ESPs in OMV Austria E&P – Performance Analysis and Benchmarking

Master Thesis

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Leoben, March 2015

Affidavit

I declare in lieu of oath that I wrote this master thesis and performed the associated research myself, using only literature and sources cited in this thesis.

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Date

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Abstract

According to the redevelopment of the 16TH Torton project OMV Austria E&P came up with the idea of analyzing their electrical submersible pump performance within a master thesis. This RD16TH campaign represents the biggest ESP installation campaign in the history of OMV Austria E&P.

During the long history of OMV Austria E&P in operating oil and gas wells, the historical development of ESP's in OMV as well as the number of current installations (33) was researched. With reference to the redevelopment of the 16TH Torton project tender the standardization of ESP's in five different groups took place. Additional to them, possible improvements for further future ESP installation campaigns were developed. The pump selection criteria, technical and economical point of view, were analyzed to find the reasons why an ESP was used as suitable artificial lift method. For the investigation of the economical point of view, a lifecycle cost calculation over 25 years showed that with the selected pumps and a production gross rate of over 180-m^3/day, an ESP installation becomes more economical in comparison to a beam pumping unit. To cover all the installation and operation experiences with an ESP, all lessons learned and best practice examples are summarized in this thesis. The performance analysis compared values of average run life of events with values from mean time between events. Therefore the average run life analysis came up with values of 550 days (running ESP's), 872 days (pulled) and 1,103 days for "true" failed ESP's. The mean times between event values are higher, due to the amount of present data, and results in values of 1,795 (pulling ESP's) and 2,468 days ("true" pump failure). Additional to this, a performance benchmark together with the OMV branch offices in Kazakhstan, New Zealand, Romania, Tunisia and Yemen was performed. Therefore, the average run life of failed ESP's varies from 230 up to 1,103 days and the mean time between ESP failures from 735 up to 2,707 days.

Kurzfassung

Durch das Neuentwicklungsprojekt „16TH Torton“ wurde in der OMV Österreich Exploration & Produktion die Idee einer Masterarbeit, mit dem Ziel die Pumpen Darbietung der Tauchkreiselpumpe (TKP) näher zu untersuchen, geboren.

Die geschichtliche Entwicklung der TKP in der OMV Österreich bis hin zum aktuellen Installationsstatus der 33 aktive Tauchkreiselpumpen umfasst, wurde durch Recherchen ermittelt. Die Standardisierung der TKP in fünf verschieden Gruppen durch den OMV Tender im Jahre 2013 wurden analysiert und Vorschläge für Verbesserung für zukünftige Tauchkreiselpumpen Kampagnen gemacht. Das Auswahlverfahren, warum TKP, wurde sowohl von der technischen als auch wirtschaftlichen Seite (Kostenrechnung über 25 Jahre) näher erörtert. Die Kostenrechnung zeigt als Ergebnis, in Abhängigkeit der ausgewählten Testpumpen, das eine TKP ab einer Bruttorate von über 180-m³/Tag wirtschaftlicher ist als eine vergleichbare Tiefpumpe. Alle Erfahrungen bezüglich Installations- und Betriebsschwierigkeiten sind in dieser Masterarbeit zusammengefasst und aufgezeigt, um für zukünftige Anwendungen zur Verfügung zu stehen. Die „gemittelten“ Standzeiten (ARL) der TKP betragen 550 Tage (laufende), 872 Tage (gezogene) und 1103 Tage für TKP Fehler. Höhere Werte, zusammen hängend mit der Menge an zur Verfügung stehenden Daten, ergab die „mittlere Zeit zwischen einem Ereignis“ Standzeit (MTB) Berechnung. Hier wurden 1795 Tage (zwischen gezogene Pumpen) und 2468 Tage zwischen einzelnen Pumpenfehlern ermittelt. Zusätzlich zu der internen Standzeitenanalyse wurde auch ein Vergleichstest „Benchmark“ mit den OMV Außenstellen in Jemen, Kasachstan, Neu Seeland, Rumänien und Tunesien durchgeführt. Dieser ergab für Pumpenfehler, Standzeitenwerte zwischen 230 und 1103 Tage, berechnet nach der „gemittelten“ Methode und Fehler Standzeiten zwischen 735 bis hin zu 2707 Tage nach der „mittleren Zeit zwischen dem Pumpenfehlerereignis“.

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Introduction

With the redevelopment of the 16^{TH} Torton campaign OMV Austria E&P increased their number of ESP installations within one year by roughly 100%. Therefore this master thesis should give information's about how well the currently installed ESP's in OMV Austria E&P are performing. Besides the history and the status of current installed electrical submersible pumps, the standardization of the ESP's into different groups, during the tender phase, was under investigation. Therefore possible improvements for future installation campaigns are found and described within this thesis. Additional to them the selection criteria from both point of views, technical and economical is under investigation. Therefore a lifecycle cost calculation, over a specific time frame, was performed with the aim of comparing beam pumping units (the most installed artificial lift method in OMV Austria E&P) with the electrical submersible pump. Regarding to the chosen reference pumps an economic border, in terms of gross flow rate was found. For the performance analyses, different key performance indicators which are widely used in the petroleum industry were investigated. The values for average run life of event (running, failed and pulled) as well as the mean time between ESP failures and pulls are calculated. Different circumstances will explain why other KPI's like pulling or failure index have no significant meaning. For future ESP installation purposes a lesson learned and best practice collection, which summarize all the experience regarding pump installation and operation in OMV Austria E&P, can be found in this thesis. Furthermore an OMV benchmark including different branch offices around the world will compare the run lives of ESP's within the OMV group. Similar to the performance analyses for OMV Austria E&P the average run life of different events as well as the mean time between different events were calculated and compared with each other. Additional to this, different graphs will give information about the operating conditions (depths, rates, GOR etc.) of ESP's within the OMV group.

1. Artificial Lift Technology

The artificial lift (AL) technology uses different techniques to increase the fluid flow to surface. This could be achieved by (1) using a mechanical device (pump) inside the well; (2) reducing the weight of the fluid mixture by injecting gas or (3) using a velocity string to improve the lift efficiency. An artificial lift technology is used in wells where the natural reservoir pressure is too small to lift the liquid to the surface [1]. Furthermore, it is possible to use artificial lift in natural flowing wells, therefore you can increase the flow rate. Different AL technologies are shortly explained and shown in figure 1.

Gas Lift:

Gas is injected via valves into the crude to reduce the density and therefore increase the lifting efficiency. The gas which is used for reinjection could be contaminated with oxygen, carbon monoxide and hydrogen sulphide which can lead to corrosion of the production string. [1]

Hydraulic Jet Pump:

A hydraulic pump converts a low pressure, high velocity “power fluid” from the surface via a nozzle into a high pressure, low velocity fluid downhole. This high pressure (equal to head) fluid lifts the crude oil to the surface. There are two possible systems, an open or closed power fluid system. The open power fluid system produces the used power fluid and the crude oil within the same tubing, therefore surface separation is necessary. In the closed system, the used power fluid and the produced crudes are lifted in two separate tubing. [2]

Plunger Lift:

A plunger lift uses the well's own energy to produce small volumes of liquids in gassy wells. Due to the movement of a piston the liquid is lifted to the surface. During the well shut-in period formation gas is stored in the casing annulus. When the well is opened, the tubing pressure will decrease and this stored gas moves the plunger to the surface. This process will be repeated several times a day. [1]

Progressive Cavity Pump (PCP):

The two major parts of the PCP are the stator and the rotor. Due to cyclic motion of the helical rotor, crude is produced by the cavities of the stator. This kind of pump is used for higher viscous crudes and is very sensitive against abrasive materials. They are limited to depth of 5,000-ft and does not produce well from deviated holes. [1]

Sucker Rod:

Is the most popular and widest used artificial lift technology around the world. Roughly 60% of all pumping operation refers to this kind of AL method. The sucker rod (beam pump or rod pump) converts reciprocating motion of the "pump jack" on the surface into vertical motion of the downhole pump barrel. Due to the large footprint they are not usable for offshore operations. Another limitation refers to the well depth and inclination. [1]

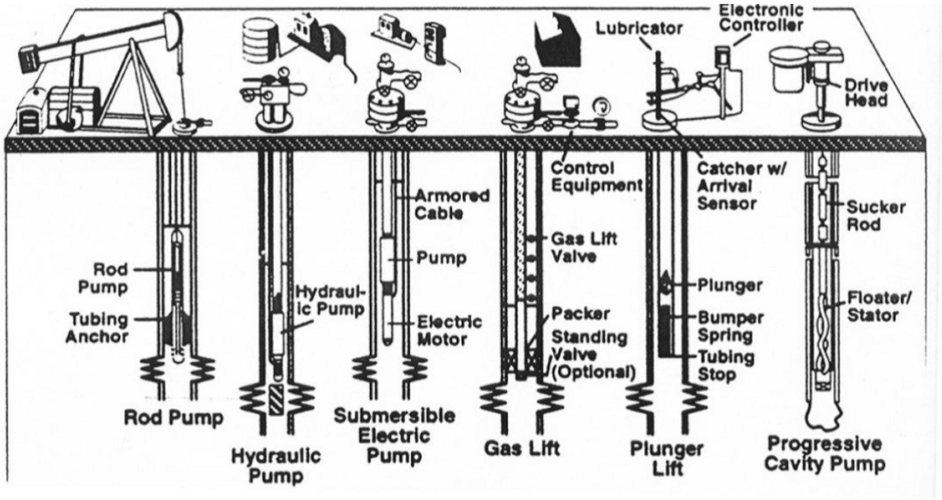
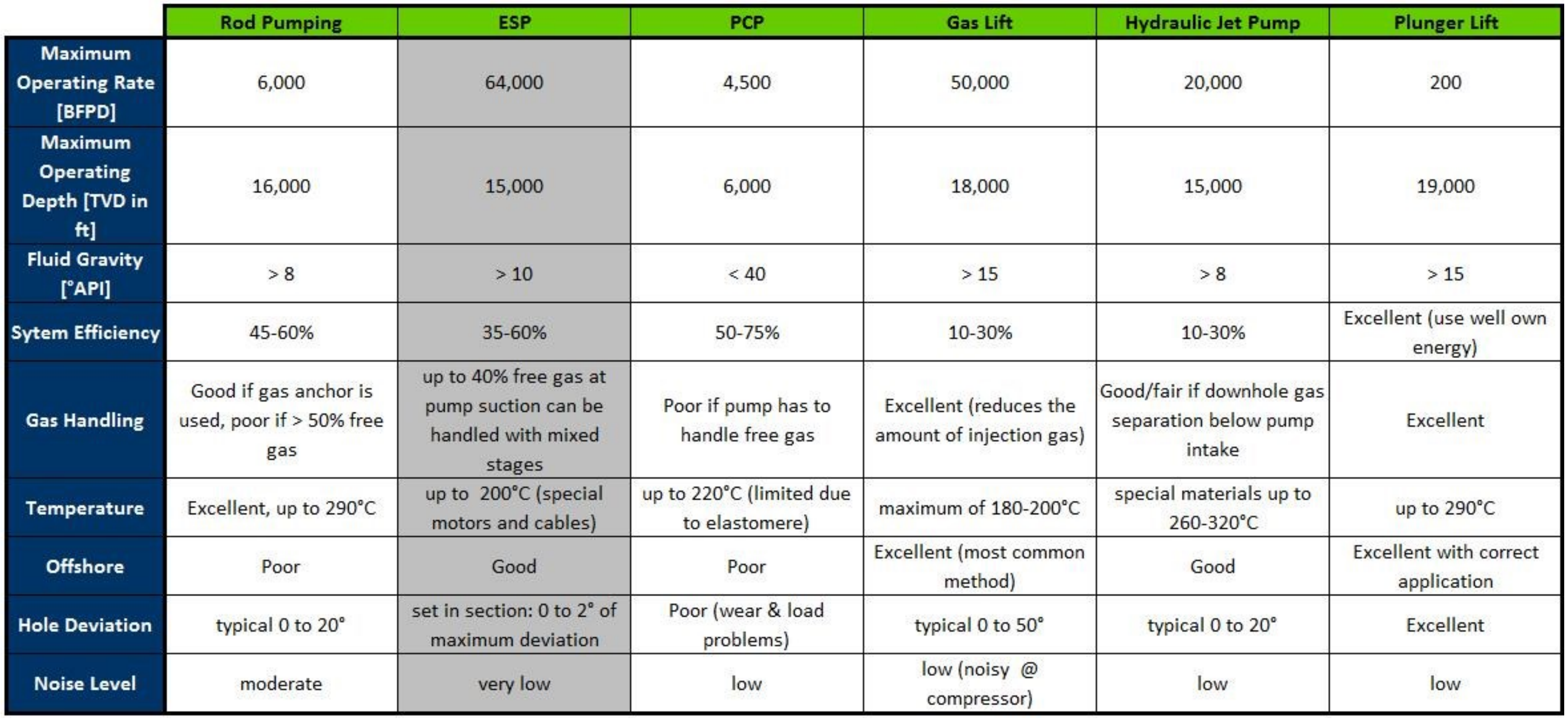


Figure 1: Artificial lift systems [2, p. 22]

2. Application of different AL methods

Table 1: Application of different AL methods [3, 4]



	Rod Pumping	ESP	PCP	Gas Lift	Hydraulic Jet Pump	Plunger Lift
Maximum Operating Rate [BFPD]	6,000	64,000	4,500	50,000	20,000	200
Maximum Operating Depth [TVD in ft]	16,000	15,000	6,000	18,000	15,000	19,000
Fluid Gravity [°API]	> 8	> 10	< 40	> 15	> 8	> 15
Sytem Efficiency	45-60%	35-60%	50-75%	10-30%	10-30%	Excellent (use well own energy)
Gas Handling	Good if gas anchor is used, poor if > 50% free gas	up to 40% free gas at pump suction can be handled with mixed stages	Poor if pump has to handle free gas	Excellent (reduces the amount of injection gas)	Good/fair if downhole gas separation below pump intake	Excellent
Temperature	Excellent, up to 290°C	up to 200°C (special motors and cables)	up to 220°C (limited due to elastomere)	maximum of 180-200°C	special materials up to 260-320°C	up to 290°C
Offshore	Poor	Good	Poor	Excellent (most common method)	Good	Excellent with correct application
Hole Deviation	typical 0 to 20°	set in section: 0 to 2° of maximum deviation	Poor (wear & load problems)	typical 0 to 50°	typical 0 to 20°	Excellent
Noise Level	moderate	very low	low	low (noisy @ compressor)	low	low

The parameters are according to the different environments and have to be adjusted from well to well.

3. The Electric Submersible Pump

The electric submersible pump (ESP) is a very effective artificial lift method to pump production fluids to the surface. Nowadays, more than 130,000 ESP's are installed worldwide [5]. Due to the wide operation range, the electrical submersible pump is the fastest growing type of artificial lift technique.

The major operating parameters are: [1]

- capable production rates varies from 70-bpd up to 64,000-bpd
- vertical operation depth up to 15,000-ft
- more than 10% of gas will lower efficiency → using gas handling devices
- RPM up to 4,000
- 4.5-in minimum allowable casing OD
- H_2S, CO_2, sand and high downhole temperatures (up to 260°C) could be handled
- increasing water cut can be handled by appropriate design
- can be deployed in vertical, deviated and horizontal wells
- economic and efficient in cost per barrel
- small footprint → offshore operations

3.1. Operation Principle

The ESP is a multistage centrifugal pump which operates in vertical position. Each stage consists out of two major parts, the impeller and diffuser. The electrical downhole motor turns the impellers (figure 2, left) via a shaft and adds kinetic energy to the production fluid. This kinetic energy is transferred into potential (pressure/head) energy due to the diffuser, figure 2 right, which lifts the fluid from the reservoir to the surface.

Each stage provides a certain amount of head. To achieve the total lifting head capacity several number of stages need to be stacked together.

Figure 2: Impeller and diffuser of an ESP [6]

According to the impeller discharge direction, ESP's can be classified in radial, mixed and vertical flow, but only radial and mixed flow are used in the industry, see figure 3. The radial flow provides more head, while the mixed flow configuration will handle gas (up to 40-% at pump suction compared to 20-% for radial flow) and solids better. [7]

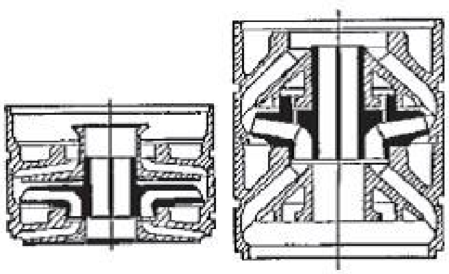


Figure 3: Radial and mixed flow [7, p. 26]

Another important issue is, if the impellers are fixed or floated. With a "compression" pump all impeller are fixed to the shaft, means if the shaft moves up or downward all impellers will follow. Therefore the shaft and the main thrust bearing (in the protector) have to hold the whole axial loads. In a "floater" pump, the impellers are allowed to move within the diffuser. The main axial loads are carried by the thrust washers between each stage (up- and downthrust washers). Smaller investment cost due to lower manufacturing time, without fixing all impellers to the shaft, will be the big advantage of floating pumps. [4, 7] Compression pumps can be used in downthrust regions (appendix D) too, while floater pumps only operates in the designed operating range.

3.2. ESP Components

The major components (downhole and surface) of an ESP system could be seen in figure 4.

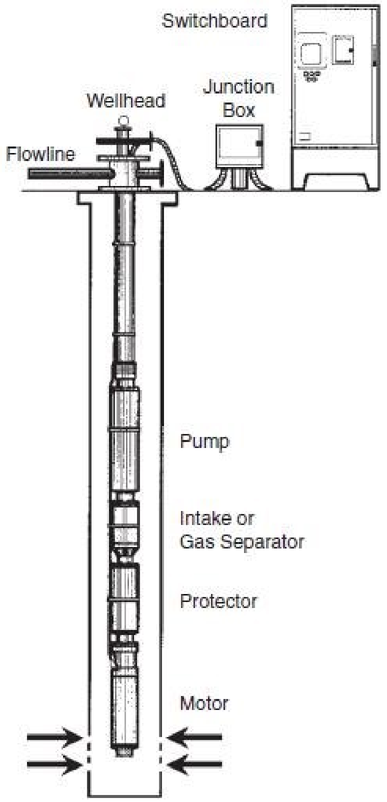


Figure 4: ESP components [7, p. 52]

downhole:

- Motor
- Protector/Seal
- Gas Separator
- Pump
- Cable

surface:

- Wellhead
- Flowline
- Junction Box
- Switchboard
- Transformer
- Variable Speed Drive (VSD)

3.2.1. Downhole components

Motor:

The ESP motor is a three-phase, two pole, squirrel cage induction type electric motor. Due to electromagnetic induction, an alternating current (AC) induces a magnetic field in the stator windings which rotates with a sinusoidal behavior in time. The rotor tries to achieve the same position and starts to move, resulting into creation of torque for the pump. The speed (RPM) of such a motor depends mainly on the frequency of the AC current. By installing a variable speed drive (VSD) on the surface, the operator is able to change the input frequency of the alternating current and therefore, the pump is more flexible regarding changes in the operation conditions.

The lubrication of the bearings, as well as the transport of the heat which is generated within the motor is done by highly refined oil. Therefore, the motor is filled up with this oil with a specific gravity of 0.80-0.83. [7]

An ESP motor is not equal to an electric motor which is used in everyday lifetime. The important differences are: [7]

- length to diameter ratio much greater (run inside casing)
- increase motor power → increase length of the unit
- cooling process by convective heat transfer of fluid flowing past the motor (surface motors are cooled by air)
- due to long cables → voltage drop occur

Another important factor which influences the performance of the motor is the operation temperature. For sufficient cooling it is proper to set the motor above the perforation. Therefore the passing flow cools down the motor if the flow speed is greater than 1-ft/s. If this cooling velocity is not reached, special motor shrouds, which increase the outer diameter has to be installed. For cooling issues a high water cut is better. The higher heat capacity of water results into higher cooling efficiency. [7]

Protector or Seal:

If the ESP motor would be complete sealed against producing fluids, the housing would burst due to the expansion of oil, as a result of the high operation temperature. To avoid this, the motor needs to keep open, but it must be protected from the surrounding harmful well fluids. Therefore the protectors are placed between the motor and the pump. The main function of the protector is: [7]

- houses the thrust bearing which carries the axial load developed by the pump
- protects the motor from well fluids
- pressure equalization of wellbore and motor due to communication of dielectric motor oil and well fluids
- allows expansion of motor oil due to temperature increase
- connection of pump and motor → transmit of torque from the motor to the pump shaft

For increasing motor protection tandem configurations (bag and labyrinth type) are used.

Gas Separator:

The operation principle of a centrifugal pump works in a way that kinetic energy is added to the fluid via the impeller. Therefore the fluid density is an important factor. The kinetic energy in the presence of gas will be much lower than if there is only oil and water. This result in a much lower pressure output of the diffuser and therefore in a much lower head the pump could develop. The higher the gas content is, the lower the pump efficiency would be.

Moreover, fluctuations of the pump output could occur which results in surges and cavitation. The gas bubbles implode and the resulting pressure lead to damages of the pump stages.

With increasing amounts of gas, gas locking could occur, where the pump action is stopped due to a complete filling of the pump with gas. [7]

The simplest form of a gas separator, for small amounts of gas, is the "reverse flow gas separator" seen in figure 5. This "static" gas separator is installed between the protector and the pump (see figure 4). Gravitational separation forces the fluid flow to change its direction and allowing the free gas to escape in the well annulus. If the bubble rise velocity is greater than the liquid counterflow velocity, gas bubbles will rise to the top of the separator and escape into the annulus through the upper perforation of the separator housing. The liquid, with the reduced amount of gas, is than sucked into the pickup impeller and transferred to the pump. [7]
This gas separator is only valid when there are moderate liquid and gas rates, and low separation efficiency is sufficient.

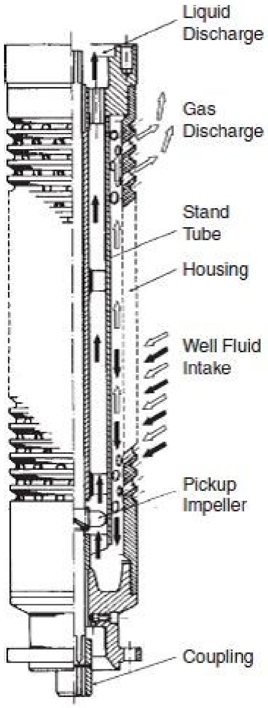


Figure 5: Reverse flow gas separator [7, p. 101]

The reverse gas separator efficiency will decrease with increasing flow rate. Another possibility will be using motor shrouds, seen in figure 6. The shroud is a section of pipe around the length of the ESP unit. It forces the entering well fluids downward in the casing/ shroud annulus where the fluid velocity is lower than 0.5-ft/s (gravitational separation take place). Therefore, gas bubbles vented out of the fluid and rises up the casing annulus. Additional cooling is guaranteed due to the flow of the produced fluid along the motor and this allows setting the motor below the perforations. [7]

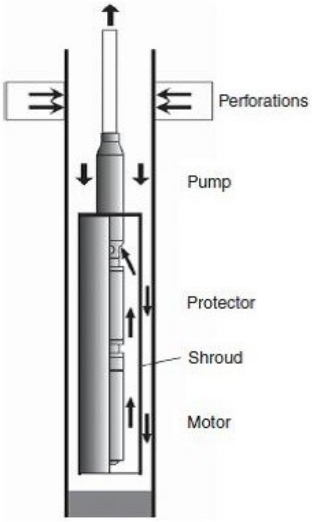


Figure 6: Shrouded ESP installation [7, p. 142]

A “dynamic” gas separator is similar to a centrifuge. With the rotational speed from the separator shaft, connected with the motor, the liquid is forced to the inner wall of the separator and the gas is concentrated near the shaft. A flow divider is used to ensure that the oil and gas flow different paths. The gas is directed into the casing annulus, whereas the oil is directed to the pump intake. Separation efficiency of rotary gas separators (figure 7) is higher than “static” gas separator and can handle a GOR up to 0.6. [7]

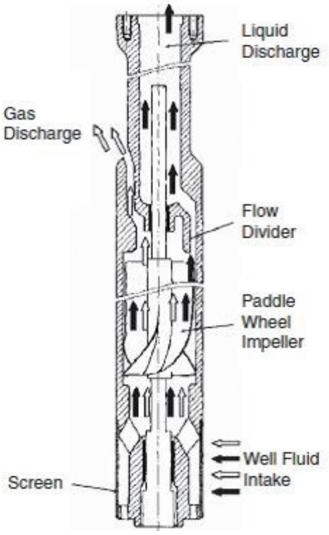


Figure 7: Rotary gas separator [7, p. 145]

ESP cable:

The electrical power for the motor supply is transmitted via a special three phase cable from the surface downhole. ESP cables have to operate in extreme environments and therefore they need to fulfill several criteria: [7]

- aggressive fluid (oil, water, gas) environment
- H_2S, CO_2 leads to corrosion
- high temperatures
- small diameter due to well spacing
- protection against mechanical damages during running and pulling operation

Taking time in a proper cable selection will increase the lifetime of the installation and decrease the number of interventions and costs.

There are two possible types of an ESP cable which can be seen in figure 8. Both cables have the same internal structure, they only differ in shape. The flat cable (figure 8, right) allows a more space saving installation in areas with smaller clearances, especially near the pump. ESP round cables (figure 8 left) requires therefore more annular space.

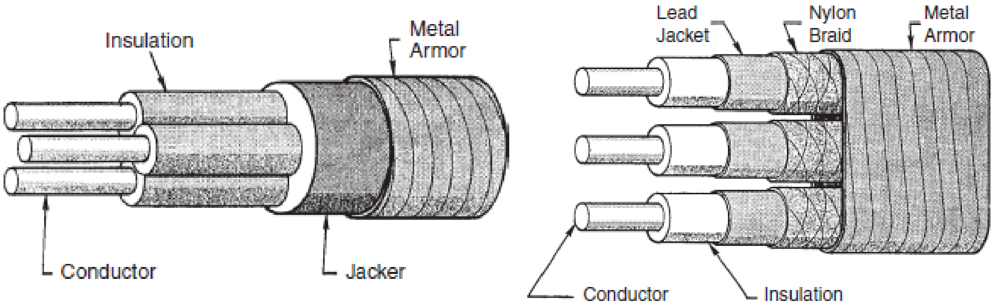


Figure 8: Round and flat ESP cable [7, p. 105]

The metal armor protects the whole cable from mechanical damaging during lifting/pulling operations. Moreover, it minimizes the swelling and expansion of the

cable due to the contact with the producing fluids. Therefore galvanized, stainless steel or Monel is used. [7]
The cable size is depending on the size of the conductor and is measured in American Wire Gauge (AWG) numbering system. Most cables are in a range from 1 to 6, where a higher number indicates a smaller cable size. [7]

The MLE (motor lead extension) is that part of the cable that is running along the pump, the gas separator and the protector. This MLE is connected with the upper "normal" part of the ESP cable via splicing and on the lower side it is directly connected with the motor via splicing or a connector (pothead connection). There is the maximum temperature acting on the cable at this lower connection point. [7]

3.2.2. Surface components

Wellhead:
The wellhead for an ESP installation should support the weight of the tubing string and provide a seal around the tubing and the cable entry as well. There are different possibilities of directing the cable through. One is the "Hercules" wellhead, seen in figure 9 left. In that design the power cable is directly moving through the wellhead. The other way would be using connectors (wellhead penetrator) from both sides, shown in figure 9 right. [7]

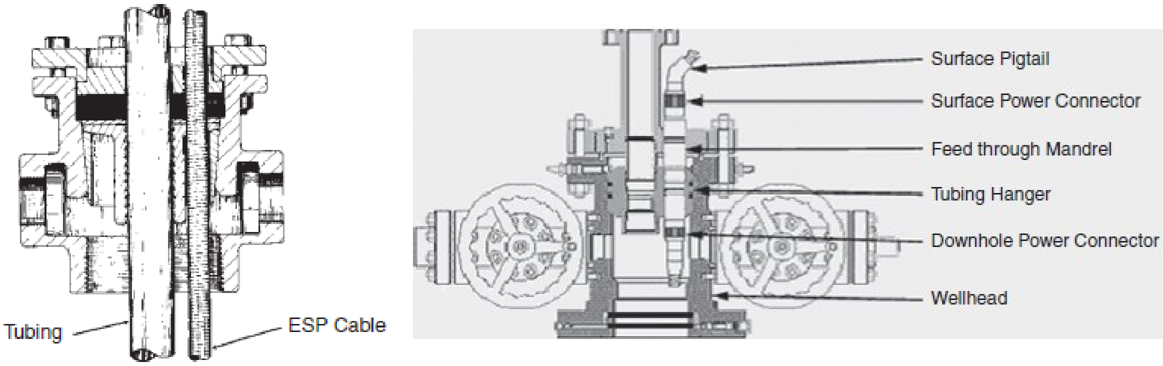


Figure 9: Different ESP wellheads [7, p. 114]

Junction box:

After the wellhead there follows the junction box (figure 10) which connects the power cable coming from the switchboard with the power cable from subsurface. Furthermore, any gas which may migrate through the cable can vented into the atmosphere. Therefore an explosive atmosphere at the switchboard would be avoided. Moreover the junction box provides a test point for checking the electrical consumption of the downhole equipment. [7]

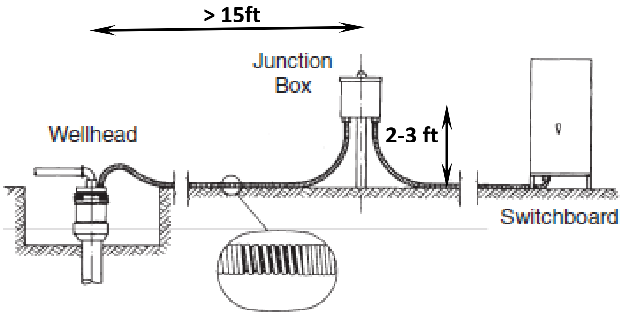


Figure 10: Junction Box and Switchboard [7, p. 115]

Switchboard:

A switchboard (shown in figure 10, right side), is the control unit of an ESP installation, containing an on/off switch for the equipment. It protects the motor from overloading due to high liquid gravity or undersized motor, as well as from underloading due to pump off. Further, the switchboard prevent from unbalanced currents, too high/low voltage or wrong phase rotation. Important operation parameters (current, voltage) can be monitored. [7]

Transformer:

The transformer is used to supply the downhole motor with the right voltage. At surface the voltage can rise up to 6,000-V or higher, while the ESP equipment needs voltage in the range of 250 to 4,000-V. [7]

Variable Speed Drive (VSD):

With a VSD, the ESP could be used in a wider operation range which allows the operator to be more flexible regarding changes in production conditions (rate, pressure etc.). A variable speed drive can varies the ESP operation frequency in a range between 30 to 70-Hz, by keeping the current at a constant level. This provides for the pump a maximum in efficiency at changing production conditions. [7]

3.2.3. Additional equipment components

Lightning Arrester:

A lightning arrester saves the whole installation from damages during a thunderstorm.

Check valve:

A check valve is used to prevent the fluid from downward flowing into the tubing when the pump is shut off. This would cause a reverse spin of the pump and when the restart happens the shaft can break.

Installation without check valves has to ensure that the whole liquid will flow back into the well before the pump will be started again. [7]

Backspin relay:

A Backspin relay is used when the usage of a check valve is not recommended. For example, when scaling problems occur and the chemicals are necessary to solve it. Therefore it would impossible to pump down the chemicals because the check valve is positioned at the lower end of the tubing string. [7]

Y-Tool:

With a Y-Tool the operator has permanent access to the horizon of interest without pulling the equipment (e.g. for additional perforation or acidizing jobs). [7]

3.3. ESP Design

Designing an ESP depends strongly on the operating conditions of the pump. In general three different stages are distinguished. Producing a single phase of oil together with water, producing wells with high gas oil ratios (GOR) or producing high viscous fluids (viscosity higher than 10-cP). [4]

The different stages of an ESP design are shown in the following.

3.3.1. Step 1: Select ESP Data

<u>Well dimensions:</u> casing/liner sizes and weights, tubing grades and weights, well depths, depth of perforations, etc. [4]

<u>Production data:</u> desired production rate, tubing/casing head pressures, flowing bottomhole pressure, static bottomhole pressure, dynamic liquid level, produced GOR, PI, water cut, etc. [4]

<u>Fluid properties:</u> specific or API gravity of produced oil, specific gravity of produced water and gas, oil viscosity, bubble point pressure, etc. [4]

<u>Power supply at surface:</u> available power and frequency [4]

<u>Well operating conditions:</u> paraffin, emulsions, abrasive materials, corrosion, high temperatures, etc. [4]

3.3.2. Step 2: Production Capacity

A single phase flow will result if the well flowing pressure (p_{wf}) is above the bubble point pressure (p_b). Therefore, the inflow performance relationship (IPR) can be expressed as straight line, see *figure D-1*. The slope, J, of this line will be given by the productivity index (PI, equation 1). [4]

Equation 1: Productivity Index [4, p. 688]

$$PI = J = \frac{Q}{(p_r - p_{wf})}$$

If the p_{wf} will be higher than p_b, gas goes out of solution and a multiphase flow will be the consequence. In that case, the inflow performance curve is not a straight line anymore (*figure D-2*) and the Vogel IPR equation should be used, see equation 2. [4]

Equation 2: Vogel IPR [4, p. 688]

$$\frac{Q}{Q_{oil,max}} = 1 - 0.2\left(\frac{p_{wf}}{p_r}\right) - 0.8(\frac{p_{wf}}{p_r})^2$$

If there is a vertical distance between the pump and the perforations, which normally would be the case, the pump intake pressure has to be corrected to this (equation 3). This Δp represents the hydrostatic pressure, height of oil/water column below pump time's specific gravity and pressure gradient.

Equation 3: Pump Intake Pressure [4, p. 696]

$$PIP = p_{wf} - \Delta p$$

3.3.3. Step 3: Gas Calculation

If there is any free gas available, there will be lower kinetic energy created by the impeller. When this is not accounted during the design phase, the pump will not be able to produce the desired liquid rate to surface. Therefore, the ESP design will result into a more complex way.

If the GOR (Rs), gas volume factor and formation volume factor of oil are not known from PVT data, these values have to be calculated. The equations can be seen in appendix D, *equations D-1 to 3*. [4]

With these values the total volumes of each phases and the percentage of free gas can be calculated. [4]

The outcome of this design step should be the total fluid volume at the pump intake, the specific gravity of the produced fluid mixture and if any further gas handling equipment is needed. [4]

3.3.4. Step 4: Calculation of Total Dynamic Head, TDH

The total dynamic head represents the pressure, converted into height, which the ESP has to generate to lift the fluid, from the reservoir to the surface. Equation 4 shows the TDH as a function of the NET lift, the friction losses within the tubing and the wellhead pressure. [4]

Equation 4: Total Dynamic Head [4, p. 690]

$$TDH = H_{Lift} + H_{Friction} + H_{Well\ Head}$$

The H_{Lift} or “NET lift”, equation 5, represents the height to lift the fluid and is calculated by subtracting the pump intake pressure, converted into head, from the pump setting depth. If a dynamic fluid level is given, the H_{Lift} is just the difference between the pump setting depth and this dynamic fluid level.

Equation 5: H_{Lift} or “NET” lift [4, p. 698]

$$H_{Lift} = PSD - (\frac{PIP}{0.433\ SG_{comp.}})$$

The 0.433 in equation 5 represents the pressure gradient of water in psi/ft.

The friction losses inside the tubing can be estimated by using a chart similar to the chart in appendix D. By using the size of the tubing and the total production rate per day, the friction head loss, in feet per 1,000 feet, can be determined. The total height, $H_{Friction}$, can be calculated, using equation 6. [4]

Equation 6: Friction loss head [4, p. 698]

$$H_{Friction} = \left(\boldsymbol{friction\ loss\ in} \frac{ft}{1{,}000\ ft}\right) \times \frac{PSD}{1{,}000}$$

The $H_{Well\ Head}$ represents the well head pressure converted into head. Therefore, equation 7 is used. [4]

Equation 7: Head due to well head pressure [4, p. 698]

$$H_{Well\ Head} = \frac{p_{WH}}{0.433\ SG_{comp.}}$$

After the TDH calculation, the pump selection can be made.

3.3.5. Step 5: ESP Pump Type Selection

For an ESP selection the manufactures pump catalogues are needed. According to their pump performance curves (*figure D-4*), the selection of the best suitable pump can be made. With the desired rate and given dimensions of the casing, the pump with the highest efficiency, close to the best efficiency point, should be taken. [4]

Using the head curve, out of the pump performance curve, the total number of stages can be calculated, see equation 8.

Equation 8: # of stages [4, p. 699]

$$\#\ of\ stages = \frac{TDH}{\left(\frac{ft}{stage}\ \boldsymbol{out\ of\ pump\ performance\ curve}\right)}$$

The selection criteria for more than one pump, with similar efficiencies, looks as follows: [4]

- Pump prices: Larger pumps and motors are normally lower in the price
- Well capacity: If, from any reason, the calculated flow rate can vary, the pump with the steepest curve characteristic should be chosen. When pump rate falls to the point where both pumps has nearly the same efficiencies, the pump with the higher number of stages can therefore produce nearest to the desired rate.

The total braking horse power, which the motor has to fulfil, can be calculated with equation 9.

Equation 9: Total Breaking Horse Power [4, p. 691]

$$TBHP = \frac{BHP}{stage} \times \#\, of\ stages\ \times SG_{comp.}$$

3.3.6. Step 6: Optimum Size of Equipment

The whole ESP equipment needs to fulfil special requirements to allow a save and sufficient operation. Therefore, well diameters, temperatures and harsh environment conditions need to take into considerations.

Gas Separator: If a gas separator is needed, it has to be selected from the pump vendor catalogue. Additional to this, the required horse power has to be mentioned for the motor selection. [4]

Motor: After calculation of the total breaking horse power, equation 9, the motor selection could be made. To optimize initial/ operating costs and efficiencies, it is recommended to take the biggest motor as possible which will fit into the casing. To ensure the lifetime of the motor, the size selection should be closely to the design conditions. [4]

Electrical Cable: The ESP cable, round or flat, is available in different sizes. The AWG (American Wire Gauge) size for the most common cable is 1, 2, 4 and 6, where the higher number refers to a thinner cable. Selection criteria which have to keep in mind are: [4]

- **Cable Type:** Strongly depends on temperature, chemical composition and available space.
- **Cable Length**: Surface connection has to be considered!
- **Cable Venting**: A venting box needs to the installed to prevent explosive conditions from migrated gases through the cable.

Additional Equipment: Selection of additional equipment like cable bands, motor controller, surface cable, well monitoring system, transformer etc. [4]

Variable Speed Drive: A VSD will help the operator to increase the operating range, by changing the frequency. Therefore, the operator is more flexible regarding to production rate changes. To select a VSD, the pump manufactures uses computerized pump selection programs. As an output, a pump performance curve, with different operating frequencies, can be shown. In such a graph, *figure D-5*, the different rates vs. pump heads as a function of the different frequencies is shown. [4]

Different service companies use different design programs. In OMV Austria E&P, the in house design program is called “SubPump”. Additional to them, Schlumberger is designing their ESP’s with “Design Pro” and Baker Hughes with a program called “Autograph PC”.

4. ESP’s in OMV Austria E&P

4.1. History of ESP’s in OMV Austria E&P

After the Second World War the “Northfield”, with 350 operating wells (first successful well in 1931), was used to carry the major part of the compensations costs for the Allies. According to a fast decline of the production rate in the middle of the 80’s, OMV Austria E&P reached a strategic point. The equipment was old and the production costs reached a high level due to the wide spread of the field, the huge water production rates and the increasing cost of water treatment and reinjection. In 1984, OMV Austria E&P decided to try a new kind of artificial lift method, the electrical submersible pump, with the aim to increase the production and decrease their costs. Oil Dynamics (ODI acquisition by Baker Hughes in 1997), Centrilift (Baker Hughes) and REDA (Schlumberger) got clear pump requirements regarding rates (40-250 m^3/day) and life time (should reach 600-900 days). With a pilot project 28 ESP’s were installed. At this stage, ODI was the only vendor which offered MONEL (nickel plus copper alloy) cables. At the beginning this pilot showed that the rates OMV wanted to achieve were possible. The huge problem regards to the life time of the installations. Some shows failure after two, three up to twelve weeks. Three main failure reasons occurred regarding to the pump cable:

- connection from cable and motor
- quality of the cable splice
- lost some cable in the well

In comparison to the installed beam pumping units, the ESP’s were not able to reach or even increase the life time of the pumping units. Many times the pumps had to be pulled and new ones had to run into. This resulted into either an increase in the stock or in long waiting times for new pumps. OMV Austria E&P found that, the smaller the production rates were, the shorter the life time of an ESP would be. Parallel to this ESP pilot, OMV started to improve their sucker rods performance (new type of protectors, new materials for the sensitive parts etc.). With this improvement of the beam pumps and the low life times reached with the ESP’s, OMV Austria E&P decided in 1989 to make a redevelopment of the “Northfield” using sucker rod pumping units. The further increase of installed ESP’s was stopped.

Hauskirchen 1 was the only exception from this “not sufficient” pilot test. This ESP reached a life time of ten years! A reason for this could be that this pump was designed exactly for a production rate of 350m^3/day, there was no gas and very seldom on/off switches of the pump.

Johann STEINEDER (retired head of OMV Austria Production in Asset department) explained in an interview:

“An *ESP is performing very well if: “*

- *the ESP is exactly designed for a specific well*
- *high rates (> 350-m^3/day)*
- *no gas*

Any deviation from these parameters will result into lower economic values compared to a beam pumping unit.”

Statement of **Josef MATZKA**, OMV field engineer for completion and testing:

“In early stages the electrical submersible pump was not only used for producing crude oil. Geothermal projects (thermal spa) also include the installation of an ESP. In the history of OMV Austria E&P, the pumps were provided from three different vendors; ODI, REDA and Centrilift. ODI showed a very good service supply and a better connection between motor and cable. This connection was just to plug and therefore easy to disconnect. With other contractors the cables had to be cut.”

In table 2 there are some of "historical" ESP wells in OMV Austria E&P shown.

Table 2: ESP history OMV Austria E&P

History of ESP oil wells in OMV Austria E&P			
year	**well**	**name**	**vendor**
1988	STU 65	St. Ulrich	REDA
1989	STU 42	St. Ulrich	REDA
1989	STU 245	St. Ulrich	
1990	STU 60	St. Ulrich	
1990	STU 123	St. Ulrich	REDA
1990	STU 249	St. Ulrich	
1991	MUE 136	Muehlberg	
1991	HAUB 17	Hauskirchen	
1993	ST 13	Schoenkirchen	
1993	STU 47	St. Ulrich	ODI
History of ESP geothermal wells			
1993, 1994		Laa	ODI
1996, 1998, 2000		Gabelhofen	REDA
1997		Payerbach	

Josef GLUECK (retired OMV Production technologist) explained that in the early stages there was a lot of skepticism against the ESP in OMV Austria E&P. This new technology required a more complex design, knowledge and handling compared to the long used beam pumping unit.

"For an ESP string use only parts which are mandatory. For example if mixed flow impellers are used do not use any gas separator (if gas content is lower 25-%). A

downhole sensor could be a possible source of failure. If your field is known very well, a sensor is not required.”

Recommendations of Josef GLUECK for the usage of an ESP in the future:

- Use one standard housing (number of stages which develop a specific head). For higher rates just attach several of this standard housing to a string. This would simplify the stock handling and will help to reduce the costs.
- Reduced numbers of splices, use of a connector (with pup joints) instead a splice below the wellhead penetrator. This will reduce the workover time and eliminate a possible failure source.
- Non factory splices are a high failure source. Especially when the splice is down in the field in winter, the quality of the splice will decrease.
- Further development of the GDB (in house database) where all possible failures of the pump will be recorded. For life time evaluation only events should be recorded which leads to direct pump failures. This is not the case at the moment.
- Use downhole sensors only in areas which are not well known. A sensor could be a possible failure source.
- If mixed impellers (up to 25-% gas) are used, do not use a gas separator additional.

Special thanks to Josef GLUECK (retired OMV production technologist), Josef MATZKA (OMV completion and testing) and Johann STEINEDER (retired head of Production in Asset department of OMV Austria) who supplied me with their times and the history information of ESP’s in OMV Austria E&P.

After this pilot project, until the redevelopment project of the 16TH Torton only few ESP’s were installed in OMV Austria E&P.

4.2. Current status of ESP’s in OMV Austria E&P

Currently there are 33 ESP’s running in OMV Austria E&P. In October 2013 there were 16 new ESP’s installed by Schlumberger as part of the “redevelopment of 16TH Torton (RD16TH)” project. Three new ESP’s are currently (July, August 2014) installed by Baker Hughes. One dual ESP from Schlumberger will be installed in August 2014. In October 2014 the second part of the redevelopment of16TH Torton campaign from Schlumberger will take place. With this campaign, 17 new ESP will be installed. The ESP’s produce between 200 and 500 m³ of liquids per day with a variation in water cut between 84 and 99 %.

Figure 11 and 12 show all wells and artificial lift system currently installed by OMV Austria E&P.

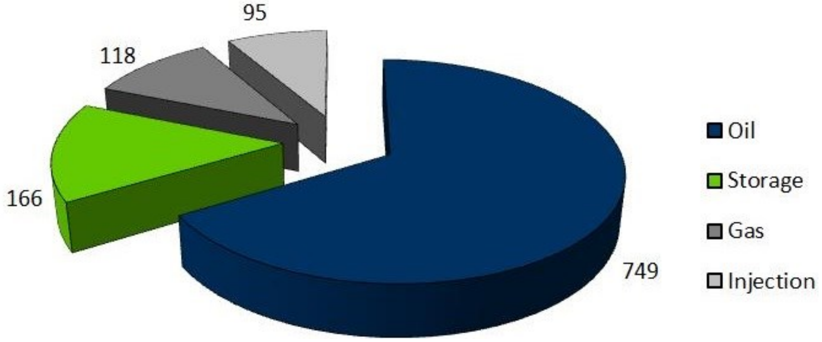


Figure 11: OMV Austria E&P Wells (status date: 30.10.2014)

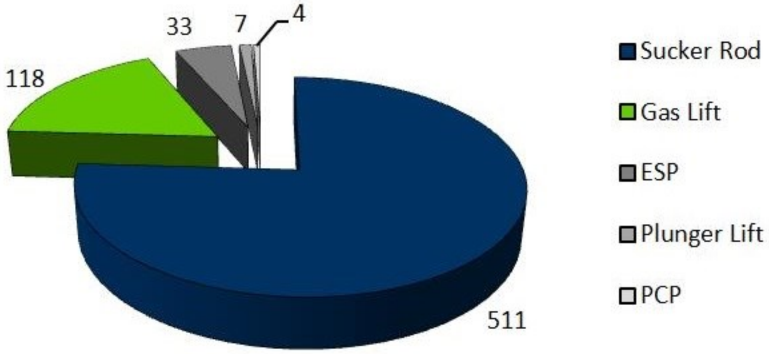


Figure 12: OMV Austria E&P Artificial Lift Systems (status date: 30.10.2014)

4.3. ESP Pilot 2012

Prior the redevelopment campaign, OMV tried an ESP field pilot in two of their wells to see if an electrical submersible pump could be the right artificial lift method for their RD16TH project.

With this pilot OMV Austria E&P wanted to see if an ESP can operate at the designed high rates (500 and 800-m^3/day) and what possible problems will occur during the operation. From the reservoir standpoint of view the wells were able to produce this rate due to the high productivity index.

During this pilot, most of the failures were related to the lower experience with this type of pumping unit. The main failures, which in detail are explained in the chapter 5 "*Best practices and lessons learned*", were:

- casing leak (hard to identify)
- wrong material selection (bearings)
- working with DIFA
- sand problems
- surface limitation (no further increase of rates was possible)
- change in department → lag of experience
- slowly startup phase

This ESP pilot gave OMV Austria E&P a feeling of how to operate and what challenges there are in combination with an electrical submersible pump. With this AL method, the desired high rates can be achieved if the preexisting problems (e.g. limitation of surface equipment) are eliminated. Furthermore, the pilot showed that the reservoir conditions allow producing crude oil at higher rates. The water cut for the pilot wells slightly decreases over this test period of one year.

4.4. Standardization of ESP’s in OMV Austria E&P

Prior of this “redevelopment of the 16^{TH} Torton” project, 14 ESP’s from Schlumberger were installed in OMV Austria E&P. All of these 14 ESP’s, covered by one single ESP standard, are completely the same and operates with an average production rate of 250-m^3/day and an average WC of 95-%.

At the tender phase, different possibilities of how to design the coming 33 new ESP’s were thought. One idea was to design one ESP for one single well. This thought was quick over thrown because this “non-standardization” will result into longer design time, higher costs and increase of the warehouse capacity. For each single ESP a spare ESP would have to be stored in the case of intervention prevention.

Another idea was to use the same standard as for the first 14 ESP’s, resulting into one ESP for all wells. The problem with this possibility is, that they desired production rates of these 33 wells varies in a range (from 200 up to 2,000-m^3/day) so that one single ESP is not able to cover this band in an efficient way.

Coming from one extreme case to the other, OMV Austria E&P developed a complete new standard. This standard splits this 33 ESP’s into five different groups. The main difference of these groups relates to the desired production rates and to the sizes of the pump and production tubing. These five groups are named as:

- Group 1 small (smaller casing size compared to other groups)
- Group 1 big
- Group 2
- Group 3
- Group 4

The individual difference in the characteristic properties can be seen in table 3.

Table 3: ESP standard OMV Austria E&P [38]

ESP standard for redevelopment of 16th Torton				
Group	flow rate range [m^3/day]	tubing diameter [in]	ESP’s in group [#]	Backup ESP’s [#]
1 small	200-300	2 3/8 VAGT	6	3
1 big	200-300	2 7/8 EUE	9	3
2	300-400	2 7/8 EUE	12	4
3	500	2 7/8 EUE	4	2
4	2,000	4 1/2 EUE	2	1

Other parameters, like pumping setting depth, operating temperature, H_2S or CO_2 content are similar for all groups. All ESP’s are set above the perforations with a constant tubing size from the wellhead to the pump unit. Additionally, no packer is installed in any of the 33 installations.

The individual pump of each group was designed for the well with the lowest productivity index (PI, appendix D) within the group. OMV Austria E&P has accepted that pumps with a higher PI, than the designed reference one, will over perform and showing therefore reduced efficiencies compared to an individual ESP design. But on the other hand, those over performing ESP’s can be operated at higher rates if necessary. This would increase the efficiency but might also be a request from reservoir engineering department. Additional to this, all ESP’s were compression pumps which allow them to use it in the downthrust region as well. This was a main request point of OMV to Schlumberger.

In figure 13 all tender ESP’s, the minimum and maximum rates of each group in relation to the operating frequencies (from 40 up to 60-Hz) and total dynamic head (TDH) are plotted. This plot is a simplification of the normal multi frequency curves (seen in appendix D) of an electrical submersible pump which will be provided from the service company. The advantage of such a “special” plot is that all different groups can be compared with each other at the same level and moment. Such a graph provided the service company for OMV at the tender phase to give the engineers a feeling of how good their standardization will be.

The left border of each group (color) represents the minimum operating rate and the right border the maximum operating rate of each group. An operating frequency of 40-Hz will be expressed by the lower border and an operating frequency of 60-Hz (maximum) is represented by the upper border line.

Group 4 is not shown in this graph due to the high rate (2000-m³/day). Therefore no intersection with any other group will be the case.

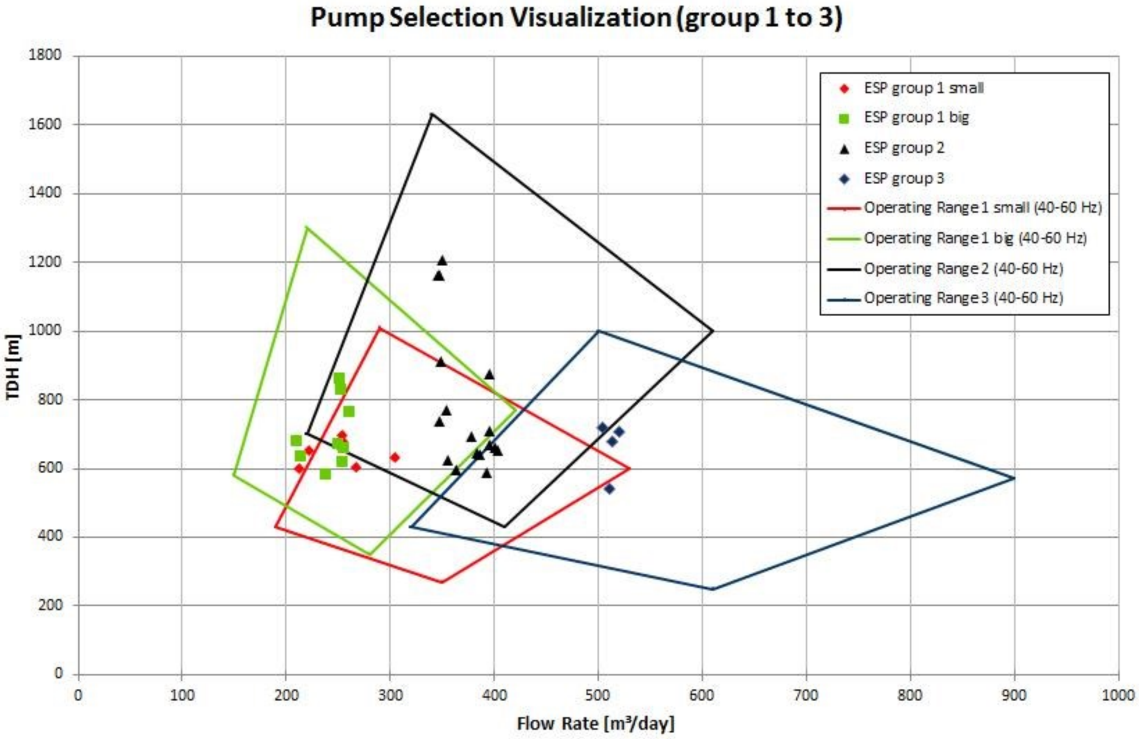


Figure 13: Simplification of rate vs. frequency range of OMV Austria E&P tender ESP’s and groups [38]

4.4.1. Improvement of ESP standard for future projects

OMV Austria E&P is focused on consistent improvement and therefore they want to develop this standard further, to allow them to use it for future projects. This ESP tender, for the redevelopment of the 16TH Torton, was the first big ESP project since a long period of time. Out of this, OMV Austria E&P results with several recommendations and suggestions concerning future ESP projects.

Group 1 big and 2:

Due to the intersection of both groups (see figure 13), OMV Austria E&P takes into consideration to combine both in one “new” group. Therefore two things are necessary:

1. Updated minimum and maximum achievable production rates and PI’s from the reservoir engineering department
2. Revision and optimization of the ESP design for both groups to allow covering the well requirements within one single group. Designing this pump for the well with the lowest flow potential (as OMV did in their standardization) and requires possibilities of increasing the flow for the wells with higher PI. *(“allow room for improvement”)*

DIFA improvement:

The DIFA (dismantling and inspection for analysis) is very important to determine the root cause of any failure which has happened. OMV Austria E&P is willing to send more failed ESP’s to DIFA, to exactly define what and why the failure has happened. With this, improvement of material selection and design can be made which will increase the run life and reduce the intervention costs of the pumps.

Idea of implementing an own ESP database:

Similar as for the beam pumping units, OMV Austria E&P keeps focus on implementing a database for ESP's where all failures, dates of events are mentioned. With this, analysis concerning key performance indicators can be performed very fast.

Optimize individual ESP groups:

There are several ways to optimize each individual group. One way could be to find the exact reason why 20-% more stages in comparison to the design are needed to reach the desired flow rate. Regardless how the pumps are designed, using programs or by hand, all pumps require 20-% more stages in reality. Either there must be a general input mistake or some factors, influencing the performance, are not considered till now. To specify the equipment to a closer operating window will in one way reduce the flexibility but on the other hand will reduce the costs.

Other competitors:

Another target of OMV Austria E&P is to get different competitors in the house with the aim to compare and get different point of views from them. For the service companies this will be a clear sign, they have to keep their service at a high level otherwise a competitor can sign the next deal.

4.5. Well selection criteria of ESP's in OMV Austria E&P

The availability of different artificial lift technologies makes it necessary to determine what the technical and economical key parameters for the usage of an electrical submersible pump are.

4.5.1. Technical View

A successful ESP installation depends on several different but interacting parameters. Starting with the reservoir, well inflow and vertical lift performance up to produced fluid quality, well completion and infrastructure related issues. [8]

The bottomhole temperature (BHT) should be below 120-°C to allow the application of standard designs, practices and materials. Higher temperature will affect the run life of the whole pump and requires temperature resistant materials (for cable and protector) and an advanced motor cooling. [8]

The ESP performance depends on the fraction of gas which is produced within the oil. More gas will result into a lower developed head by the pump (lower kinetic energy will be converted into potential energy) and these results into a lower efficiency of the whole system. Gas up to 70% can be handled by using special equipment for gas separation and special design of the impellers (mixed flow). [8]

Another key driver is the Productivity Index, which gives the amount of fluid which can be produced by a reduction of the downhole pressure. Values in a range of 7-m^3/bar/day or more, together with a sufficient water cut will make the ESP economic. Higher PI results into higher flow rates which are good, but can increase the chance of solid production, from unconsolidated formations, and therefore increasing the erosion failures of the equipment too. Additional protection devices (e.g. gravel pack) are needed. [8]

Casings with outer diameters of 4 ½ inch can be used for ESP installations. The smaller the casing, the smaller the whole equipment and therefore the higher the investment costs will be. A bigger casing results in more clearance between pump and casing and

will allow a better cooling of the motor. For offshore wells a production casing of 9-5/8 or higher would be recommended. [8, 9]
Deviated holes with dogleg severity up to 6°/100ft are acceptable for an ESP during a run in hole operation. [8]

The preferred way to operate an ESP is without any packer. Therefore the pump hangs on the tubing string. Installation with packers is possible but requires special arrangement to move the electrical power cable through the packer. If a packer is required, it should be mentioned that producing hot fluid will extend the tubing. This will result into compression of the pump and, without any allowance, to failures. [9]

For OMV Austria E&P the major goal of their "redevelopment of the 16TH Torton" project was to increase the flow rate, to increase the total oil rate to surface. To handle the desired rates of more than 200-m³/day, are one of the big advantages of the ESP. Fluctuations of the flow rate can be managed by frequency changes using the VSD and therefore allows the operator to achieve a stable rate to surface.

With a prediction of a PI in a range from 6 to 70-m³/bar/day the ESP was found to be the best artificial lift method for this project. The completion was ideal for this pump with almost vertical wells, casing sizes in the range and no packers installed.

The water cut was expected to be quite stable within the next few years. A fast increase of water production can be excluded. Moreover, the production of solids and gas was found to be at a sufficient level for the usage of an ESP.

The ESP well selection criteria for the dual ESP which will be installed in September 2014 was to produce oil from two reservoir layers at the same time (commingled production). With this pilot project OMV Austria E&P want to try how well this will work by using a dual pump. An additional benefit would be performing a well test to estimate the exact volumes of produced fluids (oil and water) within each horizon. In offshore operations this kind of pump is used as spare pump, if the first will fail, the second can hold on the production without any need of an expensive workover.

The three installed Baker Hughes ESP’s were all from the FLEXPump type series. With this new type of ESP’s, the operator is more flexible due to a wider operating range, compared to a conventional ESP. This new technology in combination with the difficult well condition, deep well (3,000-m) and alternating production rate due to the presence of a gas cap, is the key driver for this ESP installation campaign. Additional to them, OMV Austria E&P wanted to have a second, alternative, service contractor in the house. With this step, OMV want to keep the service at a high level and decrease the price policy of the different competitors.

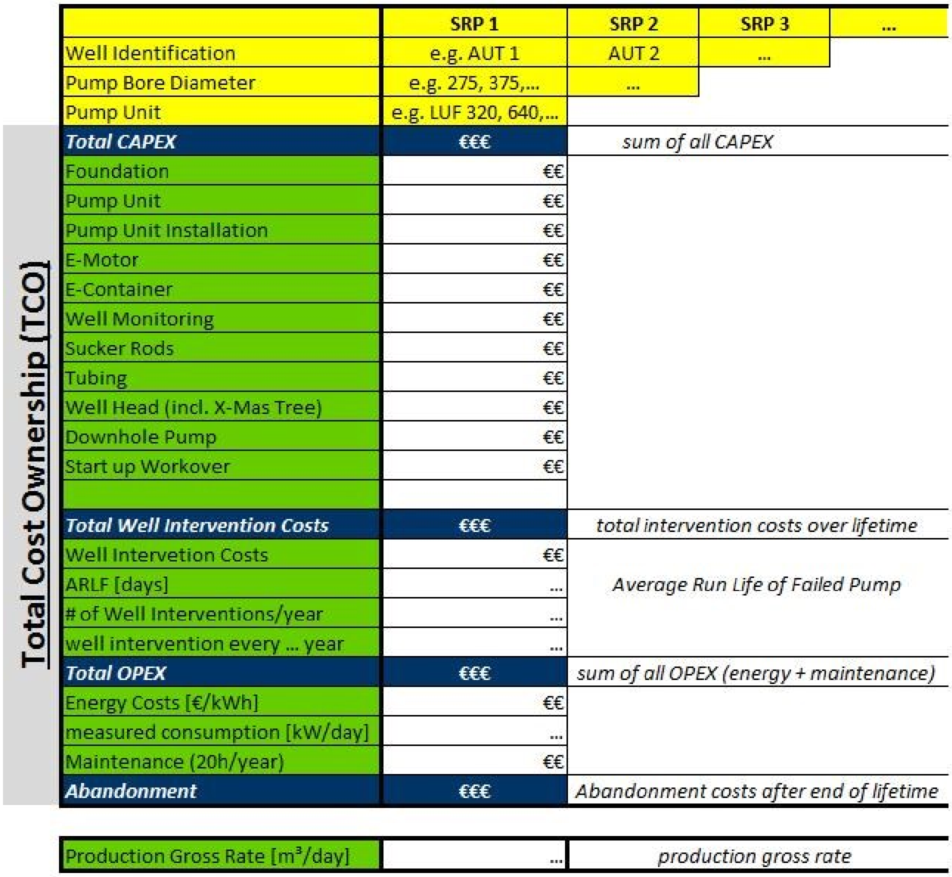
4.5.2. Economic View

In this chapter, the economic value of an electrical submersible pump is under investigation. Any pump can operate as perfect as possible but if the production costs per barrel of oil are higher than the revenues, the artificial lift method would be changed or even, the well will be shut in. From this point of view, a lifecycle cost calculation, LCC, shows the total cost of an ESP over a lifetime range of 25 years, including all CAPEX and OPEX. To cover a wider spectrum, different ESP’s, with different production rates and sizes are compared. Furthermore, to give a better understanding when, in terms of flow rate, a beam pumping unit (the most installed artificial lift unit in OMV Austria E&P) is more economic than an ESP, the lifecycle cost of both AL methods are compared with each other.

All cost influencing factors for beam pumping units can be seen in table 4. The chosen SRP’s differ from each other in operating rates, sizes of the pump bore diameter and sizes of the surface pump unit, see table 5.

To find pumps, operating from a low up to a high production rate, was the key parameter in selection of reference pumps prior this LCC.

Table 4: LCC table for sucker rod pumping unit



		SRP 1	SRP 2	SRP 3	…
	Well Identification	e.g. AUT 1	AUT 2	…	
	Pump Bore Diameter	e.g. 275, 375,…	…		
	Pump Unit	e.g. LUF 320, 640,…			
Total Cost Ownership (TCO)	***Total CAPEX***	€€€	*sum of all CAPEX*		
	Foundation	€€			
	Pump Unit	€€			
	Pump Unit Installation	€€			
	E-Motor	€€			
	E-Container	€€			
	Well Monitoring	€€			
	Sucker Rods	€€			
	Tubing	€€			
	Well Head (incl. X-Mas Tree)	€€			
	Downhole Pump	€€			
	Start up Workover	€€			
	Total Well Intervention Costs	€€€	*total intervention costs over lifetime*		
	Well Intervetion Costs	€€			
	ARLF [days]	…	*Average Run Life of Failed Pump*		
	# of Well Interventions/year	…			
	well intervention every … year	…			
	Total OPEX	€€€	*sum of all OPEX (energy + maintenance)*		
	Energy Costs [€/kWh]	€€			
	measured consumption [kW/day]	…			
	Maintenance (20h/year)	€€			
	Abandonment	€€€	*Abandonment costs after end of lifetime*		

Production Gross Rate [m^3/day]	…	*production gross rate*

The difference in in pump parameters can be seen in table 5. Therefore, the number behind “SRP” represents the operating gross rate (m^3/day) at the date of the electrical power consumption measurement. For all selected pumps, regardless if SRP or ESP, new power consumption measurements were performed.

Table 5: Difference in SRP for LCC (7 representative pumps selected)

	SRP 55	SRP 120	SRP 125	SRP 155	SRP 165	SRP 195	SRP 300
Well Identification	AUT 1	AUT 2	AUT 3	AUT 4	AUT 5	AUT 6	AUT 7
Pump Bore Diameter	275	275	375	275	275	375	375
Pump Unit	LUF 320	LUF 320	LUF 320	LUF 640	LUF 320	LUF 640	LUF 1280

The well identification (AUT 1, AUT 2 etc.) represent pseudonyms for the wells of OMV Austria E&P.

Using a different pump constellation (pump unit size and size of downhole pump) can result into the same production rate, see figure 14. For the average run life of failed pumps, which is a necessary factor for the total well intervention costs, an analysis indicates that the run lives of failed sucker rod pumps strongly depends with the size of the downhole pump. There was no significant interaction of the surface pump unit size (LUF 320, 680 and 1280) in increasing or shortening of the runtime found.

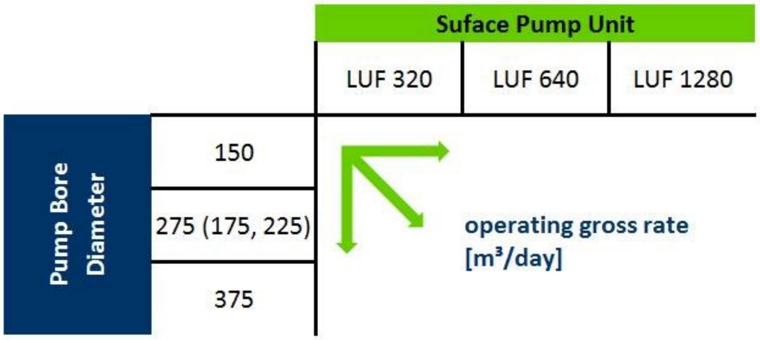


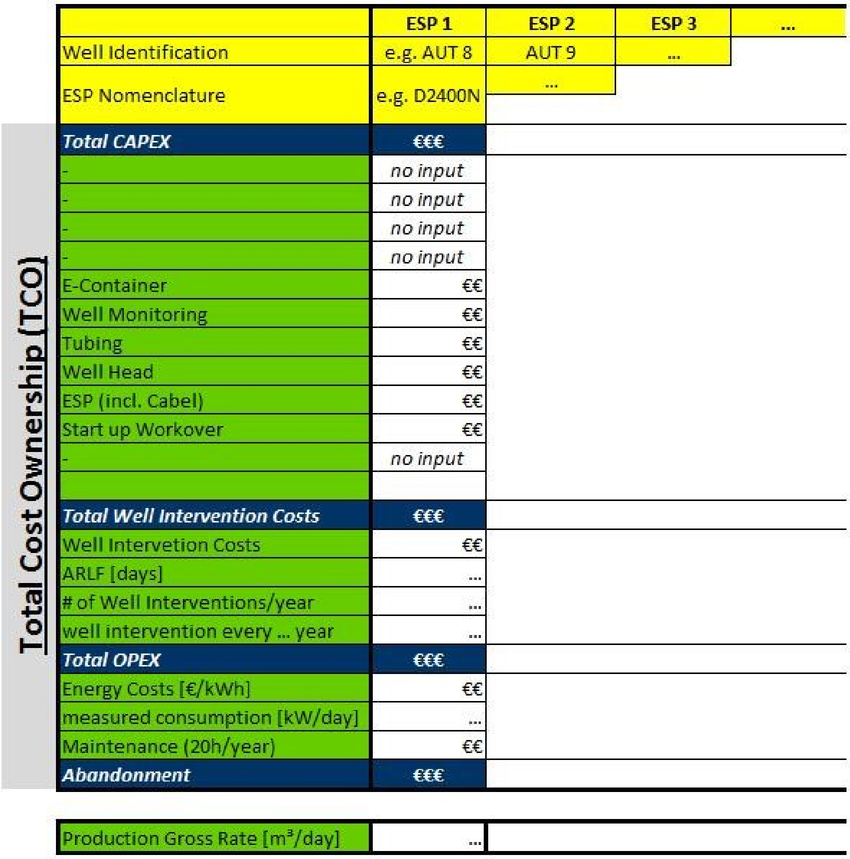
Figure 14: Operating rate as a function of different pump constellations

Therefore, the *"Gewinnungsdatenbank"* GDB (OMV database) results with 994 days for the "275" pump and 315 days for the "375" sucker rod pumps. The LCC reference pumps does not include any "150" downhole pump. By the way, the figure "150" refers to diameter of the downhole pump unit in inch, divided by 100. [4]

The well intervention cost for one work over includes the startup WO (costs for rig and man power), changing the sucker rods, tubing and downhole pump. Multiplying these costs times the duration of a pump failure and summing it up, results into the total well intervention costs over a lifetime of 25 years. The total cost ownership (TCO) is the sum of all CAPEX, OPEX, well intervention and abandonment costs.

Table 6 shows the entire cost figures for the representative ESP wells in this lifecycle cost calculation. For this calculation, electrical submersible pumps with operating gross rates from low to high were selected (table 7). Additional to this, one ESP of each tender group (chapter: *“Standardization of ESP’s in OMV Austria E&P”*) was included at least.

Table 6: LCC table for ESP



	ESP 1	ESP 2	ESP 3	...
Well Identification	e.g. AUT 8	AUT 9	...	
ESP Nomenclature	e.g. D2400N	...		
Total CAPEX	€€€			
-	*no input*			
-	*no input*			
-	*no input*			
-	*no input*			
E-Container	€€			
Well Monitoring	€€			
Tubing	€€			
Well Head	€€			
ESP (incl. Cabel)	€€			
Start up Workover	€€			
-	*no input*			
Total Well Intervention Costs	€€€			
Well Intervetion Costs	€€			
ARLF [days]	...			
# of Well Interventions/year	...			
well intervention every ... year	...			
Total OPEX	€€€			
Energy Costs [€/kWh]	€€			
measured consumption [kW/day]	...			
Maintenance (20h/year)	€€			
Abandonment	€€€			

Production Gross Rate [m^3/day]	...	

Table 7: Operating gross rate of ESP’s in LCC (10 representative pumps selected)

	ESP 85	ESP 95	ESP 205	ESP 230	ESP 285	ESP 300	ESP 305	ESP 395	ESP 515	ESP 605
Well Identification	AUT 8	AUT 9	AUT 10	AUT 11	AUT 12	AUT 13	AUT 14	AUT 15	AUT 16	AUT 17

The average run life of failed ESP’s was determined in chapter *“ESP Performance Analysis in OMV Austria E&P”*. For an ESP, the workover costs include changing the ESP unit, the gauges and the costs for rig and crew.

Results:

The result of this lifecycle cost calculation can be seen in figure 15. In this plot, the total cost ownership over the entire lifetime of 25 years, for each representative pump, is plotted over the current gross production rate. To account the time value of money, all future expenses are discounted to the present day. Therefore, the TCO value represents the Net Present Value (NPV) of all costs. A discount rate of ten percent, used in OMV Austria E&P, is used to account for the time value of money.

Based on this plot, it can be seen that a sucker rod pumping unit becomes more expensive, over a lifetime of 25 years, if the production rate is higher than 180-m³/day. This is the result of the higher run lives of an ESP compared to a beam pumping unit (1,103 days vs 994 or 315 days). Below this rate a sucker rod pumping unit is more inexpensive, due to lower work over costs, compared to a corresponding ESP unit. The smaller (diameter of casing to fit in) an ESP is, the higher the cost of the pump unit will be.

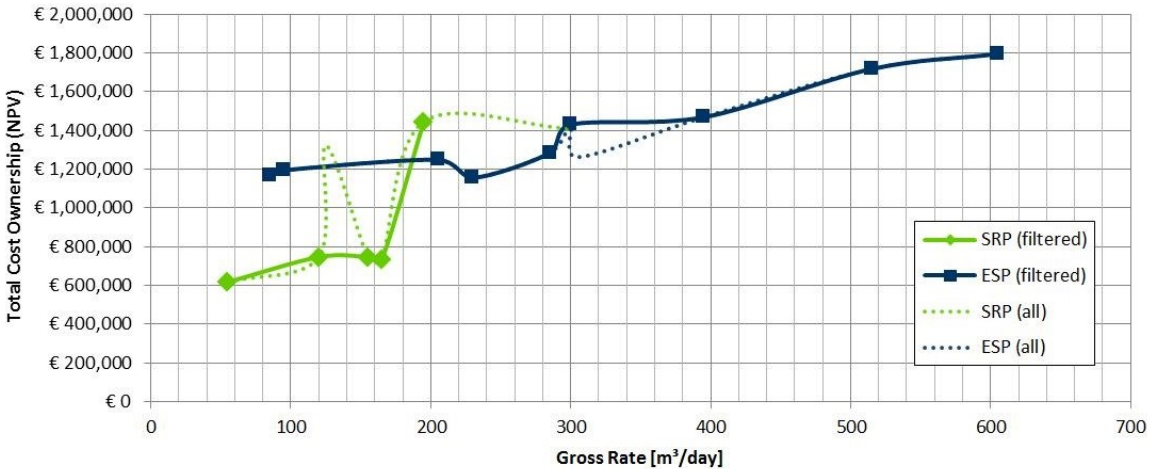


Figure 15: LCC final result

To create a trend, some of the selected pumps had to be moved/filtered out of the plot. This is represented by the two curves of both artificial lift types, filtered and all. Whereas the dotted curves include all pump units, the full line curves only include the filtered pumps. The pumps SRP 125 and 300 as well as the ESP 305 have been filtered from the plot.

The SRP 125 (125-m³/day) has a pump bore diameter of 3.75-in (375) compared to the SRP 120 with 2.75-in (275). Therefore, the lifetime is dramatically decreased (from 994 to 315 days) and due to a lower dynamic fluid level, the electrical power consumption is decreased too. As previous mentioned with figure 14, the same rate can be operated with different pump equipment, therefore the SRP 125 could be operated with a 275 (2.75-in) downhole pump as well.

The sucker rod with a daily production rate of 300-m³ is a very special case. In OMV Austria E&P this is the highest rate operated with a beam pumping unit. This was the case why it was chosen as a reference pump. But on the other hand, the dynamic fluid level is very close to the surface, resulting into low power consumption compared to the other sucker rod pumping units. Together with the lower lifetime, due to the bigger bore diameter, this pump is not following the trend of the others. This is one reason why the SRP 300 cannot be directly compared with the ESP 300. Another reason is explained in the following paragraph.

Only ESP 305 was filtered out for the ESP trend estimation. Therefore, ESP 300 is part of the tender group 1 small, with a tubing size of 2 3/8-in. Whereas ESP 305 is a so called “standard” ESP, resulting into tubing size of 2 7/8-in. This is the explanation for the higher power consumption (+50-%), of the lower compared to the higher rate pump. Higher power consumption results directly into higher OPEX and further, into higher total costs over the entire lifetime. Additional to them, due to the small sizes and wellbore inclination a sucker rod pump would not be able to produce that high production rate.

Figures 16 and 17 will strengthen the statement of an economic cross point between an ESP and a sucker rod pumping unit, around a production gross rate of 180-m³/day. In figure 16, the sucker rod pump with a daily production of 120-m³ of fluid showing a lower total cost ownership value, over the entire lifetime, compared to an ESP with roughly the same production rate.

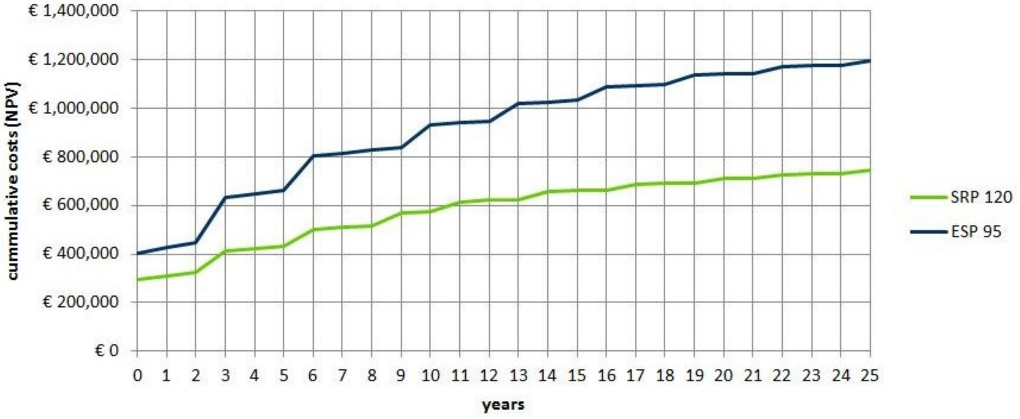


Figure 16: SRP 120 vs ESP 95

Whereas in figure 17, the sucker rod pumping unit with a production gross rate of 195-m³/day shows a TCO value which is higher compared to the corresponding (nearly the same rate) ESP.

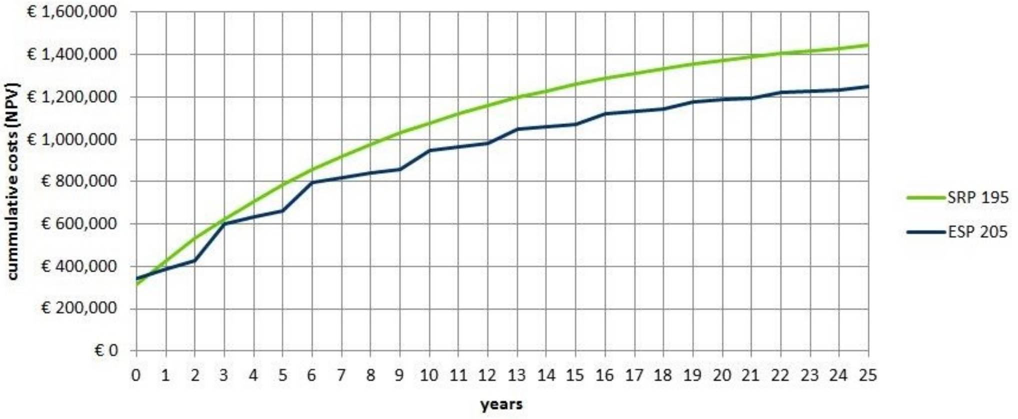


Figure 17: SRP 195 vs 205

Therefore, the economic rate must be somewhere below 195-m³/day.

Additional to the production rate border determination, figure 18 and 19 should give an idea of the fraction of cost, as part of the revenue. To avoid any assumption regarding future oil price development, these plots are only valid for the first year (2014) of installation. In 2014 the oil price is known and therefore the cost and profit for each pump can be calculated.

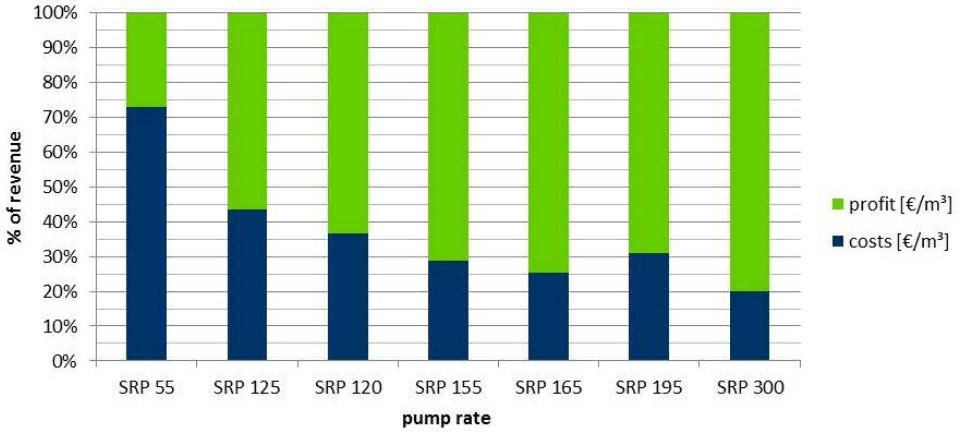


Figure 18: Profit vs Costs of SRP (estimated for the first year of installation)

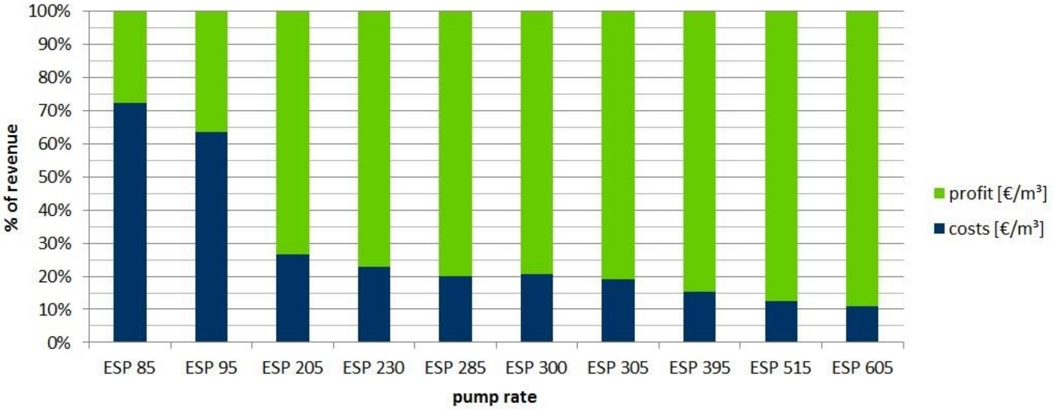


Figure 19: Profit vs Costs of ESP (estimated for the first year of installation)

For additional years, no further statement of costs as fraction of revenues per m³ can be made. The development of future oil prices depends on different circumstances and is not part of this thesis.

5. Best practices and lessons learned in operating ESP's

5.1. Installation of ESP's in OMV Austria E&P

Wrong wellhead penetrator installation:

This equipment (figure 20) type is responsible for the electrical cable connection from the wellbore via the wellhead to the surface.

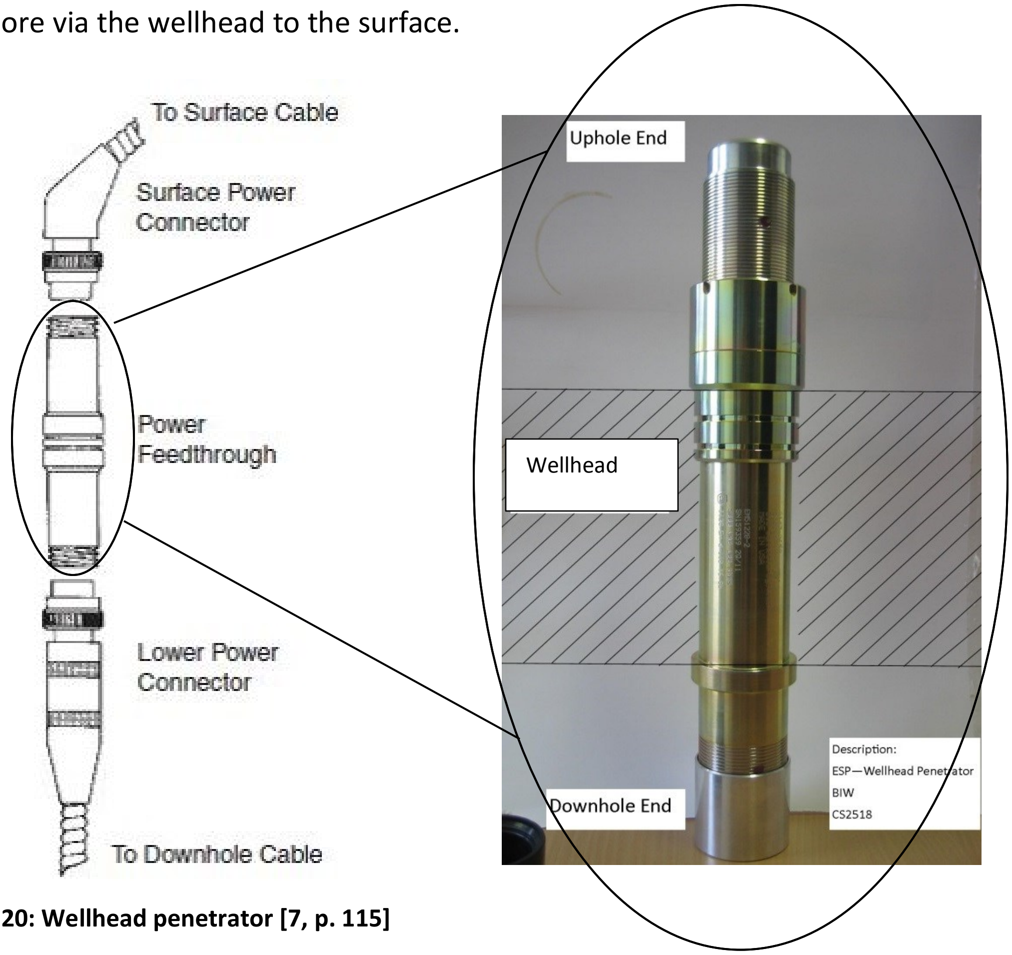


Figure 20: Wellhead penetrator [7, p. 115]

The standard installation procedure would be to disconnect the uphole end from the assembling and move the lower part of the penetrator, from the downhole side, through the wellhead and connect it with uphole part via nut and thread it again. For a better handling of the device the installation crew rotated the penetrator and moved it from the uphole side into the wellhead. Unfortunately this was possible without any kind of stuck. But the elastomer rings were not able to seal the device against gas anymore which results into a well intervention including a WO rig. Out of this lessons learned OMV Austria E&P has a closer look on the wellhead penetration installation from that moment on, see figure 21.

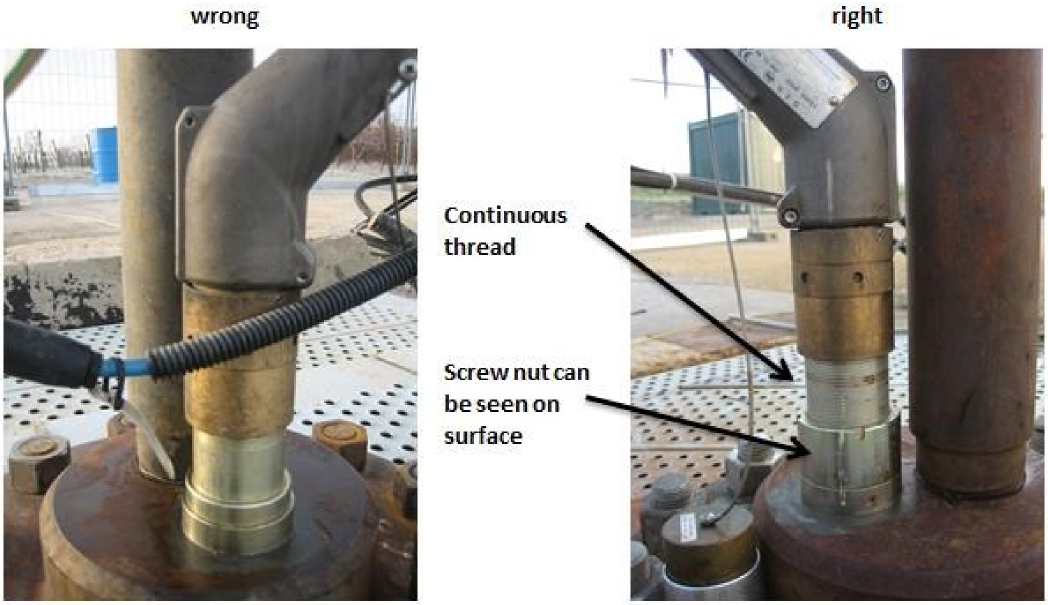


Figure 21: Wellhead penetrator installation wrong vs. right [38]

Short delivery time:

In former times the delivery time for new ESP’s reached up eight, nine months, which is far too long. For that reason, OMV Austria E&P included in their tender as well as in the final contract that the delivery time should be within ten weeks. The service company has to pay a penalty if they exceed this period. However, this penalty will not account for the production loss during this period.

Backup pumps:

Due to long delivery times and to be able to react immediately in the case of a well intervention, OMV Austria E&P decided to have backup ESP’s available for all their groups. Some of these backup ESP’s are stored directly in Gaenserndorf and some are stored in the warehouse of the service company.

Application Engineer in OMV Austria E&P:

As previous discussed (*History of ESP’s in OMV Austria E&P*, page 22), there was a long duration were only a few ESP’s were installed in OMV Austria E&P. With the redevelopment of the 16TH Torton project, the number of installed ESP’s is more than doubled within one year. The limitation of in house experience with this AL was the reason why OMV Austria wanted to have a permanent stayed application engineer, for one year, in Gaenserndorf. According to the “bathtub curve” (figure 34, page 63), where a lot of failure occur within the first weeks of ESP life, this engineer should help to monitor, optimize and to gain more experience with ESP handling.

CE Certificate:

In Austria the “Mineralrohstoffgesetz (MinroG)” says that a mining operator has to ensure that the whole mining job will operate in a safe way. If an operator would like to install a new pump unit, the so called “TUEV” will control if the whole equipment will follow the European Union standards in terms of law and norm. The agreement with these guidelines will be represented by this CE certificate. There are two different CE certificates, one for electrical devices (< 1,000-V) and one for mechanical (rotating) devices. For equipment parts (e.g. electric motor till 1,000-V) there are clear European Union standards which are to fulfil. So in that case the TUEV exactly knows how to assess the equipment. For other equipment (e.g. electric motor above 1,000-V) there is no official guideline the TUEV can follow. In the ESP tender OMV Austria E&P wanted to get all CE certificates for the equipment parts and “declaration of conformities” for all the non CE certificated parts. In this declaration of conformity, the service contractor guaranties that this equipment part can be operated in a safe way. If there are any standards for this part available they should be highlighted in this conformity. This was one of the major problems the service company had. All CE certificates and declaration of conformities (figure 22) arrived at OMV Austria E&P just a few days before the first pump of the ESP campaign was installed.

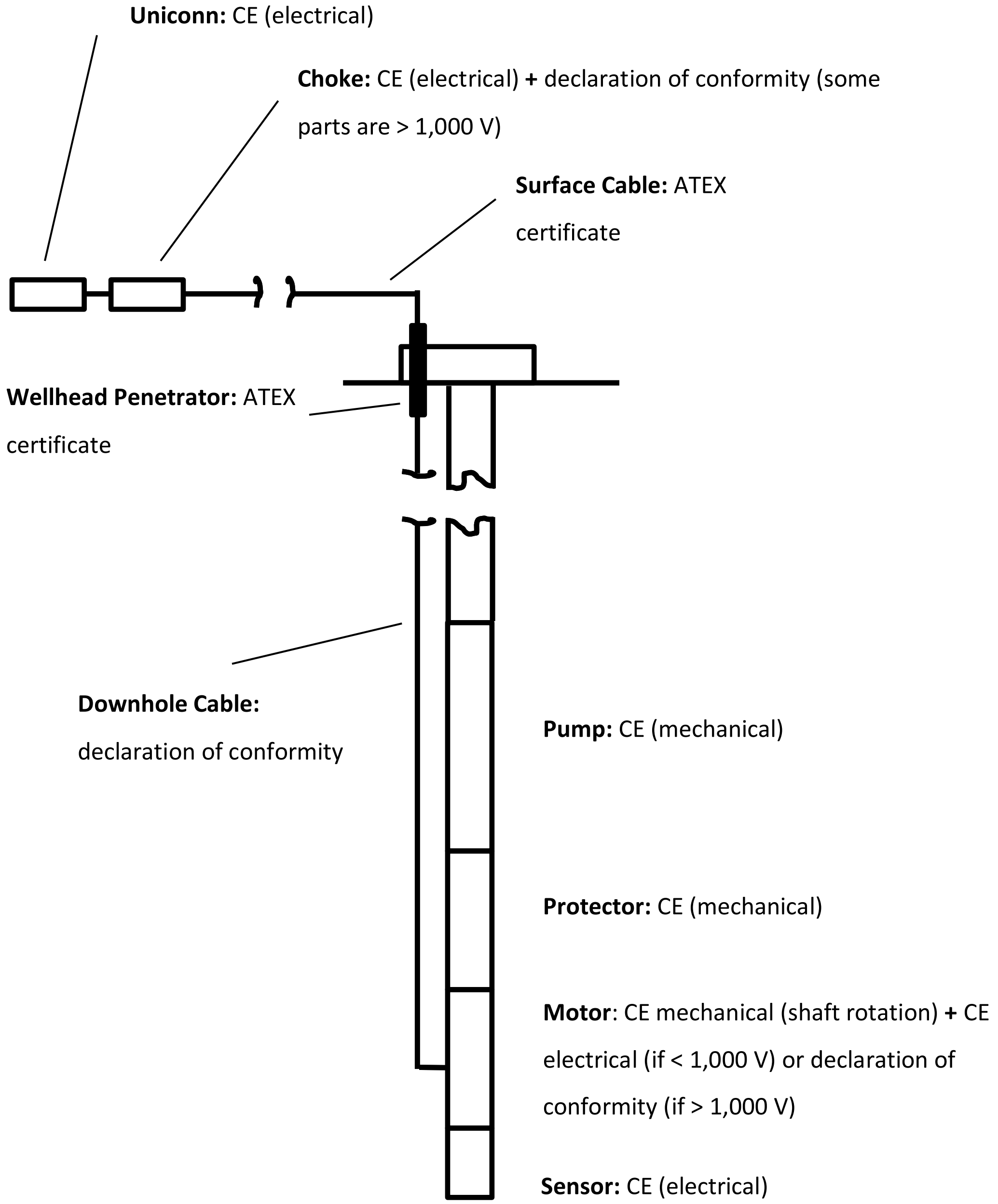


Figure 22: Required certificates for ESP equipment (schematic drawing)

German speaking field personal:

In OMV Austria E&P nearly the whole field personnel does not speak English. For previous ESP’s, the production engineers were working as kind of translators between the field people and the crews from the service contractor. Due to the size of this ESP campaign and regarding to HSSE aspects, OMV Austria E&P wanted to have at least one German speaking field engineer, in each shift, provided from the service company.

2 shifts:

The reason for two shifts will be explained in the HSSE chapter at page 62.

Downhole sensor:

In former times a downhole sensor was not used in OMV Austria E&P. The field engineers were very skeptical regarding the right measurement of parameters and therefore, they avoided such an installation. For the ESP tender, the responsible engineers wanted to know why the measurement of downhole data in previous days was not sufficient. The reason for this was related to the transformer. This was a so called "Spar Transformer" which consists only of one coil (see appendix D). The advantage of this kind of transformer is related to lower cost due to lower coil material. For downhole sensors the problem relates to the direct connected in and output side of this transformer. Therefore, some of the signals received from downhole are lost due to disturbance when they are transported to surface. This has resulted into wrong interpretation data and to skepticism against the need of downhole sensors in wells.

Limitation of electrical surface equipment:

One major problem in this ESP pilot test in 2012 occurred due to the dimensioning of the surface electrical devices (transformer and VSD). The VSD was designed to operate at 52, 53-Hz at the maximum range. As the production rate was lower than the designed (500 and 800-m^3/day), OMV was not able to increase the frequency in a range to achieve these rates. For the future OMV Austria E&P designed their VSD's and transformer to cover a wider range, from 30 up to 65-Hz.

5.2. Operation of ESP's in OMV Austria E&P

ESP housing material:

In the past carbon steel was used as housing material for the ESP's. This material was found as being not ideal because of huge pump failures due to corrosion (figure 23 to 25).

Figure 23: Broken pump/ leakage of housing [38]

Figure 24: Leakage of pump housing [38]

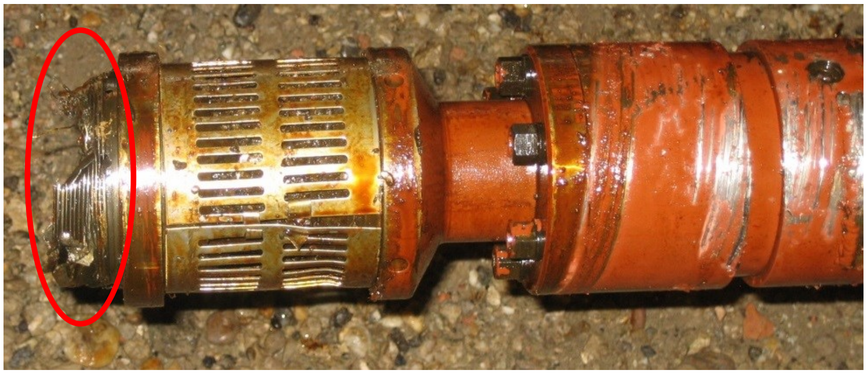


Figure 25: Intake/ gas anchor breakage [38]

As a consequence, OMV Austria E&P changed the material of the pump housing and used REDA alloy, a special alloy provided by Schlumberger. As a result no further housing failures according to corrosion problems occur any more.

For the tender OMV Austria wanted to have carbon steel with MONEL (nickel, copper alloy) coating as housing material. This reduces the pump costs in comparison to the REDA alloy but protects the material from corrosion too as this material is used also in the sucker rod pumps. Together with the use of a corrosion inhibitor there are no significant corrosion errors at the sucker rod pumps observed.

Check Valves:

The function of a check valve is described in chapter 3.2.3 (page 15). Installation of the valve in the well changed the flow of the produced fluid in a way that two points of the tubing were hit by a high impact force. A tubing leak was found due to erosion. To avoid this for the future, OMV Austria E&P do not use any check valve in their new ESP campaign if it is not technically necessary. To prevent the pump from switching on during the back spin OMV waits for 20 minutes after the shut in. After this time (from experience), all the fluid flow down the tubing is over and the ESP can be restarted in a safe way. The usage of a backspin relay, for future installations, is under investigation.

Casing Leak:

In former times a casing leak was found by applying a pressure test at the casing. Therefore a packer is set in the zone of interest and the casing is pressurized. A casing leak can be identified by monitoring the pressure over time behavior. If no pressure decrease will take place, the fluid stays in the casing and is not escaping through a possible casing leak. One well in OMV Austria E&P was shut in for eight months due to sand production and they did not know the reason for this. All the performed casing leak tests were negative. Another testing procedure was tried, the "swab" test. With this test a pump (similar to a bicycle pump) in comparison with a work over rig produces high rates of liquid and the operator controls the liquid level inside the casing. If the level will not decrease some cross flow must be the case. With this test a casing leakage between the connections (coupling) of two casings was found. Figure 26 indicates the fluid flow through the coupling and the cement as red line.

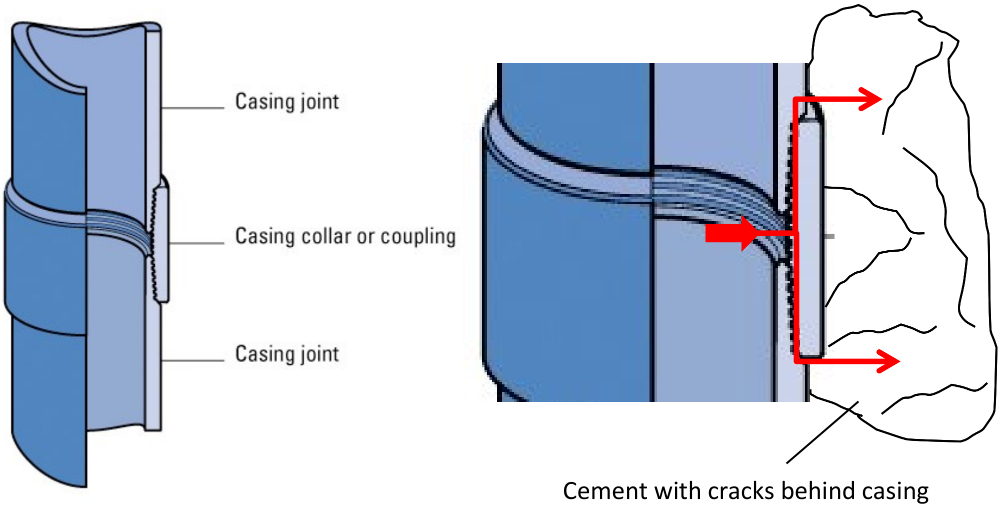


Figure 26: Casing Leakage [10]

As a conclusion for the future, OMV Austria E&P decided to check casing leaks for wells with long testing breaks with both test (pressure and swab).

H_2S study:

In 2012, OMV Austria E&P conducted a study if the H_2S content of the produced fluid can lead to hydrogen stress cracking. H_2S is a result of the water injection. Therefore, the produced water will be cleaned at surface and prepared for reinjection. During this water treatment, the reinjected water comes in contact with air and bacteria, which produces the harmful gas H_2S. To counteract this, the surface water treatment was changed in a way that the reinjected water will not come in contact with air any more. Moreover, the material selection showed that carbon steel with MONEL is able to resist the H_2S amount due to the low partial pressure of the gas.

DIFA:

The *dismantling and inspection for analysis* was first performed in the two ESP pilot projects from the year 2012. After the pump has failed (after one year) it was pulled and directly sent to the DIFA shop of Schlumberger, in Aberdeen. As result of this analysis the material selection for the bearings of the coming ESP's was re-considered. In the pilot test zirconium was used. Zirconium is a very hard but bridle ceramic. This was found to be incompatible with the producing sand from the reservoir (figure 27). As result of the DIFA zirconium was replaced by tungsten carbide which fits better the operation requirements.

Figure 27: DIFA broken zirconium bearing [38]

Figure 28: DIFA: broken shaft due to broken zirconium bearing [38]

The broken zirconium bearings results into a broken shaft which can be seen in figure 28. OMV Austria E&P decided to have bearings each one feet interval for the tender ESP's. This decision will increase the investment costs of each pump but due to one individual bearing each three stages, the loads on the shaft and bearings were reduced dramatically. The costs for this arrangement are lower than a full bearing housing (one bearing per stage) used in the ESP pilot 2012.

Training of OMV employees:

According to the low experience with ESP's in OMV Austria E&P, a special training program was designed. This program includes weekly training hours for the production engineers in the office and a comprehensive ESP course from Schlumberger in Singapore. For the field personnel, special training courses are held in regular intervals. The aim of this training program is to increase the experience and to develop awareness of how the pump performance will change if some parameters are changed (e.g. increase or decrease of frequency).

ESP design software:

During the design phase OMV Austria E&P found that their design programs (Prosper and SubPump) are limited in terms of updated pump data (e.g. pump curves, motor etc.). Therefore OMV ordered at least three licenses of the Schlumberger design program "Design Rite". With these licenses the production engineers are now able to change an ESP design if this would be necessary for any reason.

Option for external ESP surveillance:

OMV Austria E&P compared the advantages of Schlumberger "LiftWatcher" surveillance service with their monitoring tool "LOWIS" from Weatherford which is used for beam pumping surveillance as well. With "Lift Watcher" three engineers control the ESP wells with real time data in their offices in Aberdeen 24/7. If the systems show an alarm, the engineers will give a call to OMV Austria E&P. A special three month test period was signed with the service company. After this period OMV decided not to extend this service from economic considerations. LOWIS was found to be sufficient and a good alarm detection system.

20% more stages than designed:

To achieve the desired rate an increase of the total number of stages by 20-%, compared to the design software is needed. This phenomenon is not really understood so far.

All ESP's (from the past up to now) need more stages than in the design showed. The engineers in OMV Austria may think that this can be related to reservoir issues but this is not proved till now. As lessons learned, OMV Austria automatically required 20% more stages than designed for their redevelopment of the 16TH Torton campaign.

Soft startup procedure

In the pilot project of 2012 the startup production rate was found as too high. A lot of sand was produced which has filled up the surface separators. In regular time intervals (few days) the separator had to be cleaned. This was the reason why the run life of this pilot pump was lower than one year (previous DIFA section). As a consequence for the future, OMV Austria desired a startup procedure with the aim to increase the production rate very slow in the early life time of the pump.

Loss of knowledge

Between the early usage of ESP's and the pilot project in 2012 a lot of people retired or changed the department within OMV group. Unfortunately a lot of knowledge and experience was lost. As a consequence failures in installation and operation of the pumping unit had happened. To have a glossary of lessons learned and best practices examples of ESP's is one of the main tasks in this master thesis.

6. HSSE moments in ESP operations

Working Time:

The Austrian working time law (“Arbeitszeitgesetz”) allows a maximum daily working time of ten hours (§3). This working time has to follow a continuous rest time of at least eleven hours (§12). [11]

For the ESP installation campaign, in October 2013, the estimated working hours were assumed as:

- at 13 of 16 installations **> 10-h daily work**
- at 8 of 16 installations **< 11-h rest time**

So this workload was not doable with one ESP installation crew. To avoid collision with the Austrian working law, OMV Austria E&P wanted to have two shifts from the service company for the ESP installation.

H_2S:

H_2S, which can be a byproduct of hydrocarbon production, is a very harmful gas. The main properties of this gas are: [12]

- forms explosive mixtures with air
- heavier than air (sinks to the bottom)
- very toxic (even in low ppm concentrations)
- can only be smelled if concentration lower than 100-ppm (smells like foul eggs)

The reason why this gas is so harmful is that it attacks the respiratory system. Above 100-ppm of H_2S in the atmosphere the personnel could not smell the gas anymore. Over

500 ppm the gas will lead to death within 30 minutes. The MAK value ("Maximale Arbeitsplatz Konzentration") allows a safe work for eight hours a day. For H_2S the MAK value, differs from country to country, however, in Austria is 5-ppm. [12]

OMV Austria E&P did a H_2S study to estimate the maximum values in their ESP wells. This study came up with a maximum value ever measured in the 16^{TH} Torton horizon of 2.96 ppm. As conclusion, the H_2S concentration in the ESP wells is lower than the allowed MAK value (5-ppm), which means that for personnel life no further dangers are present.

Noise pollution:

Due to the fact that most of OMV production wells are in the near vicinity of populated area, noise emissions plays an important role. For each pump installation, the Austrian "TUEV" controls with measurements, if the acoustic level of an operated pump unit is within an acceptable limit. Therefore, four different test positions around the pump installation and one reference point, with a certain distance from the pump unit, are used to determine the acoustic level of the pump. Using these test reports, a quantitative statement for comparing the noise pollution of ESP's and beam pumping units can be given. The acoustic level, measured in dB (Decibel), after an ESP installation (including electric container with air conditioning) was reduced by at least 7 up to 18-dB compared to a beam pump installation. Just for notation, an increase of 5 dB will result into a doubling of the acoustic level (logarithmic scale!). Table 8 shows some acoustic level value for sucker rod pumping (prior the ESP) and electrical submersible pumping units.

Table 8: Change in noise level (ESP vs. SRP) [38]

beam pumping unit			ESP unit		
well	**meas. Date**	**value [dB]**	**well**	**meas. Date**	**value [dB]**

BO 81	11.04.2013	*91*	Bo 81	02.04.2014	*80*
BO 80	11.04.2013	*94*	BO 80	02.04.2014	*76*
BO 23	11.04.2013	*93*	BO 23	02.04.2014	*81*
BO 118	04.04.2013	*88*	BO 118	02.04.2014	*81*

Figure 29 shows the acoustic levels of different typical operations. With this figure a better understanding of how "loud" an ESP operation could be, should be given.

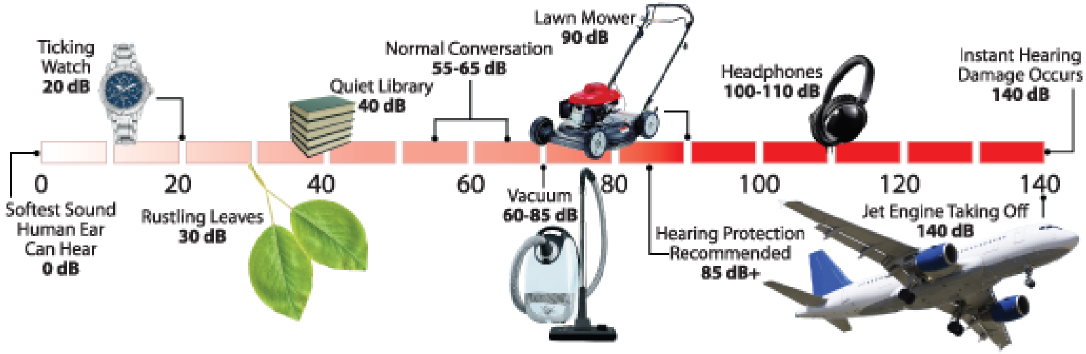


Figure 29: Typical sound level for different daily operations [13]

Small footprint:

One of the main advantages of an ESP, in comparison to the rod pumping unit, is the small footprint, especially in urban regions where free space is limited, see figure 30. Therefore the change of the environment due to installation of an electrical submersible pump will be reduced to a minimum.

Figure 30: Footprint, beam pumping unit (left) vs. ESP (right) [38]

ESP cable spool:

During the installation phase of the ESP cable the amount of working people is limited due to the danger of a broken cable. If this cable breaks it can hit someone and let to harmful injuries, see figure 31. Only three people (two for running the pump assembly in hole and one for operating the cable spool) are working during this time on the near wellbore side.

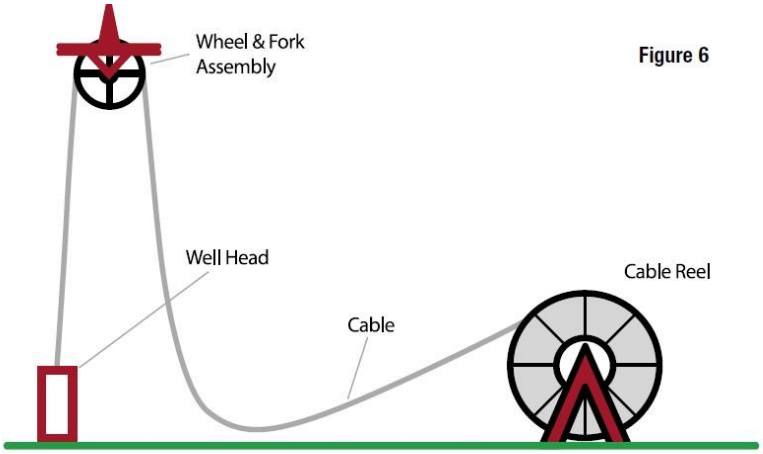


Figure 31: ESP cable installation [14, p. 22]

TENORM certificate:

The natural occurrence of radioactive material like uranium, thorium and radium in the soil makes it necessary to protect people against coming in contact with this radiation. This *technically enhanced naturally occurring radioactive materials* (TENORM) certificate will therefore ensure that if downhole equipment (pump) is pulled, the radioactive radiation of the whole equipment will be within a certain limit. For a DIFA analysis, where the pumps is pulled and send to the work shop in another country, a TENORM certificate for all sent parts is mandatory to enter the country.

No electrical test on the rig floor:

An explosive atmosphere can be given due to the availability of flammable gases and air, in the right mixture ratio. This mixture together with an ignition source (open flame or spark) can lead to an explosion. There are three different explosive zones, indicated by the figure 32, which describe the presence of an explosive atmosphere: [15]

- **Zone 0**: explosive air gas mixture is always present or for a long time (e.g. inside a tank)
- **Zone 1**: explosive air gas mixture is likely to happen in normal operations
- **Zone 2**: explosive air gas mixture will not likely happen in normal operations and if yes, only for a short period of time

Figure 32: Explosive atmosphere indicator plate [15, p. 94]

Therefore the electrical integrity testing of the cable (each 100 meters) has to make outside of these zones. These measurements should avoid cable failure in the early installation phase.

6.1. Geothermal energy of produced water

Geothermal energy is a renewable source of energy which results from the natural decay of radioactive materials (uranium, thorium etc.). The heated water (temperatures from 5, 10-°C up to several hundred degrees), coming out from the soil and can be used either for heating or electricity purposes. If the temperatures are higher than 100-°C, the steam can be used to drive turbines which produce electricity. If the temperatures are lower than 100-°C, heat exchangers are used to heat up houses, greenhouses or thermal spas. [16]

The *Lindal* diagram (named after the Icelandic engineer Baldur Lindal, figure 33) describes the required temperature of different geothermal energy possibilities. [17]

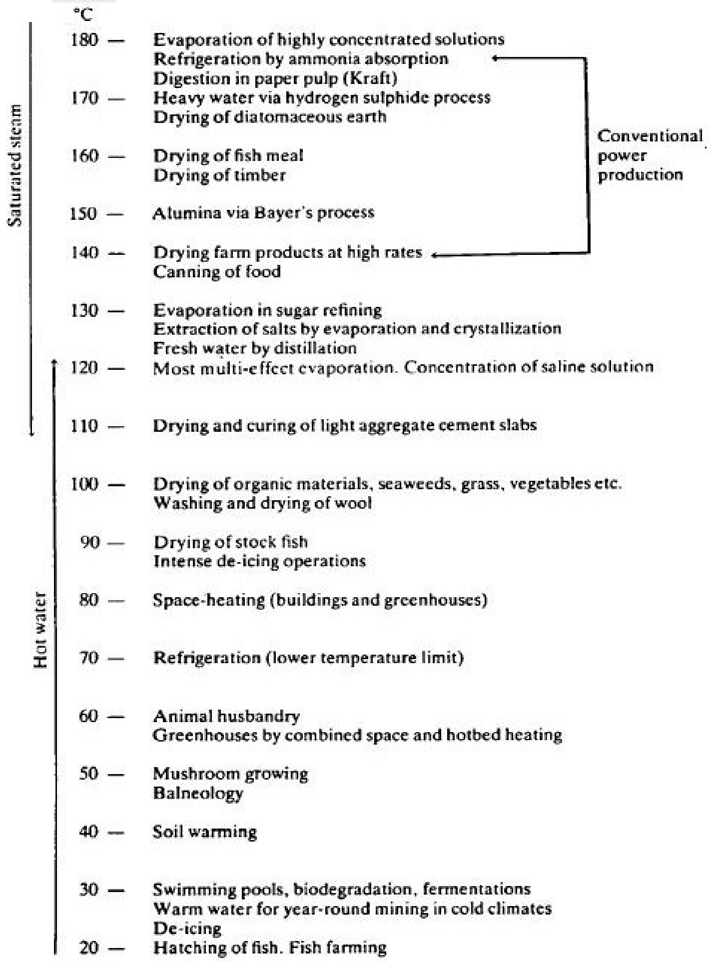
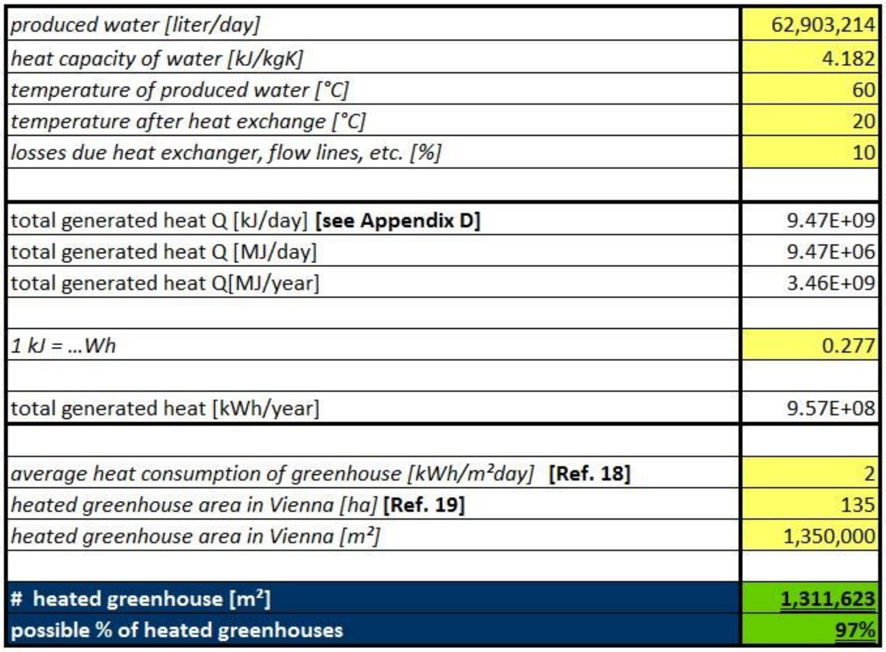


Figure 33: Lindal diagram for usage of geothermal energy [17, p. 15]

Besides the oil, huge amounts of water are produced during the lifetime of a well. This water has to be handled (cleaned) on surface and prepared for reinjection to enhance further production. In OMV the heat potential of the produced water, with temperatures of 50 to 60-°C, is not further used. In times of global warming and better energy balance, a possible concept for the future could be to use the geothermal energy of water for other environment purposes. According to the produced temperature and the Lindal diagram, the geothermal heat can be used for greenhouses, soil warming, heating swimming pools or fish farming before the water is reinjected back.

As possible scenario, OMV Austria E&P can use the 60-°C of the produced water to heat some greenhouses in their vicinity. For that possibility table 9 will show how much of the Vienna greenhouses can be heated by OMV. As example for the input data the “MATZEN” field was used, this represents the biggest production field in OMV Austria E&P.

Table 9: Geothermal heating of Vienna greenhouses



produced water [liter/day]	62,903,214
heat capacity of water [kJ/kgK]	4.182
temperature of produced water [°C]	60
temperature after heat exchange [°C]	20
losses due heat exchanger, flow lines, etc. [%]	10
total generated heat Q [kJ/day] **[see Appendix D]**	9.47E+09
total generated heat Q [MJ/day]	9.47E+06
total generated heat Q[MJ/year]	3.46E+09
1 kJ = ...Wh	0.277
total generated heat [kWh/year]	9.57E+08
average heat consumption of greenhouse [kWh/m²day] **[Ref. 18]**	2
heated greenhouse area in Vienna [ha] **[Ref. 19]**	135
heated greenhouse area in Vienna [m²]	1,350,000
# heated greenhouse [m²]	**1,311,623**
possible % of heated greenhouses	**97%**

From that table it can be seen that nearly the whole greenhouse, which are used for growing vegetables or flowers, can be heated by using the geothermal energy of the produced water from the MATZEN field.

With the remaining 20-°C after the heat exchanging process, some fish farms, where the temperature speeds up the fish growing, can be heated additional.

Additional to that, table 10 will show how much of alternative heating energy can be saved by using the geothermal energy of the water. The four shown energy sources (oil, coal, gas and pellets) are by the way, the main energy sources for currently heating greenhouses in Austria. [20, 21]

Table 10: Saving of alternative energy per year

other heating fuels	heat value	unit [ ]	savings	unit [ ]
heating oil	9.8	kWh/liter	97,702,555	liter
gas	10.1	kWh/m^3	94,800,499	m^3
coal (incl. coke)	8.1	kWh/kg	118,208	ton
heating with pellets	4.8	kWh/kg	199,476	ton

7. ESP Performance Analysis

7.1. Key Performance Indicators

A key performance indicator (KPI) is a performance measuring tool which allows an operator to get a quick overview about either the whole company or an ongoing project. Therefore many different KPI's (finance, sale or technical) has to be distinguish according to the field they are used.

In this thesis only technical KPI's regarding to ESP performance for OMV Austria E&P were analyzed.

7.1.1. Mean Time between Failure

A mean time between failure (MTBF) describes the expected time between two failure of a system happens. It will be calculated by summing up all running days of installed ESP's and divided by the number of failed ESP's, see equation 10.

Equation 10: MTBF calculation [22]

$$MTBF = \frac{\sum_{t=0}^{t=tp} installed\ ESP\ run\ days}{\#\ of\ failed\ ESP's}$$

Operators and service contractors have different views on this value. While a service contractor is interested in the mean time between the failures of equipment occurs, an operator is more interested in the mean time between pulling (MTBP) operations take place. The reason is obvious; a pulling job (regardless of the reason for pull) will result in a loss of production and money.

To exactly define, "what is a failure and what is not", regardless for operator or service contractor, is very important for the usage of this KPI.

The big advantage in comparison to the average run time calculation is that in the MTBF calculation statistically accounts for both, running and failed ESP's over a defined (fixed) rolling time window (e.g. three months or one year). [23]

A disadvantage of the MTBF calculation is that it will not take into account that more failures will happen in the older stage of equipment. This effect will be described in the "bathtub curve", see in figure 34. There we can see that the failure rate of any equipment (e.g. ESP) has higher values at the beginning and at the end of a lifecycle. In this curve three phases can be classified. Phase A refers to ESP failures directly in the starting phase (e.g. due to wrong installation). Than phase B will be followed which represents the failure rate in operation (nearly constant). In the last stage of an ESP lifecycle, phase C will cover the failure regarding to the natural wear of equipment parts. [24]

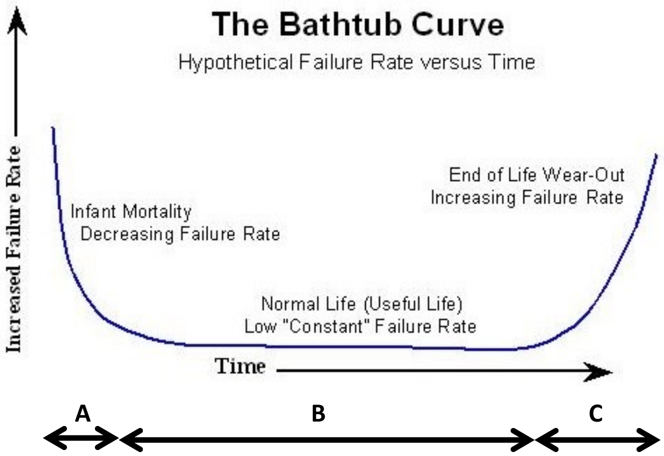


Figure 34: Bathtub curve [25]

To increase the accuracy and the interpretation weight of MTBF, a sufficient amount of data should be available. If there are lots of ESP's installed with significant number of failures, this KPI can be strong interpretation tool. On the other hand, there will be a high level of uncertainty in this number for a young ESP population. [26]

Just for notation, per definition, the meantime between failures is a key performance indicator which should be used for repairable equipment. If an ESP fails, the pump will be replaced completely. In that case this KPI will be called MTTF, mean time to failure. [22]

7.1.2. Average Run Life

The average run life of an event (ARLX) estimates the statistical average of a desired event (e.g. running, failed, pulling ESP etc.). It will be calculated by summing up the run life of the ESP's with event X, divided by the total number of these events, see equation 11.

Equation 11: Average run life of event X [27]

$$ARLX = \frac{1}{n}\sum_{i=1}^{n} RL_{xi}$$

This KPI will just account for one single event (differs between running and failed ESP's). Due to this statistical averaging it will also ignore the difference between long and short running ESP's.

For ESP's the most used average run life KPI's are: [27]

- average run life of running ESP's (ARLR)
- average run life of pulling ESP's (ARLP)
- average run life of failed ESP's (ARLF)

For small populations, new field with new ESP's with a low failure rate (as this is the case in OMV Austria E&P), the average run life calculation gives the operator an idea how they are performing. If the value of this KPI's is going down, this could be an indicator of another installation campaign. [26]

7.1.3. Other KPI's

MTBF and ARLX are the widest used key performance indicators for ESP's in the petroleum industry.

In addition to this numbers, several others can be used:

Failure Index:

This index describes the number of failures per well and per year. It can help to forecast the total number of failures across a coming annual period. This may help to plan and to budget future resources which are required. The formula of the failure index can be seen in equation 12. [23]

Equation 12: Failure Index [23]

$$Failure\ Index = \sum_{t=0}^{t=\#\ of\ intervals\ in\ a\ year} \frac{ESP\ failures\ during\ interval\ period}{\#\ of\ ESP\ wells\ operating}$$

Number of pulls:

The number of pulls or pulling job index (equation 13) is a key performance indicator to measure the efficiency of the system.

Equation 13: Pulling Index [28]

$$Pulling\ Index = \frac{\sum_{i=1}^{n} Pull\ jobs\ per\ year}{\sum_{i=1}^{n} Total\ installed\ ESP\ wells}$$

7.1.4. KPI's used in OMV Austria E&P

The database for the whole artificial lift run time data in OMV Austria E&P is stored in the GDB ("Gewinnungsdatenbank"). Just with one click, OMV is able to see the run times of all different artificial lift methods which are used. Such a visualization chart, for example, for the run times of sucker rod installation units over the last ten years can be seen in figure 35.

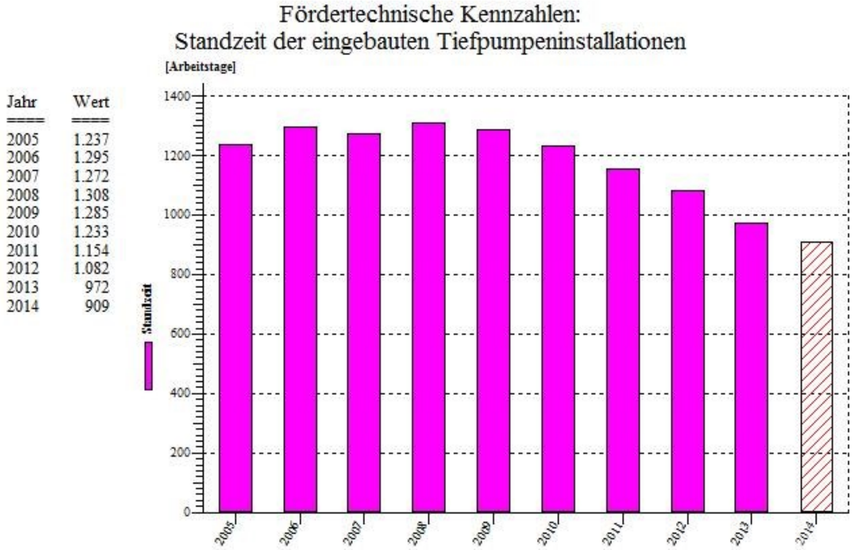


Figure 35: GDB run time visualization from 15.09.2014 [38]

With a closer look behind this GDB it can be seen that this “lifetime” will be calculated in the same way as the average run life of running ESP’s is calculated . The database sum up all working days of currently running ESP’s, within the special year, and divides by the total number of running ESP’s. This number, for each individual year, can then be seen in the chart.

At the moment, there are no other technical key performance indicators for ESP’s used in OMV Austria E&P. Therefore, one task of this master thesis is to investigate if there could be other KPI’s used too.

As previous explained the gained information out of a lifetime indicator strongly depends on the amount of data which is available to calculate such a KPI. According to the low number of installed ESP’s, in comparison to the total number of artificial lift installations, the input parameters , in terms of failure information in OMV Austria E&P, is very limited. Due to the fact that the majority of the currently running ESP’s are installed within the last 12 months, a MTBF value would not be a sufficient interpretation tool for the pump performance. Mean time between failure calculations, which includes both, running and failed ESP’s, will show higher accuracy with higher number of input data. Therefore, for the small number of installed electrical submersible pumps, the average run life calculation would give more trustworthy numbers. An idea of how both, MTBF and average run life with the same input parameters, varies from each other will give the table in the chapter 7.3 (*ESP performance analysis in OMV Austria E&P*).

As additional, future key performance indicator, the failure index, explained in the previous chapter, can be a useful tool. With increasing lifetime and number of ESP installation and get therefore, more information about failures and pulls, this can be a good tool for failure prediction in the future.

But nevertheless, to increase accuracy, of any current or possible future KPI, a sufficient route cause analysis has to be considered. This can be achieved by increasing the number of DIFA analysis. To exactly determine, why the pump fail and if this fail was a “true” pump fail ,and not some casing or tubing leak, will increase the meaning of the calculated KPI to a higher level.

7.2. ESP Failure

This following section will give a short overview of the most common reason for ESP failures and how the can be detected.

7.2.1. Reason of an ESP failure

The main reasons for ESP failures are: [7]

- **improper ESP design:** to reach a sufficient run life it is important that the pump will be operated in the designed ranges (production rate, frequency etc.)
- **inadequate equipment, failure during installation:** wrong equipment handling (not testing, polluted, harsh handling, etc.)
- **harsh well conditions:**
    - corrosive environments (attacks motor pump housing, and cables)
    - scale formation (can increase motor winding temperature or completely plug the pump stages)
    - sand or abrasive materials (erosion of impeller, gas separator, bearings etc.)
    - high temperature (effects motor and cable)
    - gas (affects efficiency of the pump and the cable)
    - high viscosity (higher motor loading)
- **electrical problems:** power supply problems (unbalanced phases, lightning strikes, harmonics etc.) or poor cable splicing quality
- **vibrations:** determination of frequency will give hint of possible failure (**API RP 11S8**)
    - mass imbalance of rotating parts (material heterogeneity)
    - hydraulically induced (pumping gassy or viscous fluids)
    - mechanical rubbing between rotating and non-rotating parts
    - defect bearings

7.2.2. ESP monitoring

ESP troubleshooting was in former times performed by using an ammeter chart. In this chart, shown in a circle form, the current consumption of the motor is represented over a timeframe of 24 hours. Due to different shapes of the motor current curve, different failures can be identified. The problem with the ammeter chart is that it will provide a very one sighted view on equipment because it takes just current measurements into account. Change of the current often refers to mechanical problems and therefore no additional information can be received. [7]

Nowadays with a downhole sensor the operator has the chance to gain real-time data of the ESP pump performance. With the right handling and understanding of this data an increase in production and life time can be achieved. The downhole sensor sits at the very end of the pump and is able to measure different parameters like: [29]

- intake pressure
- intake temperature
- discharge pressure
- discharge temperature
- motor winding temperature (better than motor oil temperature)
- vibrations
- current leakage

The level of this information can be increased by connecting the downhole sensor with a SCADA (*supervisory control and data acquisition*) system. With this system, the data from the sensor is transmitted to the office without any need of personnel on the well site. Moreover, SCADA controls the gained data and is able to send immediately an alarm if some measured values are out of the normal range. Therefore the required time for the working crew on the well site can be reduced to a minimum. [30]

7.2.3. Identification of ESP failures with downhole sensors

The downhole sensors creates huge amount of real time data. To identify if the pump is operating well or has some problems, this data bulk has to be evaluated. Figure 36 shows a chart where all measured properties (intake pressure and temperature, motor temperature, etc.) is plotted over time. This chart, called *trend analysis plot*, represents a typical ESP startup phase within the first 2 hours of an ESP run life. An increase in frequency will result in a decrease in intake pressure (turquoise, due to increasing flow to surface) and a slightly increase in motor temperature (purple). The discharge pressure (black) remains nearly constant. [31]

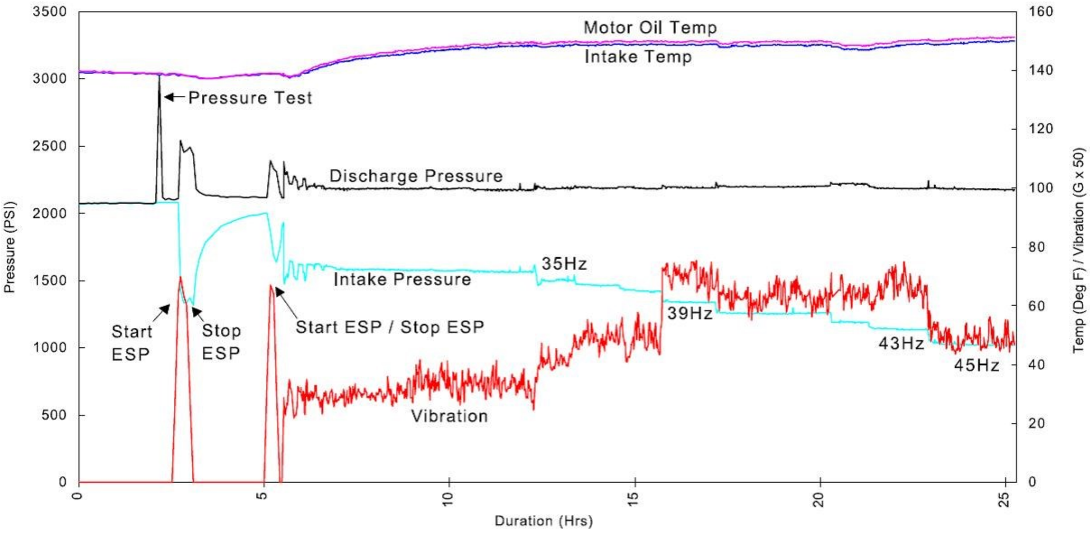


Figure 36: Typical chart of ESP startup [31, p. 3]

Looking at a "trend analysis plot", see which parameters abrupt change helps the operator to identify problems that has happened to the pump.

Table 11, developed by Awaid et Al. (2014), shows possible failures and how the operation parameter will change regarding to a specific failure. This table, together with experienced field people can be the key to reduce the intervention times in the field and therefore the production and money losses during the shut in time of the pump. [29]

Table 11: ESP failure identification

Problem	Q	WHP	Amps	$P_{discharge}$	P_{intake}	ΔP_{pump}	T_{motor}
Broken shaft	↓	↓	🟩 ↓↓	↓	↑	🟩 ↓↓	↗
Tubing Leakage	↘	↘	→	↘	↗	↘	🟩 ↗
Blockage of pump intake	↘	↘	↘	↘	↗	↘	↗
Blockage of perfortions	🟩 ↘	↘	↘	↘	🟩 ↘	↗	↗
Water Cut increase	↘	↘	↗	🟩 ↗	↗	↗	→
Blockage of pump stages	↘	↘	🟩 →	↘	↗	↘	↗
Reservoir pressure increase	🟩 ↗	↗	→	↗	🟩 ↗	↘	→
Increase of free gas at pump intake	↘	↘	🟩 ↘	↘	↗	↘	→
Worn out stages	↘	↘	↘	↘	↗	↘	↗
Frequency increase	↑	ꜛ	🟩 ↑	ꜛ	↓	↑	🟩 ꜛ
Open choke	↑	🟩 ↓	→	↓	ꜜ	ꜜ	→

🟩	unique characteristics
↓↓	large decrease
↓	decrease
↘	small decrease
ꜜ	very little decrease
→	constant
ꜛ	very little increase
↗	small increase
↑	increase

For example, if a tubing leak happens, the produced fluids will circulate into the casing. Therefore the fluid level outside the tubing will increase which results into an increase of the intake pressure of the pump. Moreover the motor winding temperature will significant increase due to a lower fluid movement passing the motor, resulting into lower cooling efficiency, see figure 37. [30]

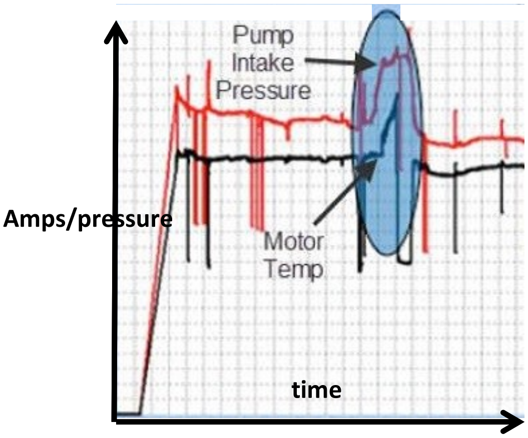


Figure 37: Identification of tubing leak [30, p. 7]

A plugged intake (Figure 38) can be classified with increasing of intake pressure and a decrease of amperage, due to higher friction. Plugging (e.g. due to scale) results into a restriction of flow into the pump and therefore, into an increase of the fluid level. [30]

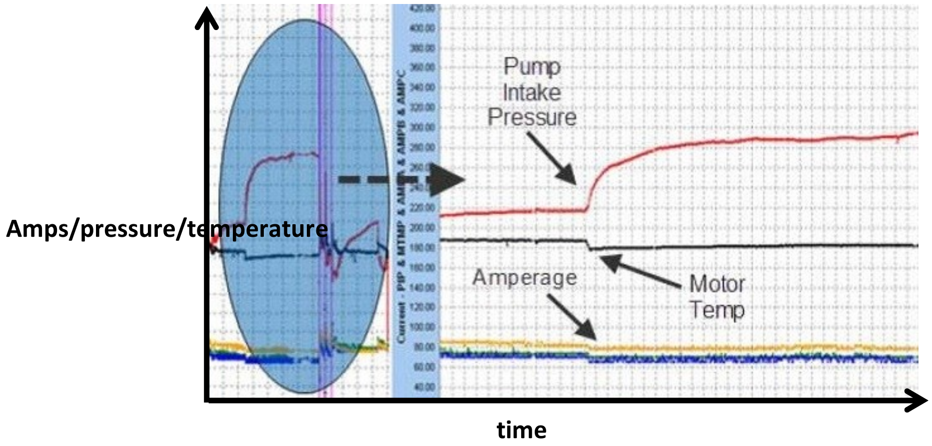


Figure 38: Identification of plugging intake [30, p. 8]

7.2.4. Failure identification with downhole sensors in OMV Austria E&P

The way, from the wellbore to the office, of the sensor data in OMV Austria E&P can be seen in figure 39.

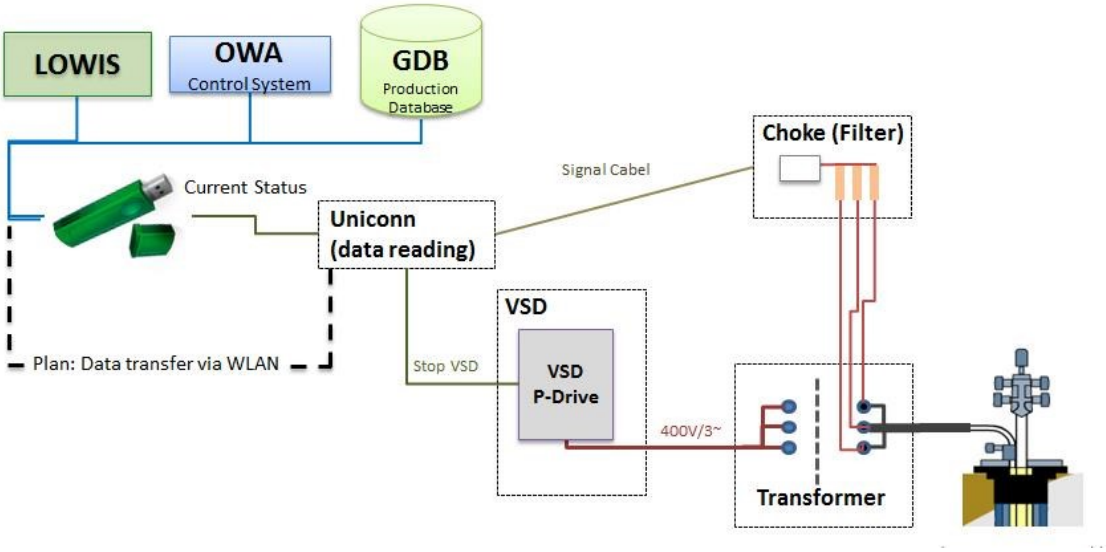


Figure 39: Transfer way of sensor data in OMV Austria E&P [38]

The measured signal is coming from downhole via the cable and the choke (filter for harmonics) to the Uniconn where the signal is read and the data is stored. At the moment, the stored data is transferred to the office via an USB stick. A SCADA system transferred and visualized the recorded data to use it for the LOWIS (Weatherford) and OWA (Oil Well Automatization) system. Together with the GDB (house intern database), OMV Austria E&P monitors their wells and is able to react immediately in case of an interruption. As future project OMV wants to connect their wells directly with LOWIS, including the real time data coming via a WIFI system from well site to the office. Moreover, discussions are ongoing to allow an automatic shut in of the wells in case of emergencies.

One example for the benefit of using a downhole monitoring tool was seen on an OMV well on 4th of March 2014. Figure 40 shows a detail of the trend analysis plot for this day. The whole plot can be seen in appendix C.

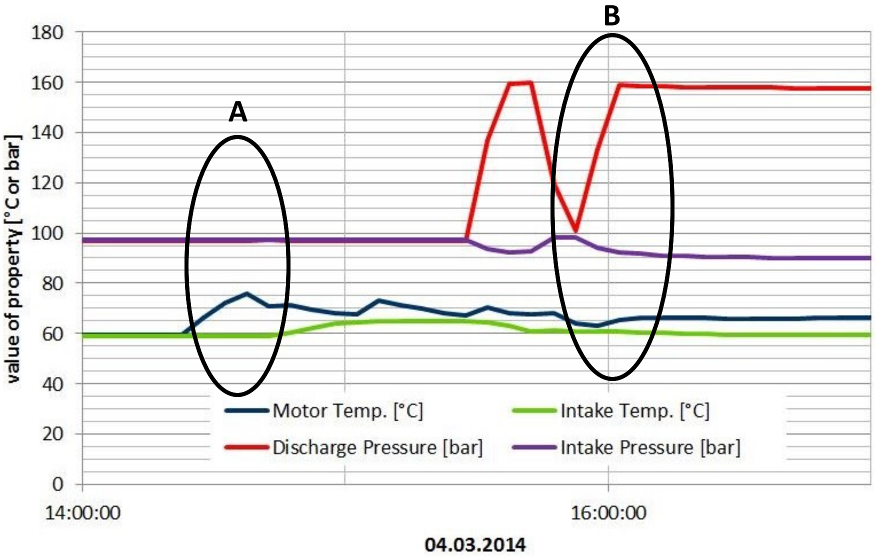


Figure 40: Detail from OMV Austria E&P sensor data from 04.03.2014

At the morning of the 4th of March the ESP was shut down due to surface maintenance of some electrical devices. As the field engineers wanted to restart the pump (A, 14:30) the motor temperature (blue) started to increase significantly. However, the pump was not producing any fluid (intake and discharge pressure remained equal and constant). After a stop and waiting (cool down) period, the electrical phases of the motor were changed and the unit was restarted again (15:00). At changed rotation direction, the motor temperature increased again. After another cool down period the phase were changed again and the procedure was repeated for several times. At 16:00 (B), the pump could be fully restarted with a production to surface. Settling down of sand after the pump has shut in for maintenance work could be the possible reason for these restarting problems. When the field engineers wanted to start, the shaft of the pump has stuck due to the high sand concentration at the bottom. With every new restart (with changed direction of rotation) the pump was able to act more against this sand. Without any sensor installation and the Uniconn reading on the field side, OMV Austria E&P would not able to identify when the motor was overheating. Motor burn down or a broken shaft, due to high torque acting on the shaft, would have been the consequence and resulting into a reduced life time of the equipment.

At 29th of March 2014 (Saturday!) the downhole sensor of another OMV well identified a problem related to the motor temperature. A detail of the trend analysis plot (appendix C) can be seen in figure 41.

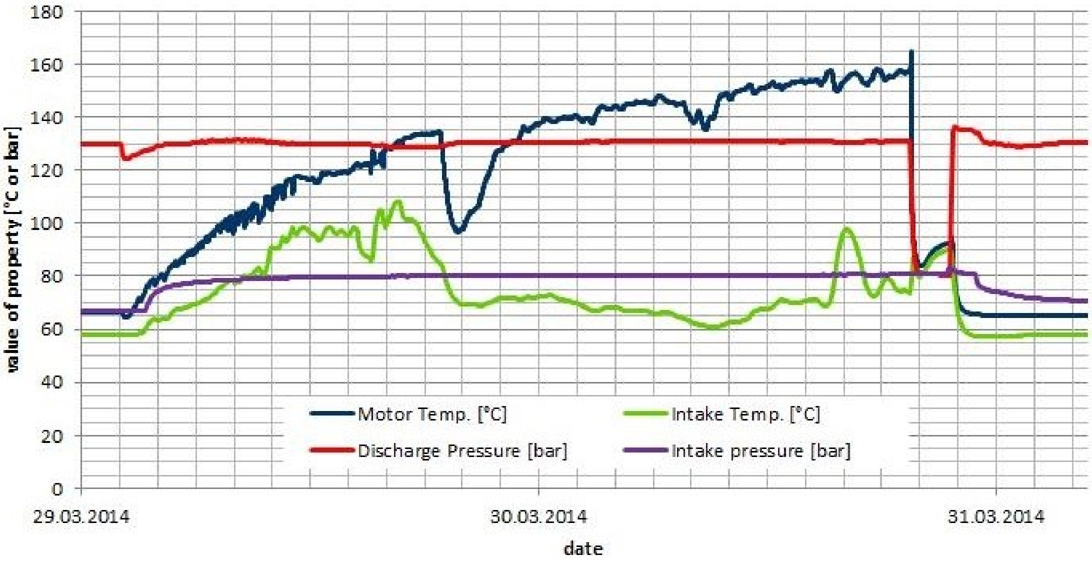


Figure 41: Detail from OMV Austria E&P sensor data from 28.03-01.04.2014

OMV Austria E&P wanted to perform a production test on the 29th of March 2014. The test separator (sketch in appendix C) showed no inflow from the test well. However, the downhole sensor showed an alarm regarding to the increase of motor temperature, but the field crew ignored all the alarms. On the next following working day the production engineers analyzed the sensor data of the past weekend. Out of the data it was shown that the motor temperature (blue) increased up to 160 °C until the field personnel has shut in the well. At the beginning of the temperature increase the intake pressure increased too but the discharge pressure (pressure above the pump) remained nearly constant. As result of this huge increase of the motor temperature and no production to surface, OMV thought that there must be any blockage in the flowline. Maybe on surface, a valve ("Schieber") could be kept closed by mistake. This would explain why the temperature was rising. Producing against a closed valve would result into reducing the flow passed by the motor and therefore reducing the cooling efficiency of the produced fluids. Moreover the liquid level above the pump will rise which will result into an increase of the intake pressure. Due to the low flow rate, the slope of the pressure curve is very little (appendix C). This could be the reason why the discharge pressure remained constant and not increased as expected. Without any downhole sensor the motor temperature would have increased further, resulting in a burn down of the motor and a pump fail. As further lessons learned, OMV Austria E&P trained their field personnel to understand the important meaning of the alarm signals of a downhole sensor.

7.2.5. ESP failures in OMV Austria E&P

This chapter will give information about the failures that has happen, in OMV Austria E&P, during ESP operations. Some failure reasons were found by a DIFA analysis and some by doing a route cause analysis directly in Gaenserndorf.

In figure 42, all failures regarding to the currently installed ESP's are shown.

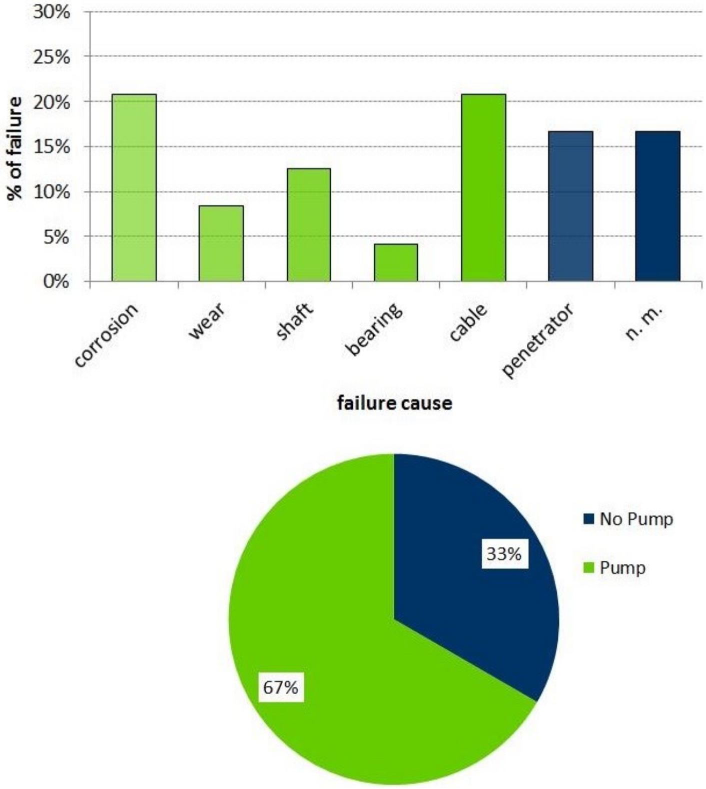


Figure 42: ESP failures in OMV Austria E&P (status date: 30.10.2014)

These diagrams show that most of the failures (67-%), which happened in OMV Austria E&P in the past, were directly regarding to a pump failure. The “no pump” failures, which represent 33-% of the total failures, were classified into two different groups, penetrator and not mentioned problems. Out of the diagram it can be seen that the majority of the ESP failures in the past related to cable and corrosion issues (both 21-%) followed by problems with the shaft (13-%). For pump lifetime estimation (e.g. average run life of failed ESP’s), only the direct pump failures have to be accounted, whereas the others were not accounted. Penetrator problems are not directly linked to pump failures. Therefore the work over rig has to raise the wellhead to allow service work at the penetrator. This fact will be not considered in the average run life of failed ESP calculation (explained in the next chapter). Failures which are stated as *not mentioned* are failures where no root cause analysis was done in the past. Therefore they could not classify into one group.

7.3. ESP Performance analysis in OMV Austria E&P

The ESP performance analysis for OMV Austria E&P is performed on average run life calculation. To show that a mean time between failure calculation, for the current number of installed ESP’s in OMV, is not a representative tool, the MTBF values are calculated too. Table 12 represents the final results of the performance analysis.

Table 12: ESP pump performance analysis OMV Austria E&P (status date: 30.10.2014)

	Average Run Life Analysis	[days]	# ESP's
Current ESP's in OMV Austria E&P	ARLR (Average Run Life of running ESP's): all!	550	33
	ARLR (Average Run Life of running ESP's): Tender only!	236	18
	ARLR (Average Run Life of running ESP's): without Tender!	926	15
	MAX Run Life	2,542	AUT 18
	MIN Run Life	27	AUT 19
			# jobs
ESP History of current installed ESP's	ARLJ (Average Run Life of ESP's jobs): from 2004-now	628	34
			# failures
	ARLF (Average Run Life of "true" failed ESP's): from 2004-now	1,103	16
			# pulls
	ARLP (Average Run Life of pulled ESP's): from 2004-now	872	22
	MTBF Analysis	[days]	
2004 - now	Run Days of installed ESP population (run + pull + NOT pull)	39,488	
			# failure
	# of failed ESP's (pull and pump failure)		16
	MTBF (Mean Time between Pump Failure)	2,468	
	Run Days of installed ESP population (run + pull + NOT pull)	39,488	
			# pulls
	# of pulls		22
	MTBP (Mean Time between Pulling)	1,795	

The average run life of (currently) running ESP's has reached 550 days. This relative low value is the consequence of the big ESP installation program in 2013. Therefore, 16 new ESP's were installed as a part of the redevelopment of the 16TH Torton project. If these tender ESP's would not be considered, which is not representative for the real case, the average run life of running ESP's would increase up to 926 days. This shows the big influence of just currently (within one year) installed ESP's on this calculation.

The highest run life of a single ESP reaches a value of 2,542 days (roughly seven years!) whereas the shortest pump run life (installed previous month), reaches a value of 27 days.

For performance indication the average run life of failed ESP's is more representative. Therefore, the KPI says that every 1,103 days an ESP failure occurred. With failure only ESP events are mentioned which were directly related to pump failures. Therefore, no casing leak problems, penetrator problems etc. are considered.

Furthermore, average run life between all ESP jobs and pulls are shown. As ESP job, all events which resulted into a shut in of the well were taken into account, independent if the pump had been pulled or not. Whereas in the average run life of pulled ESP's, only this intervention were taken into account where the pump has really been pulled.

The mean time between failure analyses shows values which are by far higher than the average run life calculations. Therefore, the meant time between pulling (MTBP) operations is 1,795 days, compared to the 872 days from the ARLP calculation. This doubling of the duration results from accounting both, running and failed ESP's in the MTBP calculation. The number of pulls is the same for both KPI's. Dividing the higher dividend (duration of failed plus still running pumps) with the same divisor (number of pulls) will result into a higher number of the MTBP calculation.

The same argument is valid for the mean time between failed ESP (MTBF). This value, 2,468 days, is more than doubled compared to the equivalent average run time value.

The results of this pump performance analysis will confirm the statement that for mean time between failure calculations, the input data field has to reach a significant size. Otherwise, the estimated values will not represent the real case and interpretations, based on the results, shows a lower level of accuracy.

Furthermore, the average run life of failed ESP was used as input parameters for the lifecycle cost calculation. With this number, the intervention (workover) costs over a lifetime period of 25 years, was calculated. The results are shown in the chapter 4.5.2.

Additionally, the average run life data of OMV Austria E&P is compared with the run life data of other OMV branch offices around the world. This will be further discussed in the following chapter.

8. ESP Benchmarking

"Benchmarking is an instrument of competitor analysis. It is the continuous comparison of products, services, processes and methods with (multiple) companies, to close the performance gap to the so-called, best in class (business, processes, methods, etc.) systematically. The basic idea is to determine what differences exist, why these differences exist and what opportunities for improvement there are." [32]

Benchmarking allows comparing same products/data, which are coming from different locations in the world at the same level. The aim for OMV Austria E&P to create an ESP benchmark, including different branch offices from different locations in the world, is to get an idea of the challenges of operating an electrical submersible pump in the other locations. Resulting from that different run times will be calculated. To compare their data with the data coming from the OMV branch offices will help OMV Austria E&P to improve their lifetime performance and increase the efficiency of the ESP's which are currently running and will be running in the future.

Figure 43 shows the schematic lifecycle of a benchmarking process.

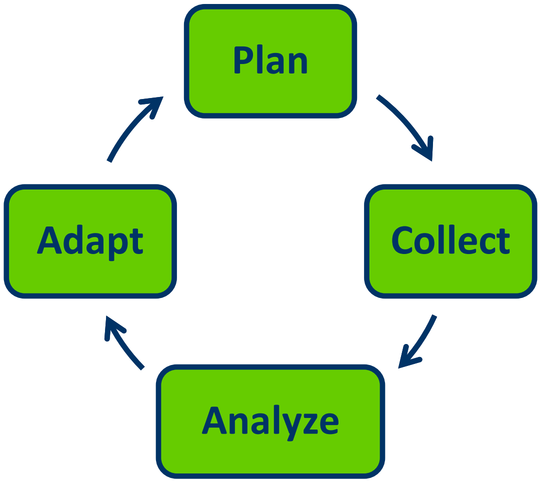


Figure 43: Benchmarking lifecycle [33, p. 15]

8.1. OMV Benchmarking

At the very beginning of this benchmark, it is important to decide which data can be helpful to improve the own performance. One of the major input parameters, OMV Austria E&P wanted to receive from their branch offices, was regarding to the installation and pulling dates of other ESP's, in different operating fields. The reason for dates and not individual key performance indicator values as MTBF or average run life are to ensure, that the data will be compared at the same level. Different branch offices can calculate this KPI's in different ways, regarding failure interpretations or running time. With the exact dates and the comments of the special events, the values for MTBF and average run life can be calculated for each branch office in the same way. This increases the accuracy of this performance benchmark. To ensure that we will not compare apples with pears also characteristic field and equipment data was asked. All the asked data input can be seen in the tables, shown in appendix A.

The lifecycle of a benchmark (figure 43) was adjusted for OMV Austria E&P in the following way:

Plan:

Selection of the most important input parameter for the benchmark data sheet, see appendix A. The input data includes general field data as well as specific well data to allow OMV Austria E&P to calculate the pump performance of each individual ESP.

Collect:

Send the data sheet, Microsoft Excel file, to the branch offices around the world and waiting for reply.

Participants of this benchmark are the following OMV branch offices:

- OMV Kazakhstan
- OMV New Zealand
- OMV Petrom Romania
- OMV Tunisia
- OMV Yemen

Analyze:

Analysis of received input files. Finding similarities between ESP’s in Austria and ESP’s in different branch offices. Calculation and comparison of key performance indicators, average run life of events and mean time between events, between OMV Austria E&P and OMV branch offices.

Adapt:

This includes interpretation of data and finding reasons for possible differences. To ensure the accuracy of this benchmark, it is very important that the compared data is at the same level. If a branch office will show higher performance, detect the reason for this.

8.1.1. Results

At the beginning of this chapter I have to clarify. All the numbers and graphs, shown in the following, are the results of the **provided data** from the different branch offices of OMV. I do not want to say, that all the estimated numbers, according to run lives and other parameters, will represent the performance of the whole branch office. From the organization point of view, a cutoff date for the run life was used. All running ESP’s are referenced to the 15th of September 2014 as chosen cutoff date.

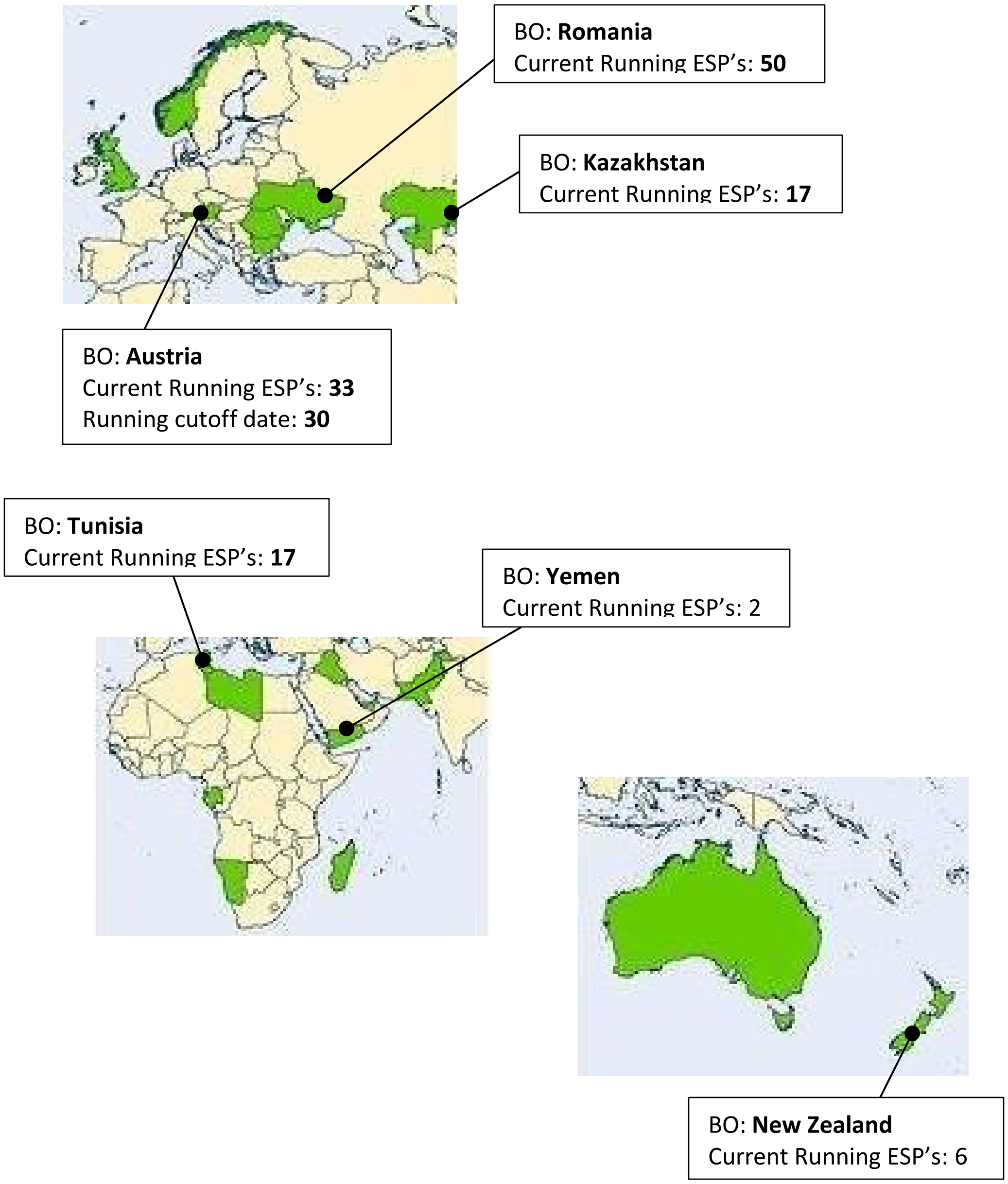


Figure 44: Running ESP's in OMV global [38]

Figure 44 will give a statement about how significant this OMV benchmark would be. There, all current installed (running) ESP's, in all branch offices where OMV is the operator, can be seen. In the other countries, which are highlighted in green in the map, OMV has either no ESP installed or is not the operator in this field. To compare this total number with the number of ESP's included in this benchmark, figure 45 can be used. In this figure all current running ESP’s as well as the number of all (past) installed ESP’s, for each branch office, is shown.

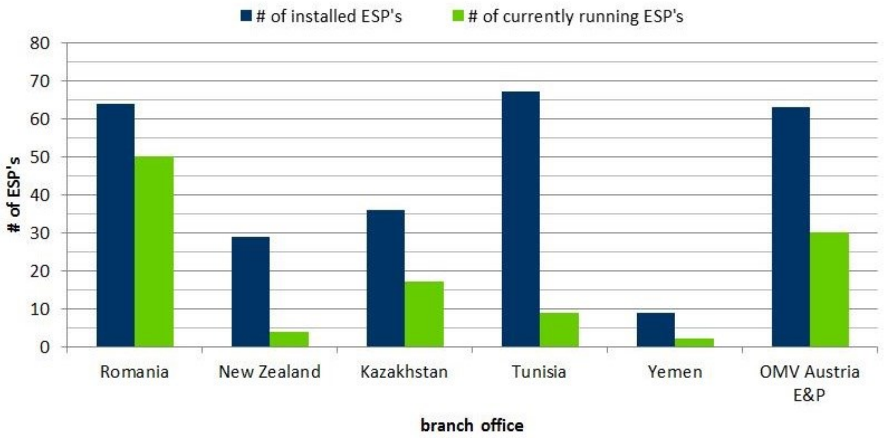
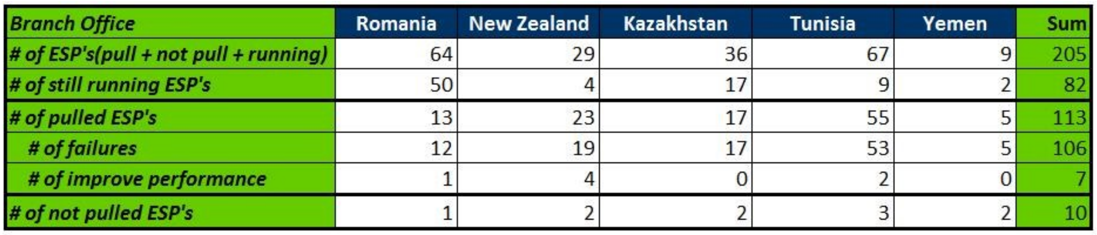


Figure 45: ESP’s of OMV benchmark

According to figure 45, the total number of provided ESP’s is 205, where 82 of them are currently running. The data from OMV Austria E&P (referenced to cutoff date!) includes, 63 ESP’s where 30 of them are currently in operation.

In table 13 the total number of ESP’s is subdivided into running, pulled and not pulled ESP’s. The reason for pull is either a failure or, a so called, improve performance (increase production rate due to a new ESP) purpose. Waiting for the work over rig refers to a not pull job.

Table 13: Number of ESP’s (running, pulled and not pulled)



Branch Office	Romania	New Zealand	Kazakhstan	Tunisia	Yemen	Sum
# of ESP's(pull + not pull + running)	64	29	36	67	9	205
# of still running ESP's	50	4	17	9	2	82
# of pulled ESP's	13	23	17	55	5	113
# of failures	12	19	17	53	5	106
# of improve performance	1	4	0	2	0	7
# of not pulled ESP's	1	2	2	3	2	10

The numbers of failures related to an ESP unit are shown in table 14. As so called "true" ESP failures all failures related to pump, protector, separator, motor and cable parts were counted. Therefore the difference between the "true" failures and the number of failures in table 13 corresponds to failure related to tubing/casing leaks, scale not in ESP region, debris, water shut off etc.

Table 14: Number of ESP failures

Branch Office	Romania	New Zealand	Kazakhstan	Tunisia	Yemen	Sum
# of "true" ESP failure	10	6	14	43	3	76

Regarding the data, the average run life of event X is shown in figure 46. All the run lives are exactly calculated in the same way as for OMV Austria E&P, chapter 7, and can therefore directly compared with the run lives of the different OMV branch offices.

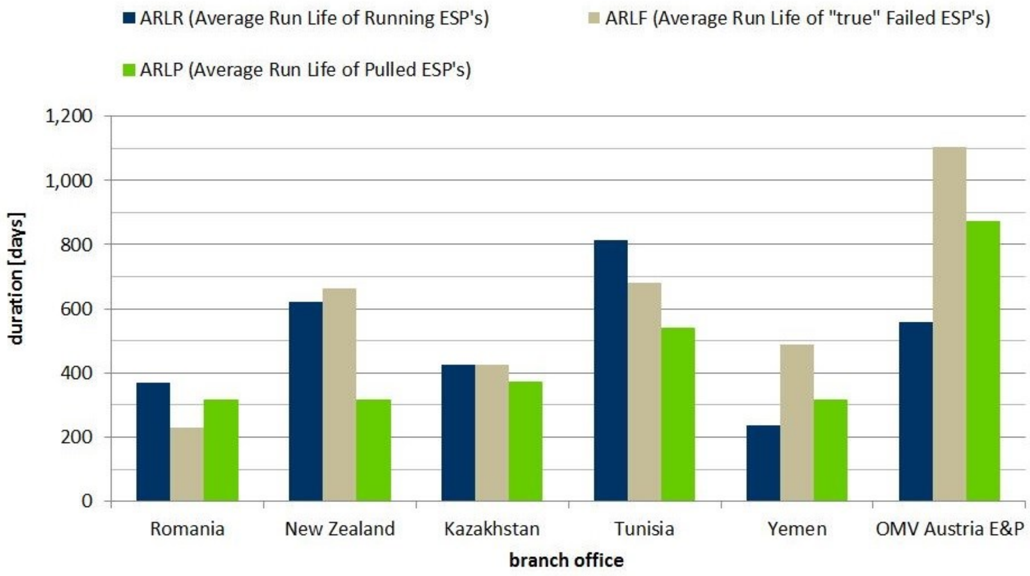


Figure 46: Average Run Life of event X, OMV benchmark

For average run life of running ESP's (ARLR), the values ranges from 236 days (Yemen) up to 815 days (Tunisia). The reason for the relative low value of the Yemen BO results from the little ESP data received from there. From nine ESP wells, only two are currently in operation with installation dates in 2013 and 2014.

The average run life of “true” failed ESP’s (ARLF) is in a range from 230 days (Romania) up to 1,103 days (OMV Austria E&P). Romania’s run life results from the fact that the most of the received ESP data includes running ESP’s, with installation dates within the last two years. There were only ten (out of 64 ESP’s), so called “true” ESP failures.

The average run life of pulled ESP’s (ARLP) varies from 316 days (Romania) up to 872 days (OMV Austria E&P). New Zealand (317 days) and Yemen (318 days) therefore are close to the data received from Romania. For the pulled run life calculation, all failures regardless if related to pump or not, are counted.

Figure 47 represents the results of the mean time between event calculations for all branch offices.

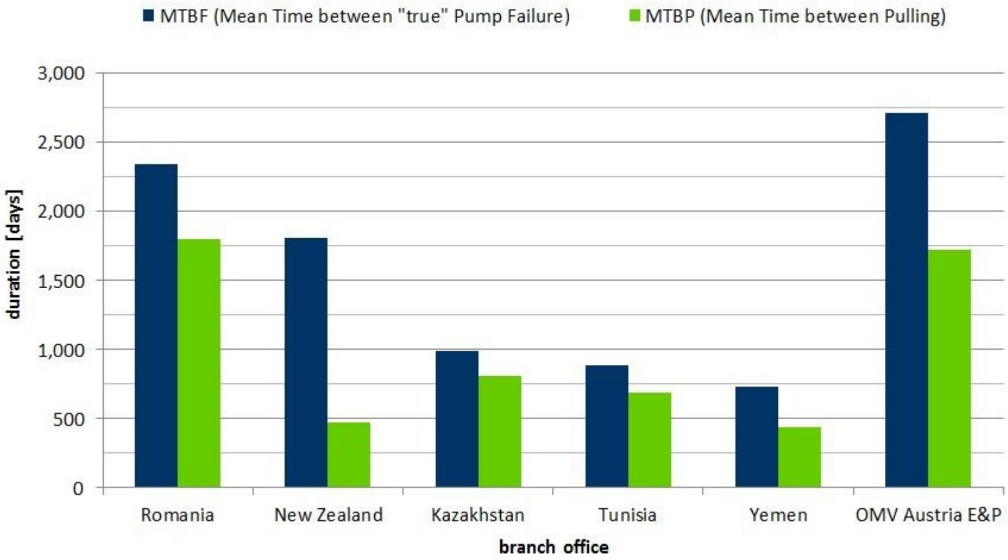


Figure 47: Mean Time between event X, OMV benchmark

These values have to be handled with care. The mean time between “true” pump failures (MTBF) varies from 735 days (Yemen) up to 2,707!!! days in Austria. The reason for these high values in Austria as well as in Romania (2,342!) can be explained by looking at tables 13 and 14. For the mean time between event calculations, all run lives, running and failed, are summed up and divided by the number of "true" ESP failures. For example, in Romania, where 50 out of 64 ESP's, are currently running, the total run lives are summed up and divided by ten ("true" failures). Whereas, for the ARLF calculation, only the ten run lives of the failed ESP's are considered. This is the same reason as for OMV Austria E&P explained in the previous chapter.

In other words, to receive a meaningful value of the mean time between event calculations, it is necessary to have enough data available. The data from Tunisia includes 43 "true" failures which result into a MTBF of 884 days compared to the ARLF of 680 days. This will indicate that even 43 failures (out of 67 ESP's, roughly 64-%), the highest number of "true" failures of all OMV branch offices including Austria, will result into a difference of 204 days in both KPI calculations.

For the mean time between pulling operations (MTBP), the values ranges from 441 days (Yemen) up to 1,802 days in Romania. These values are by far closer to the ARLP values than the MTBF values. But nevertheless, more data is needed to increase the accuracy and the informative value of this key performance indicator.

The "lower" values from Kazakhstan and Tunisia can be explained by the amount of provided data (table 13 and 14). All input parameters (number of pulls, failures and running ESP's) are nearly in the same ranges compared to other branch offices. The data received from Yemen was too less to make accurate interpretations of this KPI's.

Final statement from **Luis LOBIANCO**, Schlumberger ESP Service Engineer for OMV Austria E&P: *"If the values for mean time between event and average run life of event differ by far, this will be an indicator of lot of new ESP installations in the field".*

The result of this performance benchmark tells that the ESP's in OMV Austria E&P operates well in comparison to other branch offices. If the average run life of event is used as performance indicator, OMV Austria E&P shows in two out of three cases the highest numbers. Only the average run life of running ESP's is lower in Austria compared to Tunisia or New Zealand. As earlier explained, a lot of new ESP's were installed in the last year in OMV Austria E&P as a part of the redevelopment of the 16TH Torton project. This campaign will reduce the ARLR values.

If the mean time between events is used as performance indicator, OMV Austria E&P shows the highest results together with Romania. But keep in mind, for an accurate interpretation of this KPI, more data is needed.

Additional to the performance benchmark, appendix E will show further ESP related information of OMV Austria E&P and the branch offices which took part in this benchmark.

From the authors view, intensive knowledge exchange events between branch offices would help to improve the performance of ESP's and to get an even better understanding of this relatively complex artificial lift method.

8.2. ESP-RIFTS

In 1999, several operators decided to share their ESP run life and failure data with the goal to gain knowledge and increasing their ESP run life for the future. Therefore, they created a Joint Industry Project (JIP) called ESP-RIFTS *"ESP Reliability Information and Failure Tracking System"*. [34]

One major purpose was to create a standard for collecting, tracking and sharing ESP run life and failure data. This standard was the main source for the input data sheet used in this OMV benchmark. [34]

C-FER Technologies, a third party in this project, ensures that sharing this information will take place in an effective way. They are maintaining the project website and developing new analysis tools, to increase the level of information which the participants can achieve. [35]

At current state, there is recorded data from more than 105,000 ESP out of 758 fields in this database. The joining companies can be seen in figure 47. [35]

Figure 48: ESP-RIFTS joining companies [35]

Recommendation:

For increasing the run life of ESP's, as well as for a better understanding of different pump failures, OMV Austria E&P can gain more information about this ESP-RIFTS program. To join this project could be a useful way for increasing their pump performances in the future.

9. Summary & Recommendations

With this master thesis the currently installed ESP's in OMV Austria E&P were under investigations in terms of performance, costs and related problems during the installation and operation process. Comparing ESP with sucker rods resulted with an economic border of over 180-m^3/day. Above this value the usage of an ESP results into lower costs. The currently 33 installed ESP's showing average run lives of 550 days (running), 872 days (pulling) up to 1,103 days for failed pumps. Comparing these values with the mean time between pulling of 1,795 days and 2,468 days for the mean time between failures, it was found that this sort of key performance indicator is not the right at this state. Due to the fact that a lot of new ESP's were currently installed, as a part of the redevelopment of the 16TH Torton project, the usage of the average run life analyses will result in more trustworthy values. If the ESP population becomes bigger, with more dates of failures and the reason why the failure will happen, the meant time between event calculations will show more accurate results. Furthermore the OMV benchmark has shown that the ESP's operate in Austria are working well in comparison with the other branch offices in the OMV group. Regarding the average run life analyses, OMV Austria E&P shows in two out of three cases (failed and pulled) the highest numbers. The mean time between event calculations showed values which differs, in some chase a lot from the average run times calculations. This was found as a fact of the amount of failed data which was received from the different branch offices. To increase the root cause analysis, together with more DIFA analysis will help to become more information about the failure that has happen regarding an ESP. This information therefore can strongly increase the meaning of the different KPI's explained in this thesis. As another recommendation and future improvement the ESP RIFTS project can be jointed. With this database information the performance and lifetime of this artificial lift method in OMV Austria E&P can be increased further.

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[38] OMV Austria E&P internal material

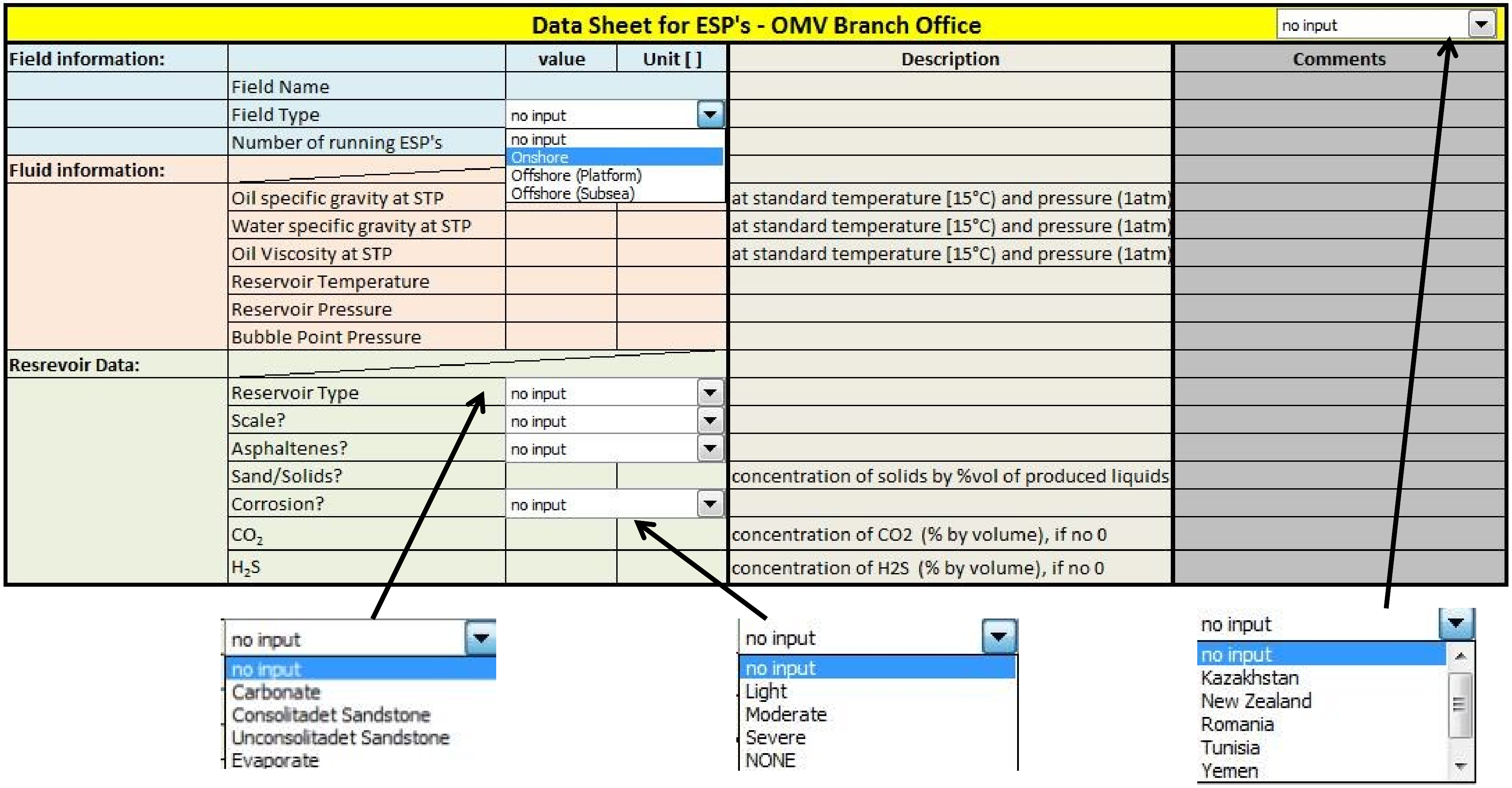
11. List of abbreviations

AOFP	Absolute Open Flow Potential [BPD]
BEP	Best Efficiency Point
BHP	Breaking Horse Power [hp]
B_G	Formation Volume Factor Gas [scf/bbl]
B_O	Formation Volume Factor Oil [bbl/STB]
BO	Branch Office
c	Heat Capacity (of water) [kJ/kgK]
CAPEX	Capital Expenditures [€]
IPR	Inflow Performance Relationship
LCC	Lifecycle Cost Calculation
NPV	Net Present Value [€]
m	Mass (of produced water) [kg]
OD	Outer Diameter [in]
OPEX	Operation Expenditures [€]
P_b	Bubble Point Pressure [psi]
PI	Productivity Index [bbl/psi day]
PIP	Pump Intake Pressure [psi
ppm	parts per million [ ]
Pr	Reservoir Pressure [psi]
PSD	Pump Setting Depth [ft]
PVT	Pressure/Volume/Temperature Data
Pwf	Well Flowing Pressure [psi]
ΔQ	Heat Amount (Geothermal Energy) [kJ]
RPM	Revolution per Minute [ ]
R_S	Solution Gas Ratio [scf/STB]

$SG_{comp.}$	Specific Gravity Composition [ ]
SG_G	Specific Gravity Gas [ ]
SG_O	Specific Gravity Oil [ ]
SG_W	Specific Gravity Water [ ]
SRP	Sucker Rod Pump
TBHP	Total Breaking Horse Power [hp]
TCO	Total Cost Ownership [€]
TDH	Total Dynamic Head [ft]
ΔT	Temperature Difference [ ]
T_F	Temperature [°F]
tp	time period of interest (MTBF equation) [days]
T_R	Temperature [R]
VSD	Variable Speed Drive
WC	Water Cut [%]

12. Appendix A - Input datasheet for internal benchmark

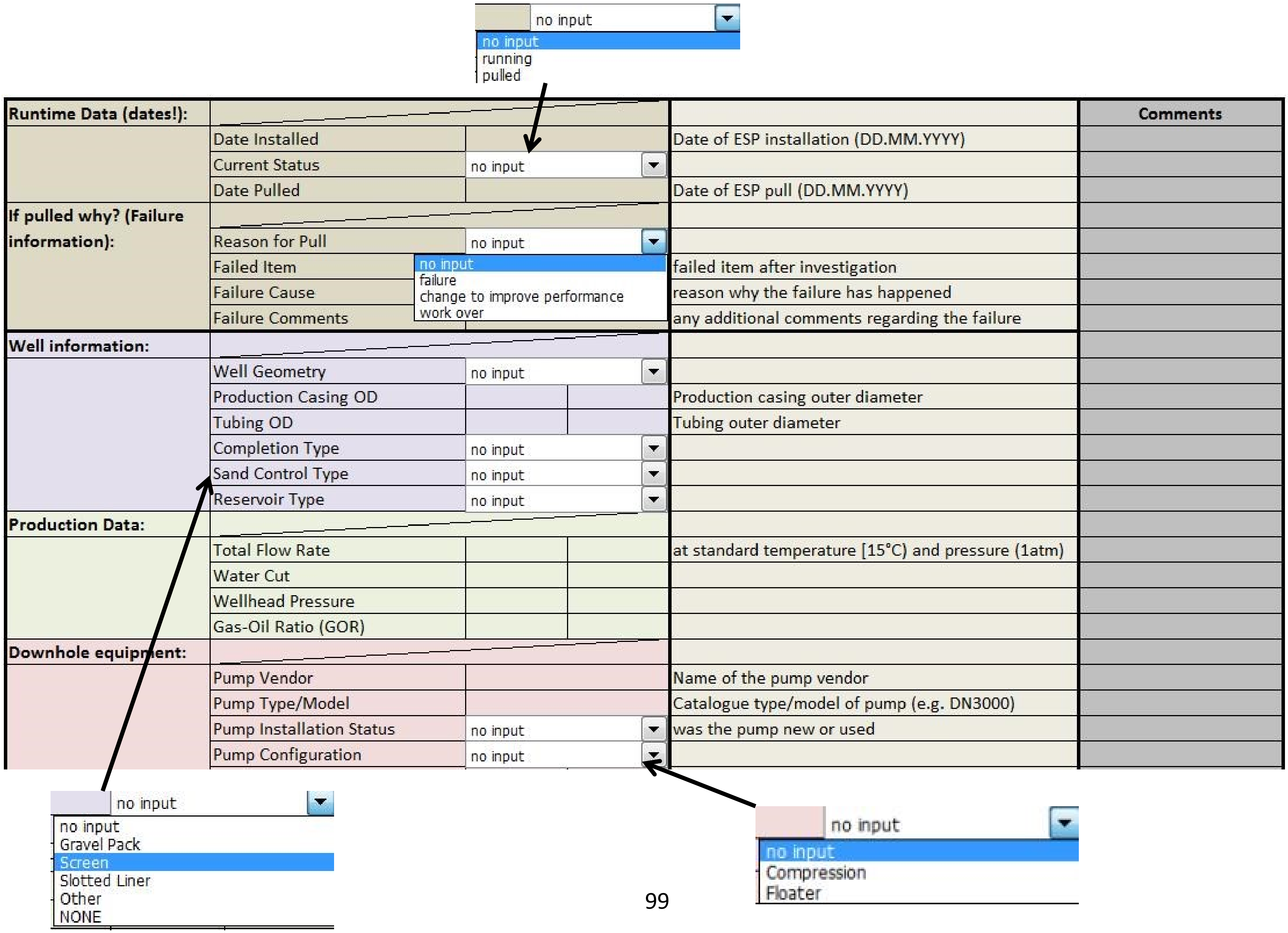
Table A - 1: Benchmark Data Sheet – General Input [34]



Data Sheet for ESP's - OMV Branch Office — no input

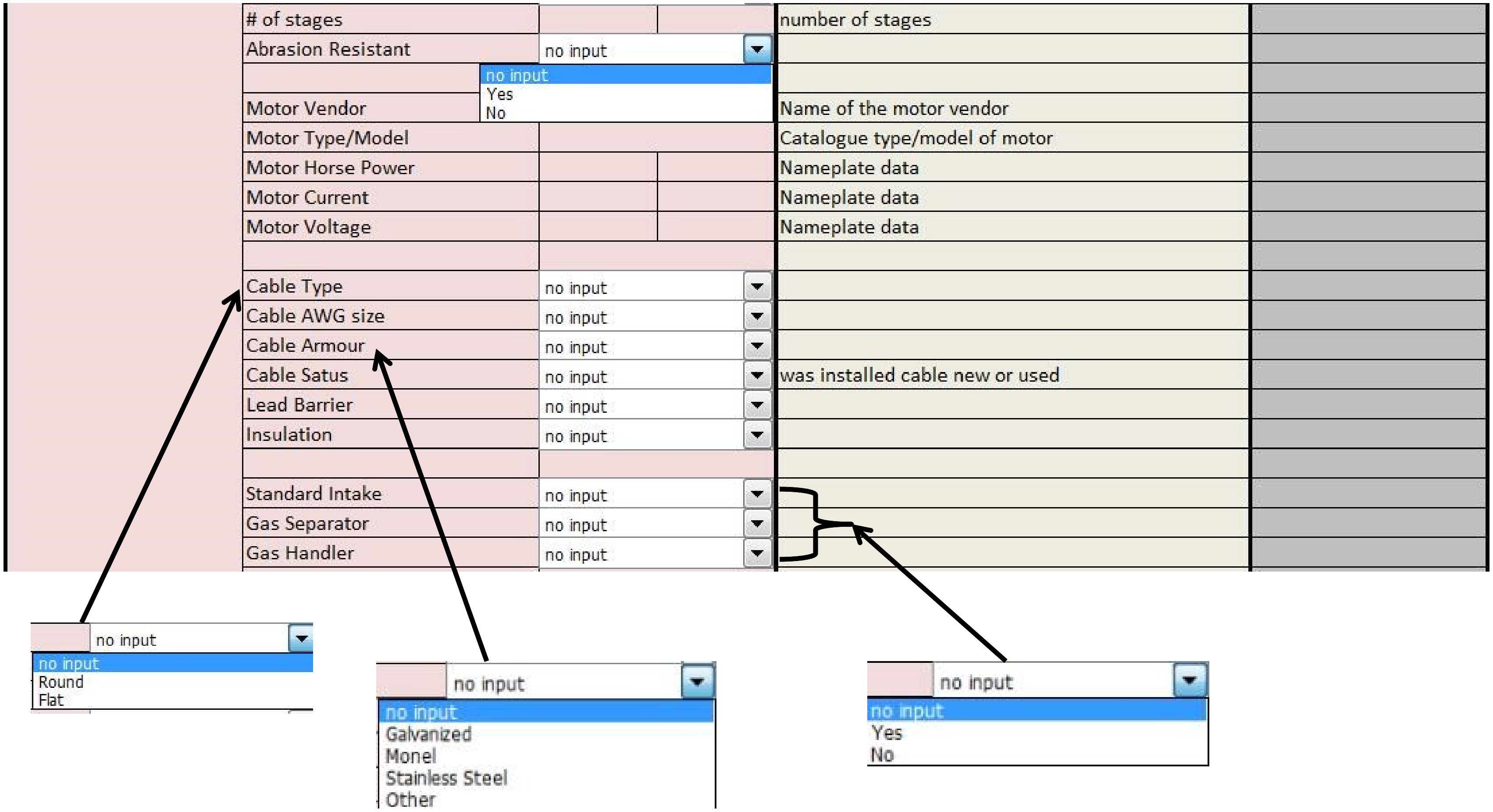
Field information:		value	Unit [ ]	Description	Comments
	Field Name				
	Field Type	no input			
	Number of running ESP's				
Fluid information:					
	Oil specific gravity at STP			at standard temperature [15°C) and pressure (1atm)	
	Water specific gravity at STP			at standard temperature [15°C) and pressure (1atm)	
	Oil Viscosity at STP			at standard temperature [15°C) and pressure (1atm)	
	Reservoir Temperature				
	Reservoir Pressure				
	Bubble Point Pressure				
Resrevoir Data:					
	Reservoir Type	no input			
	Scale?	no input			
	Asphaltenes?	no input			
	Sand/Solids?			concentration of solids by %vol of produced liquids	
	Corrosion?	no input			
	CO_2			concentration of CO2 (% by volume), if no 0	
	H_2S			concentration of H2S (% by volume), if no 0	

Table A - 2: Benchmark, Data Sheet - Specific ESP Input part 1 [34]



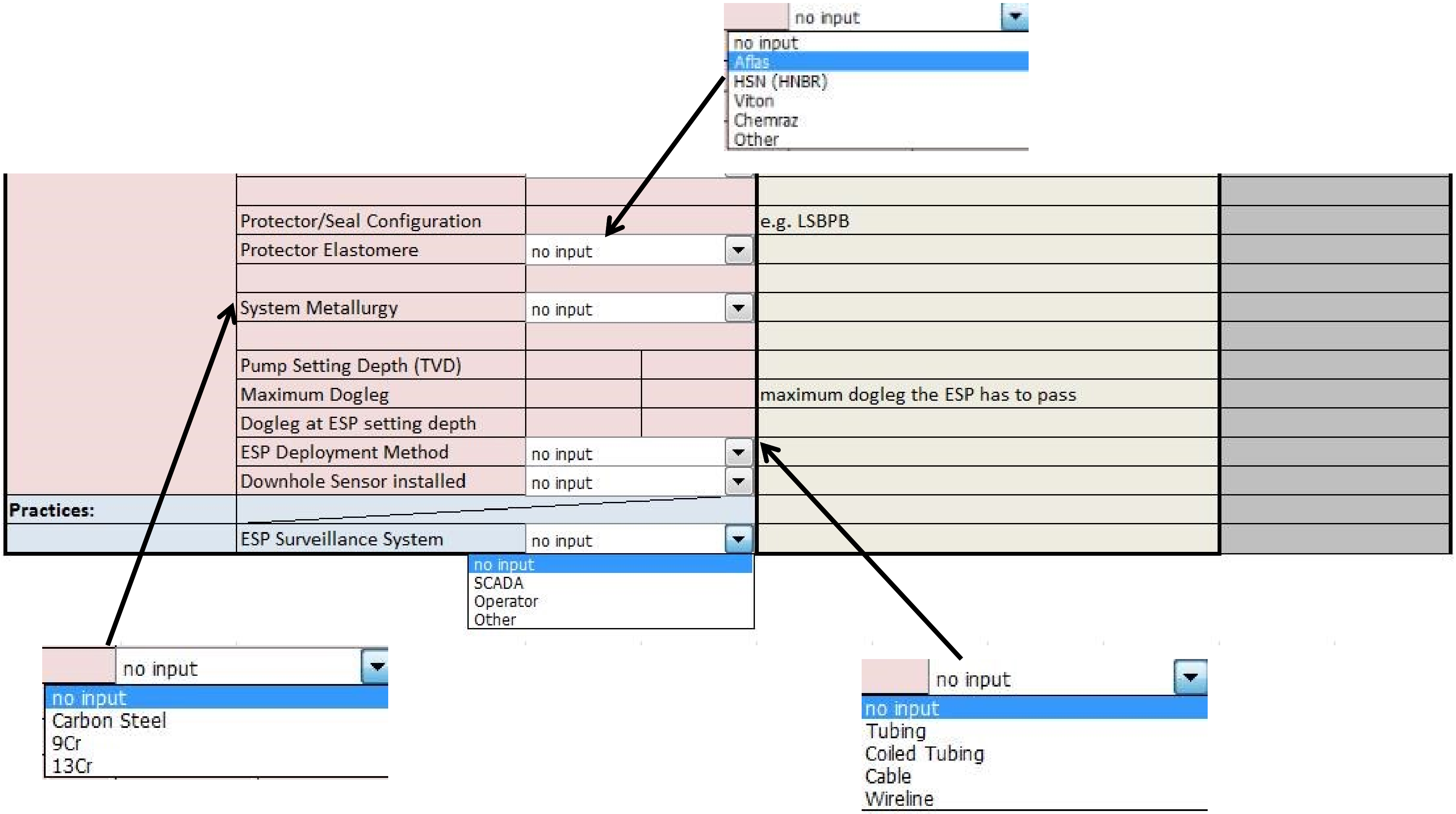
Runtime Data (dates!):					Comments
	Date Installed			Date of ESP installation (DD.MM.YYYY)	
	Current Status	no input			
	Date Pulled			Date of ESP pull (DD.MM.YYYY)	
If pulled why? (Failure information):					
	Reason for Pull	no input			
	Failed Item			failed item after investigation	
	Failure Cause			reason why the failure has happened	
	Failure Comments			any additional comments regarding the failure	
Well information:					
	Well Geometry	no input			
	Production Casing OD			Production casing outer diameter	
	Tubing OD			Tubing outer diameter	
	Completion Type	no input			
	Sand Control Type	no input			
	Reservoir Type	no input			
Production Data:					
	Total Flow Rate			at standard temperature [15°C) and pressure (1atm)	
	Water Cut				
	Wellhead Pressure				
	Gas-Oil Ratio (GOR)				
Downhole equipment:					
	Pump Vendor			Name of the pump vendor	
	Pump Type/Model			Catalogue type/model of pump (e.g. DN3000)	
	Pump Installation Status	no input		was the pump new or used	
	Pump Configuration	no input			

Table A - 3: Benchmark, Data Sheet - Specific ESP Input part 2 [34]



# of stages		number of stages
Abrasion Resistant	no input	
Motor Vendor		Name of the motor vendor
Motor Type/Model		Catalogue type/model of motor
Motor Horse Power		Nameplate data
Motor Current		Nameplate data
Motor Voltage		Nameplate data
Cable Type	no input	
Cable AWG size	no input	
Cable Armour	no input	
Cable Satus	no input	was installed cable new or used
Lead Barrier	no input	
Insulation	no input	
Standard Intake	no input	
Gas Separator	no input	
Gas Handler	no input	

Table A - 4: Benchmark, Data Sheet - Specific ESP Input part 3 [34]



	Protector/Seal Configuration		e.g. LSBPB
	Protector Elastomere	no input	
	System Metallurgy	no input	
	Pump Setting Depth (TVD)		
	Maximum Dogleg		maximum dogleg the ESP has to pass
	Dogleg at ESP setting depth		
	ESP Deployment Method	no input	
	Downhole Sensor installed	no input	
Practices:			
	ESP Surveillance System	no input	

13. Appendix B - Projekthandbuch

Prior the start of my thesis I decided, together with my supervisor from OMV Austria E&P, to create a project management hand book. Therefore, all objectives, work packages and time guidelines are included in this handbook and shown on the following pages.

Projekthandbuch

ESP's in OMV Austria E&P – Performance Analysis and Benchmarking

001

Version 0.4

Projektleiter/in: Ilhami Giden

Datum: 04.06.2014

Änderungsverzeichnis

Versions-nummer	Datum	Änderung	Ersteller
0.2	11.7.14	Adaptierung Ziele von Prof. Hofstätter hinzugefügt	Ilhami Giden
0.3	06.7.14	Kein External Benchmarking, Wärmeenergie von Wasser	Ilhami Giden
0.4	14.8.14	Arbeitspakete für Korrektur eingefügt	Ilhami Giden

Ansprechpartner

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Projektauftrag

<table>
<tr><td>standard projekthandbuch
001</td><td>PROJEKT-
AUFTRAG</td></tr>
<tr><td>Projektstartereignis:
• Projektstartworkshop</td><td>Projektstarttermin:
• 4.6.2014</td></tr>
<tr><td>Inhaltliches Projektendereignis:
• Übergabe der finalen Version der Diplomarbeit
Formales Projektendereignis:
• Endpräsentation der Diplomarbeit</td><td>Projektendtermine:
• 19. 1. 2015
• 19. 1. 2015</td></tr>
<tr><td>Projektziele:
• Status ESP’s in OMV Austria (development of ESP standards)
• Best practice / lessons learned
  • Including: Well selection criteria
  • Including: HSSE aspects
• Performance Analysis (MTBF, Runlife, Lifecycle costs, KPI (development))
  • Including: Performance optimization & control
• Benchmarking (internal)
• Wärmeenergie von Wasser (wie nutzbar)</td><td>Nicht-Projektziele:
• Existierende Best Practice Handbuch updaten
• ESP Designs verbessern
• ESP Monitoring</td></tr>
<tr><td>Hauptaufgaben (Projektphasen):
• Literature Review
• ESP’s in OMV Austria - status
• Best practices and lessons learned in operating ESP’s
• Performance Analysis of ESP’s in OMV Austria E&P
• Benchmarking
• Summary</td><td>Projektressourcen und –kosten:
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Zugang zu GDB, Sondenarchiv, PE-Ordner
Arbeitsplatz</td><td></td><td></td></tr>
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Projektauftraggeber:
- Thomas Florian

Projektleiter:
- Ilhami Giden

Projektteam:
- Fabio Reinweber
- Ilhami Giden

....

Thomas Florian, (Projektauftraggeber)

....

Ilhami Giden, (Projektleiter)

Projektzieleplan

standard projekthandbuch 001	**PROJEKTZIELE-** **PLAN**	
Zielart	**Projektziele**	**Adaptierte Projektziele per …**
Ziele:		
• **Hauptziele**	• Status ESP's in OMV Austria Best practice / lessons learned • Performance Analysis (MTBF, Runlife, Lifecycle costs) • Benchmarking (internal)	
• **Zusatzziele**	• KPI (development) • Development of ESP standards • Occurred ESP Failure reasons – statistics * Sensor data analysis * Well selection criteria * HSSE aspects * Performance optimization & control * Welche Wärmenergie besitzt produziertes Wasser (vl. nutzbar?)	
Nicht-Ziele	* Existierende Best Practice Handbuch updaten * ESP Designs verbessern * ESP Monitoring	

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BESCHREIBUNG VORPROJEKT- UND NACHPROJEKTPHASE

1) Beschreibung von Ergebnissen der Vorprojektphase

Das Projekt betreffende Entscheidungen/Ereignisse. Wie ist es zu dem Projekt gekommen?

ESP's are used in OMV Austria E&P since many years. Until 2012 ESP's were installed in 15 wells. In the majority of the cases these ESP's were high gross volume producers. In 2012 a field redevelopment project (Redevelopment of 16. Torton reservoir) was initiated. One main goal of this project was to increase gross rates in this reservoir to increase oil production. For this gross increase further ESP's were considered as the main artificial lift method. Until summer 2014/15 additional ESP's were installed in a campaign and further 17 will be installed until summer 2015 in another campaign. After having finalized the first campaign, the idea was born to conduct a thesis on the topic of ESP's in OMV Austria E&P.

Für das Projekt relevante Dokumente (zB „Protokoll mit ...“, „Besprechung mit ...“, Inhalt der Dokumente ist hier nicht gefragt, NUR die Dokumente!)

* Thesis Proposal – Fabio Reinweber

*

Erfahrungen aus ähnlichen Projekten

* -

2) Beschreibung von Ergebnissen der Nachprojektphase

Was wird nach dem Projekt passieren (Folgeaktivitäten, -projekte, etc.)?

Projektumwelt-Analyse

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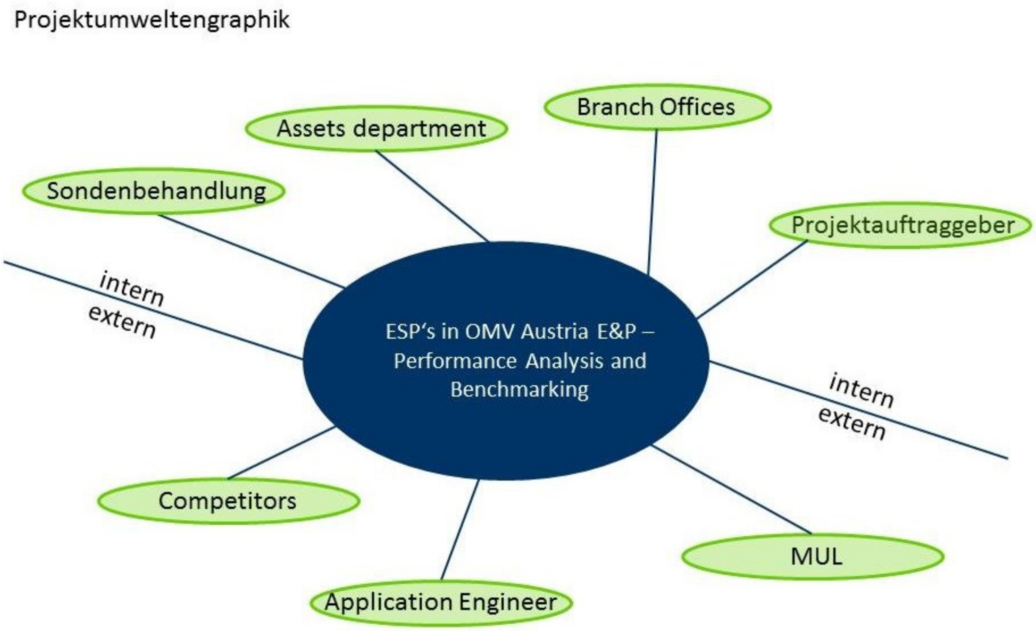
PROJEKTUMWELTEN-GRAPHIK



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PROJEKTUMWELTEN-BEZIEHUNGEN

Umwelten	**Beziehung** (Potential/Konflikt)	**Maßnahmen**	**Wer / Wann** **PSP Code**
Projektauftraggeber	Positiv eingestellt		
Branch offices	Neutral – skeptisch	Informationsemail	
Assets	Neutral – skeptisch	Information und vorstellen	
Sondenbehandlung	Neutral – skeptisch	Information und vorstellen	
MUL	Neutral – skeptisch	Absprachen	
Application engineer	Neutral	Information	
Competitors	kritisch	Internet recherché	

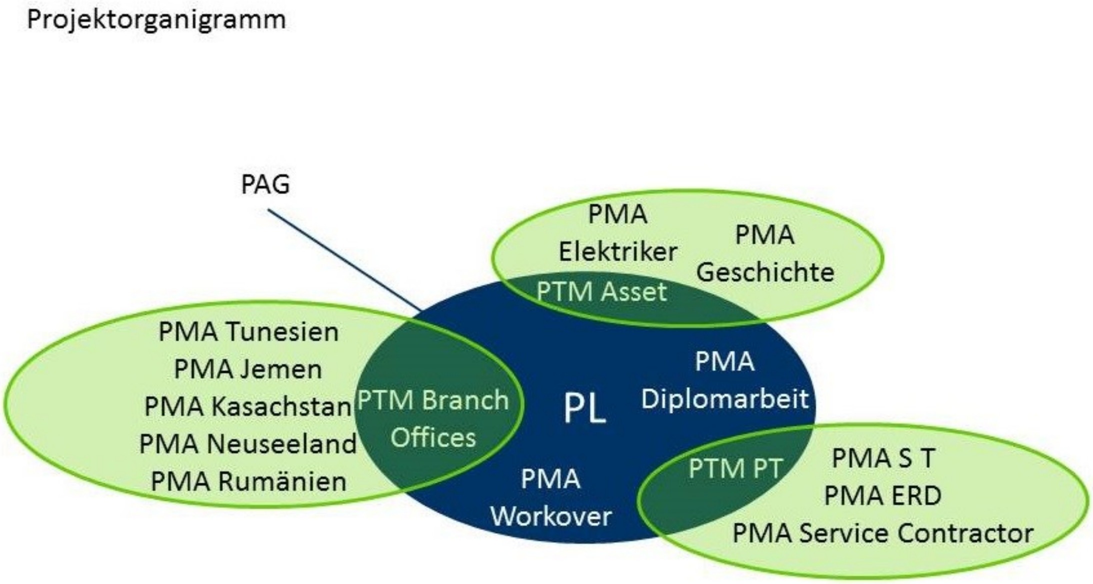
Beziehungen zu anderen Projekten

und Zusammenhang mit den Unternehmenszielen (sachlicher Kontext)

standard projekthandbuch 001	**BEZIEHUNGEN ZU ANDEREN PROJEKTEN**		
Programme/ Projekte/ Kleinprojekte	**Beziehung** (Potential/Konflikt)	**Maßnahmen**	**Wer / Wann** **PSP Code**
	Keine Beziehungen zu anderen Projekten		

standard projekthandbuch 001	**ZUSAMMENHANG ZU DEN UNTERNEHMENSZIELEN**
Unternehmensziele	**Beschreibung des Zusammenhangs**
Produktion für 2014 auf hohem Niveau halten (35900 bbl/d)	ESPs, die einen Teil der Produktion leisten, möchte das Unternehmen einen Status Quo erheben um Optimierungen in Zukunft durchführen zu können.

Projektorganigramm



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PROJEKT-ORGANISATION

Projektrolle	**Aufgabenbereiche/Skills**	**Name**
ProjektauftraggeberIn		Thomas Florian
ProjektleiterIn		Ilhami Giden
Projektmitarbeiter Diplomarbeit	Diplomarbeit erstellen	Fabio Reinweber
Projektteam-Mitglied Asset	Geschichte ESPs in OMV AUT	Josef Hess
Projektteam-Mitglied Production Technology	= gleichzeitig PMA Projekt Schönkirchen Tief Infos	Timur Cimitoglu
Projektmitarbeiter Workover	Geschichte ESPs in OMV AUT	Josef Matzka
Projektteam-Mitglied	Verbindung herstellen mit Branch Offices	Christoph Marschall
Projektmitarbeiter Asset Geschichte	Geschichte ESPs in OMV AUT	Johann Steineder
Projektmitarbeiter Asset Elektrik	Stromaufnahme SRP/ESP	Josef Gerlinger
Projektmitarbeiter PT Erdpreß	Infos Projekt Dual-ESP	Michaela Hoy
Projektmitarbeiter BO	Infos ESPs Jemen	Jesse Terry
Projektmitarbeiter BO	Infos ESPs Tunesien	Jesse Terry
Projektmitarbeiter BO	Infos ESPs Kasachstan	Patrick Bürßner
Projektmitarbeiter BO	Infos ESPs Neuseeland	Michael Milner
Projektmitarbeiter BO	Infos ESPs Rumänien	Sasa Blazekovic

Betrachtungsobjekteplan

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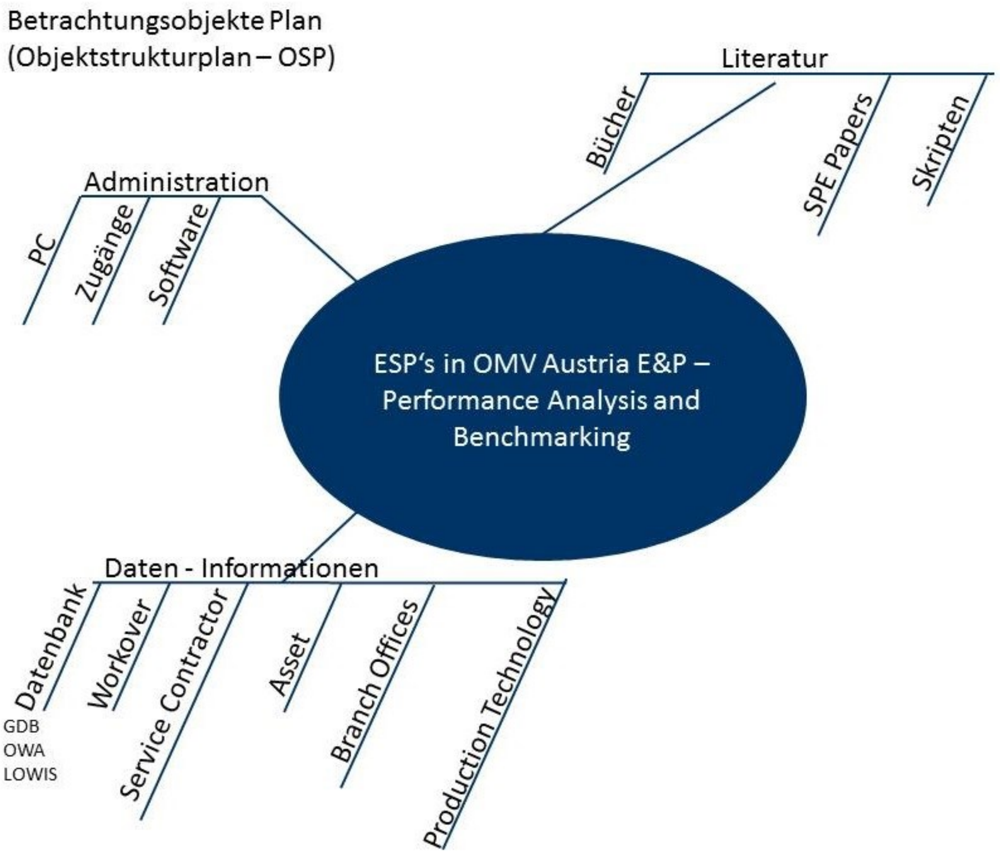
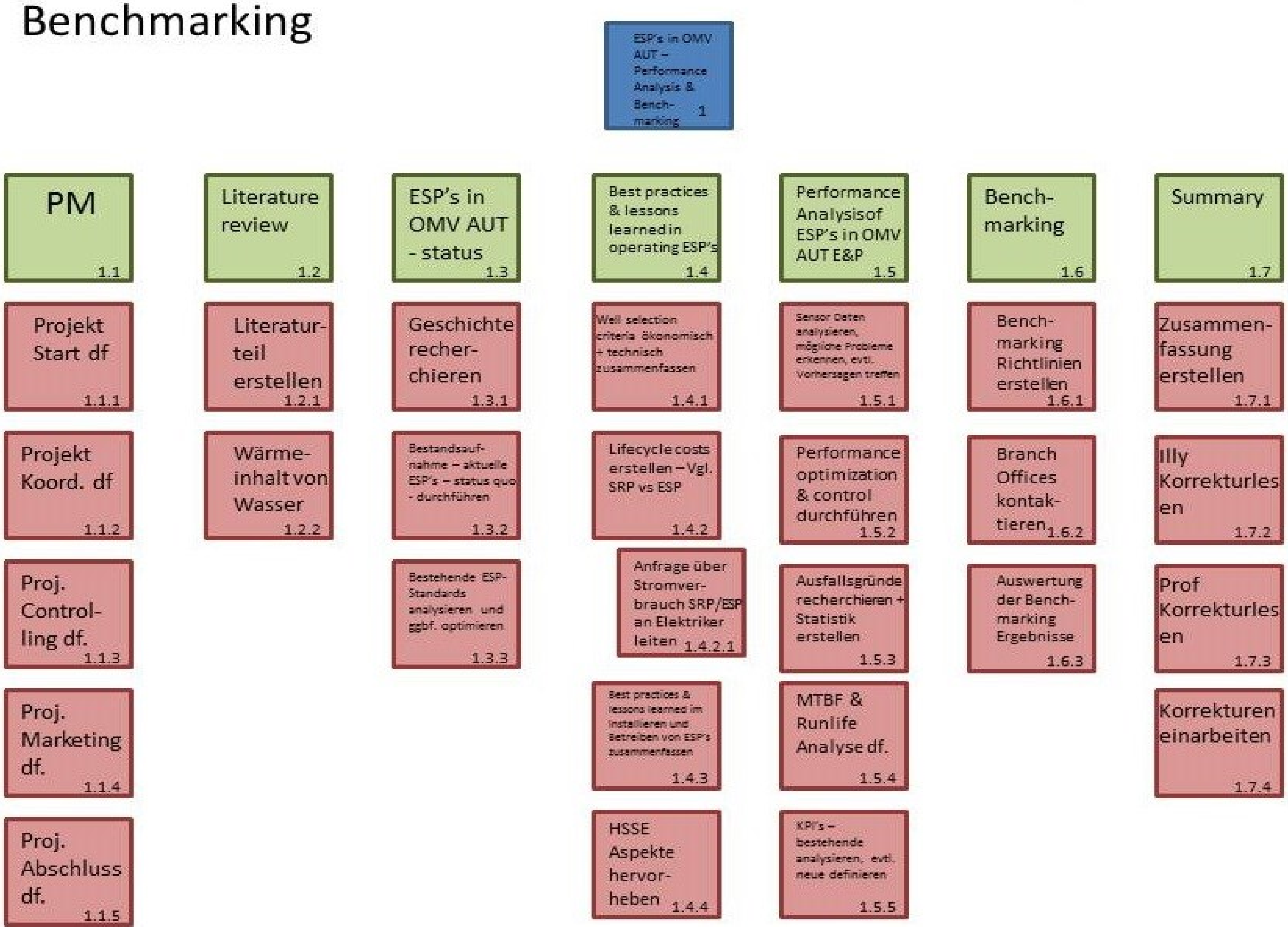


Projektstrukturplan

PSP - ESP's in OMV Austria E&P – Performance Analysis and Benchmarking

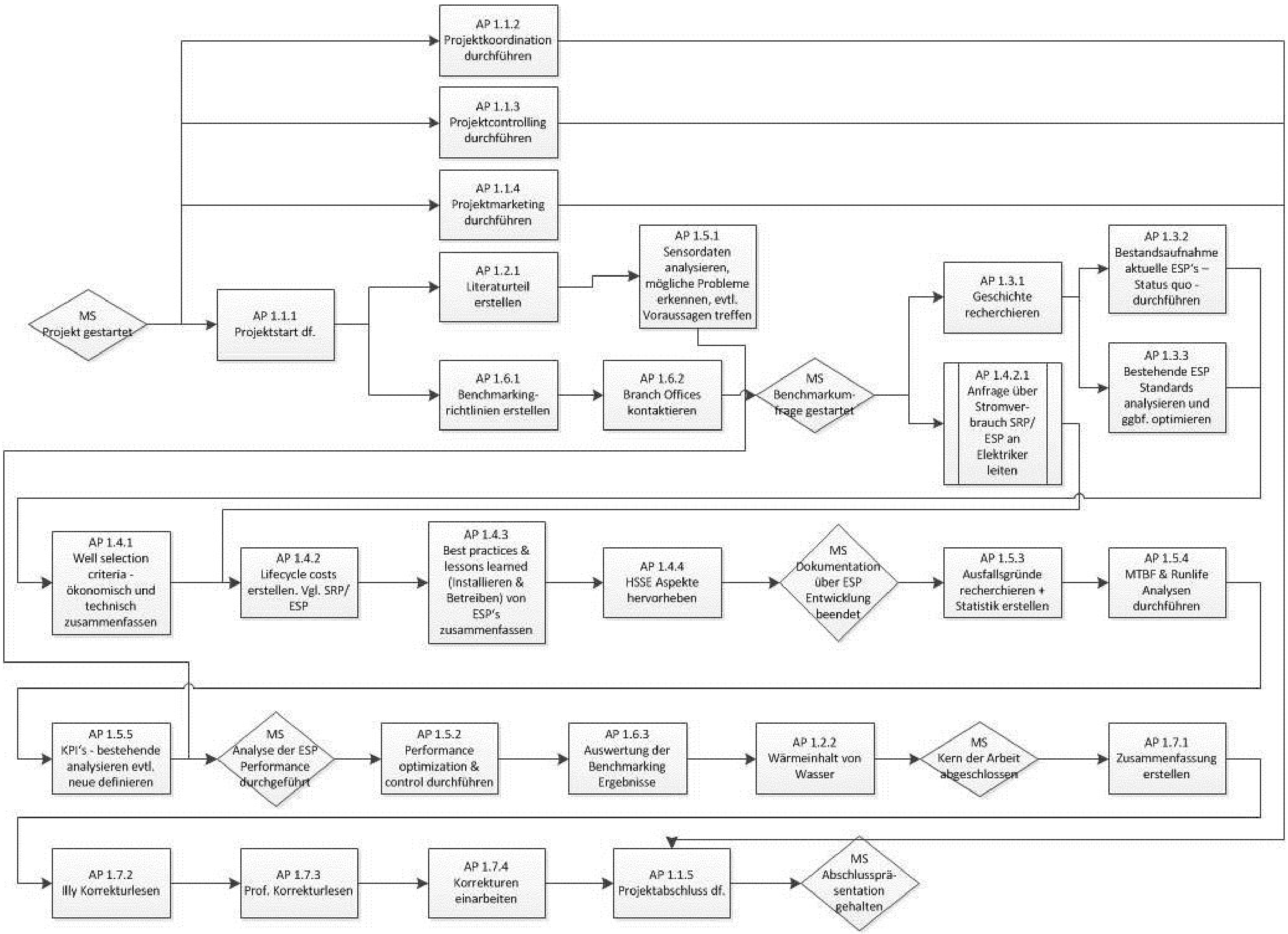


Arbeitspaket-Spezifikationen

standard projekthandbuch 001	**ARBEITSPAKET-SPEZIFIKATIONEN**
PSP-Code 1.2.1 **AP-Bezeichnung:** **Literaturteil erstellen**	**AP-Inhalt** (*Was soll getan werden?)* * Literaturteil für die Diplomarbeit erstellen mit Hilfe von: * Büchern, SPE papers, Skripten, Produktkataloge etc.
PSP-Code 1.3.1 **AP-Bezeichnung** **Geschichte recherchieren**	**AP-Inhalt** (*Was soll getan werden?)* * OMV Mitarbeiter sollen befragt werden, wie die Entwicklung der ESP's in der OMV Austria stattgefunden hat. Folgende Mitarbeiter sollen befragt werden (nach Möglichkeit): * Matzka Josef * Hess Josef * Steineder Johann
PSP-Code 1.3.3 **AP-Bezeichnung** **Bestehende ESP Standards analysieren und ggf. optimieren**	**AP-Inhalt** (*Was soll getan werden?)* * Bestandsaufnahme, wie die aktuellen ESP Typen zustande gekommen sind und ob die ursprünglich angenommenen Kriterien erfüllt werden. * Analysieren, ob die vorgenommene Gruppierung der ESP's weiter verbessert werden kann * Analysieren, ob die vorgenommene Gruppierung der ESP's auch für zukünftige Projekte Gültigkeit besitzt
	AP-Nicht-Inhalte (*Was soll nicht getan werden?)* * Neu-einführung von Untergruppen
PSP-Code 1.5.1 **AP-Bezeichnung** **Sensor Daten analysieren,**	**AP-Inhalt** (*Was soll getan werden?)* * Allgemeine Informationen über Sensoren bei ESP's sollen gesammelt werden. * Vor- und Nachteile von Sensoren sollen dargestellt werden. * Welche ESP Zustände, kann man durch welche Sensorparameter erkennen?

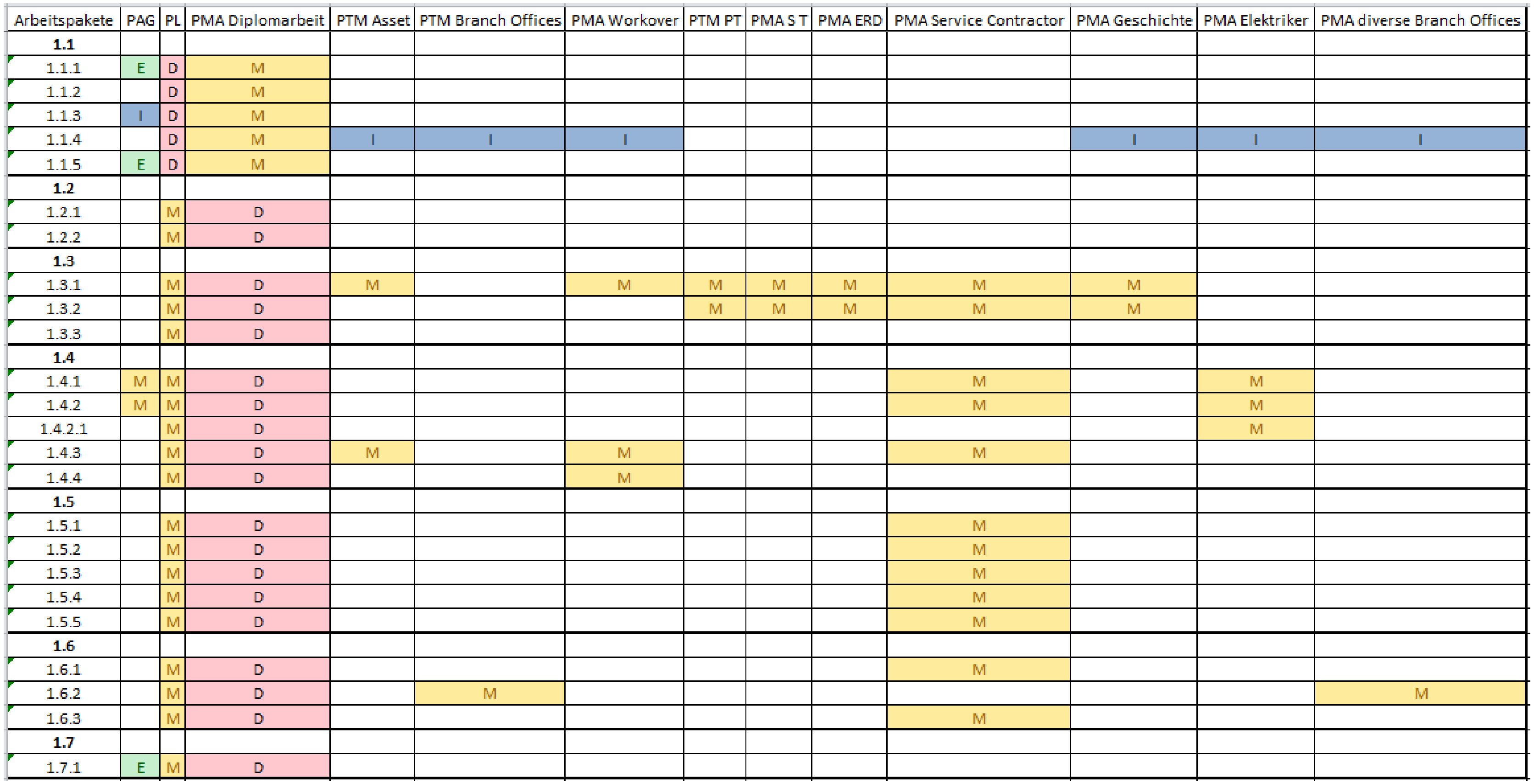
mögliche Probleme erkennen, evtl. Vorhersagen treffen	* Kann man Vorhersagen bzgl. der nahen Zukunft der ESP treffen? *
	AP-Nicht-Inhalte *(Was soll nicht getan werden?)* * OMV ESP Sensordaten analysieren. *
PSP-Code 1.5.2 **AP-Bezeichnung** **Performance Optimization & Control durchführen**	**AP-Inhalt** *(Was soll getan werden?)* * OMV ESP’s anhand der Sensordaten analysieren (Momentaufnahme) * Interessante Vorkommnisse, die anhand von Sensordaten aufgezeigt werden können * Ggbf. Vorschläge, wie das Kontrollieren der Performance durchgeführt und verbessert werden kann
	AP-Nicht-Inhalte *(Was soll nicht getan werden?)* * Permanente Überwachung der OMV ESP‘s
PSP-Code 1.5.5 **AP-Bezeichnung** **KPI’s – bestehende analysieren evtl. neue definieren**	**AP-Inhalt** *(Was soll getan werden?)* * Industrieweite KPI’s in Bezug auf ESP’s aufzeigen + Vorteile, Nachteile * Wenn möglich angewandte Beispiele mit vorhandenen Daten bringen * Wenn möglich KPI’s zeitlich dynamisch gestalten
PSP-Code 1.6.1 **AP-Bezeichnung** **Benchmarking Richtlinien erstellen**	**AP-Inhalt** *(Was soll getan werden?)* * Evtl. Benchmarking in anderen Industrien * Aufzeigen, ob es industrieweite Methoden des Benchmarking bzgl. ESP’s gibt * Definieren welche Parameter, KPI’s etc. verglichen werden sollen, damit man Gemeinsamkeiten und Unterschiede im Betreiben von ESP’s erkennen kann, z.B. MTBF, Runlife, Umfeldbedingungen (Gas, Sand/Sedimente, Ölparameter, Reservoirparameter, On-/Offshore,…),…

Netzplan


AP 1.1.2 Projektkoordination durchführen
AP 1.1.3 Projektcontrolling durchführen
AP 1.1.4 Projektmarketing durchführen
MS Projekt gestartet
AP 1.1.1 Projektstart df.
AP 1.2.1 Literaturteil erstellen
AP 1.5.1 Sensordaten analysieren, mögliche Probleme erkennen, evtl. Voraussagen treffen
AP 1.6.1 Benchmarking-richtlinien erstellen
AP 1.6.2 Branch Offices kontaktieren
MS Benchmarkumfrage gestartet
AP 1.3.1 Geschichte recherchieren
AP 1.4.2.1 Anfrage über Stromverbrauch SRP/ ESP an Elektriker leiten
AP 1.3.2 Bestandsaufnahme aktuelle ESP's – Status quo - durchführen
AP 1.3.3 Bestehende ESP Standards analysieren und ggbf. optimieren
AP 1.4.1 Well selection criteria - ökonomisch und technisch zusammenfassen
AP 1.4.2 Lifecycle costs erstellen. Vgl. SRP/ ESP
AP 1.4.3 Best practices & lessons learned (Installieren & Betreiben) von ESP's zusammenfassen
AP 1.4.4 HSSE Aspekte hervorheben
MS Dokumentation über ESP Entwicklung beendet
AP 1.5.3 Ausfallsgründe recherchieren + Statistik erstellen
AP 1.5.4 MTBF & Runlife Analysen durchführen
AP 1.5.5 KPI's - bestehende analysieren evtl. neue definieren
MS Analyse der ESP Performance durchgeführt
AP 1.5.2 Performance optimization & control durchführen
AP 1.6.3 Auswertung der Benchmarking Ergebnisse
AP 1.2.2 Wärmeinhalt von Wasser
MS Kern der Arbeit abgeschlossen
AP 1.7.1 Zusammenfassung erstellen
AP 1.7.2 Illy Korrekturlesen
AP 1.7.3 Prof. Korrekturlesen
AP 1.7.4 Korrekturen einarbeiten
AP 1.1.5 Projektabschluss df.
MS Abschlusspräsentation gehalten

Projektfunktionendiagramm

Funktionen
D ....Durchführungsverantwortung
M ....Mitarbeit
I ....bekommt Information
E.........Evaluiert



Arbeitspakete	PAG	PL	PMA Diplomarbeit	PTM Asset	PTM Branch Offices	PMA Workover	PTM PT	PMA S T	PMA ERD	PMA Service Contractor	PMA Geschichte	PMA Elektriker	PMA diverse Branch Offices
1.1													
1.1.1	E	D	M										
1.1.2		D	M										
1.1.3	I	D	M										
1.1.4		D	M	I	I	I					I	I	I
1.1.5	E	D	M										
1.2													
1.2.1		M	D										
1.2.2		M	D										
1.3													
1.3.1		M	D	M		M	M	M	M	M	M		
1.3.2		M	D				M	M	M	M	M		
1.3.3		M	D										
1.4													
1.4.1	M	M	D							M		M	
1.4.2	M	M	D							M		M	
1.4.2.1		M	D									M	
1.4.3		M	D	M		M				M			
1.4.4		M	D			M							
1.5													
1.5.1		M	D							M			
1.5.2		M	D							M			
1.5.3		M	D							M			
1.5.4		M	D							M			
1.5.5		M	D							M			
1.6													
1.6.1		M	D							M			
1.6.2		M	D		M								M
1.6.3		M	D							M			
1.7													
1.7.1	E	M	D										

Projektmeilensteinplan

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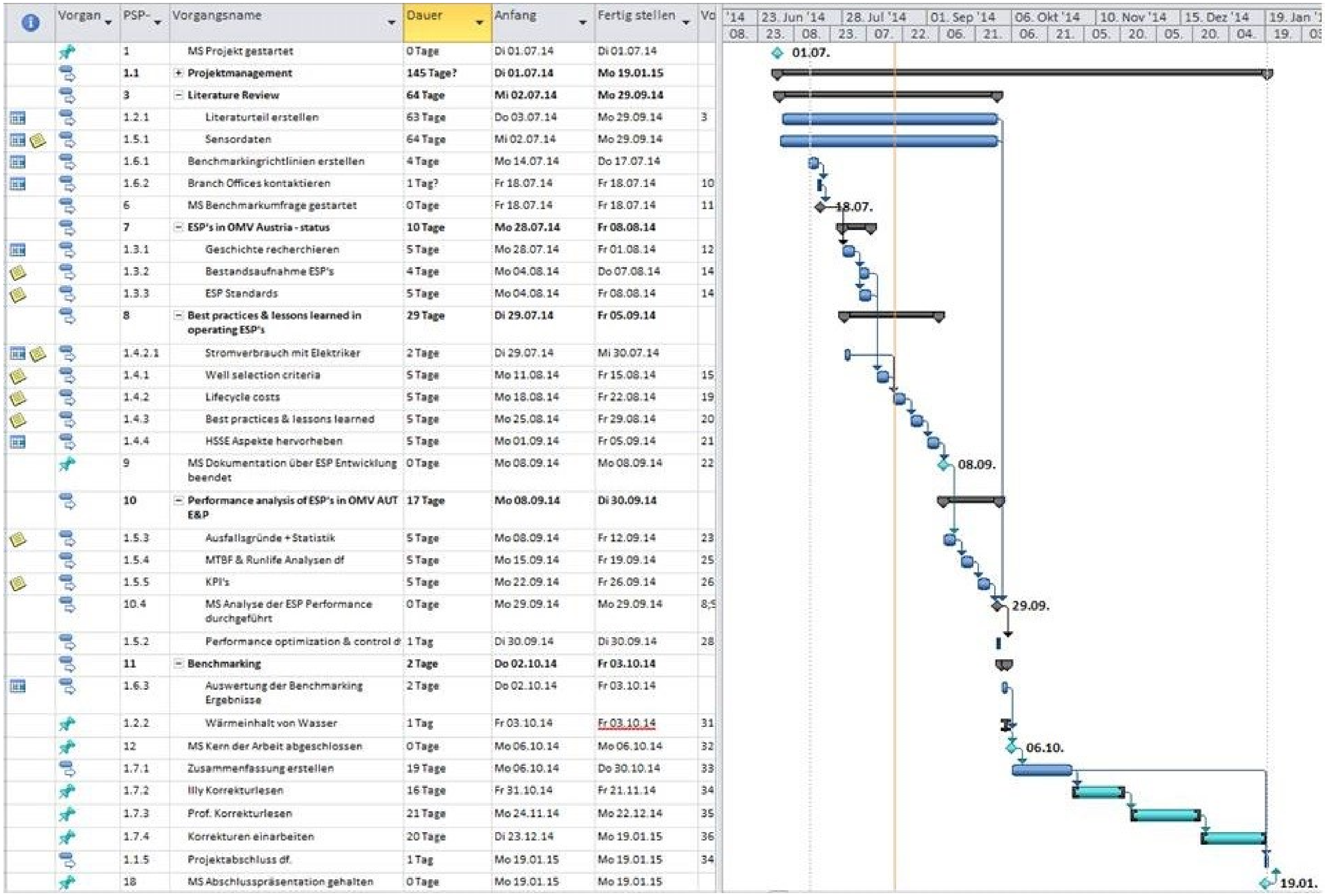
PROJEKT-

MEILENSTEINPLAN

PSP-Code	Meilenstein	Basis-termine	Aktuelle Plantermine	Ist Termine
	Projekt gestartet	1.7.2014	1.7.2014	
	Benchmarkumfrage gestartet	18.7.2014	18.7.2014	
	Dokumentation über ESP Entwicklung beendet	8.9.2014	8.9.2014	
	Analyse der ESP Performance durchgeführt	29.9.2014	29.9.2014	
	Kern der Arbeit abgeschlossen	6.10.2014	6.10.2014	
	Abschlusspräsentation gehalten	19.1.2015	19.1.2015	

*Termine chronologisch nach Planterminen reihen!

Projektbalkenplan



Vorgan	PSP-	Vorgangsname	Dauer	Anfang	Fertig stellen	Vo
	1	MS Projekt gestartet	0 Tage	Di 01.07.14	Di 01.07.14	
	1.1	**+ Projektmanagement**	**145 Tage?**	**Di 01.07.14**	**Mo 19.01.15**	
	3	**− Literature Review**	**64 Tage**	**Mi 02.07.14**	**Mo 29.09.14**	
	1.2.1	Literaturteil erstellen	63 Tage	Do 03.07.14	Mo 29.09.14	3
	1.5.1	Sensordaten	64 Tage	Mi 02.07.14	Mo 29.09.14	
	1.6.1	Benchmarkingrichtlinien erstellen	4 Tage	Mo 14.07.14	Do 17.07.14	
	1.6.2	Branch Offices kontaktieren	1 Tag?	Fr 18.07.14	Fr 18.07.14	10
	6	MS Benchmarkumfrage gestartet	0 Tage	Fr 18.07.14	Fr 18.07.14	11
	7	**− ESP's in OMV Austria - status**	**10 Tage**	**Mo 28.07.14**	**Fr 08.08.14**	
	1.3.1	Geschichte recherchieren	5 Tage	Mo 28.07.14	Fr 01.08.14	12
	1.3.2	Bestandsaufnahme ESP's	4 Tage	Mo 04.08.14	Do 07.08.14	14
	1.3.3	ESP Standards	5 Tage	Mo 04.08.14	Fr 08.08.14	14
	8	**− Best practices & lessons learned in operating ESP's**	**29 Tage**	**Di 29.07.14**	**Fr 05.09.14**	
	1.4.2.1	Stromverbrauch mit Elektriker	2 Tage	Di 29.07.14	Mi 30.07.14	
	1.4.1	Well selection criteria	5 Tage	Mo 11.08.14	Fr 15.08.14	15
	1.4.2	Lifecycle costs	5 Tage	Mo 18.08.14	Fr 22.08.14	19
	1.4.3	Best practices & lessons learned	5 Tage	Mo 25.08.14	Fr 29.08.14	20
	1.4.4	HSSE Aspekte hervorheben	5 Tage	Mo 01.09.14	Fr 05.09.14	21
	9	MS Dokumentation über ESP Entwicklung beendet	0 Tage	Mo 08.09.14	Mo 08.09.14	22
	10	**− Performance analysis of ESP's in OMV AUT E&P**	**17 Tage**	**Mo 08.09.14**	**Di 30.09.14**	
	1.5.3	Ausfallsgründe + Statistik	5 Tage	Mo 08.09.14	Fr 12.09.14	23
	1.5.4	MTBF & Runlife Analysen df	5 Tage	Mo 15.09.14	Fr 19.09.14	25
	1.5.5	KPI's	5 Tage	Mo 22.09.14	Fr 26.09.14	26
	10.4	MS Analyse der ESP Performance durchgeführt	0 Tage	Mo 29.09.14	Mo 29.09.14	8;9
	1.5.2	Performance optimization & control d	1 Tag	Di 30.09.14	Di 30.09.14	28
	11	**− Benchmarking**	**2 Tage**	**Do 02.10.14**	**Fr 03.10.14**	
	1.6.3	Auswertung der Benchmarking Ergebnisse	2 Tage	Do 02.10.14	Fr 03.10.14	
	1.2.2	Wärmeinhalt von Wasser	1 Tag	Fr 03.10.14	Fr 03.10.14	31
	12	MS Kern der Arbeit abgeschlossen	0 Tage	Mo 06.10.14	Mo 06.10.14	32
	1.7.1	Zusammenfassung erstellen	19 Tage	Mo 06.10.14	Do 30.10.14	33
	1.7.2	Illy Korrekturlesen	16 Tage	Fr 31.10.14	Fr 21.11.14	34
	1.7.3	Prof. Korrekturlesen	21 Tage	Mo 24.11.14	Mo 22.12.14	35
	1.7.4	Korrekturen einarbeiten	20 Tage	Di 23.12.14	Mo 19.01.15	36
	1.1.5	Projektabschluss df.	1 Tag	Mo 19.01.15	Mo 19.01.15	34
	18	MS Abschlusspräsentation gehalten	0 Tage	Mo 19.01.15	Mo 19.01.15	

14. Appendix C - Sensor trend analysis plot

OMV well at 04.03.2014:

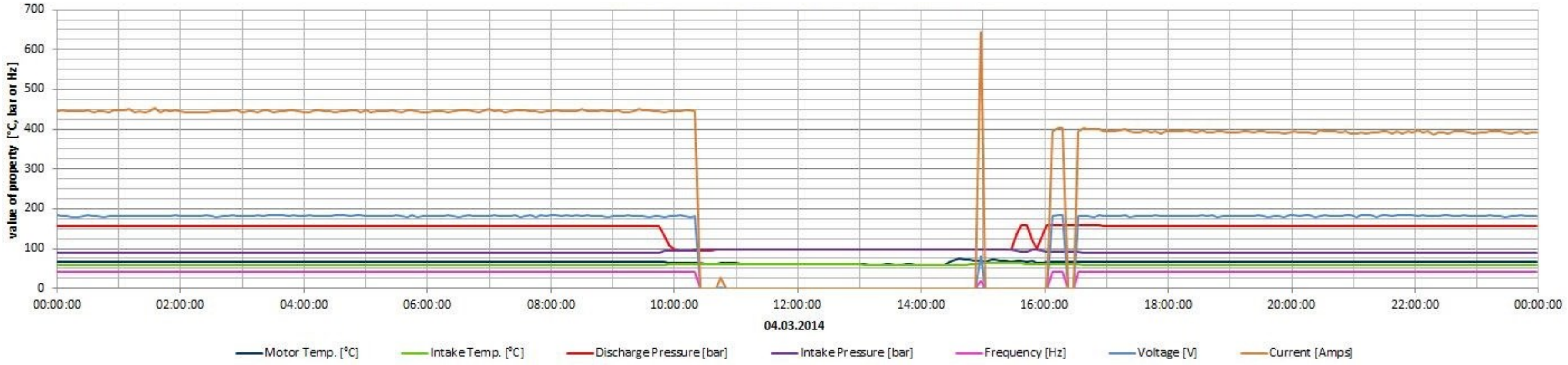


Figure C - 1: OMV Austria E&P Sensor data (04.03.2014) [38]

OMV well at 28.03.-01.04.2014:

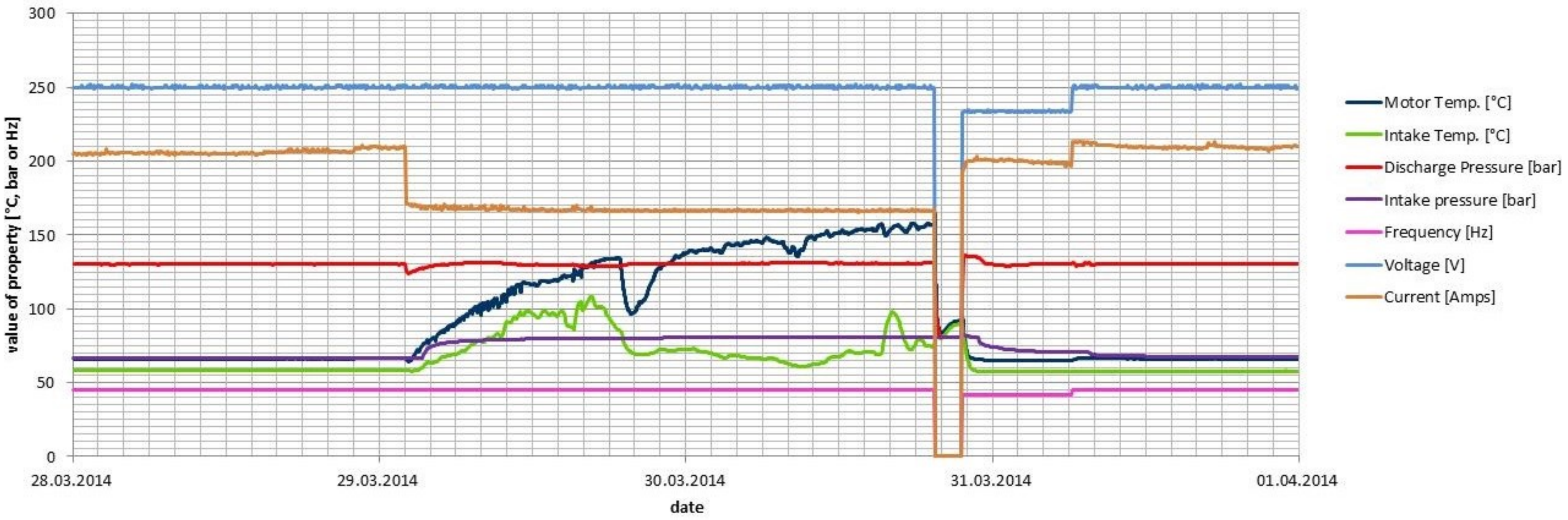


Figure C - 2: OMV Austria E&P Sensor data (28.03-01.04.2014) [38]

OMV Austria E&P production test facility:

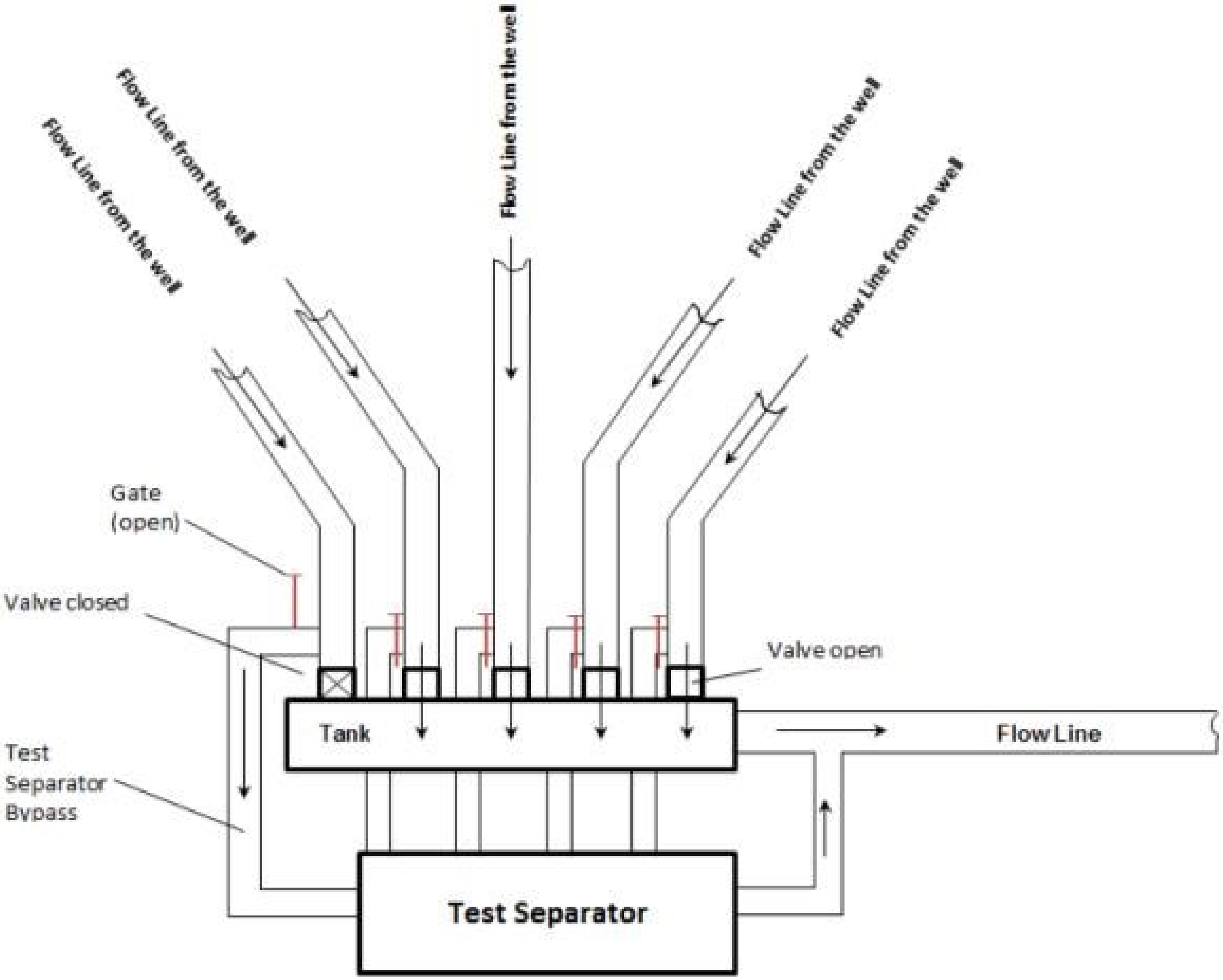


Figure C - 3: Sketch of OMV Austria E&P production test facility [38]

15. Appendix D – Additional Explanations

Inflow Performance Relationship, IPR:

For conditions where the well flowing pressure is above the bubble point pressure, the IPR curve can be expressed as straight line, *figure D-1*. Therefore, the PI, slope of the line, can be calculated with equation 1. The absolute open flow potential (AOFP) refers to the maximum rate, a well is able to flow, against a “theoretical” atmospheric reservoir backpressure. [4]

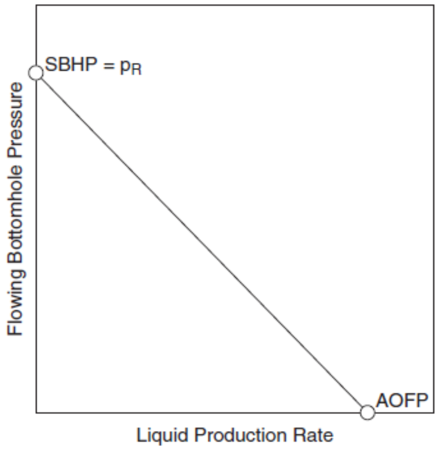


Figure D - 1: IPR curve ($p_{wf} > p_b$) [7, p. 12]

For conditions where P_{wf} is below P_b, the IPR curve is shaped and described by the Vogel equation, see *figure D-2*.

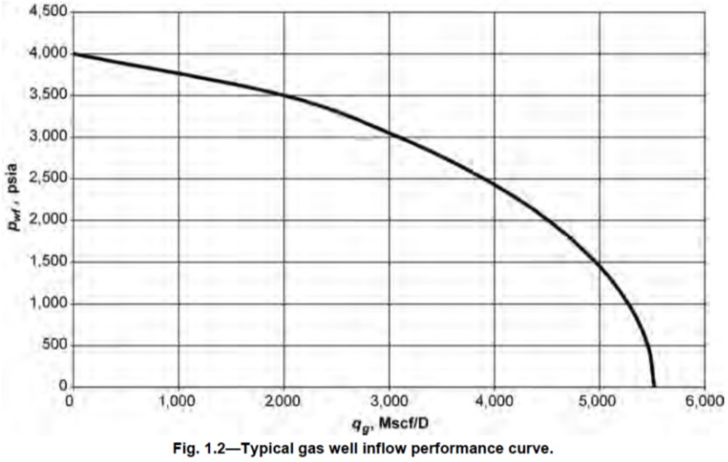


Figure D - 2: IPR curve by Vogel ($p_{wf}<p_b$) [4, p. 7]

Formation Volume Factor Oil, B_O:

The formation volume factor describes the ratio of the oil volume at reservoir conditions (pressure and temperature) divided by the volume of oil at standard conditions (14.5-psi, 273-K).

Equation D - 1: Oil Formation Volume Factor [4, p. 689]

$$B_O = 0.972 + 0.000147\, F^{1.175}$$

$$with\ F = R_s\left(\frac{SG_g}{SG_o}\right)^{0.5} + 1.25\, T_F$$

Formation Volume Factor Gas, B_G:

Equation D - 2: Gas Formation Volume Factor [4, p. 689]

$$B_G = \frac{5.04\, Z\, T_R}{p}$$

For B_G at the pump intake, p needs to be replaced by PIP.

Solution Gas/Oil Ratio, R_S:

Equation D - 3: Solution Gas/Oil Ratio 4, p. 689]

$$R_s = SG_g\left[\frac{p_b}{18}\,\frac{10^{0.0125\ °API}}{10^{0.00091\ T_F}}\right]^{1.2048}$$

For the solution GOR at the pump intake, the p_b needs to be replaced by the PIP.

Friction loss within the tubing:

Such chart (*figure D-3*) will be provided by the pump vendor or service company.

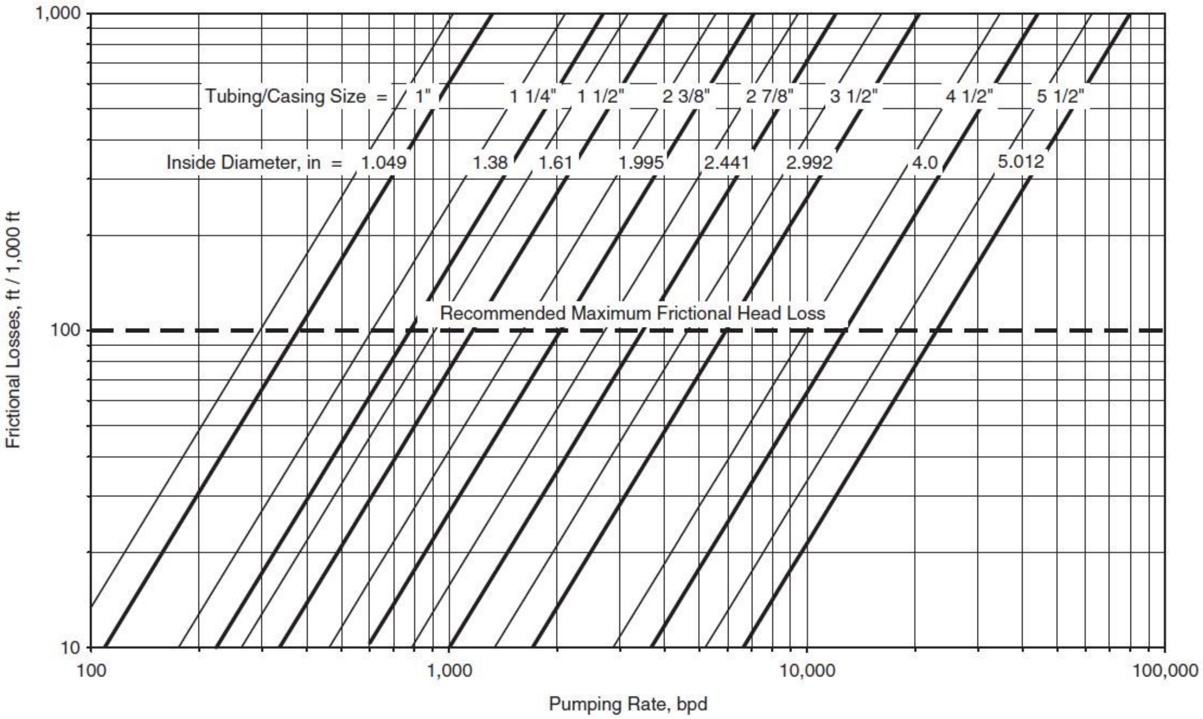


Figure D - 3: Friction pressure losses within the tubing [7, p. 360]

ESP pump performance curve:

In this curve (individual for ESP and RPM) the pump efficiency (green), brake horsepower (required horsepower, red) and head capacity (blue) per stage are shown. To receive the total head the pump is able to operate, the head per stage has to multiply with the total number of stages. These curves, provided for 50-Hz or 60-Hz, uses always water (SG=1) as reference medium. The operating range area indicates the best efficiency area. Outside (down- and upthrust region), the pump operates with higher wear. The best efficiency point BEP, is indicated by the peak of the efficiency curve. [4]

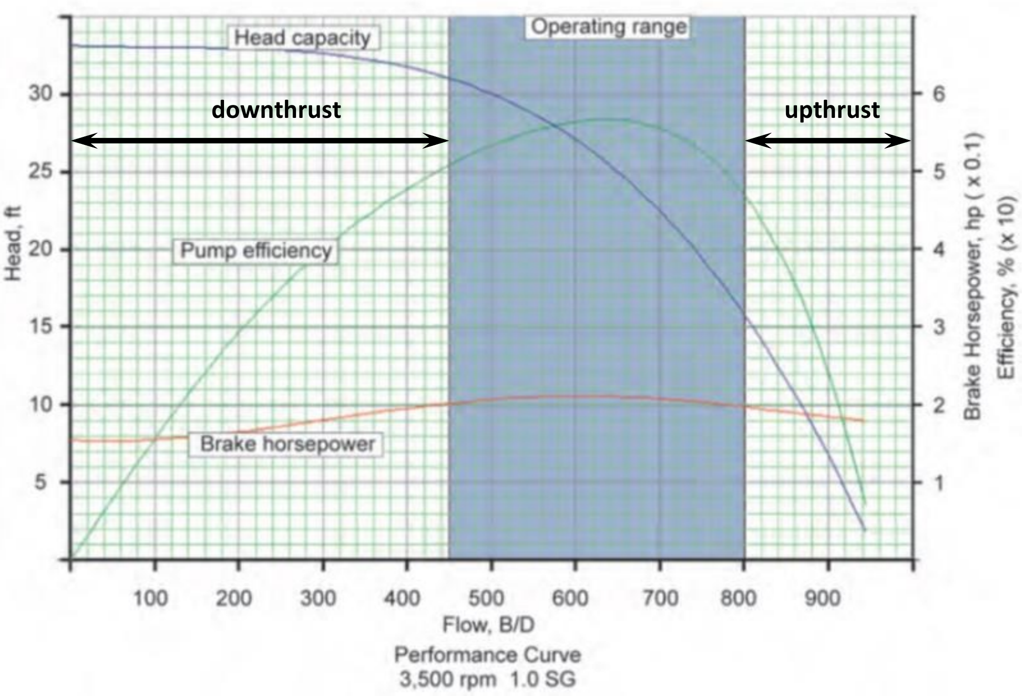


Figure D - 4: ESP pump performance curve [4, p. 639]

Multi frequency curve:

This curve, *figure D-5*, is valid for one single pump. The head on the left side is achieved for one stage and the flow rate will be measured in barrel per day. A simplification of such a curve for all tender ESP's in OMV Austria E&P can be seen in this master thesis.

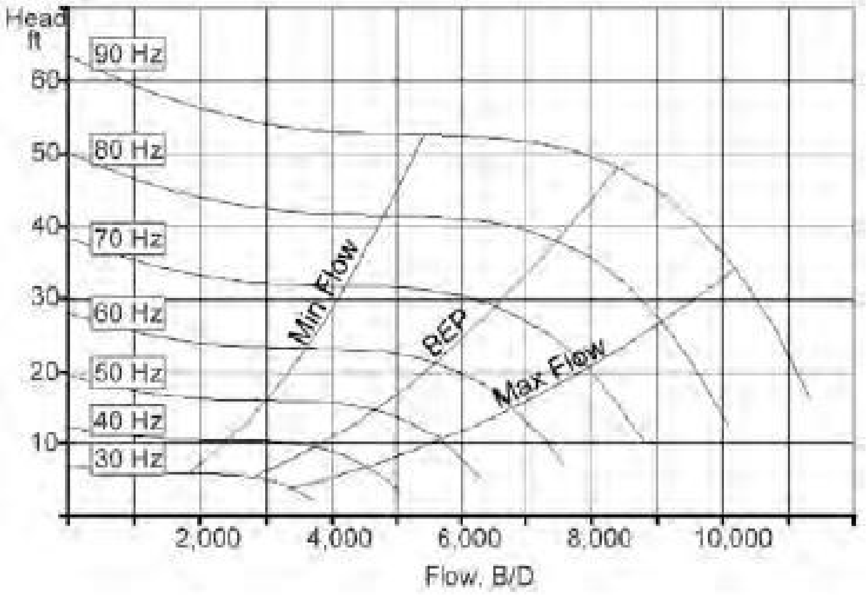


Figure D - 5: ESP multi frequency curve [4, p. 664]

Spar Transformer:

Spar transformers consist only of one coil which is used for the primary and secondary circuit. Therefore, the part where primary and secondary coil is used together is called “parallel winding” and the other part, which is either used for the primary or secondary circuit, is called “serial winding” (*figure D-6*). [36]

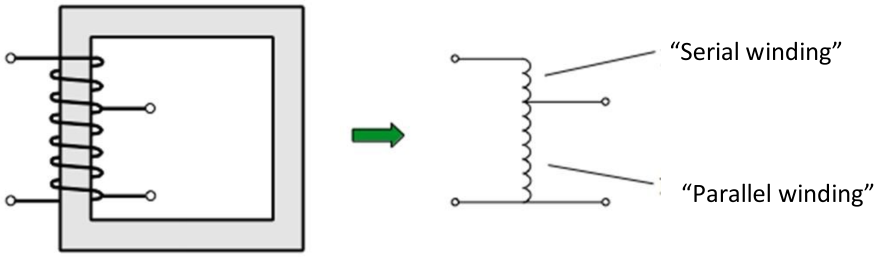


Figure D - 6: Principal drawing of spar transformer [36]

Due to the combined usage of the winding, the energy would be transferred via the direct connection of primary and secondary side as well as due to the magnetic field, within the iron core, see *figure D-7*. [36]

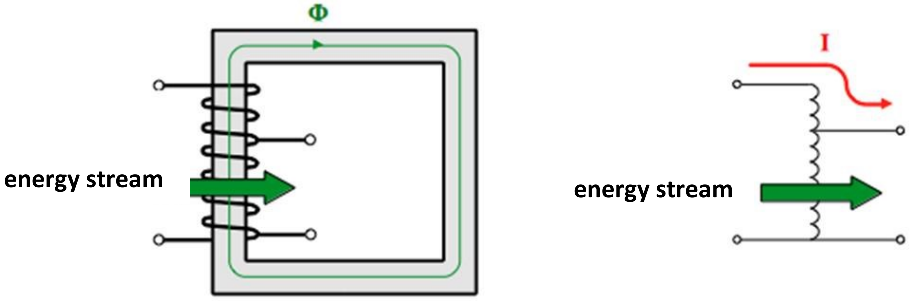


Figure D - 7: Energy transport via a spar transformer [36]

Related to the figures, it can directly been seen that just one coil is used which results in saving of coil material. Additional to them, the saving will be increased to the fact that only a part of the energy will be transferred via the iron cor. The volume of the core and therefore the material, iron, can be reduced.

Geothermal Heat, Q:

The heat of the produced water, in OMV Austria E&P, can be used for heating purposes, see chapter 6.1. Equation D-4 show how the amount of heat [kJ] can be calculated.

Equation D - 4: Geothermal Heat [37]

$$\Delta Q = c \times m \times \Delta T$$

16. Appendix E – OMV Austria E&P Benchmark

Analysis of ESP vendors:

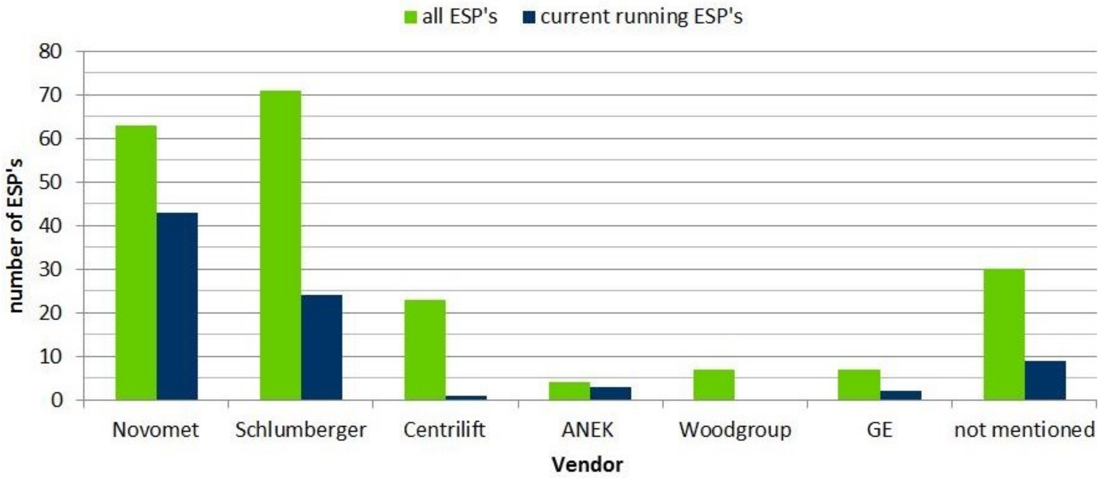


Figure E - 1: ESP vendors, OMV branch offices

Not mentioned means, no input in the Excel data sheet of the corresponding branch office.

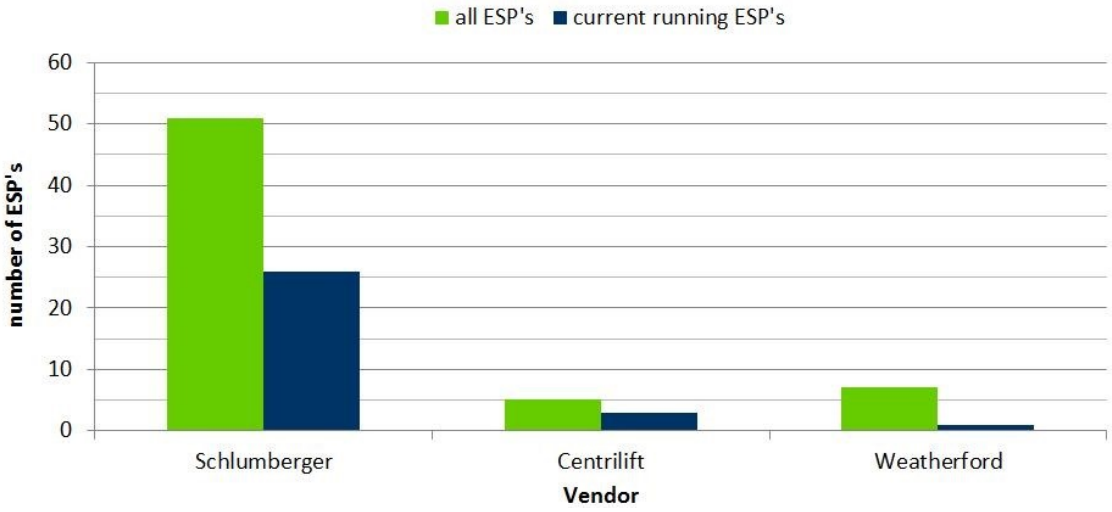


Figure E - 2: ESP vendors, OMV Austria E&P

Analysis of ESP operating rate:

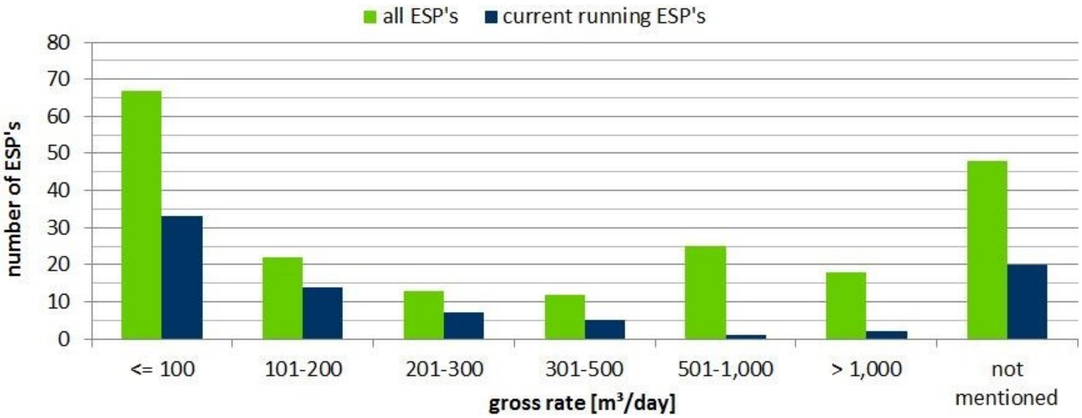


Figure E - 3: ESP operating rate, OMV branch offices

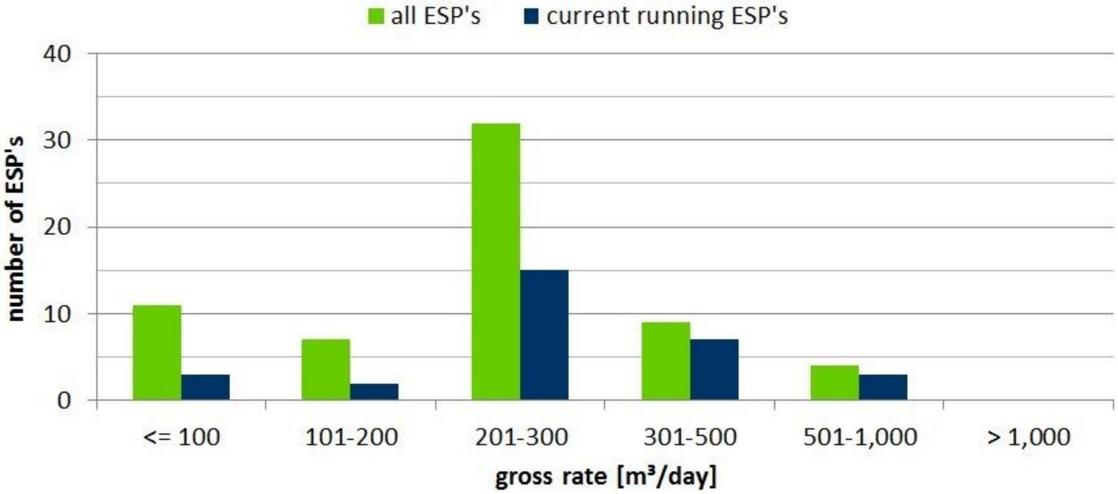


Figure E - 4: ESP operating rate, OMV Austria E&P

Analysis of ESP operating GOR:

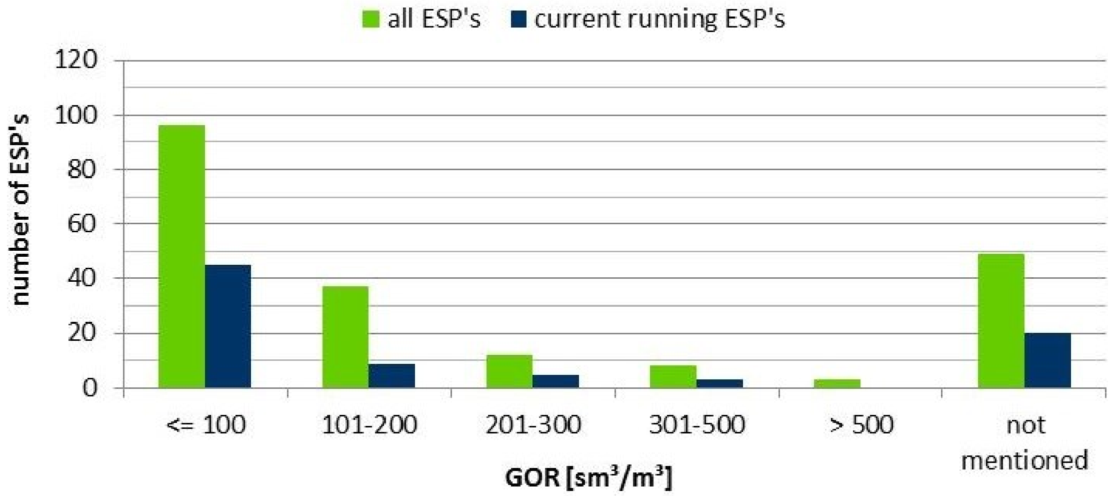


Figure E - 5: ESP operating GOR, branch offices

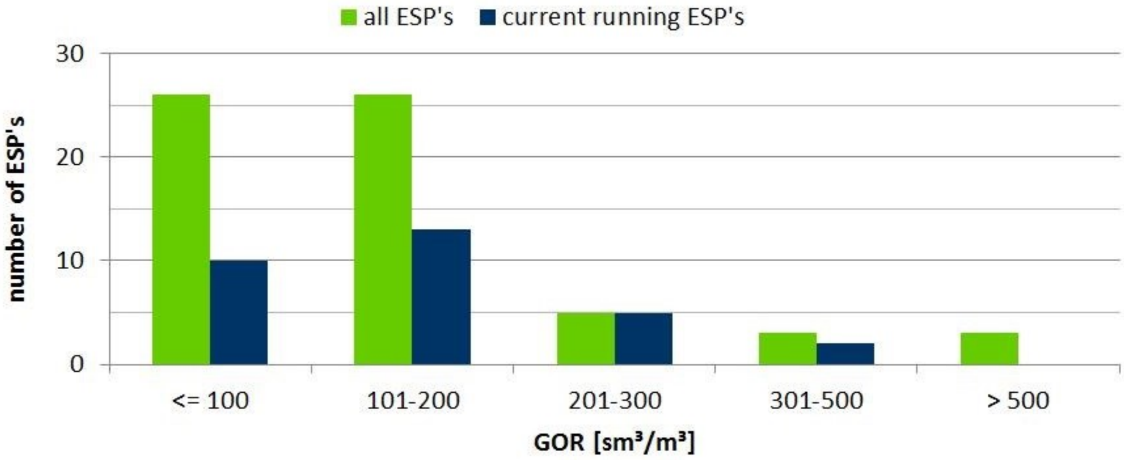


Figure E - 6: ESP operating GOR, OMV Austria E&P

Analysis of ESP setting depth:

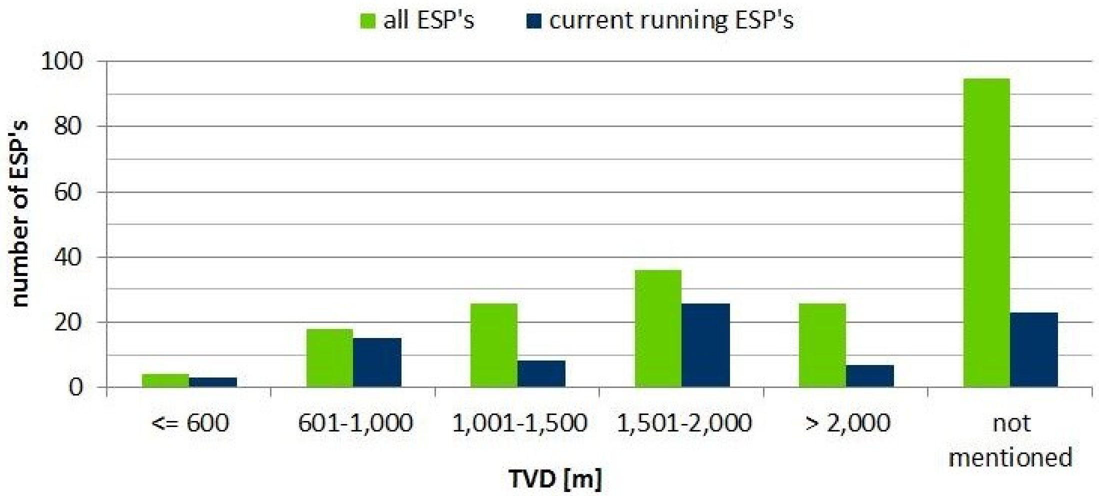


Figure E - 7: ESP setting depth, branch offices

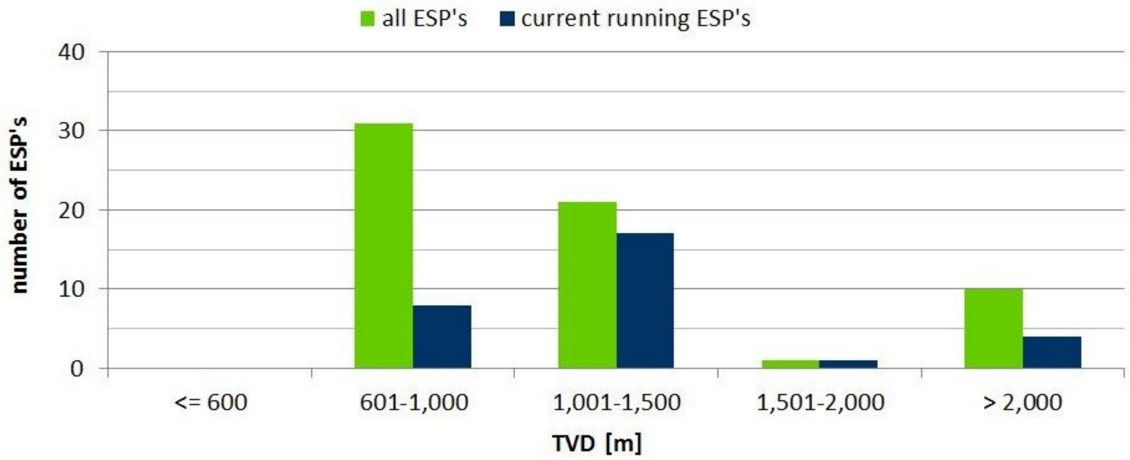


Figure E - 8: ESP setting depth, OMV Austria E&P

Analysis of ESP gas handling device:

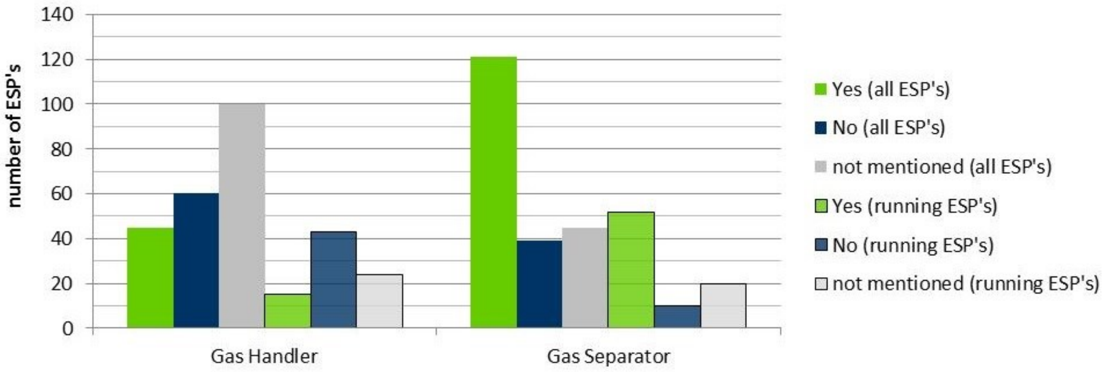


Figure E - 9: ESP gas handling device, branch offices

In OMV Austria E&P, no gas handler is installed.

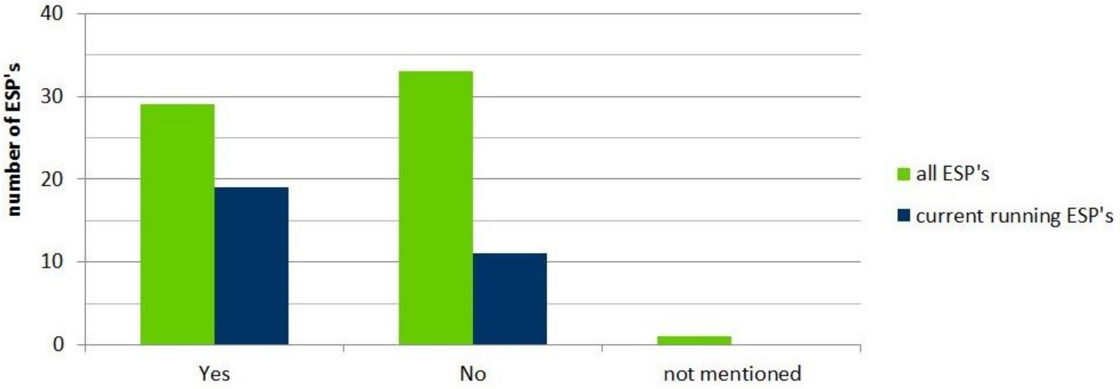


Figure E - 10: ESP gas separator, OMV Austria E&P

Analysis of ESP failures:

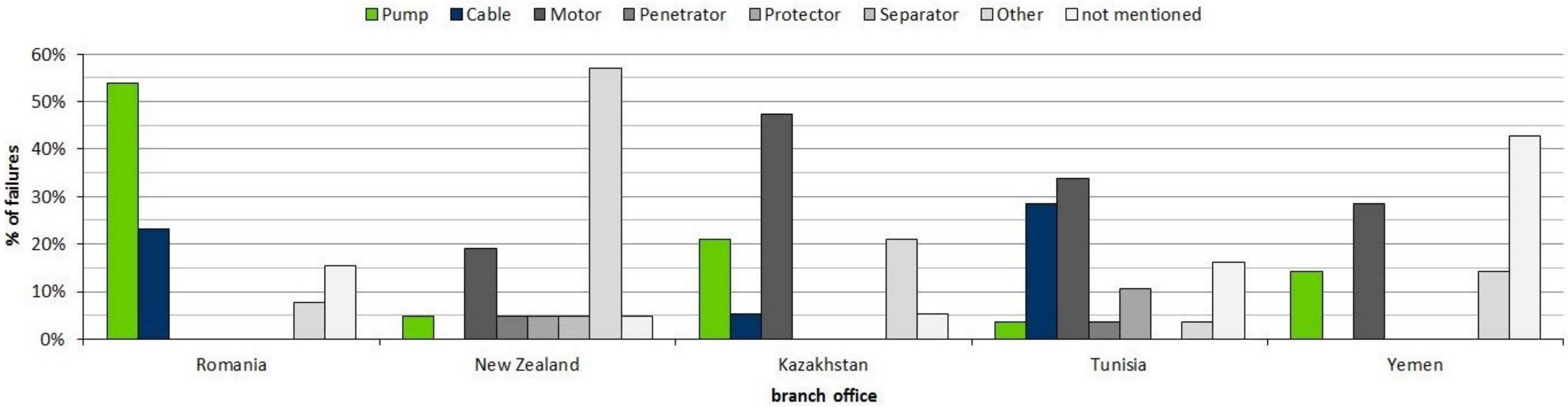


Figure E - 11: ESP failures, branch offices

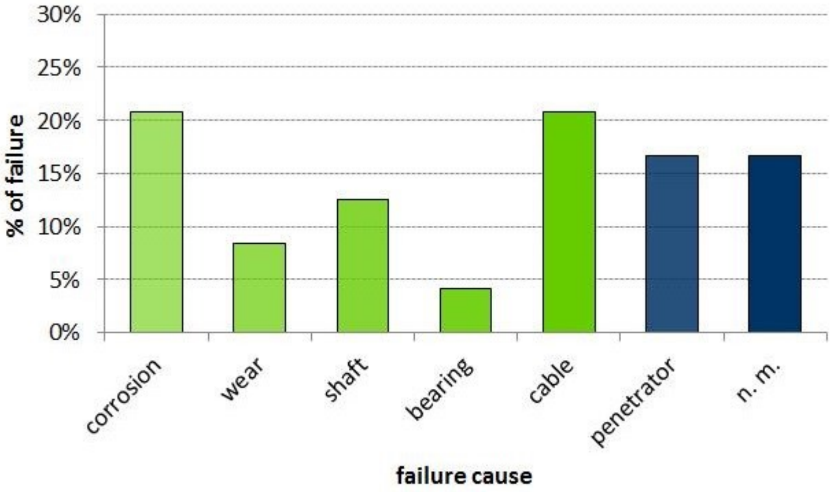


Figure E - 12: ESP failures, OMV Austria E&P