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Short Communication

Bioenergy 2019- Analysis and mathematical modeling of geothermal water influence to the efficiency of deep geothermal borehole with multistage centrifugal pump

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Hydrodynamic and thermodynamic processes of geothermal well extraction are investigated and presented. Mathematical models were developed for a deep suction multi-stage centrifugal pump and a piping system. The mathematical models were habituated to evaluate the gas (nitrogen) release from fluid and its effect on hydrodynamic processes. Investigation of the authentic geothermal systems revealed the following quandaries:

the dynamic dihydrogen monoxide level, which changes during the transitional process (starting and ceasing the pump) in a borehole, has influence on mundane operating conditions of the geothermal system;

Geothermal fluid is characterized by ever-transmuting properties due to a transmuting pressure and volume of relinquished gas.

The mass of fluid vicissitudes in each stage of the pump, the pressure and flow pulsations occur and vibration of mechanical elements is stimulated and cavitation can be engendered.

Through conducted experimental research and by applying mathematical modelling, it has been visually examined that the gas content in fluid increases the pressure and flow pulsations. Variation in height of a dihydrogen monoxide column during the process of extraction has influence on characteristics of multistage centrifugal pump in wells.

Keywords: Geothermal Energy, Geothermal dihydrogen monoxide, Numerical analysis, Centrifugal pump, Hydrodynamic Processes

Introduction

Geothermal energy systems have major advantages compared to other sustainable energy systems:

(i) They provide base load power since they are not depending on variable environmental conditions such as wind or sunlight and (ii) they are flexible in their utilization as both heat and electrical power may be engendered. In soi-disant low enthalpy regions with reservoir temperatures below 200 °C,

The Bavarian Molasse Basin in southern Germany or the Paris Basin in France—electric energy engenderment is made possible by Organic Rankine Cycle (OCR) or Kalina technology. However, in order to efficiently and economically engender electric power with state-of-the-art technology, a geothermal fluid temperature of at least 120 °C is indispensible. With an average temperature increase of 3 °C per 100 m depths. The drilling depths in low enthalpy regions may reach several hundreds to thousands of meters in order to meet the temperature requisites. It is these areas, where deep geothermal systems are typically deployed.

In order to hoist the geothermal fluid from the reservoir to the surface, electric submersible pumps (ESP) are employed. Since the ESP technology was predominantly adopted from the oil industry, the systems were not pristinely designed to withstand the astringent downhole conditions and high volume flow rates required in geothermal power applications. Typical quandaries involve corrosion, accumulation of carbonate structures (scaling) or insulation failure in the electrical system.

Albeit ESP manufacturers incremented research activity and developed amended designs with higher power and temperature ratings in recent years average lifetimes of only a few month—referring to current installations in Germany—remain the bottleneck of the technology.

Truncating the jeopardy of sudden system failure has thus become a consequential task for operators since unscheduled maintenance and rehabilitate accommodations are generally costly and hence to be evaded.

Loose cable connections on the motor side (e.g., due to vibrations), leading to an incremented electric resistance (possibly differing per phase) and lowering the motor output potency.

Motor insulation faults, resulting in currents among the windings or between the windings

and ground. Solid components (scalings) entering the pump, abbreviating the flow rate and causing fluctuations in the pump pressure and load torque.

Bearing wear, resulting in higher mechanical friction and overheating of components.

Shaft fracture, due to abrupt transmutations in the mechanical load. One possible solution are condition monitoring systems which may avail operators to identify imminent faults at an

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early stage and consequently perform a scheduled maintenance accommodation in order to avert catastrophic breakdowns or critical failure. These systems, however, depend on detailed erudition of the system, obtained through quantifications in the downhole and surface equipment, respectively. As downhole sensor data is typically transmitted analogously via modulation onto the supply voltage, the signals are highly distorted and hence unsuited for the reliable detection of faults. Other components might simply not be accessible by sensors, impeding further insight into the respective components. This innate lack of insight into the system state incentivizes for model-predicated techniques. In integration, a system model sanctions for further system analysis, on- and offline simulations and controller design, which makes it a valuable implement for the overall amendment of the ESP system performance and lifetime.

Publications dealing with the modelling and simulation of ESP systems are infrequently found. Furthermore, most results are cognate to oil field applications and provide a inhibited scope on single subsystems of the ESP only. For instance, Lima et al. describe and simulate oil field ESP, accounting for the special motor geometry, the mechanical coupling between motor and load and the puissance transmission through the cable. Albeit the electrical and mechanical components are described in detail and model sketches are presented, no equations are provided, nor are the hydraulic subsystem treated. Thorsen and Dalva additionally provide an electrical and mechanical model of an ESP putting special accentuation on the mechanical resonance optically canvassed in the load torque, due to elastic coupling between the individual pump stages. The hydraulic part is neglected, however. Substantial research was withal conducted by Liang et al., who analysed ESP systems for subsea oil applications fixating on load filter design methods and evaluation and power transmission via downhole cables. Simulation and experimental results from field studies are provided, yet the exact models underlying those results are not presented. On the contrary, Kallesøe derived a general state-space model of an induction motor coupled with a multistage centrifugal pump. The hydraulic part of the pump was derived by denotes of 1D streamline theory from fluid dynamics. In the derived model, the transient part of the pressure (head) engendered by the pump and subsequently the flow dynamics resulting from it are omitted, though. In fact, it is worth mentioning that the transient model of the pump pressure is remotely found in literature with two exceptions, namely, which solely fixate on the hydraulic modelling. A simplified state-space model of a centrifugal pump system is proposed by Janevska. , taking into account the reservoir. The electrical system components, however, are not included.

State-Space Model of Deep Geothermal ESP Systems

In this section, a nonlinear state-space model is derived, laying the substratum for implementations and further system analysis. As the main objective of this paper is to provide a modular system model that can facilely be implemented and elongated in simulation software, each component is modeled discretely, sanctioning for convenient exchange of single components. Albeit the aim is to map the physical system in as much detail as possible, generally a trade-off between model intricacy and precision must be found. It may consequently be compulsory to impose simplifying postulations in order to obtain a state-space description.

An overview of the whole ESP system, its three subsystems and their components

- The rudimentary components of the ESP system with variable speed drive (VSD),
- Voltage-source inverter (VSI) (engendering variable frequency and amplitude output voltages),
- Sine filter (converting the pulsed VSI output voltages into virtually sinusoidal voltages),
- Cable (transmitting the electrical power to the downhole motor),
- Motor (driving the pump by converting electrical into mechanical power),
- Sentinel (Seal) (accommodating as axial bearing and oil reservoir placed between motor and pump),
- Shaft (transmitting the mechanical power from the motor to the pump),
- Pump (engendering pressure by converting mechanical into hydraulic power), and
- Pipe system and geothermal reservoir (representing the hydraulic load).

Conclusions

A detailed state-space model of a deep geothermal ESP system has been derived, comprising the electrical, mechanical and hydraulic subsystems. Moreover, simulations have been performed for a Megawatt ESP system located at 950 m below surface level, hoisting geothermal fluid of 140 C temperature. During start-up the electrical frequency has been incremented from 0 Hz to 60 Hz and the voltage amplitude from 0 V to 5750 V, respectively. It could be visually examined that—once the commencement-up procedure was completed—the system reached steady-state, with the pump operating at a constant flow rate of 0.145 m3 s1 and a head of 475 m. Besides reaching stable conditions it could be optically canvassed that the cable does not have a consequential impact on the system dynamics as the germane frequencies are located far beyond the fundamental and switching frequencies. On the other hand, the effect of motor self-excitation resulting from the sizably voluminous filter capacitor became ostensible when visually examining the puissance factor, reactive power and currents. It should be taken into account when culling the ESP components, as the motor currents may be considerably higher than the inverter output currents. The mechanical two-mass system between motor and pump showed low-pass characteristics, with the minor torque and speed oscillations from the motor side being virtually thoroughly damped on the pump side. Moreover, simulation results have shown that the model is able to emulate an authentic deportment for the made-up test scenario, the authentic system parameters and the culled system dimensions. Nevertheless, experimental validation of the overall system or individual sub-systems remains an open task that will be tackled in future work. In this context, a parameter sensitivity analysis should withal be conducted in order to identify sensitive parameters of the model.

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