INTI JOURNAL | Vol.2025:03
eISSN:2600-7320

Analysis of Submersible Pumps Systems to Increase Their Efficiency, Reduce Their Carbon Emission, and Improve Their Ecological Footprint

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Abstract

The focus of this study is to present and discuss the results of an investigation in relation to the behavior of comparable submersible pumps under identical environmental circumstances under the influence of constantly changing operating conditions due to external effects. Changing operating conditions have a negative impact on energy efficiency and hydraulic performance, which shortens the longevity of submersible pumps, thereby downgrading both the carbon footprint of the application and the ecological footprint of the product. The aim of this study was to develop a test setup to simulate almost actual operating conditions such as in mining or tunnel construction and to record measurement data (primary data) with a smart control and monitoring system. As the applied methodology primary data (flow rate, flow pressure, power consumption, water level, horizontal and vertical vibration) were recorded over 10 weeks and evaluated by statistical analysis. The main objective of this study is to demonstrate, by means of statistical analysis, that changing operating conditions are closely related to the longevity (wear and tear) and the overall life cycle assessment of the application. A precise analysis of the application and a corresponding technical design based on the present study, in connection with a smart control system, will reduce the carbon footprint, and the ecological footprint will be permanently improved. For suppliers and for end users as well as for society, such intelligent systems which react accordingly to changing conditions are essential for the development of ecological and social sustainability as well as for economic efficiency.

Keywords

Energy Efficiency, Ecological Footprint, Life Cycle Assessment, Circular Economy, Variable Operation Conditions

Introduction

The production of products is still linear nowadays, which explains the growth strategy of many companies with the exponential development of the demand for primary raw materials (Pufé, 2017) in a fiercely competitive global market with growing demand for faster development, more flexibility and more effective resource utilization (Alkhlaifat & Koloszár, 2023). The growing

Submission: 3 July 2024; **Acceptance:** 14 January 2025

need for new consumer goods and products also results in a high need for primary raw materials (Herzner & Schmidpeter, 2022). The environmental impact of production companies is not only on the production of their products, the necessary primary and secondary raw materials, as well as the energy required for packaging, operating resources and auxiliary materials also have a significant influence on growth strategies (Hansen et al., 2021). The principle of "produce, use and throw away" is still typical of our consumer behavior and economy - which we will not be able to afford in the future for ecological, economic or social reasons (Herzner & Schmidpeter, 2022). The use of secondary materials presents manufacturers with new challenges, as their quality is often poorer and must first be improved using complex processes and by adding additives (Tonini et al., 2022).

For many years there have been political efforts and strategies to find an optimal way to reduce the extraction of non-renewable raw materials to the necessary minimum and to only extract renewable raw materials in the quantity in which they are available in the same amount of time until the next one removal can regenerate (Eisele, 2021). As part of the European Green Deal, politics and legislation are trying to protect the earth's climate from the effects of climate change by massively reducing greenhouse gas emissions and making Europe climate-neutral by 2050 (Wittpahl, 2020). There is undoubtedly a connection between environ-mental pollution and climate change (Climate ADAPT, o. J.) which in manufacturing companies affects not only the production waste generated during production, but also that left at the end of the product's life (EoL). A distinction can be made between political steering instruments that support progress (research and development) and those that raise public awareness through regulation (laws, guidelines, norms and standards) (Hansen et al., 2021).

Tsurumi (Europe) GmbH in Germany (TEG) with its parent company, Tsurumi Manufacturing Co., LTD. In Japan, set the common goal to evaluate their products (submersible pumps) based on a life cycle assessment and thus to implement 7 of the 17 sustainability goals in the future (Tsurumi Pump, o. J.). With a view to SGD 13 (SGD: Sustainable Development Goal "Take urgent action to combat climate change and its impact"), emission sources are classified according to the GHG Protocol (Greenhouse Gas Protocol) guidelines for company-related CCF (Corporate Carbon Footprint) and product-related PCF (Product Carbon Footprint) according to the "Scope-1 -2-3 concept" (Schwager et al., 2022). The basis of Tsurumi's climate protection strategy will be the determination of its own CO2 emissions, from which reduction targets will follow.

The focus of this study is on the product use phase. The decision was made in this phase because short-term successes can be achieved without significant investments. Essentially, it's about understanding the user's application and working with them to find the best possible solution. The best possible solution according to Tsurumi's definition is the product with the longest possible lifetime, with the lowest energy requirements and maintenance effort. The longevity of a submersible pump depends on its intended use. Pumps in a process engineering production plant are selected for a specific operating point, which is ideally close to the best efficiency point of the pump. The technical characteristics (viscosity and density of the medium, length- and diameter as well as the quality of the pipes) are usually almost constant and are subject to only very small (predictable) changes. In mining and tunnel construction, the operating parameters can change at any time (unpredictable operating conditions). Every small change in the system can change the distance between the best efficiency point (manufacturer-specific information - head and volume flow) and the actual operating point. The bigger the distance between the points, the heavier and faster wear can occur, which in any case has a negative impact on the longevity of the pump and can also mean a higher energy requirement.

In an experiment, 6 submersible motor pumps were tested for ten weeks under almost real operating conditions in specially developed test stations. The purpose of this series of tests was to observe the behavior of the system under changing conditions and to learn more about the behavior of submersible pumps. Existing production systems with a globally net-worked infrastructure can only be slowly adapted to new requirements for regulatory, financial or organizational reasons (Hansen et al., 2021). Overcoming these barriers across the entire value chain (suppliers, retailers, and manufacturers) must be divided into short, medium and long-term goals along the infrastructure. TEG had set itself the short-term goal of optimizing the use of existing products together with users to such an extent that greenhouse gas emissions were reduced to the possible minimum.

Methodology

The hypothesis is: the use of submersible pumps in mining and tunnel construction can be optimized by observing the operating parameters by using intelligent control systems and thus increasing energy efficiency to reduce GHG (Greenhouse gas) emissions. The hypothesis could also be supported by literature research and calculations from “good engineering practice”. However, assessing technical problems as part of preliminary planning is already common practice at TEG (Tsurumi (Europe) GmbH) to support Tsurumi's customers. In mining and tunnel construction there are no permanently stable operating conditions compared to chemical plants. Depending on the progress of the work (depth of the bores), the density, viscosity, and (Potential of Hydrogen) pH value of the fluid can change within a short time. In subject to the progress of the work, the delivery height (head) and the pipe lengths also change at regular intervals. Due to the environmental circumstances and constant changes, submersible motor pumps cannot only be operated at one (single) operating point. The hydraulic efficiency of a submersible motor pump essentially depends on the degree of wear of the hydraulic components (impeller, wear plate, shaft, mechanical seal). The bigger the distance between the (operating point or duty point) DP and the (best efficiency point) BEP, the heavier the signs of wear caused by vibration, cavitation.

TEG is not aware of any publicly available studies that examined different pump models in one experimental series at the same time under identical conditions. For this reason, TEG decided to conduct a quantitative study. As part of the experiment, primary measurement results were collected about 69 days under changed operational conditions. In addition to the Tsurumi pump, 5 other pumps from other manufacturers with almost identical technical characteristics were selected for the series of experiments (Fig. 1). This decision was made for reasons of objectivity - if an end user chooses the pump neutrally and based only on the technical characteristics for the application. In a tunnel or mine, existing pipelines are extended as required to meet the progress of work. The interchangeability of products (submersible pumps from different manufacturers - for reasons of availability) is an essential aspect of sustainable development from Tsurumi's perspective.

Each test station consists of one (Intermediate bilk containers) IBC container (type: Schütz MX-1000), one steel frame as a support for the pipeline (Diameter Nominal) DN80 (Pressure Nominal) PN16 88.9*3.2mm made of steel, two ifm (producer) vibration transmitter type; 10-1000HZ VTV121 (for vertical and horizontal measures), one ifm pressure sensor type: 0-10 bar PA3024, one TIVAL (producer) submersible probe type: TST-HD135K 200 mBar, one E+H (producer) flow meter type: Promag W300 5W3B80 DN80 3", 1x HAWLE (producer) gate valve E3 EKB PN16 and, one TSURMI-Connect-Box control and monitoring system. The length of the pipeline (20m) was chosen according to the necessary pipe friction resistance. The height of the pipeline (6.5m) had to be neglected in the calculation because the water was pumped in a circle, and it was built higher solely for reasons of space. The DP (flow rate) was set by using the gate valve. The experiment was divided into different phases. Pumps are usually selected by end users based on operating data or availability. The performance curves differ from each other despite identical operating data and the influence of the system curve is usually neglected. This behavior was also considered in the experiment, so the test series was divided into the following 5 phases.

From May 15 to May 17, 2023, phase of installation and commissioning of (6) stations - test run medium: water, (Q=flow rate, P1=pump 1) QP1to P6≈57 m^3/h. From May 17 to June 2, 2023 – 1. test phase, medium: water QP1 to P6≈57 m^3/h. On June 2, 2023, process stopped – Installation of gate valves. From June 2 to June 16, 2023 – 2. test phase, medium: water, QP1-P6≈57 m^3/h. On June 16, 2023, process stopped – Installation of the pressure sensors above the pumps and addition of 40kg of sand and 40kg of gravel. From June 16 to June 19, 2023 – 3. test phase, medium: water-sand-gravel mixture, QP1-P6≈26 m^3/h. From June 19 to June 22, 2023, the process stopped - repair of P6 due to leakage on the temperature sensor. From June 22 to July 5, 2023 – 4. test phase, medium: water-sand-gravel mixture, QP1-P6≈36 m^3/h. From July 5 to July 21, 2023 – 5. test phase, medium: water-sand-gravel mixture, QP1-P6≈57 m^3/h. The following data (statistical features) was recorded and stored in the experiment over the entire period with the Tsurumi Connect Box (TCB): vertical vibration [mm/s], horizontal vibration [mm/s], flow pressure [mBar], water level [cm], volume flow [m^3/h] and current consumption [A]. Each measuring station was equipped with its own TCB so that all stations worked independently of each other. The measurement data was transferred to the Tsurumi Connect Cloud (TCC) and saved every 10 seconds. During the experiment, up to 496,750 measurement data (values per variable) were measured and saved per feature and measuring station. The total number of measuring data recorded is 496,750 * 6 = 2,980,500 measuring points per measuring station - without error messages (when minimum and maximum limits are exceeded) and without (Long Term Evolution) LTE connection data to the TCC.

The plausibility check should first determine whether the measurement methods and measuring equipment used were suitable. The following questions were then answered from the basic data: a) Are there deviations between the data transmission and the event log? b) are the measured values within the tolerances of the manufacturer? c) Can measurement errors (big measurement deviations) be justified, and can systematic measurement errors be ruled out? The test stations were designed so that the examinations can be repeated at any time or continued with changed parameters, which also explains the reliability of the experiment. For reasons of objectivity, the manufacturers and pump type designations are not mentioned in any records. The information is only accessible to a limited number of people who have no influence on the evaluations and results - this also explains the objectivity of the experiment.

Results and Discussion

The measurement results for P1 to P6 were sent daily via email in an Excel report with the individual measurement values from the TCC. At the end of the experiment, all individual Excel reports for each pump were combined into one report using Excel Power Query, each containing 496,750 measurement data. This step already made it possible to identify and filter out data inconsistencies. High deviations from the diagrams (Figure 1) were not filtered out. These deviations will be examined in more detail in a later phase of evaluation. From the cumulative reports for P1 - P6, 6x 6 = 36 diagrams were created (Figure 1) - one diagram for each statistical characteristic with all values of characteristics. Taking all characteristics into account, the behavior of the system can be derived from the diagrams for each phase.

Further statistical assessments were carried out from the data from the cumulative reports, including calculating the standard deviation of the power consumption for each pump. Conclusions about the behavior can be drawn from the diagram of the respective pump. The flow rate, vertical vibration and power consumption are directly related to each other. In phase 1 with 57m³/h, the operating point of the pump is outside the performance curve, far on the right side of the diagram at a delivery head of ≈ 2.0m and thus explains the high vibration value. The current consumption in phase 1 is between 4.6-4.8 A. In phase 2, after installing the gate valves, the volume flow was set to 26m³/h. This means that the vibration values and at the same time the delivery height (to ≈ 15.5m) increased (and thus the pipe friction resistance), but the deviation from the mean value became significantly smaller and the current consumption also dropped to 4.0 A.

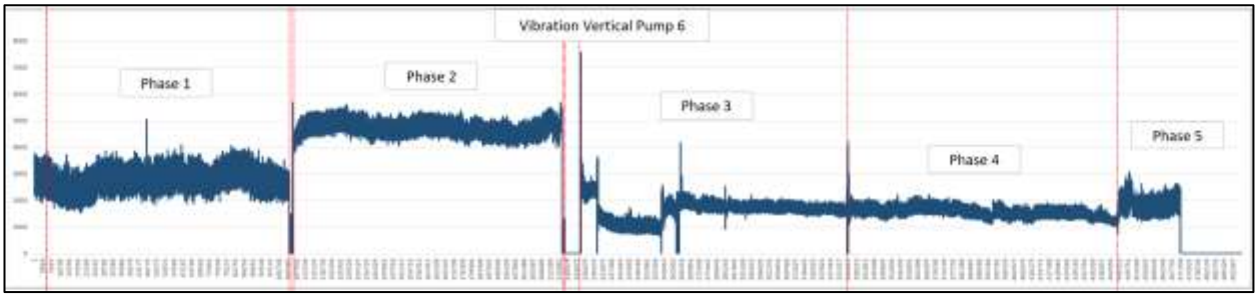

Fig. 1. Example of data evaluation – diagram vertical vibration pump no. 6 (source: S.Rostás, own editing)

The change in density by adding sand and gravel in phase 3 initially led to high vibration values, high flow pressure and a high current consumption of 5.0A. After a while, the sand and gravel mixture were deposited on the bottom of the container around the strainer of the pump and the gravel worked like a filter that filtered the sand out of the water, so that after a certain time almost clean water was pumped. The operating parameters normalized in phase 4 and remained almost at the same level. In phase 5, an attempt was made to pump the mixture of sand and gravel out of the container by setting a higher flow rate. Increasing the flow rate only led to poorer operating data and the sand-gravel mixture remained at the bottom of the containers. Even small changes in operating conditions influence the behavior of the pump and the entire system. From the energy efficiency perspective, pumps should only be turned on when circumstances require it (MacKay & Both Elődd, 2011). An intelligent control system can take over the task of monitoring the entire system. A division into the external and internal system helps to define the system boundaries. The external system includes, for example, the size of the basin, the quantity and speed of the incoming medium and the required delivery volume and time for further delivery of the medium, as well as all environmental conditions that can influence the system. All other information about the piping system, delivery head and medium data belong to the internal system. After processing all this input information and disturbance variables, the intelligent system decides whether to switch the pump on or off - this is the first step to being in line with the energy efficiency requirements. With a frequency converter, the system could choose to run at a higher speed if conditions require it and then the system can reduce the speed again to reduce power consumption.

Important aspects are at the forefront of all considerations. First, to reduce the power consumption (throttle the energy consumption) to reduce the GHG emissions of the pump and the entire drainage system and at the same time to extend the life cycle of the products to the possible maximum, to improve the ecological footprint (to use less raw materials). All pumps were tested, some of them far beyond their performance limits, to determine when the electrical or mechanical limits were reached. The inspection (3D measurement before and after) of the hydraulic components showed that only minor (3-6%) signs of wear were noticeable. However, in 2 pump models the mechanical seals failed completely, in 3 pump models water had already penetrated the oil housing and in only one pump the mechanical seal was perfect - with no water in the oil housing and no oil loss.

Conclusion

The results so far support the hypothesis and give reason to actively work on further improvements as part of a life cycle assessment to reduce GHG emissions more quickly. This work and the results so far prove that even smaller efforts with existing resources can be successful in the beginning. This requires options for designing processes that take existing and newly acquired knowledge into account, so that appropriate technologies and processes can be developed to increase energy efficiency(Has, 2022). In addition, there must be a willingness to accept and use new technologies in order to exploit the scope for design in a social sense.

Acknowledgements

This Work was supported by the Tsurumi (Europe) GmbH, Wahlerstraße 10, 40472 Düsseldorf, Germany

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