system component failures and root causes.



Plot - 1

**Average ESP Run Life (ERL):**

ERL is defined in KOC to be the actual number of days from the day of ESP installation till the day of ESP failure (including running and shut down days). Target run life (TRL) specified in the ESP lease contracts is 1,000 days for Field “A” which should be achieved by the ESP contractor other wise pay penalty as per contractual obligations. The deal (including but not limited to: monthly payment, compensation, penalty, owner ship, etc.) between KOC and the ESP contractor is linked to the ERL.

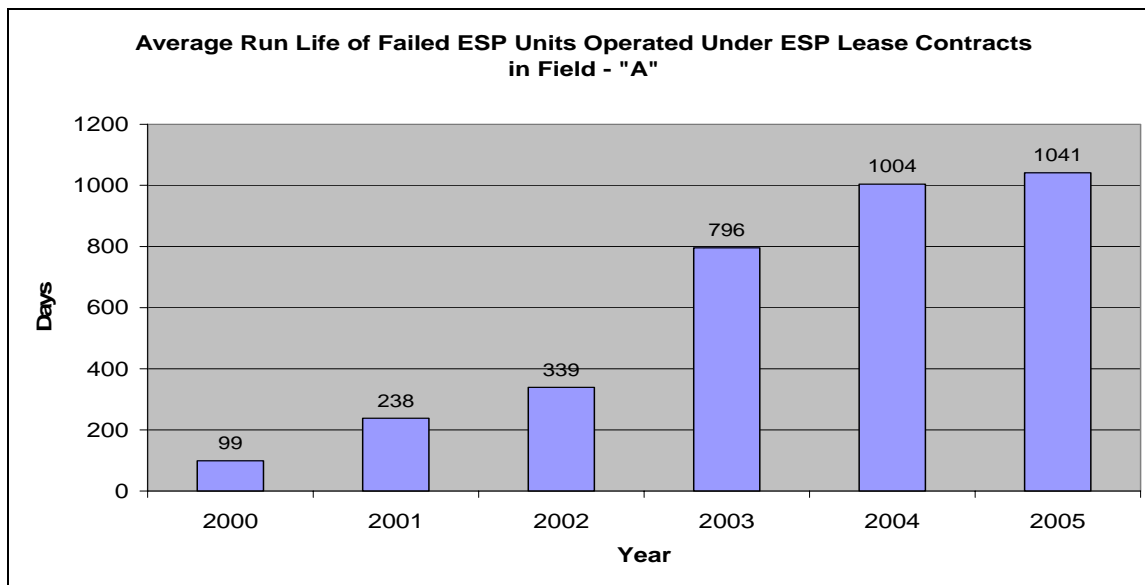
Average ERL is another important element which is used to evaluate the success rate or failure rate of the ESP operations in a certain field or during a certain period. The average ERL can be calculated for failed ESP only or for running and failed ESP together.

Plot – 6 shows the average ERL of the failed ESP in Field “A” between the periods from May 2000 to December 2006. The record of Average ERL in Field “A” shows continuous improvement in value by time and it indicates better and better ESP operations and performance.

Table – 2 is an example of average ERL calculation and it shows the average ERL in the year 2003 in Field “A”.

Sr. No.	Well No.	Commissioning Date	Failure Date	ERL	Pull out Reason	Cause of Failure Group
1	UG-X1	18-Jan-01	17-Jan-03	729	The ESP was pulled out on 17 Jan. 2004. The motor lead extension was melted and shorted.	ESP cable
2	UG-X2	15-Sep-00	19-Jan-03	856	The ESP was pulled out on 16 Jan. 2004. The ESP motor was shorted.	ESP Equipment
3	UG-X3	30-Dec-00	19-Jan-03	750	The ESP was pulled out on 10 Mar. 2004. The lower pigtail was shorted.	ESP cable
4	UG-X4	26-May-00	8-Feb-03	988	The ESP was pulled out on 24 Jan. 2004. The protector failed and resulted in motor shortage.	ESP Equipment
5	UG-X5	4-Aug-00	9-May-03	1008	The ESP was pulled out on 22 Sept. 2003. Failure in the splice between the motor lead extension (MLE) and the main cable.	ESP cable
6	UG-X6	6-Feb-02	24-Jun-03	503	ESP was pulled out on 14 Aug. 2003. The motor lead extension blown out due to corrosion.	Corrosion
7	UG-X7	18-Feb-02	17-Aug-03	545	The ESP was pulled out on 17 Sept. 2003. The Motor Lead Extension (MLE) was burnt below the splice. The system was operated against closed valve.	Operations Procedure
8	UG-X8	1-Feb-02	8-Sep-03	584	The ESP was pulled out on 29 Oct. 2003. Failure in the pothead of the motor lead extension.	ESP cable
9	UG-X9	29-Nov-00	13-Sep-03	1018	The ESP was pulled out on 26 Jan. 2004. The lower pigtail was shorted	ESP cable
10	UG-X10	20-Dec-00	7-Dec-03	1082	The ESP was pulled out on 17 Feb. 2004. The motor lead extension was shorted.	ESP cable
11	UG-X11	4-Feb-02	28-Dec-03	692	The ESP was pulled out on 22 Feb. 2004. The motor lead extension and the UT motor were damaged due to emulsion.	Well Condition
Average Run Days of Failed ESPs (days) =				796		

Table - 2



Plot - 2

### **Recommendations and actions taken to improve the ESP Run Life.**

The following recommendations are made to improve ESP performance:

#### **Recommendations for Equipment**

- Monel armored cable to be installed in wells where corrosion is known to be one of the failure modes. Also upgrading of down hole equipment specifications for using corrosion resistant down hole equipment is recommended.
- Use of 13-Chrome Y-tools in high water cut wells requiring surveillance access for reservoir monitoring.
- Install pressure switches on all wells flow lines as well as on well heads and function test these at regular intervals to avoid failures resulting from switching ESPs on, while valves at flow line or Gathering centre end are closed. Install soft starters on all wells to minimize damage to down hole equipment due to frequent starts/stops.
- Introduce down hole chemical injection through capillary tubing for corrosion inhibition as well as to avoid formation of emulsion in the well bore.
- Avoid use of cable bands including MLE bands and use cable protectors to reduce the risk of cable damage and also the accumulation of lost bands in wells, especially completed with down hole master valves.

#### **Recommendations for operating procedures**

- Ensure that running and pulling of the ESP system is done slowly and smoothly to avoid equipment damage during trips in or out of the well. Based on our experience, recommended trip speed is 8 stands/hour.
- Plan wire line and rig less jobs with planned generator maintenance on wells with captive power source to minimize starts and stops.
- Conduct tear down analyses for all ESP failures, including systems which completed/exceeded target run life.
- Expedite failure analyses of pulled units to capture learning's and incorporate these in next installation on the same well.

- Do not treat the pumping wells like natural flow wells and minimize the number of starts and stops to avoid undue stress to the ESP system.
- Educate operating personnel on safe operating practices.
- Conduct frequent production rate tests on each pumping well to ensure the ESP operation within the recommended range, no up thrust or down thrust.

### **Acknowledgments:**

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### **References**

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2. Minutes of meetings held during the years 2001 to 2006 of a Multidisciplinary team to enhance ESP run life in KOC.
3. Various failure reports submitted by M/S Schlumberger and M/S Al-Khorayef.