AUTOMATIC WELL FAILURE ANALYSIS FOR THE SUCKER ROD PUMPING SYSTEMS

By

Ramez Maher Aziz Zaky Abdalla

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Petroleum Engineering

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Under the Supervision of

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Title of Thesis:

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Key Words:

Sucker Rod Pumping System; Back Propagation Neural Networks (BPNN); Support Vector Machine (SVM); Dynamometer Card; Elliptical Fourier Descriptors (EFD)

Summary:

This study is a contribution to the area of fault automatic detection and diagnosis in the sucker rod pumping systems. Therefore, an intelligent system capable of detecting downhole sucker rod pumping systems problems was developed.

Acknowledgments

First of all, I would like to express my endless thanks to **ALLAH** for giving me the ability to perform this research.

I would like to extend thanks to many people who so generously contributed to the work presented in this thesis.

I would like to express my deepest thanks and appreciation to the supervisors of this thesis: ***Prof Dr. Ahmed Hamdy El-Banbi***, and ***Prof Dr. Mahmoud Abu El-Ela***, Mining, Petroleum, and Metallurgical Engineering Department, Faculty of Engineering, Cairo University for their extremely helpful advice, sincere assistance, continuous guidance, and encouragement in creating this work. Simply, without their kind helps, this work would not come to light.

I also appreciate the support of **Agiba Petroleum Company** for their support. They generously host me in Meleiha oilfield. That helped me to touch the practical part of my work. I would like to express my gratitude and deepest thanks to the family and the team of the ***Agiba Petroleum Company,*** especially, ***Eng. Osama Ahmed El Baqly*** (EGAS Chairman and Former Chairman and Managing Director of Agiba Petroleum Company)***, Eng. Mohamed Abdu***, (Operations Manager - Agiba Petroleum Company) and ***Eng. Michael Georg***e (Production Engineer - Agiba Petroleum Company) for their continuous follow-up and for their valuable discussion and advice during this work

I would like also to direct my gratitude to ***Eng. Samir Siso*** (Operations Manager at Badr El Din Petroleum Company), ***Eng. Doaa Mousa*** (Reservoir Engineering Department Manager - Belayim Petroleum Company) and ***Eng. Mostafa Gad*** (Production Engineer - Belayim Petroleum Company) for their help during the phase of the model validation.

Similarly, I would like to send my gratitude to ***Prof. Dr. Leizer Schnitman*** Electronic Engineering and Computing Department, The Federal University of Bahia and ***Eng. Galdir Reges*** (Researcher - Technological Training Center for Industrial Automation at the Federal University of Bahia) for their valuable discussions and support.

Last but not least, I would like to thank my professors and my colleagues, in the Petroleum Engineering Department, who encouraged me and gave me all the needed support during my academic life.

Dedication

To my parents.

This humble work is a sign of my love to you!

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Nomenclature

Symbol

$a_i^{(j)}$	Hidden layer function of node i in layer j
a_n	The 1st Fourier coefficient corresponding to n_{th} harmonic
b_n	The 2nd Fourier coefficient corresponding to n_{th} harmonic
c	The cost of classification
c_n	The 3rd Fourier coefficient corresponding to n_{th} harmonic
d_n	The 4th Fourier coefficients corresponding to n_{th} harmonic
$\mathcal{F}_\mu$	The elliptical Fourier descriptors
$\mathcal{F}_1$	The elliptical Fourier descriptors corresponding to 1st harmonic
$g(x)$	Activation function
$\nabla g_i(x)$	Gradient of the activation function
$H(y, y')$	Cross entropy function
$h_\theta(x^{(i)})$	Hypothesis function
$k(w, x)$	Kernel functions
k	The order of Fourier coefficients to calculate
m	Number of training examples
n	Harmonic number
p	The index of the chain link.
S	Scale factor
T	Summation of all t increments
t_p	The lengths of the chain at the path link.
v	Number of input feature vector
w	Vector perpendicular to SVM hyper-plane
x_p	Links summation on x-axis.
y_i	The predicted probability distribution of the class i
y_i'	The true probability for that class
y_p	Links summation on y-axis.

Greek

Θ	Weights vector
γ	Gaussian Kernel parameter handle non-linear classification

Abbreviations

ANN	Artificial Neural Network
BFPD	Barrel of Fluid per Day
BOPD	Barrel of Oil per Day
BPNN	Back Propagation Neural Network
EFD	Elliptical Fourier Descriptors
ESP	Electrical Submersible Pump
FN	False Negative
FP	False Positive

KDD	Knowledge Discovery in Database
PCP	Progressive Cavity Pump
PIP	Pump Intake Pressure
RBF	Radial Basis Functions
ReLU	Rectified Linear Unit
SOM	Self-Organized Maps
Softmax	The Softmax Function
SV	Standing Valve
SVM	Support Vector Machine
TN	True Negative
TP	True Positive
TV	Travelling Valve
TWM	Total Well Management

Abstract

Sucker rod pumping is one of the most common methods of artificial lift technologies. Monitoring the working conditions of the sucker rod pumping system is important to sustain acceptable productivity levels. Dynamometer cards are one of the main tools for rod-pumping well performance analysis. In this work, Back Propagation Neural Networks (BPNN) and Support Vector Machine (SVM) algorithms are used to analyze the features of the downhole dynamometer card and identify the sucker rod pumping system conditions.

A description model for the dynamometer cards was established. This model can reflect the characters of the dynamometer cards. Then, machine learning techniques were trained to generate failure prediction models to recognize downhole faults of the rod pumping systems. The failure prediction models were validated and tested with real field applications.

The proposed model is trained and tested by using real field data of 6,385 dynamometer cards. 29.2% of these cards represent sucker rod pumping systems of normal conditions, and 70.8% of these cards represent faulty sucker rod pumping systems. These field data collected from pumping unit API designations. The faulty systems include thirteen pumping condition: pumping off, plugged pump intake, gas interference, tubing anchor malfunctions, gas lock, standing valve leak, travelling valve leak, pump hitting on bottom, pump hitting on top, viscous oil problem, bent polished rod, shallow rod parted and deep rod parted. These data have been collected from several oil fields. The neural network model used 958 dynamometer cards for validation (to reduce overfitting). Finally, the model was tested against another 958 real dynamometer cards.

The BPNN model outperformed the SVM model in accuracy. The two models identified the sucker rod systems failure successfully with accuracy 98.5% for BPNN and 86% for SVM. The Proposed model successfully predict rod pumping system downhole condition with precision 89.9% and Recall 89.1% for API designated rod pumps.

This study is an original contribution to automatically analyze the dynamometer cards and accurately diagnose the downhole faults of the rod pumping systems.

Chapter 1 : Introduction

Artificial lift techniques are widely applied in oil industry to enhance production either to maximize production rate of a naturally flowing well or to lift a dead well. Although there are several artificial lift techniques in the industry (such as Gas Lift, Electric Submersible Pump, Progressive Cavity Pump and Sucker Rod Pumps), the beam pumping system is the most commonly used technique. In which there are surface pumping unit and the sucker-rod string that runs down the well to connect them [1]. The most commonly applied artificial lift technique worldwide is rod pumping systems with more than 750,000 of the lifted wells use sucker-rod pumps [2].

In the Egypt's Western Desert fields, sucker-rod pumping is the major choice of oil producers. According to Lufkin Middle East statistics in 2008, approximately 85% of all Western Desert wells are artificially lifted using sucker rod pumping system as shown in Fig. 1.1 [2]. Those are making an average of +/- 57,000 barrels of fluids per day (BFPD) (+/-35,000 barrels of oil per day (BOPD)). Of the rest wells 13% are lifted with ESPs, the reminder are gas lift, hydraulic pumps, and other artificial lift methods. These statistics indicate that the dominance of rod pumping for onshore operations [2].

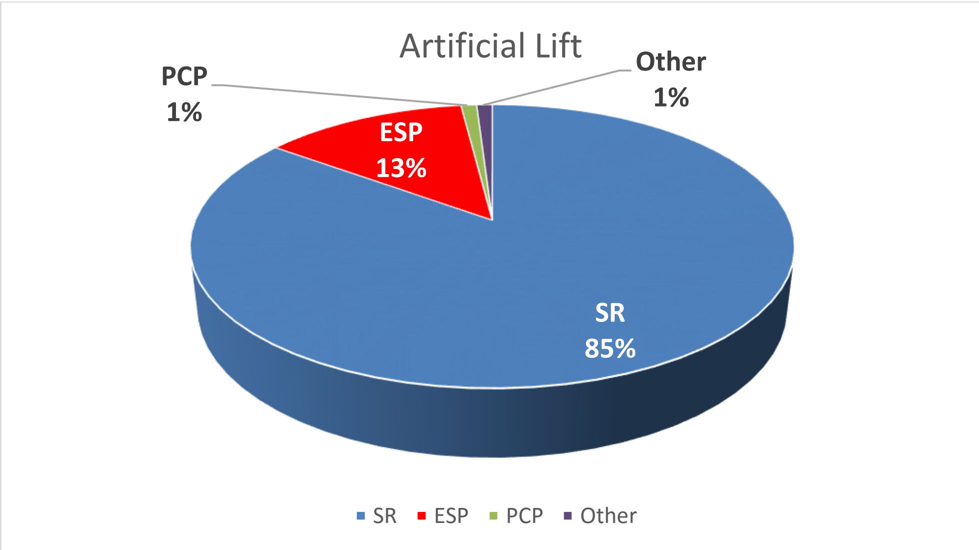

Fig. 1.1- Lufkin Middle East statistics for the artificial lift systems in the Western Desert fields

Well failures in oil field can drastically cause production loss and can greatly increase the lifting costs. Well failure in sucker rod pumping system is mainly identified from the anomalies of the dynamometer card [3]. Experts with rich experience are capable of identifying various types of anomalies via combining various types of information such as a well's recent performance, its events log and its neighboring well performance. Such anomalies, once identified, have high probability to be followed by a failure in the