DEVELOPMENT OF A COMPUTATIONAL METHOD TO ESTIMATE FLUID FLOW RATE IN OIL WELLS WITH AN ELECTRICAL SUBMERSIBLE PUMP

BY

TAREK AL-ARBI O. GANAT

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Kulliyyah of Engineering
International Islamic University Malaysia

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ABSTRACT

A significant challenge in the oil and gas industry is the simultaneous measurement of commingled gas, oil and water streams, using the three phase test separator or multiphase flow meter (MPFM). The major issue in the application of using either test separator or MPFM in oil field is the uncertainty of the measurements, due to different process and operations conditions. To date, there are no sets of rules proving the technique for comparison between the test separator and the multiphase flow meter. Hence, there is a need for more accurate and reliable methods to be adapted as alternatives to the current flow rate measurements techniques, which must be capable of working at any fluid composition and production flow environment conditions. At first, this thesis will show, through an experimental study, wide variations of the liquid rate measurements between the conventional test separator and MPFM at several periods of time. Then, it proposes a new computational method to estimate the electrical submersible pump (ESP) oil well flow rates. The research idea is to close the wellhead wing valve as the ESP is kept running normally, and the wellhead flowing pressure before well shut-in and the build-up of wellhead flowing pressure after the well shut-in is measured. The total shut-in time period is recorded, and it is dependent on the individual oil well production conditions. Explicit physics concepts for estimations of the multiphase fluid flow rate in a vertical pipe were employed. The formulas deal with changes of fluid flow parameters along the vertical pipe in the well, as a function of pressure and temperature variations with depth. A Microsoft visual basic program was also developed based on the oil mechanistic and empirical equations that can estimate oil rate for ESP oil wells. The new method was applied on 48 ESP oil wells in North African oil fields and lead to very reliable estimation results, which have about a +/-10% relative error. As a result, a regression correlation equation was developed based on the computational results. OLGA software has been used to make comparison with multiphase flow model available in the OLGA software against each nominated ESP oil well parameters obtained from measured field data. The objective was to verify the obtained shut-in wellhead pressure after closing the choke wing valve (WHPa) from the measured field data with the obtained shut-in wellhead pressure valve from the simulation model. The simulation results showed that the estimated WHPa are in agreement with the measured WHPa. The relative errors for individual oil field are within accuracy standard specification (typically +/- 5%). The overall relative errors are low and within acceptable uncertainty range, where the aggregate relative error for all wells was less than +/-4%. Therefore, the results have demonstrated that the new computational method can be applied to all fluid types and under any production conditions. Generally, the results show that the new computational approach is more accurate when compared with test separator measurement within the specified range of accuracy.

خلاصة البحث

التحدي الكبير في صناعة النفط والغاز هو عملية القياس المتزامنة لتدفق الغاز والنفط والمياه في آن واحد ,وذلك بأستخدام محطة العزل للسوائل المنتجة (Test Separator) أوباستخدام عدادات ذات خاصية قياس التدفق للسوائل المتعددة (MPFM). هناك العديد من عدادات قياس السوائل التي تم تطويرها مند مطلع سنة 1980م بواسطة مراكز الأبحاث والشركات المنتجة للنفط والغاز. هناك بعض الدراسات التي أظهرت نتائجها اختلافا كبيرة في نتائج قياسات السوائل مابين الطريقتين على فترات زمنية مختلفة. إلى اليوم لاتوجد قواعد اساسية لضبط عملية المقارنة بين النظامين, لذالك دعت الحاجة إلى ضرورة إيجاد طرق أكثر أعتماداً وذقةً لحساب تدفق السوائل المنتجة. هذة الأطروحة تقترح طريقة حسابية جديدة لتحديد معدل تدفق إنتاج النفط من الأبار التى تعمل بأستخدام المضخة الكهربائية الغاطسة (ESP). فكرة البحث تعتمد أساسا على غلق صمام رأس البئر النفطي مع ترك المضخة تعمل بصورة طبيعية ويتم قياس ضغط رأس البئر (WHP_b) قبل قفل الصمام أثناء عملية الأنتاج وبعد قفل الصمام (WHP_a) , (على الأقل يزداد ضغط رأس البئر50 رطل أخرى عن ضغط رأس البئر قبل القفل), وتسجيل الفترة الزمنية الكلية لعملية قفل الصمام. تم أستخدام المعادلات الفيزيائية والمعادلات المعملية اللازمة في حسابات خصائص السوائل المتدفقة عند حدوث أي تغير في الضغط ودرجة الحرارة على طول عمق البئر العمودي. في هذا الأطروحة أيضا تم أستخدم برنامج مايكروسوفت (Visual Basic) لبناء العمليات الحسابية للطريقة الجديدة. الطريقة طبقت على عدد 48 بئر نفطي يستخدم المضخة الكهربائية الغاطسة لحقول نفط في شمال أفريقيا. الطريقة الجديدة أظهرت نسبة الخطاء النسبي حوالي +/-10%. ونتيجة لذلك، تم تطوير معادلة الأنحدار على أساس النتائج الحسابية المتحصل عليها. هذا البحث أستخدم أيضا برنامج النموذج الرياضي (OLGA) وذلك لحساب ضغط صمام رأس البئر أثناء القفل (WHP_a) المتحصل عليها من النموذج الرياضي ومقارنتة مع ضغط قفل صمام رأس البئر المتحصل عليها من القياسات الحقلية لكل بئر. النتائج كانت جيدة أيصا حيث أن نسبة الخطاء النسبي كانت +/-5% لكل بئر. وبالنظر الي الخطاء النسبي لجميع الأبار مجتمعة كانت حوالي 4%. لذا أعتبرت ذقة نتائج التي أظهرتها الطريقة الحسابية الجديدة مقبولة ويمكن الأعتماد عليها كطريقة جديدة يمكن تطبيقها على جميع الأبار التي تستعمل المضخة الكهربائية الغاطسة وتحت أي ظروف عملية و أنتاجية.

APPROVAL PAGE

The thesis of Tarek Al-Arbi Omar Ganat has been approved by the following:

Meftah Hrairi
Supervisor

M.N.A. Hawlader
Co-Supervisor

Osman Farj
Field Supervisor

Sher Afghan Khan
Internal Examiner

Abdulrahman Hamid Nour
External Examiner

Rahmat Mohsin
External Examiner

Noor Mohammad Osmani
Chairman

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Tarek Al-Arbi Omar Ganat

Signature .... Date ....

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LIST OF ABBREVIATIONS

API	Oil specific gravity
A	Pipe cross-sectional area, sq ft
B_g	Gas formation vol. Factor, res. cf/scf
Bo	Oil formation vol. Factor, res. bbl/stb
Bob	Oil formation volume at bubble point pressure, bbl/STB
Cnt	Count
d	Inside pipe diameter, ft
dp/dz	Total pressure gradient (friction pressure loss is considered).
f	Friction losses factor
FVF	Formation Volume Factor
g	Gravity
HG	Gas holdup
HL	Liquid holdup
H1	Bubble point pressure location depth before closing the wellhead valve, ft
H2	Bubble point pressure location depth after closing the wellhead valve, ft
mt	Mass flow rate, lb/day
N_{Lv}	Liquid velocity number
N_{gv}	Gas velocity number
NL	Liquid viscosity number
Nd	Pipe diameter number
NCL	Correction for viscosity number coefficient
q_o	Oil flow rate stb/day

q_w	Water flow rate stb/day
q_g	Gas flow rate stb/day
q_L	Liquid flow rate stb/day
qm	Measured flow rate stb/day
QC	Quality Check
P	Average pressure, psia
Pb	Bubble point pressure, psia
Pr	Pseudo-critical pressure of gas mixture, psia
Psc	Pressure at standard conditions, psia
PSD	Pump setting depth
SGG	Specific gravity of gas
STB	Stock tank barrel
rw	Wellbore radius, ft
Rs	Solution gas-oil ratio, scf/stb
Rsb	Solution gas at bubble point pressure, (cf/scf)
Re	Reynolds number
T	Average temperature, °F
t	Shut-in time, min
Tr	Pseudo-critical temperature of gas mixture, psia
Tsc	Temperature at standard condition, ^{o}R
Tr	Reservoir temperature, °F
VR	Gas volume at down-hole conditions, ft3
Vsc	Gas volume at standard condition, ft3
VS_L	Superficial liquid velocity, ft/sec
VS_g	Superficial gas velocity, ft/sec
V_m	Mixture velocity, ft/sec

WHP_a	Wellhead pressure after closing the well, psia
WHP_b	Wellhead pressure before closing the well, psia
WC	Water cut (non-dimensional)
WHT	Wwellhead temperature, °F
W	Water vapour density
Z	Gas compressibility factor

LIST OF SYMBOLS

ΔP	Drawdown pressure, psia
HL/ψ	Holdup factor correlation
γo	Oil gravity
γw	Water gravity
γg	Gas gravity
σ	Surface Tension
ΔH	The differences between bubble point pressure location depth before and after closing the wellhead valve, ft
ρ_o	Oil density lbm/ cu ft
ρ_g	Gas density lbm/ cu ft
ρ_w	Water density lbm/ cu ft
ρ_L	Liquid density, Ib/cu ft
ρ_m	Mixture density, Ibm/ cu ft
μ_o	Oil viscosity, cp.
μ_g	Gas viscosity, cp.
μ_L	Liquid viscosity, cp

Subscripts

g_s	Gas at standard condition
h	Hydrostatic
L	Liquid
m	Mixture of liquid and gas

o	Oil
sc	Standard condition
w	Water

CHAPTER ONE

INTRODUCTION

1.1 MULTIPHASE FLOW MEASUREMENTS

The problem of how to meter oil-water-gas mixtures has been of interest to the petroleum industry since the early 1980's. A number of such meters have been developed by research organizations, manufacturers, oil and gas production companies, and other interested parties (Benlizidia, 2009). Different technologies and various combinations of technologies have been employed to produce prototypes which are dissimilar in form and function. While some lines of development have been abandoned, a number of meters have become commercially available, and the number of applications and users is rapidly increasing (Corneliussen et al., 2005). Gas/oil flow rate of production well is an important parameter for evaluating oilfield production (Nian, 2015). Oil producers used three-phase test separators or Multiphase Flow Meters (MPFM) to measure the total volume of fluids produced by individual wells in a large upstream production field.

Traditionally, metering of the multiphase flow is carried out by utilizing two or three phase test separators using single-phase flow meters installed at the outlets of the oil, water and gas legs. These have an acceptable accuracy limit, depending on operator's skills, maintenance work and various other factors such as fluid properties variation (Hosseini et al., 2011). The test separators are practical and the accuracies acceptable during the early production stages. However, the test separator accuracy is highly dependent on changes in Gas Oil Ratio (GOR) and Water Cut (WC) which yield to changes in the flow regime and fluid characteristics. Besides, test separators are expensive, occupy valuable space on a production platform and require a long time to monitor each well because of the stabilized flow conditions required. In addition, test separators cannot be used for continuous well monitoring.

During the late 1980's, the oil and gas industry started to realize that the availability of multi-phase flow meters could have a large economic impact on the infrastructure of oil and gas developments (Scheers and Wee, 2011). Multiphase flow meters (MPFM), on the other hand, do not rely on separation (100%) of the fluid and operate under various conditions for flow measurement, but these are also considered as unreliable measurement tools at high GOR and high WC. In addition, Multiphase flow meters are also very expensive to install. Hence, there is a need to adopt more accurate and reliable methods as alternatives to the current flow rate measurements techniques, and it must be capable of working in any fluid composition and production flow environment conditions (Falcone et al., 2009). In practice, down-hole measurement devices in the tubing string are not available due to the complication of fluid properties and conditions in terms of multiphase flow (Wee and Skjaeldal, 2009).

This research work proposes a new computational method to estimate the hydrocarbon fluid flow rate of the ESP oil wells. It is based on the estimations of multiphase fluid flow parameter variations along the vertical pipe in an oil well as pressure and temperature changes with depth, using principles of multiphase flow mechanistic equations and empirical correlations. A Microsoft visual basic program was also developed based on the oil mechanistic and empirical equations that can estimate oil rate for ESP oil wells. Besides, OLGA simulation model was used to verify the field input data used with the simulation model results.

1.1.1 Research Ground Work

This research work proposes a new method by which to determine fluid flow rate from the ESP oil well. It is based on the computation of fluid properties variation as a function of pressure and temperature changes with depth, in the vertical well pipe. This method is used in oil wells through an artificial-lift technique such as Electrical Submersible Pump (ESP). A sample of 48 ESP oil wells from G, W, and D oil fields in North Africa were chosen to apply the new approach.

This new method is applied by keeping the oil pump running, and by closing the wellhead pressure wing valve for a few minutes (depending on the individual oil well condition) to build up the wellhead pressure to at least 50 psi. The mechanism of calculation is based on the difference in gas volume at different bubble point pressure location depths, before and after closing the wellhead wing valve. From this incremental buildup of measured pressure, a new method will be developed to compute the hydrocarbon fluid flow of the ESP oil wells. The new method can be applied to different fluid flow composition and flow regime.

The algorithm program was developed using a Microsoft visual basic program (Evangelos, 2008) to estimate the fluid flow of the ESP oil wells through specific algorithm codes. The algorithm program is a diagrammatic representation of the steps used in solving the computational method using multi-physics equations (Keyes et al., 2013) and (Anders, 2015). The program identifies all the major steps and sub-steps in a process. In this algorithm, the initialization step is run to obtain the bubble point pressure location depth, before and after closing the wellhead wing valve. Based on the verification and validation of the new computational approach outputs, a new estimation oil flow rate regression equation was developed. A mathematical procedure for finding the best-fitting curve was used to measure and estimate data points by