Pump Test Facility for research, testing, training, and teaching

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Abstract

This paper presents the Pump Test Facility at Montanuniversitaet Leoben and describes its application for testing, training and teaching as part of the cloud-based testing and learning architecture of the university.

The cloud-based testing and learning architecture consists of three connected levels: Facility & Hands-on Training Level, Data Center & Administration Level and Teaching & Data Analytics Level. Accordingly, Pump Test Facility aims for testing field equipment, like Sucker Rod Pumps, Electric Submersible Pumps, Rod Strings, etc. under various field conditions while offering hands-on training to students within the educational program. The recorded data is stored on a data center for visualization and future access and during special courses, the students retrieve it for big data analytics and cloud processing to provide feedback and operation optimizations for running the facility.

The idea behind the construction of Pump Test Facility, which is to successfully allow the combination of research and education in the field of artificial lift systems, is therefore achieved. The facility not only evaluates the latest technologies and ideas for better field practices, but also manages to serve the educational entity by providing staff and students with research opportunities and practical experience away from the field. The three-level architecture enables a full understanding of various artificial lift systems, their components and operating mechanism for students. From the workshop all the way to data processing and through providing feedback on the operation, the process loop is closed and students can directly investigate the results of their analysis, optimizations and designs on the system.

The novelty of this facility is the flexibility in the construction of the three modules and its applicability in research and education. This means, specific experiments can be performed at close to field conditions, providing valuable data that leads to faster technology development.

Introduction

The challenges faced by the petroleum industry have now entered a new decade. Geopolitical conflicts and global health crises, on the one hand, and the growing trend towards primary, yet environmentally friendly energy sources on the other, have not only reduced the unit price of oil and gas but also kept a strong front against the exploration and production of the fossil fuels. Therefore, for developing novel oil field technologies that lead to efficient operations and increased mean time between failures, the stakes have never been higher than today.

While a firm understanding exists about the necessity of petroleum and its byproducts in our daily lives, at least for the next century, it is still believed that production operations have a long journey to reach optimum efficiency. With the high costs of lost time, due to interventions and the complexity of field tests, many companies are opting for construction of off-site test and simulation facilities that could represent an ideal model of the field and allow for a trial run of new equipment and material before they are deployed in the actual production site. With Europe being one of the pioneers of technological developments in the world, the significance of such test facilities is emphasized even more. Innovations are taking place every day for different drilling, completion, and production tools, and the opportunity to observe the performance of such novel technologies under a variety of different operating conditions would benefit the businesses in technical as well as economic aspects.

For the new generation of engineers, this also highlights the necessity of hands-on training for every student as part of their university education. In former days, this kind of training was often provided by the oil and gas industry in the form of internships or practical opportunities to conduct a thesis, often to a large number of students. However, the current market uncertainties have hindered companies' ability to award such opportunities. Consequently, universities have to step up and gradually take over this responsibility, with a growing extent in the near future.

Following this ideology, the Department of Petroleum Engineering (DPE) at Montanuniversitaet Leoben (MUL) in Austria has become a close partner to several regional and global companies with different expertise. MUL and all its scientific disciplines aim to follow the future global trends through industrial and scientific development, as outlined by the H2020 programs of the European Union. DPE is, therefore, committed to play its role both at educating the next generation of engineers and at maintaining and strengthening its ties to the industry. To fulfill these tasks, there are several laboratories and test facilities with different focal points, constructed and operated by the three chairs of the department.

At the Chair of Petroleum and Geothermal Energy Recovery, a principal focus is the study of artificial lift systems. To cover the full range of theory, research, simulation, artificial intelligence and testing, the Pump Test Facility (PTF) was constructed. The idea was initially raised in 2012 and the design of basic components of the structure was conducted together with industry partners. The PTF, officially in operation since 2015, is based on a modular design that allows full flexibility for adjustment to any kind of experiment or any planned setup. So far, three main modules have been built to test the performance of Sucker Rod Pumps (SRPs), Electric Submersible Pumps (ESPs), and Wire Ropes (WRs).

The test facility not only serves the industry and its requirements for novel technology but also assists in teaching and research purposes at DPE. Constructed and owned by the Chair of Petroleum and Geothermal Energy Recovery, the test facility resembles a practice ground for some of the most common and yet challenging production operations in the petroleum industry. During relevant practical courses, the PTF is the core element to teach hands-on key competence in artificial lift. Besides, several final theses are conducted at the facility by students every year.

Existing Pump Test Facilities for Testing, Training, and Teaching

The idea of constructing lab-scale versions of artificial lift systems for initial performance evaluation and further development has been around in the industry for decades. Besides the pump manufacturer's facilities, only a few setups were built by universities and research institutes with the potential to present educational opportunities. Those setups, however, are typically constructed to run only one specific type of artificial lift system.

The Laboratory-Instrumented Sucker-Rod Pump (Podio, A.L. et al., 2003) at the artificial lift facilities of the Petroleum and Geosystems Engineering Department of University of Texas at Austin, represents a research-based duplicate of a full-scale Sucker Rod Pumping system. The pump jack is a beam-balanced type API 16-53-30. This replica of a tubing pump, in original size, is used in a wellbore setup built with acrylic pipes as casing and tubing. The only alteration is the use of plexiglass as the pump barrel so that the open/close mechanism of the valves is visualized. Measuring pressure, load and position, the pressure drop across the ball valves, pump filling and compression of gas are among the investigations performed on the system.

Another setup is the full-system small scale demonstration model of a Sucker Rod Pump at the University of Buea, Cameroon. This design is constructed by Fozao et al. (Fozao, K. F. et al., 2015) and is called the "Golden Horse Head," which is unique for implementing cheap and simple material in its body. The model is understandably down-scaled in all parameters. Nevertheless, it offers an easy to understand structure used for teaching as the entire pumping mechanism can be practically operated and observed. Real mixtures of oil and water can be injected into the system to be pumped and later separated in a vertical separator.

The most sophisticated system is built at the University of Oklahoma (Teodoriu, C. and Pienknagura, E., 2018). The intention is to employ the Internet of Things (IoT) to create access for all students on the campus to work with an experimental Sucker Rod Pump setup and observe its performance during experiments. The main focus is on the pump itself with the activation done by a linear actuator, similar to a rack and pinion unit. All components are exact field replicas, and the entire height of the system is 45 ft. Through the use of IoT, pressure, load, and location of the rods are recorded, with stress and strain sensors and flow measurements to be added later for future tests.

Other assemblies can be found at Texas A&M University and at the University of Ploiesti, Romania, where small scale models in the lab, as well as an outdoor pumpjack for visualization and mechanical analysis of the surface unit, are available for education.

Considering ESP testing, there is a lack of facilities constructed in the academic sector to promote training and teaching specifically. Most experiments conducted to observe ESP performance take place at the manufacturing service company and follow the respective API Recommended Practice, version 11S2 (API RP 11S2, 1997). Schlumberger owns Assembly Repair and Testing Centers (ART) around the world with ESP test facilities in Singapore, the US, and the UK. These facilities are capable of conducting performance as well as failure diagnostic tests within instrumented test wells and also offer "full system integration" tests when necessary (Schlumberger, 2017).

At the C-FER facility in Edmonton, Canada, a test facility is built to perform experiments on artificial lift systems that work simultaneously during steam-assisted gravity drainage operations. For this purpose, a high-temperature flow loop is constructed, and a variety of fluids such as oil, water, steam, emulsions, and non-condensable gas are used at temperatures up to 260 °C in a simulated wellbore using a 9 5/8 in. casing. Tests on the performance of ESPs, in particular, include observations of thermal cycles, which simulate periods of work and shutdown of the pump, as well as the effects of temperature on components such as motor and seal section. To track the performance of ESPs, the institute has created a platform called ESP-RIFTS (Electric Submersible Pump Reliability Information and Failure Tracking System), where the performance and failure history of over 24 different operating

companies from 758 fields is stored for open access (Wagg, B., 2015).

Another facility was developed at the Southwest Research Institute in San Antonio, Texas, owning a flow loop that could be adjusted for different ESP testing purposes. Several experiments were conducted with multiphase, high-pressure, sand-slurry, and high-viscosity flow loops, including tests in casings at different inclination angles (Owston, B., 2015).

Lastly, for wire rope testing, the existence of facilities for performance analysis comes down to the purpose behind the application of wire ropes. Naturally, for manufacturers of wire ropes, quality testing is an integral part of the production line. As the wire ropes are delivered for individual applications, whether to the petroleum industry or not, depending on the complexity of its upcoming duties, further experiments may be conducted on the wire rope. Yet, for the particular purpose of use in SRPs, which is the aim of the WRs test module at the PTF, no similar facility was found in the literature or other research institutes, meaning that the PTF could potentially be the pioneer for experiments in this particular field of research.

Objectives of the Pump Test Facility at MUL

In 2012, the idea of building the PTF was raised by industry partners and researchers at MUL, initially to test new ideas developed within joint projects. The discussions concluded that the PTF not only has to fulfill all requirements for evaluating the performance of novel and existing technologies, but it should also be fully incorporated into the educational program of the department and to partially replace hands-on industry training in the artificial lift sector. Lab testing, despite its shortcomings, presents several benefits over field-scale testing.

Macro – Scale Experiments:

- Low-risk testing in a controlled environment
- Testing at near field conditions
- The fast development of innovations because of fast implementation of changes

Field – Scale Experiment:

- Field testing is very costly
- Potential system failure costs
- Interferes regular field operation
- Increased HSE risk
- Uncontrolled test environment

Lab tests allow operation at low risk and controlled environment, typically at near field conditions. The development of innovations can, therefore, be achieved more rapidly because changes can be implemented immediately. Additionally, no workover rig or personnel are needed for installation and removal. In contrast, field tests provide real field environment testing. Yet, in the case of system failures, high costs can be associated due to production losses and system removal. Moreover, regular field operations are interfered during testing, and HSE risks are increased since testing takes place in uncontrolled downhole conditions.

Today there are numerous technologies available to support requirements in pumping, but bringing them to the application in the field requires long quality control periods, re-design, and re-engineering, which would be too risky and costly to be directly done in the oilfield. Hence, the Pump Test Facility aimed to accomplish the following objectives for the education of students as well as higher-level research and development:

Education:

- Presenting the basic knowledge about the components, materials and the working principles of standard artificial lift systems
- Hands-on training in assembly, installation and operation of the most common pumping systems
- Developing skills in identification and interpretation of equipment malfunctions
- Establishing an understanding of the hardware-software interaction and the automation of artificial lift systems
- Providing training in data recording and processing, as well as analyzing real pumping systems using, e.g., internet of things, cloud processing, etc.
- Creating a platform to transfer all theoretical and practical knowledge from scientists to students

Research and Development:

- Performance testing of artificial lift systems
  - Independent testing of the systems at regular operation conditions
  - Examination of the pump behavior under specific system failures
  - Investigation of innovations and possible upgrades in-house
- Testing of artificial lift systems for alternative use under non-standard conditions
  - Production of enhanced oil recovery fluids
  - Production of high viscosity fluids
  - Production of geothermal fluids
  - Production of high sand rate fluids
- Optimization of an artificial lift system using engineering models and data-driven techniques
- Investigation of new materials and equipment designs
- Automation via Matlab Simulink and observing its interaction with the experimental setup
- Combination of tests and simulations to overcome shortcomings of the facility (e.g. rod string length, tubing column) and break down hurdles faced during field tests (e.g. precise downhole measurements)
- Data generation and creation of a database for big data analysis, especially for operating modes that cannot be achieved in the field and would significantly increase the prediction accuracy of data analysis techniques
- Central data acquisition and storage to ensure quality and allow all kinds of data analytics

Cloud-based testing and learning Architecture

The cloud-based testing and learning architecture at the university enables the effective combinations of research - teaching and lab tests – data analysis. The availability of big data and its integration into lab tests, independent of the actual presence of the scientists or students in the lab, is the core idea. The cloud-based testing and learning architecture consist of three levels (see Figure 1). The first level represents the facility and hands-on training, where students get in touch with pump equipment and learn how to assemble components of a particular pumping system. Additionally, they are trained in the automation principles of the facility as the university staff operate the test stands. The facility operator is responsible for installing the assembled pumping systems, starting, stopping, and parametrizing as well as implementing the functions provided by the user.

The second level is the data center and administration level. Within this stage, the administration of the internal data server takes place. User access rights are defined, and data security measures are applied. It is worth mentioning that PTF is connected to the network; hence, all non-manual tasks can be done remotely.

Level three represents the teaching and data analytics level. The students investigate the recorded data

by using, e.g. cloud analytics, processing models, etc. and elaborate operation recommendations. The feedback and necessary optimization are provided to the facility operator, to feed to the programmable logic controller (PLC) and to test the now altered configuration. The communication between the facility and the data server is in real-time, which allows immediate cloud processing of the recorded values.

Design and Control of the Digital Pump Test Facility

The modular principle behind the construction of the PTF allows flexibility not just within the experimental goals, but also in various educational programs intended for the students. Until now, three main modules have been built to test the performance of Sucker Rod Pumps, Electric Submersible Pumps, and wire ropes.

PTF itself is located at one of MUL's buildings designated for laboratories and workshops. The facility is two floors below the ground. It contains multiple monitoring systems and a storage area, as well as a shaft that goes 10 m below room level, along which all the modules of the facility are built in parallel. The design of the modules imitates common field operations at the well site. Yet, the structure of the modules, together with their instrumentation, follows and even exceeds those at the well site.

Sucker Rod Pump Module:

The Sucker Rod Pump Module consists of three main elements: a housing of the downhole components, a polished rod, and a linear drive. The 8 m long housing is a casing of size 6 5/8 in. and is made of stainless steel. The casing allows for pressures up to 40 bar and temperatures up to 60 °C, representing conditions of a 500 m deep pumping installation. On top of the pressure vessel, the linear drive is installed, which allows stroke lengths of 2 m and lift forces to 15 kN. The setup is constructed to perform vertical and inclined testing. Therefore, the whole test stand can be tilted stepwise from an upright position to 30 degrees of inclination (see Figure 2). There are two options to guide the fluid to the intake of the downhole pump. The first option is by using the intake ports at the casing, which allows for the simulation of the dynamic fluid level in the barrel – casing annulus. The second option is to directly connect the feed pump to the intake of the downhole pump, which enables more accurate testing of gas interference scenarios. The intake pressure can range between 2-10 bar at a flow rate of up to 100 m³/day. This module has already been successfully used for hydraulic pump demonstration and testing. The instrumentation concentrates on the electric motor controller (delivering motor torque, current), the polished rod variables (measuring load, position, vibration, fluid temperature and pressure, flow rate, etc.) and the downhole conditions (including intake pressure & temperature and annular pressure).

Electric Submersible Pump Module:

The Electric Submersible Pump Module is constructed to test pump stages under vertical conditions in all pressures and temperatures experienced in the field (see Figure 3). The main components, besides the pump stage, are the rotary drive, which is a 55 kW standard electrical engine that is positioned below the pump stage, the inlet, where the three phases are mixed by a static mixer, and the pressure regulating valve at the discharge of the pump (see Figure 3). The system can handle inlet pressures up to 40 bar and discharge pressures up to 160 bar, and a temperature range from ambient to 80 °C. The inlet system can mix up to 20 m³/h of water that is stored in a pressure vessel charged by compressed air, with 3 m³/h of synthetic oil provided by a screw pump, and together with 50 kg/h of separately provided compressed air. Regulating valves are installed to allow flexible mixing of the three phases at the inlet. A heat exchanger is additionally in place to keep the temperature constant in closed-loop circulation mode. The instrumentation of the ESP module concentrates on the electric motor controller (returning power, current, rotation speed, etc.), the intake conditions (meaning flow rate of each phase, intake pressure, and temperature) and discharge conditions.

Wire Rope Module:

The Wire Rope Module aims to test ropes and strands that can potentially replace the conventional string. The setup consists of a vertical pressure vessel and a hydraulic system. The pressure vessel is 8 m long, has an inner diameter of 7 5/8 in. and is capable of withstanding 160 bar (see Figure 3). A mixture of water with salts and minerals, with the possibility of preheating up to 85 °C, is injected into the vessel to achieve the desired pressure. As for the hydraulic system, a cylinder is fixed at each end of the pressure vessel, together adding a length of 2.3 m to the structure. Different types of wire ropes can, therefore, be installed between the two cylinders and inside the pressure vessel. The cylinder at the top of the vessel pulls the rope with forces up to 72 kN during the upstroke, simulating loading conditions of a wellbore as deep as 1700 m.

On the other hand, the cylinder at the bottom accommodates movement and reaction forces of the wire rope during the downstroke. To simulate wear, particularly in wells with doglegs, a secondary bent pipe can be installed inside the pressure vessel for the wire rope to pass through. The rope can also be rotated during upstroke using an additional motor to distribute the wear on the wire rope surface. The stroke length of the cylinders is 1 m, and the reciprocating motion can be done at 10 SPM.

Facility and Hands-on Training Level

The PTF is grounded on the principles of industrial facilities and accounts for all relevant HSE features as part of its mission. The control system consists of two programmable logic controllers, where a safety PLC controls all safety-relevant features, like the start of motors or heating systems. The main PLC is responsible for motion and data control and is connected to the safety PLC via a Sercos gateway. This gateway allows the main PLC to read signals from the safety PLC and use the information in the main PLC's program. The main PLC is connected to the network and can be programmed and operated by any computer remotely. Still, for safety and security, only the facility operator's PC is reached remotely, not the entire PLC system directly.

The manipulation of the main PLC program is done by using the open core interface of Bosch Rexroth and Matlab Simulink. A dashboard is created, having a general section as well as one interface for each module (see Figure 4). Three general operation modes can be used within these interfaces: manual mode, automatic mode and autonomous mode.

The manual operation mode allows providing input to the motors and actuators of the facility individually and is not coordinated with any other operation. This mode is often used to install equipment or to test a particular configuration. In the SRP module, for instance, the slide of the linear drive can be moved to an absolute position. In the ESP module, the frequency of the ESP motor and the regulating valve positions are among the parameters that can be set individually. In the Wire Rope Module, the hydraulic cylinder positions can be defined.

The automatic mode allows operating the facilities at a more advanced level. The input parameters are provided to the system via a table (see Figure 5). The first column represents the time and the others, the motor/actuator type, and their default value. The system automatically changes the input parameters according to the table at certain times.

In the automatic mode, the SRP module can be operated cyclically, principally running any kind of stroke profile within the boundary conditions of the facility. Here, two profiles are worth mentioning: the constant speed profile and the pump plunger stroke profile. The constant speed profile is a periodic profile that represents an acceleration ramp to a defined constant speed, followed by the constant speed section itself and, lastly, a deceleration at the end of the stroke. The pump plunger stroke profile, however, represents the movement of a pump's downhole plunger. Therefore, the implemented model converts the polished rod movement, applied via a defined pump jack, into the downhole movement while accounting for rod string dynamics and fluid loads. The model results are directly forwarded to

the drive system, therefore allowing it to operate cyclically. For other modules, for instance, the Wire Rope Module, the automatic mode allows for the cyclic movement of the hydraulic cylinders together with the rotation of the wire rope.

The autonomous mode is organized specifically for teaching and data analytics tasks. The data recorded at the facility are evaluated and analyzed in real-time by researchers and students, using analytical methods, cloud analytics, and artificial intelligence. The analysis targets are various, and their results can be directly fed back to the Pump Test Facility, which can start a new test run and prove the quality of the results.

Within the educational program, PTF is used for demonstration and hands-on training. The students visit the test facility and get introduced to the different test modules, their working principles, and their capabilities. They also get familiar with the components of each pumping system by learning how to assemble and disassemble Sucker Rod Pumps, Hydraulic Pumps, and Electric Submersible Pumps (see Figure 6). Wear patterns on different pieces of equipment, and their corresponding causes are explained, failure mitigation measures are shown, and pump operation modes are discussed. Moreover, auxiliary equipment, like sand screens, gas anchors, downhole desander, etc. are presented.

Since the development of PTF, several small- and large-scale projects were carried out on the developed setups in the past, and many more are planned to be performed in the future. These projects are often in cooperation with the industry and involves real challenges faced in the field. Depending on the work scale, a part or the entirety of the project is handled by Bachelor's and Master's students. This means that students have the opportunity to choose from the variety of existing research topics that deal with testing new hardware. Upon the conclusion of the tests and providing a written thesis, they will be awarded a degree. This leads to unique opportunities for students to gain hands-on experience with actual field equipment, yet within the university premises.

The completed technology projects at PTF were related to innovations in SRPs and ESPs. One project was conducted to investigate the Sucker Rod Pump downhole desanders for their efficiency (C. Langbauer et al., 2020). In this project, different types and sizes of desanders were tested at PTF under near-field conditions, while an analytical model was simultaneously developed. The investigation criteria, in this case, were the geometry of the desander vanes and the distance between the sand separation location and the pump intake. Field tests proved later on the validity of the results obtained at PTF.

Another project challenged the effects of slippage on SRP's volumetric efficiency (Kochtik and Langbauer, 2018; Langbauer, C., Kochtik, D., Volker, L., 2020). These effects were examined by analyzing not just the pumping speed but also the differential pressures created by the plunger under various fluid viscosities.

On one of the smaller testing setups at PTF, an analysis of rod guides' lifetime was performed (Langbauer, C., Permanschlager, T., Sirghii, V., Pavlov, M., Hofstätter, H., 2018). Conventional rod guides were tested under various temperature, pressure and load conditions and at different reciprocating velocities to inspect wear patterns. The results showed an operational timeline as well as the traveled distance while considering two key parameters: tubing roughness and normal forces.

Currently, the development of an anti-buckling system for Sucker Rod Pumps is in progress(Langbauer, C., Fruhwirth, F., Hartl, M., Hofstätter, H., 2018). This system prevents the occurrence of compressive loads in the Sucker Rod string and essentially increases the system's mean time between failures. Successful lab testing has led to a field test prototype, which is running for almost two years in the oil field.

Data Center and Administration Level

The data center and administration level present the second stage of the cloud-based testing and learning architecture. A data server is a virtual machine, situated in the network of the university that provides enough storage and processor capacity to handle all relevant signals from the Pump Test Facility. On the virtual machine, the PI – System OSISoft software is handling the data storage, processing and visualization task. In total, more than 200 tags are provided by the PTF. Among them, there are sensor readings, position indicators, frequency converter input parameters, status pointers and set values. The set values are defined by the user but stored as well to improve traceability in case of errors.

The PLC is directly connected to the network. The tags can be accessed by the data server via the OPC UA server installed at the PLC. Depending on the PLC load, the sampling frequency of the tags can reach several hertz. At the data server, data conversion and identification can be performed, scaling of the analogous reading takes place and warning and error messages are created in case of unexpected situations. These messages are submitted via mail or SMS to the facility operator. In total, for analysis, there are more than 350 tags available at a sampling frequency of about 5 Hz.

The stored data can be accessed in multiple ways. Access via spreadsheet calculation programs or Matlab is very comfortable for small to medium size data. Using the PI Integrator for Business Analytics enables to load big amount of data for analysis, for instance, in a cloud system.

Besides, the user and permission roles for accessing tags can be set. Each tag is assigned to certain user groups with read-only or write permissions. For instance, maintenance tags are not relevant to students, thus, student users cannot see them.

At this level, the status and history of all tags can be visualized using PI ProcessBook and PI Vision. Figure 7 presents the basic visualization of the Pump Test Facility. It shows general information about the main PLC status, the status of safety features and emergency stops. It provides links to other pages by simply clicking on the pictures or the underlined elements. This simplifies the orientation.

The construction of visualization pages of the PTF and its processes is a part of the teaching concept of the department. Based on the student's knowledge, gained in the Facility and Hands-on Training Level, they have to process the tag information, generated during their experiments and prepare the visualization in an organized and representative way.

Figure 8 shows the visualization of the Sucker Rod Pump module. The position of slide valve, which regulates flow directions, is presented. The inclination of the module as well as the fluid levels in the tanks are also shown. An indication of stopped and running motors is provided and recorded signals and setpoint values are shown. The diagrams represent the trend of the most important parameters, like intake and discharge pressures and temperatures. Polished rod load is shown, and drive parameters are additionally indicated.

Figure 9 provides information about the ESP module. Intake stream conditions (pressure, temperature, rate) of the water, oil and gas are shown in the diagrams. Temperature and pressure increase over the pump are highlighted and presented together with the position of regulating valves. Further information can be accessed by clicking on the link to, e.g. motors to see rotation speed, power requirements, torque consumption, etc.

Figure 10 visualizes the conditions at the Wire Rope Module. The rotation speed of the rod rotator is shown as well as the pressure and position of the hydraulic cylinders. The wire rope tensile load is presented, and the motion characteristics are displayed in the diagrams. Actual fluid pressure and

setpoint values are indicated and fluid level is shown.

Teaching and Data Analytics Level

The Chair of Petroleum and Geothermal Energy Recovery offers a variety of courses at BSc and MSc level to the students studying for a Petroleum or Geothermal Engineering degree. It is, in particular responsible for providing theory and know-how in the field of Production Engineering.

At the Master's level, the chair holds a lecture titled "Artificial Lift Systems," which is divided into two equally evaluated parts: a theoretical lecture and a practical course. While the theoretical lecture provides the initial knowledge and basic concepts about this critical topic in petroleum production, the practical course presents common problems and exercises their solutions. These will be practiced and solved initially through hand calculations and later on via commercial software, accessible through the university's computer lab. A few sessions of the practical course, however, are dedicated to training at PTF. As described so far, the facility offers different teaching and training opportunities to serve the educational purposes of the department, and the introduction and hands-on experience with field equipment are practiced during this course. In this sense, the students will attend sessions at PTF, either altogether or in groups, and will be introduced to the different modules, their purpose, mechanism, comprising components and monitoring systems (Facility & Hands-on Training Level). They will become familiar with individual components such as pumps, drive units and other auxiliary equipment available. The students will later be divided into smaller groups, where they can rotate and observe the components, practice their assembly and disassembly and experience a short period of operation where applicable. This will be similar to a company visit or a field trip and offers real insights to students as opposed to relying solely on figures and videos found in literature or on the internet. The students will also be able to make individual or group appointments and visit PTF outside of the course schedule to practice what they had learned and ask further questions.

The purpose of the Teaching and Data Analytics Level is training in data analysis. Over the years, the Chair of Petroleum and Geothermal Energy Recovery has been in contact with several companies for the purchase and installation of equipment at PTF. Successful negotiations with these industrial partners have recently provided the chair with several new PLCs that can be employed for training. The aim is to offer students the possibility to be trained in programming various setups and provide an understanding of the automation and digitalization processes involved. Considering the necessity of digitalization in today's field operations, this training opportunity will offer all the fundamentals required for future roles that have first-hand interactions with the digital data.

For this purpose, two courses have been defined by the chair and have been approved by the university to be included in the MSc curriculum. This training starts in the course "Digitalization", where the students will begin to learn the principles of measuring systems, like strain gauges, flow meters, pressure transducers, etc. They will then be introduced to the PLC and the data center at PTF to have access to real-time recorded data and learn about the stages of data processing in a real system. This is where the recently acquired PLCs will come into play. Later on, the course "Production Data Analysis" will present the necessity of data recording, processing, and analysis. It contains all the necessary theory required for data analysis and brings real examples from field recorded data. The course also describes the challenges of big data and explains different methodologies developed by data scientists over the years to remove outlier data from a recorded bunch. As part of both courses, the students analyze the data, recorded at the PTF, during the Artificial Lift Systems course. Students get access to the data server and use cloud analytics to evaluate and analyze their characteristics. Based on this information, they elaborate on feedback and recommendations for operation optimizations of the facility. Besides, multiphase flow simulations and the simulation of the flow characteristics in the production system are elaborated. Virtual clones of the modules are implemented and trained as a significant part of the education.

The teaching methodology of this course will be based on "Project-based Learning". This means that after the described preliminary training, the students will be divided into groups and presented with a test plan requested from one of the industry partners. The request will be handed to all groups in a written form, and the groups will have a week to discuss the problem description and brainstorm ideas on how to solve the problem, decide on its requirements, and come up with a basic preliminary work plan. They will then have a chance to ask questions from a company representative in a one-on-one session. Once the work plan and goals are clearly defined, the students will work in their groups to develop the necessary test program and plan for data acquisition and processing procedures with the help of the PLCs, for which all necessary infrastructure will be provided by the chair. They will have two further opportunities to sit with the lecturer to provide updates and ask further questions. Upon completion of the course, each group will present its work, which will be graded by the lecturer. The simplest and most practical work plan will then be chosen to be implemented at PTF and will later be presented to the industry partner.

Conclusions

The paper presented the digital and interactive Pump Test Facility at the Montanuniversitaet Leoben. The highly flexible facility consists of three modules to work on Sucker Rod Pumps, Electric Submersible Pumps, and Wire Ropes. The presented three level architecture allows a full integration of research and education. For the educational purpose, students start with hands-on practice in the workshop to understand the presented artificial lift systems, the principles of sensors, and control systems. In the data center and administration level, the data are stored, simple processing takes place, and data visualization happens. The Teaching & Data Analytics Level enables high sophisticated big data analysis and cloud processing of the recorded data and a feedback loop to the operation of the facility as part of the research and the student's education. Virtual clones and performance prediction models are created, implemented, and tested. In the future the shown concept will be extended, on the one hand by further research projects to be performed, and on the other hand by an extensive use of the facility for educational purpose.

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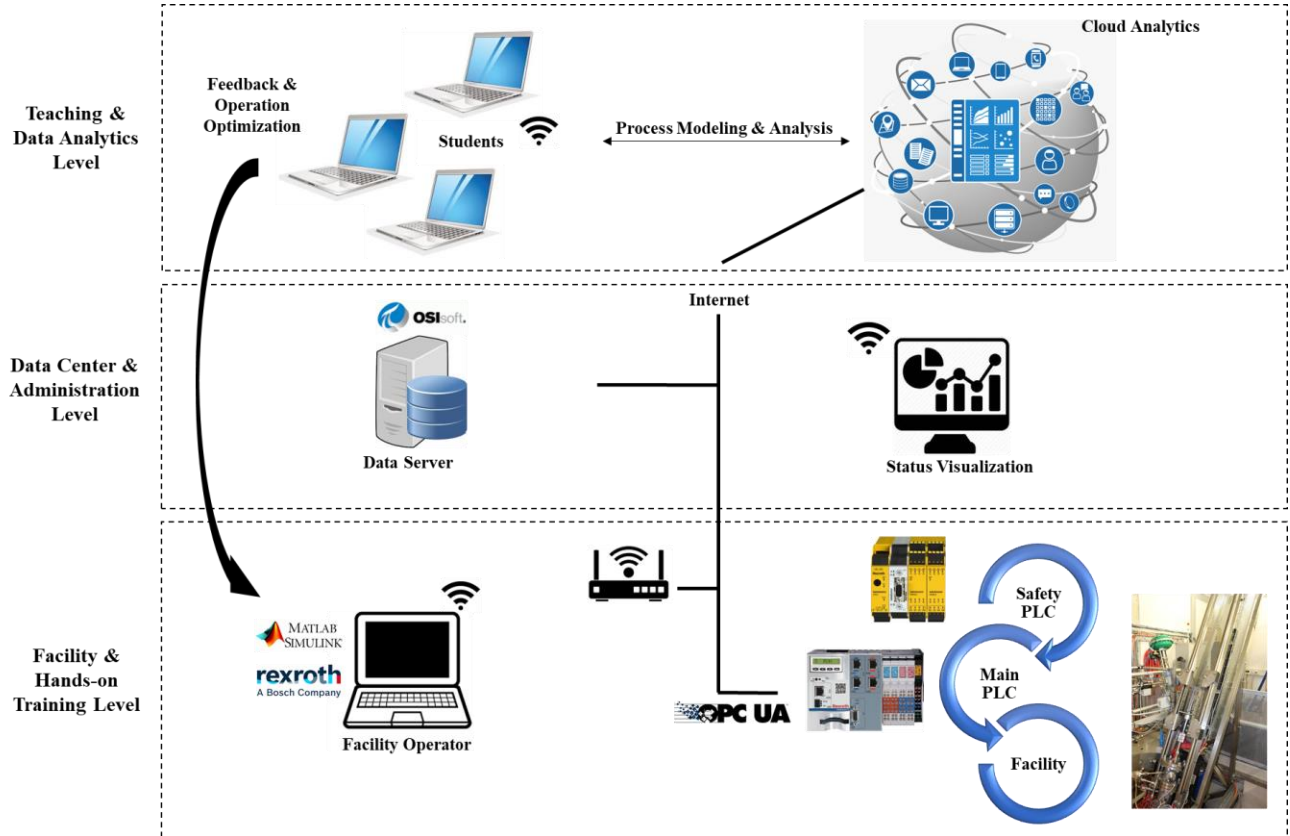
Figures

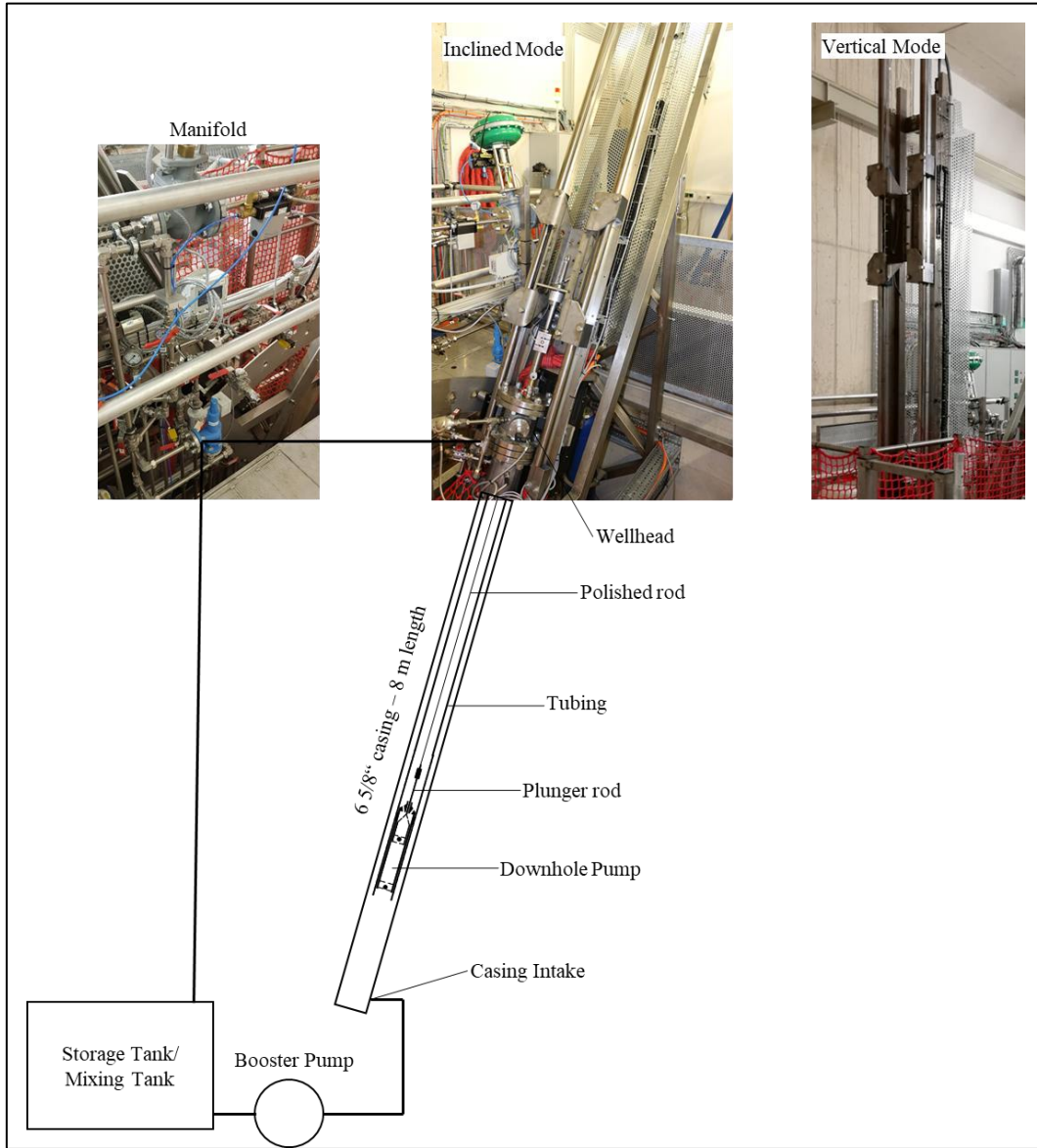Figure 1: Cloud-based testing and learning Architecture
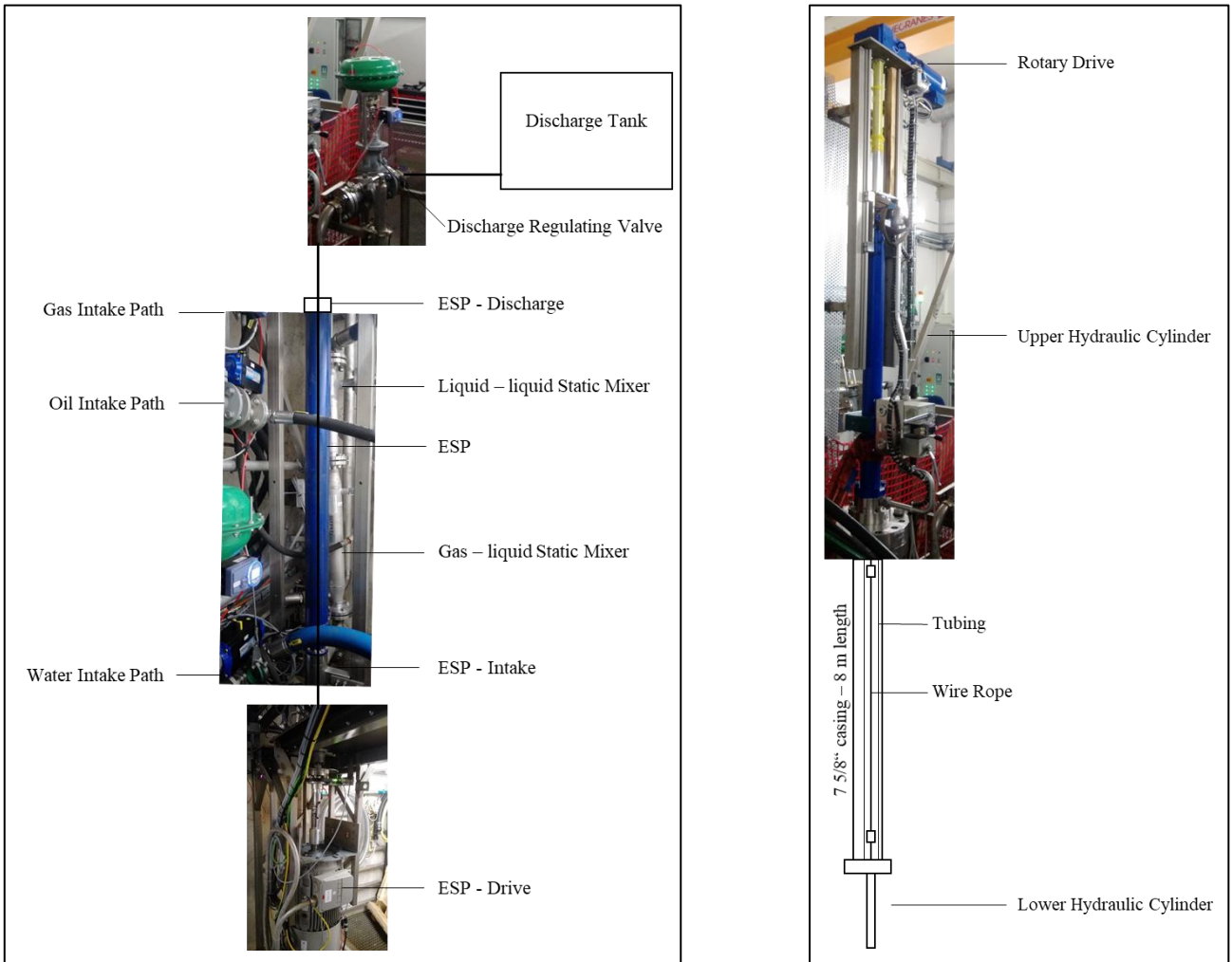
Figure 2: Sucker Rod Pump Module

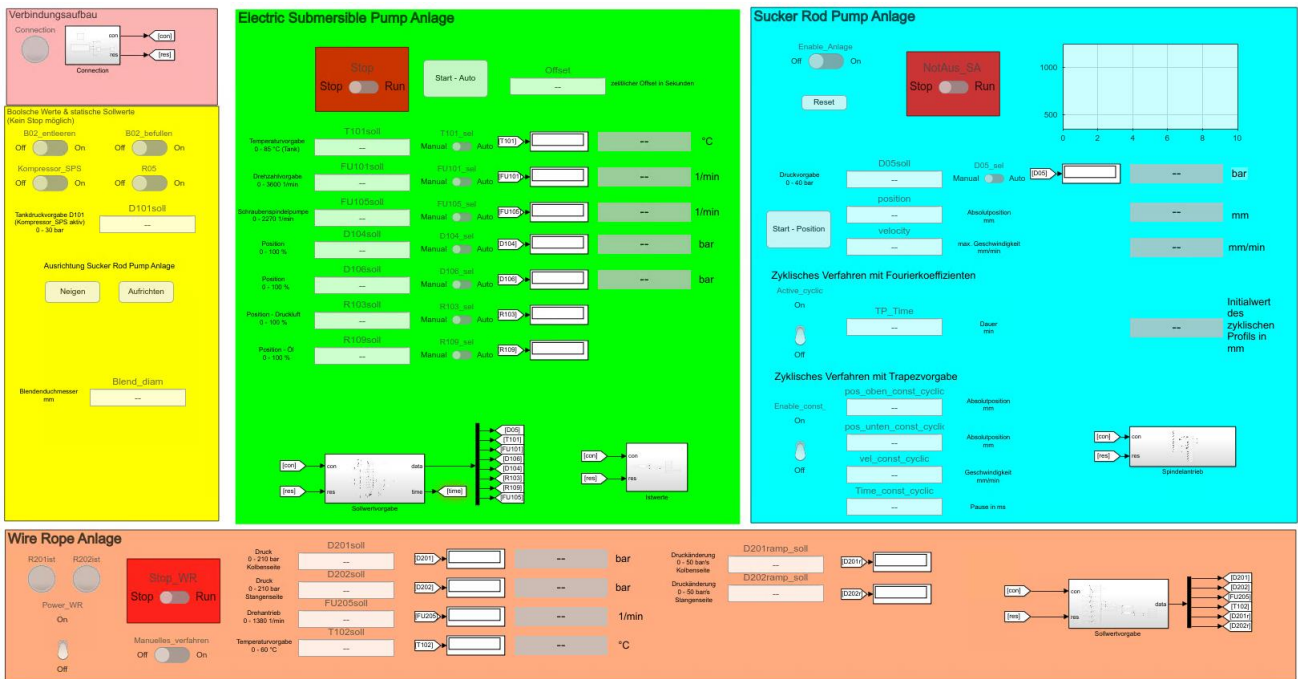Figure 3: Electric Submersible Pump Module (left) - Wire Rope Test Module (right)

Figure 4: Matlab Simulink OpenCore Interface

Time	FU101soll	D104soll	T102soll	D106soll	T101soll	R103	R109
s	*1/min*	*%*	*°C*	*%*	*°C*	*%*	*%*
0	0	100	15	100	15	100	100
130	2200	90	15	80	15	95	95
210	2400	90	15	80	15	95	94
290	2600	90	15	80	15	95	93
370	2800	90	15	80	15	95	92
450	0	100	15	100	15	100	100
86400	0	100	15	100	15	100	100

Figure 5: Input Table for Automatic Mode

Figure 6: Example of Hands-on training – Disassembles ESP

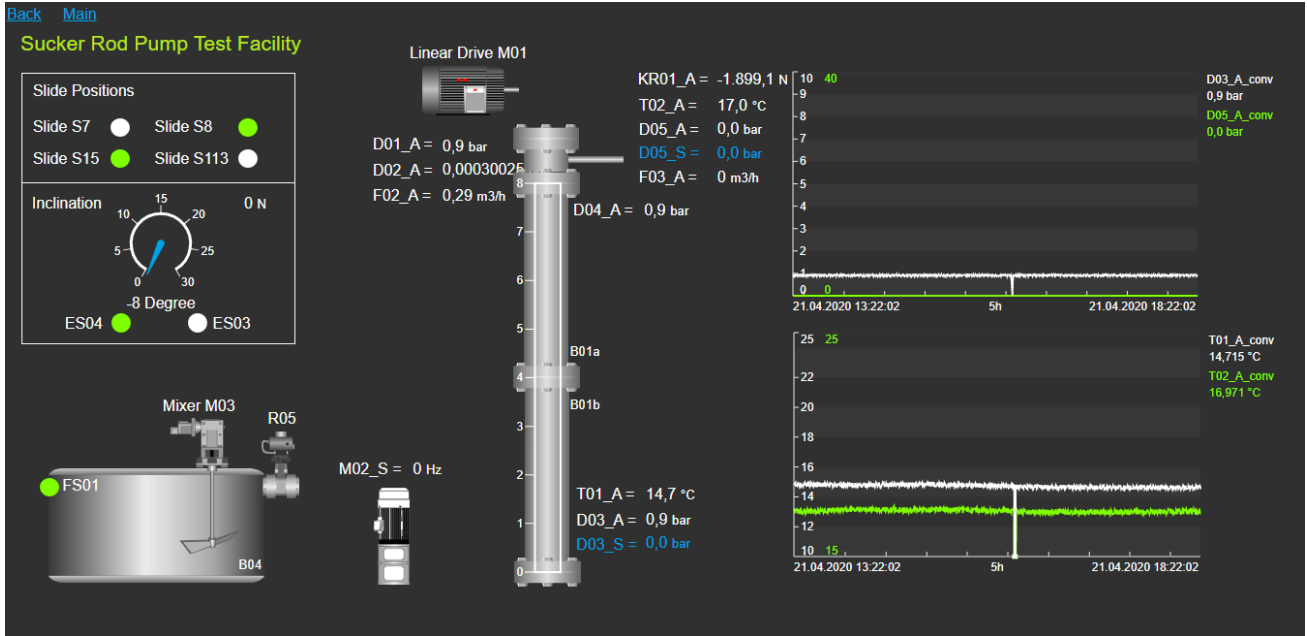Figure 7: Visualization of Pump Test Facility
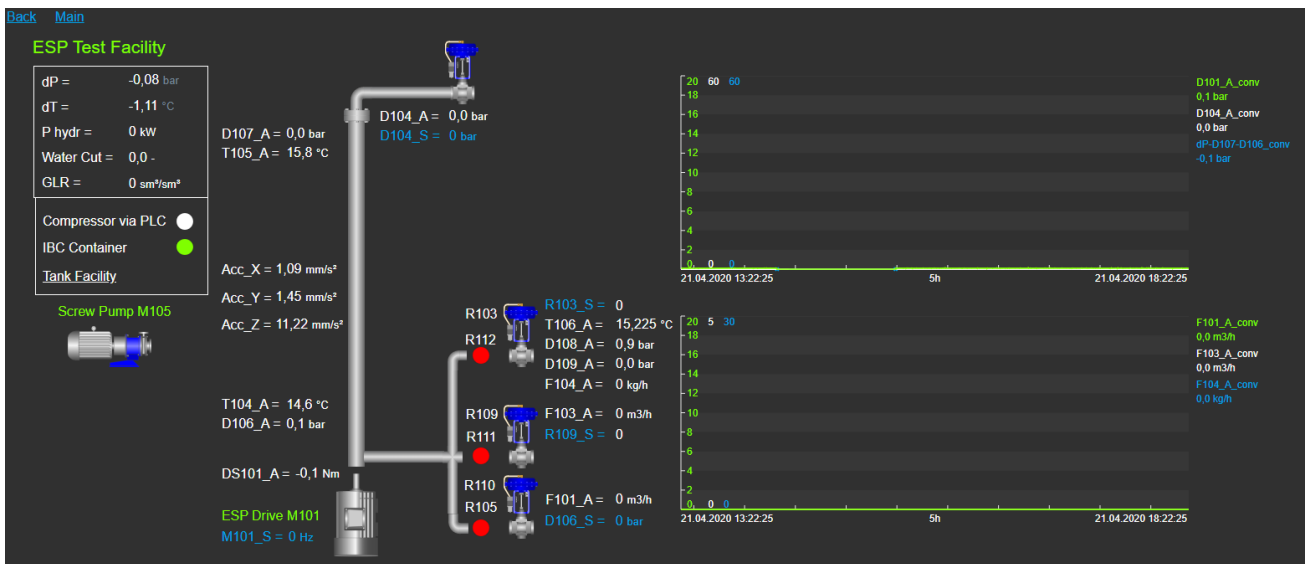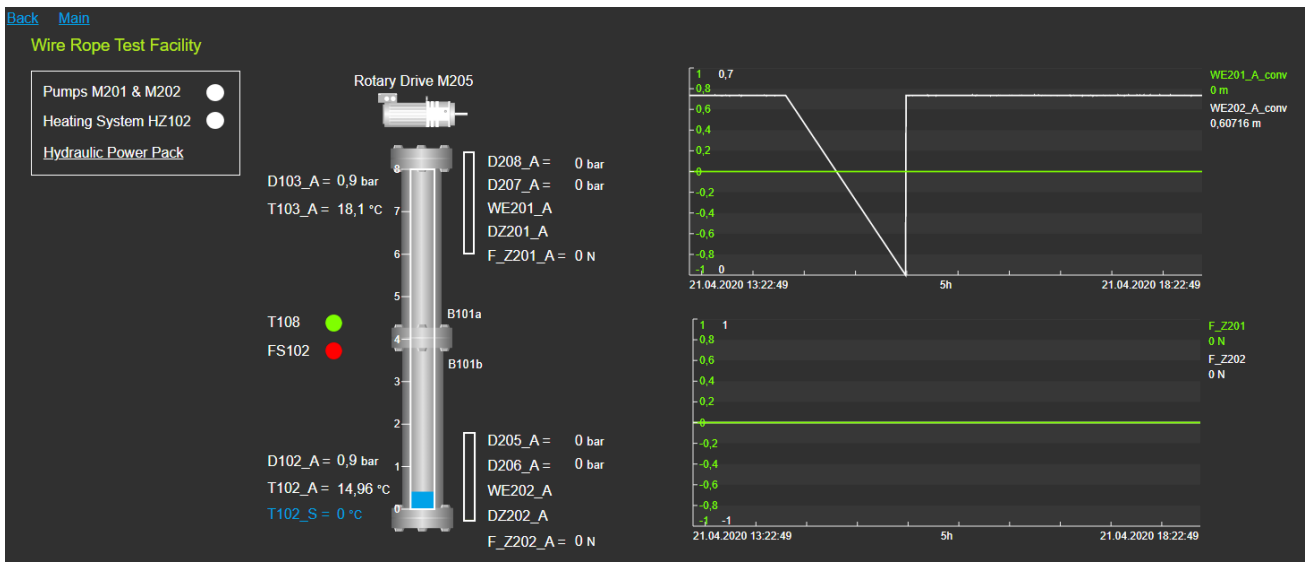
Figure 8: Visualization Sucker Rod Pump Module

Figure 9: Visualization ESP module

Figure 10: Visualization Wire Rope Module