INFLOW CONTROL DEVICE IN OPENHOLE HORIZONTAL WELL

NURATHIRAH BINTI HASBULLAH

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“My dearest parents, husband, children, family, Assoc. Prof. Issham and friends.”

This is for all of you

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ABSTRACT

An Inflow-control device (ICD) is a permanent completion hardware that is installed as part of well completions which often known as an equalizer or choking device. It offers numbers of unique benefits especially in the horizontal application, but it is not adjustable or non-retrievable hardware. Frictional pressure drops caused by fluid flow in horizontal section resulted in higher drawdown pressure at the heels section which causing an unbalance fluid distribution profile. Hence the main challenge of horizontal wells is an early water and/or gas breakthrough near the heel section which leads to a loss in production and reserves extraction, and ultimately, a decrease in profitability. Therefore, the purpose of this study is to develop the best ICD modelling design for a specific case study (Well ETA-06) and to investigate the effect of few important parameters towards the performance and functionality of the ICD along horizontal wellbore. ICD modelling was developed using NETool^{TM} software for appropriate number of open-flow ports and the optimum length and/or numbers of ICDs required for evenly distributing the flow profile along the screen length in order to achieve the proactive functionality of the ICDs. A sensitivity study has been run towards the best resulted ICD parameters, namely (1) ICD size, (2) flow port size, (3) swell packer usability, (4) flow rate, (5) ICD roughness, and (6) discharge coefficient in simulating influx along the horizontal wellbore by coupling fluid flow through porous media and hydraulic flow into nozzle type of ICD completion architecture. In the homogeneous reservoir, the heel section tends to produce more oil compared to the toe section thereby will allow water or gas production in a brief period. On the other hand, the ICD has reduced or choked the fluid inflow at the higher permeability section and produces more at the low permeability area. In general, ICDs are unchangeable; once installed downhole in the well, the location of the device and the relationship between the rate and pressure drop are fixed. Consequently, the best design of a well completion and ICDs is extremely crucial in order to ensure the functionality and effectiveness of the ICDs in obtaining the optimum production at lesser water or gas production.

ABSTRAK

Peranti kawalan aliran masuk (ICD) ialah perkakasan kekal yang dipasang sebagai sebahagian daripada pelengkapan telaga. Perkakasan ini dikenali juga sebagai peranti pencekik atau penyama. Walaupun mempunyai banyak kelebihan terutama bila digunakan pada telaga mendatar tetapi peranti ini tidak boleh dilaras atau diguna semula. Kejatuhan tekanan geseran yang disebabkan oleh aliran bendalir di dalam lubang mendatar menyebabkan terjadinya surutan tekanan yang lebih tinggi pada bahagian tumit, lalu berlaku profil taburan bendalir yang tidak seimbang. Oleh itu, cabaran utama pada telaga mendatar ialah berlakunya bulus air dan/atau gas berhampiran tumit, lalu mengakibatkan berkurangnya pengeluaran dan keuntungan. Oleh itu, tujuan kajian adalah untuk membangunkan reka bentuk model terbaik ICD untuk kajian kes (Telaga ETA-28), dan digunakan untuk mengkaji kesan beberapa parameter terhadap prestasi and fungsi ICD di sepanjang lubang telaga mendatar. Pemodelan ICD menguna pakai perisian NETool^{TM} bagi menentukan bilangan liang aliran, panjang optimum, dan/atau bilangan ICD yang harus dipasang supaya profil aliran adalah sekata di sepanjang tabir. Kajian kepekaan telah dilaksanakan terhadap (1) saiz ICD, (2) saiz liang aliran, (3) pengunaan penyendat ampul, (4) kadar aliran, (5) kekasaran ICD, dan (6) pekali luahan bagi menyelaku kemasukan sepanjang lubang mendatar dengan menggandingkan aliran bendalir menerusi media berliang dengan aliran hidraulik ke dalam ICD jenis muncung. Di dalam reservoir homogen, bahagian tumit cenderung untuk menghasilkan lebih banyak minyak berbanding bahagian hilir. Dengan itu, air atau gas akan turut segera keluar. Pada ketika yang sama, ICD akan mengurangkan aliran masuk bendalir pada bahagian berkebolehtelapan tinggi dan membolehkan pengeluaran lebih banyak di kawasan berkebolehtelapan rendah. Secara umum, ICD tidak boleh diubah; sebaik sahaja terpasang di dalam lubang telaga, lokasi pemasangan dan hubungannya dengan kadar aliran dan kejatuhan tekanan adalah kekal. Akhirnya, reka bentuk pelengkapan telaga dan ICD adalah penting supaya pengeluaran secara optimum dengan kadar iringan air atau gas yang lebih rendah boleh dicapai menerusi penggunaan ICD.

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LIST OF ABBREVIATIONS

AMSL	-	Above Mean Sea Level
API	-	American Petroleum Institute
BC	-	Base Case
BFPD	-	Barrel Fluid Per Day
BHP	-	Bottom Hole Pressure
BOPD	-	Barrel Oil Per Day
BPD	-	Barrel Per Day
BWPD	-	Barrel Water Per Day
DIF	-	Drilling Fluid
EOR	-	Enhance Oil Recovery
ER-ICD	-	Electrical Resistivity Inflow Control Device
ESS	-	Expandable Sand Screen
FBP	-	Flowing Bottom Hole Pressure
FP	-	Frac Pack
GP	-	Gravel Pack
ICD	-	Inflow Control Device
ICV	-	Inflow Control Valves
ID	-	Internal Diameter
MD	-	Measured Depth
mD	-	miliDarcy
MSL	-	Mean Sea Level
NBA	-	Net Benefit Analysis
OBM	-	Oil Based Mud
OD	-	Outer Diameter
PI	-	Productivity Index

PO	-	Port Open
PMF	-	Porous Metal Fibre
PMM	-	Porous Metal Media
PPS	-	Pre-Packed Screen
PVT	-	Pressure Volume Temperature
RKB	-	Rotary Kelly Bushing
ROP	-	Rate of Penetration
SAS	-	Stand Alone Screen
SCON	-	Sand Consolidation
TVD	-	True Vertical Depth
TVDSS	-	True Vertical Depth Subsea
WBM	-	Water Based Mud
WWS	-	Wire Wrapped Screen

LIST OF SYMBOLS

ΔP	-	Pressure drop across orifice
ρ	-	Average fluid density
v	-	fluid velocity through orifice
Q	-	Fluid flow rate through orifice
A	-	Area of orifice
D	-	Diameter of orifice
C	-	Flow coefficient
Cd	-	Discharge coefficient
K	-	Pressure drop coefficient
$d_{effective}$	-	Effective diameter
m	-	Meter
Qo	-	Oil flow rate
Qw	-	Water flow rate
ΔPI	-	Different in productivity index
ΔWC	-	Different in water cut

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CHAPTER 1

INTRODUCTION

1.1 Background

Completion is part of well construction. It is defined as a series of activities or processes of making a hole ready for production or injection in a controlled manner (Buzarde *et al*., 1972; Ismail, 2000). Completion type can be divided into two categories which are upper and lower completion (Ismail, 2003). Part of the completion below the production packer is called as lower completion which can be subcategorized into few types. One of them is the sand screen or screen liner, including wire wrapped sand screens, slotted liners, pre-packed screens, and premium screen (Weatherford, 2010; Bellarby, 2009; *Matanovic et al*., 2012) which often deployed in poorly consolidated formation.

Sand production or sand influx is one of the major problems facing almost all fields that produce from unconsolidated sandstone formation (Durrett, 1977). Malaysian fields which comprise young rocks of Tertiary age are no exception (Tjia, 2000). The sand influx into producing well affects the economic limit for various reasons (Mann *et al.*, 1962): (1) the replacement or maintenance of flowlines, chokes, valves and meters due to erosion by the flowing sand, (2) workover due to the sanding out of wells, (3) loss of wells due to casing or liners collapse, (4) increase in operational cost due to removal of sand and silt from the produced crude , (5) lowering production rates to decrease sand cuts which would subsequently reduce oil revenue, (6) frequent cleaning out surface facilities, (7) increase in operational cost due to installation of downhole sand control devices, etc.

Apart from the sand production, the application of horizontal wells at the loose sandstone reservoir can lead to some problems in the uniformity of the fluid influx along horizontal wellbores. Fernandes *et al*. (2009) found that higher pressure drawdown around the heel section results in frictional pressure drop of fluid flow in the wellbore which causes non-uniform fluid influx along the length of the wellbore and higher production rates at the heel. This often leads to early break-through of water or gas, which causes a reduction in oil recovery and uneven sweep of the drainage area.

Hence, the Inflow Control Devices (ICDs) with the integration of the sand screen were proposed as a solution to address this problem. Principally, ICD is a choking device installed as part of sandface completion hardware which has been utilized for more than two decades. Subsequent field experiences have proven the potential and beneficial of ICDs to extend well life by extending the plateau period, minimizing or delay water or gas coning, eliminate and minimize annular flow, and ensure a uniform inflow along the horizontal wellbore at the cost of a small pressure drop (Al-Khelaiwi and Davies, 2007).

In the early 1990's, Norsk Hydro drilled most of the horizontal wells on the Norwegian Continental Shelf. At that time, the issue was to deal with water breakthrough after producing the wells for a short time. The idea was then emerged to install the ICDs along the horizontal section of the well in order to delay water breakthrough and achieve desired pressure drop in the ICD. Then, in 1998 the first installation of the helical channel type of ICD was completed in Troll field (Al Marzooqi *et al.*, 2010; Adonoy, 2008).

The simulation model of the ICD's placement and port configurations can be established using the NETool™ software, which is a micro-nodal analysis tool that integrates reservoir properties and completion architecture in the wellbore's vicinity. (Rios, 2016; Halliburton, 2009). The placement and setting of the ICD is important to ensure a uniform inflow at the optimum production rate that has been achieved after installation of the devices. The detailed design and mechanism of an ICD have been discussed further in Chapter 2.

1.2 Problem Statement

With advances in drilling technology over the past 30 years, horizontal and multilateral wells have become a basic well architecture in current field development. These advanced technologies facilitate the drilling and completion operations for such wells with the primary objective of maximising reservoir contact (Joshi, 1990; Fernandes *et al.*, 2009). The wellbore offers a great contact area with the productive layer through the extension of well length which helps to lower the pressure drawdown required in order to achieve the same rate and enhance the well productivity. The field experiences have verified the advantages of horizontal wells in improving recovery and lowering the cost per unit length (Joshi, 1990; Al-Khelaiwi and Davies, 2007).

However, the increase in wellbore length and exposure to different reservoir facies came at a cost. Frictional pressure drops caused by fluid flow in horizontal sections resulted in higher drawdown pressure at the heels section of the completion, causing an unbalance fluid influx. Hence, the challenges and risk of horizontal wells applications are discussed as follow (Weatherford, 2009a):

(1) Early water and/or gas coning near the heels section in the horizontal wells can lead to a loss in production and reserves extraction, and ultimately, a decrease in profitability.
(2) Water and/or gas production from high permeability formations or fractures.
(3) Non-uniform inflow profile in heterogeneous reservoirs.
(4) Annular flow and cross-flow in non-compliant completions.
(5) Screen erosion failure in sand control completions due to hot-spotting.

To tackle these issues, the ICD technology has been introduced to reduce early water or gas production in horizontal wells, which can be installed together with the stand-alone-screens (SAS). ICDs are intentional choke in horizontal wellbore and will slow down some zones which enforce the inflow balance. They also induce a pressure drop across the completion due to the choking effect (Oyeka *et al*., 2014). Besides, by reducing the tendency of early water or gas production, the ICD enables the reservoir to drain more efficiently while maximizing production and recovery. The device provides uniform production and flow contribution along the wellbore in horizontal wells, extending the well's life.

Hence, this study was mainly focusing in the solving and optimizing the design of the ICDs which involved their sizing, the best nozzle sizing of ICD as well as the number of ICDs' port openings. These criteria were crucial in order to provide the best functionality and effectiveness of ICDs in adjusting the imbalance of inflow profile arising from fluid frictional losses in homogeneous reservoirs and from permeability variation in heterogeneous formation (Weatherford, 2009b). The pressure drop across an ICD is strongly depending on the fluid density and insensitive to fluid viscosity. Therefore, the device has the tendency to prevent early water and gas breakthrough and encourage oil production (Weatherford, 2009a).

However, the main problem with ICD is it is a permanent device installed during well completion deployment and the design of ICD is based on the initial reservoir conditions and simulation prediction of the reservoir performance. The ICD is not adjustable and non-retrievable. Once installed downhole, the hardware will function as it remains in the well through the life of the well (Fernandes *et al.*, 2009; Al Arfi *et al.*, 2009). Hence, the main objective of this research study is to tackle the disadvantage of ICD and the study has been designed to investigate the behaviour of ICD's port sizing/port opening towards the pressure drop of the reservoir for future technology development.

Abdelfattah *et al.* (2013) successfully proved that the breakthrough of unwanted fluid (gas or water) is invertible especially at the later stage of the well life even with the usage of the ICD. The typical productive well life may be divided into three stages which are the first stage, second stage and the final or last stage of the well life cycle. The first stage of the production life which also called as the start-up stage includes the flowing back completion fluid that was initially in the well. The production influx of the targeted reservoir fluid will occur at the second stage of the well life. The last stage includes the production of the unwanted fluid such as gas or water from the reservoir. Abdelfattah *et al.* (2013) also mentioned that ICDs as an effective solution in controlling the reservoir influx is at it early or first stage of the production life and its efficiency will decline over the time especially at the last stage of well life. Therefore, this study has also proposed the best solution or future technology that would be able to tackle the advantage of ICD.

To accomplish the design and simulation works of this ICD, the NETool^{TM} software is used as a primary stimulator tool. NETool^{TM} is a steady-state numerical simulator — integrates the reservoir simulatorand the lift design software — which enables engineers to simulate the flow in pipes uses the nodal analysis method. This software demonstrates the application of ICD in promoting the uniformity of the hydrocarbon influx from the reservoir along the horizontal section of the well. The proactive functionality of ICD subsequently shows the delay of onset of water breakthrough.

1.3 Hypotheses

The hypotheses of this study are as follow:

(1) The optimum size of an ICD and suitable number of ICDs are required to equalize the pressure drop along the drain length in order to achieve a uniform flow through the formation thereby delaying undesired water or gas breakthroughs.

(2) The appropriate selection of the flow port size is critical to obtain an efficient reservoir sweep and recovery as well as uniform inflow profile which must be maintained across the horizontal length interval (i.e., 1/8" or 3/32").

(3) The number of open-flow ports which has been successfully designed based on the pressure drop across the horizontal length could achieve the desired flowing

profile. This operation is typically set on the onshore or offshore, without using rig time.

1.4 Objectives

The objectives of study are:

(1) To design the model of an ICD along the horizontal length using NETool^{TM} software.

(2) To investigate the effect of important parameters towards the performance and functionality of the ICD along a horizontal wellbore.

1.5 Scope of Study

The scope of the study has been divided into two main sub-sections which are: (1) Engineering — the design stage or modelling of the ICD placement and the port setting, and (2) The ICD offshore installation operation. The details are as follow:

(1) Designing and developing the NETool^{TM} model of ICD across the production profile to ensure the appropriate number of ICDs, ICD sizing and port sizing as per reservoir condition and well architecture.

(2) Comparing the result between NETool^{TM} base case/openhole scenario (without ICD) and NETool^{TM} ICD case in order to see the effect of the ICD in the horizontal section.

(3) Modelling or predicting the relationship behaviour between the best resulted ICD port sizing/opening and the pressure drop of the reservoir for the case study or well.

(4) Establishing/running sensitivity study towards important parameters, such as size of ICD, flow port sizing, the usage of swell packer, flow rate, ICD roughness and ICD discharge coefficient in order to observe the effect of these parameters towards the performance and functionality of the ICD in simulating influx along the horizontal wellbore by coupling fluid flow through porous media and hydraulic flow into nozzle type of ICD completion architecture.

1.6 Significance of the Study

The findings of this study can definitely benefit oil and gas industry considering that ICDs play a significant role in the lower completion section of a long horizontal hole with large water aquifer. Having a great understanding in the functionally of the ICD itself is not enough to be part of the team in installing the device in the well. However, they require a deep understanding in designing the ICD placement along horizontal wellbore as well — which is not restricted to the ICD nozzle sizing and the number of open-flow ports — in order to ensure the effect of ICD is not detrimental.

Apart from that, having the knowledge of how the ICD sizing or port opening has responded with the pressure drop of a reservoir significantly benefits the industry in developing or improvising the technology for future use.

On top of that, the process flow and appropriate execution procedure of ICDs installation play an important role as well in order to accomplish the job as required and maintain the effectiveness of the ICDs. During the drilling process of an entire openhole section, the mud must be conditioned to ensure possible formation damage/screen plugging potential is kept to an absolute minimum. The use of clean mud is critical to the success of sand control completion and ICD effectiveness (Weatherford, 2008; Weatherford, 2010; Weatherford, 2012).

1.7 Chapter Summary

The efficiency of the ICD in postponing or delaying the water or gas break-through as well as prolong the well life has been proven in a wide range of reservoir environment. However, the effectiveness of an ICD strongly depends on the appropriate design and planning of ICD placement and configurations which require the knowledge of the actual reservoir and geology data, such as permeability, porosity, reservoir pressure, oil/water saturation distribution, and well deviation data.

The main study of this thesis includes both the planning and design of the ICD placement and configuration and the wellsite deployment operations. The simulation model of the ICD has been run using NETool™ software which is a nodal analysis software. One case study has been demonstrated in this research project and has been discussed in detail the process flow from the planning and design stage up to the wellsite installation operations.

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