CHAPTER 2

MULTILATERAL WELL AND INTELLIGENT COMPLETION

2.1 Multilateral Well

The first multilateral well was debuted in 1953 in the Bashkiria field, Russian federation. The well, called **simply 66/45** with nine lateral branches designed by Alexander Mikhailovich Grigoryan, was drilled with turbo drilling system through a carbonate reservoir. The technique increased the exposure area and production by 5.5 and 17 times, respectively while the cost increased only 1.5 times comparing with the cost of drilling a vertical well. Other 110 multilateral wells were drilled in Russian oil fields within the following 27 years (Bosworth *et al.*, 1998).

Although multilateral wells were first implemented in 1950's, they had not gained momentum until the last ten years. There is a 50 % increase in the number of the multilateral wells comparing with the previous ten years. Both delimitation and development of the field facilitated the construction of horizontal and multilateral wells, increasing the well productivity. Meanwhile, such development decreased the total number of wells used in hydrocarbon exploration (Bosworth *et al.*, 1998).

The re-entry drilling technique, used to drill multilateral well, has helped to find particularly productive or undrained areas. The lateral branches were drilled from a vertical well with an installation of a special packer called whipstock and the use of directional drilling system. The combination of these techniques has also given large economical benefits by mean of reducing the construction of many vertical wells (Jones, 1995).

2.1.1 Definition

Basically, a multilateral well is a single well with one or more branches radiating from the main borehole. It can be an exploration well, an infill developing well, or a re-entry into an existing well. Its configuration can be branched out into many categories which generally can be represented in two basic types: vertically staggered laterals and horizontally spread laterals.

2.1.1.1 Vertically Staggered Laterals

Vertically staggered laterals are multilateral well geometries which are suitable for multiple targets in horizontally different depths. This well geometry helps increase production performance and improves hydrocarbon recovery from multiple zones. Some examples of this well geometry are described below:

- **Stacked laterals**

The lateral branches radiate from a vertical mainbore at different depths in the same direction to independently drain hydrocarbon from more than one target layers as shown in Figure 2.1a.

- **Lateral into vertical hole**

The well geometry has a similar feature as that of stacked laterals. The difference is that the varying azimuth of lateral braches dash into different targets as depicted in Figure 2.1b.

2.1.1.2 Horizontally Spread Laterals

Horizontally spread laterals are multilateral well geometries which drain fluid from the same target. The main objectives are to increase the production rate and improve hydrocarbon recovery from a single zone. Some examples are described as follows:

- **Forked laterals**

This well geometry looks like a fork with lateral wells spreading from a horizontal mainbore at the same location and dashing into the same horizontal planar as shown in Figure 2.1c. This well geometry can improve production and total recovery of the field in which reservoir fractures are unknown.

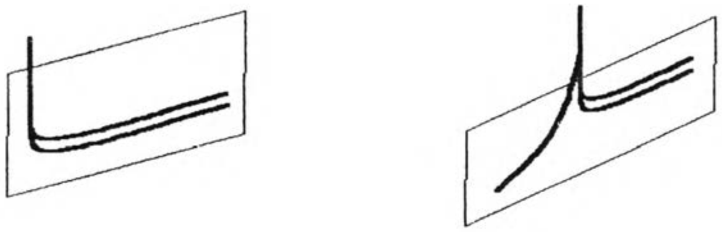
- **Dual-opposing laterals**

The well consists of two opposed lateral branches radiating from a vertical mainbore at the same location as depicted in Figure 2.1d. It also looks like two opposed traditional horizontal wells with an overlapped vertical mainbore. This well geometry suits for the case in which reservoir fractures are known.

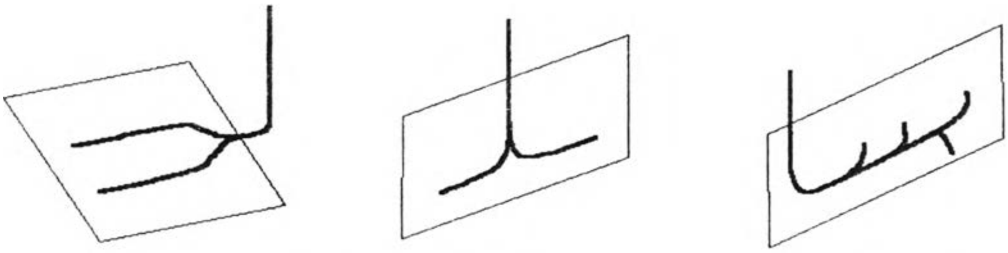
- **Lateral into horizontal hole**

This well geometry is generally called spine-and-rib or fishbone. The lateral branches radiate from a horizontal mainbore at different locations and dash into the same planar as illustrated in Figure 2.1e. This well geometry gives a satisfactory result in non-fracture and matrix-permeability reservoirs.

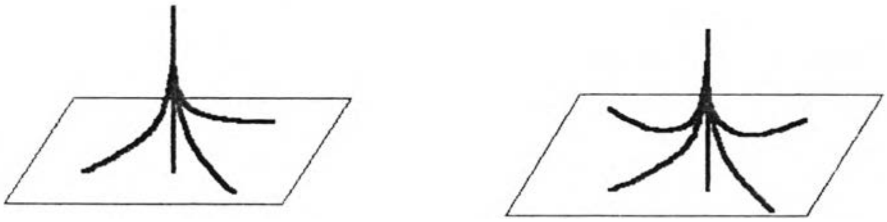
There are other well geometries which utilize three or more lateral branches such as **planar trilateral** and **planar quadrilateral** having respectively three and four lateral branches as shown in Figure 2.1f and g., respectively.



a. stacked laterals b. Lateral into vertical hole



c. forked laterals d. dual-opposing laterals e. Lateral into horizontal hole



f. planar trilateral g. planar quadrilateral

Figure 2.1: General well geometries of multilateral well.

2.1.2 Classification of Multilateral Well

Based on complexity and functionality, multilateral wells can be categorized into six levels according to the criteria set up during a forum on Technology Advancement of Multi Laterals (TAML) in Aberdeen, Scotland in 1997 under execution of Shell UK Exploration and Production. The multilateral technology is classified based on three characteristics: connectivity, isolation, and accessibility (Hogg, 1997) as described below:

- **Level 1: Open/unsupported junction**

This is the simplest and most economical multilateral with openhole in the mainbore and lateral branches. There is not either a mechanical support, a hydraulic isolation, or completion equipment. It is not possible to re-complete or intervene the well during the production life of the well (such as treatment of some reservoir zones). Figure 2.2a shows general configuration of openhole completion system.

- **Level 2: Mainbore cased and cemented, lateral bore open**

The more complexity in this level is that the central mainbore is cased and cemented while the lateral branch is openhole or simply completed with slotted liners or pre-packed screens as shown in Figure 2.2b. The most common completion for this level is to straddle the upper lateral branch with two packers and locate a sliding sleeve between them. Fluids from two lateral branches can be produced as commingled production or can be isolated by closing the sliding sleeve or placing cement plug upon the lower branch when the upper or lower part needs to be closed.

- **Level 3: Mainbore cased and cemented, lateral bore cased but not cemented**

This level includes a mechanical support at lateral junction. The central mainbore is cased and cemented while lateral branches are cased without cementing. Lateral liners are anchored to the mainbore by a linear hanger as depicted in Figure 2.2c. The junction is protected from sand infiltration and potential collapse. This level can be completed with a sliding sleeve system like level 2 or with the lateral entry system. Comparing with level 2, the disadvantage of this geometry is a high cost to construct the junctions.

- **Level 4: Mainbore and lateral bore cased and cemented**

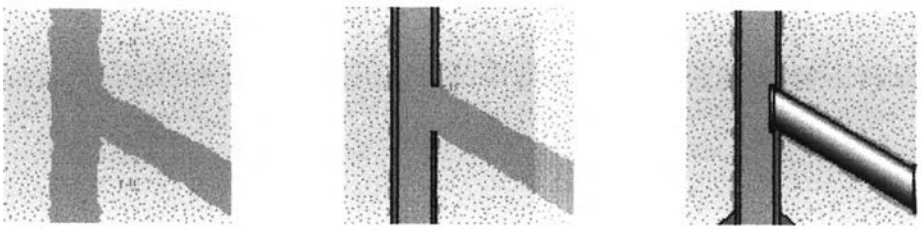
This level suits for a well that is surrounded by an unconsolidated formation at the junction with a high pressure difference. The junction and production string are completely separated. The difference between this level comparing with level 3 is that lateral branches are completed as illustrated in Figure 2.2d. There are two kinds of production scenario: isolated or commingled production. The configuration is flexible for intervention, re-completion, and abandonment in the future.

- **Level 5: Pressure integrity at the junction provided by completion equipment**

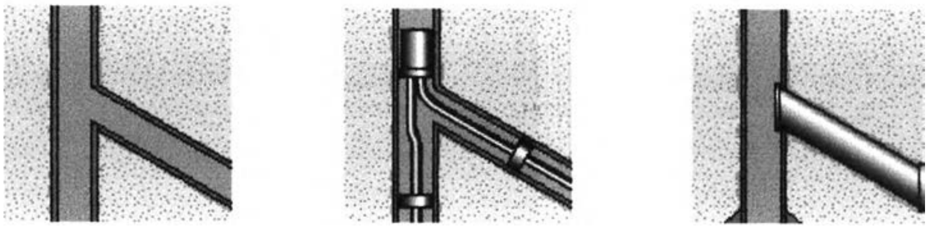
This level features both a mechanical support and a hydraulically isolated multilateral completion with full re-entry and production isolation capability into either bore. It requires a complex configuration of isolation packers and junction. The production can be either separated or commingled. The completion configuration is shown in Figure 2.2e.

- **Level 6: Pressure integrity at the junction achieved with casing**

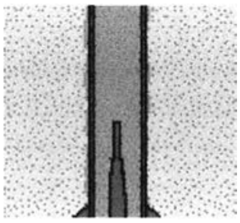
The difference between level 6 and level 5 is an additional downhole completion equipment (isolation packers) to create a hydraulic integrity of the junction as depicted in Figure 2.2f. The level 6S is sub-classified from level 6 by placing downhole splitter or subsurface wellhead assembly that divides the mainbore into two parts as illustrated in Figure 2.2g. Another unique property of this level 6S is the higher pressure resistance at the junction (about 172 bar).



a. Level 1 b. Level 2 c. Level 3



d. Level 4 e. Level 5 f. Level 6



g. Level 6S

Figure 2.2: Multilateral well classification (Bosworth, 1998).

2.1.3 Advantages of Multilateral Technology

- **Cost-saving**

The primary justification for multilateral technology is cost-saving: reducing the number of vertical wells, the cost of well construction and completion (fewer well head installations and less cementing). While the technology is useful for both onshore and offshore operation, it offers a remarkable time-saving advantage in offshore fields, where drilling and installation costs are high. Multilateral technology not only increases the reserve recovery, but also accelerates hydrocarbon production from the field. Sometimes, applying conventional well techniques to marginal fields is not economical, so new well architectures are developed in order to enhance and economize marginal fields (Vij *et al.,* 1998).

- **Accessibility and productivity improvement**

Since the branches of multilateral wells can be drilled in any direction, it is possible to access hydrocarbon bearing zones and increase the drainage area.

Fractured reservoirs, with their complexity, represent one of the frontiers in reservoir engineering. Hydrocarbon production which is conditioned to sub-vertical natural fractures can be substantially improved by intercepting and connecting the natural fractures with other potential zones at high permeability. In this case, multilateral technology provides a great capability of drainage and a high possibility to intercept the high permeability zones (Vij *et al.,* 1998; Sugiyama *et al.,* 1997).

Multilateral wells can be employed to optimize water and gas injection in order to maintain reservoir pressure or to improve the sweep efficiency by designing a sufficient number of lateral branches with appropriate length, inclination, and position. It is also possible to increase the productivity and reduce water or gas coning effects in a thin-layer reservoir.

- **Application with complex reservoir**

It is possible to produce from a complex reservoir with dual stacked or dual opposing stacked lateral geometries by producing from both or many productive zones. In multiple-layer reservoir, the use of a stacked lateral geometry provides the most effective exploitation. Multilateral systems are also adaptable to draining attic oil reservoirs.

In multilayered reservoirs where there is a big permeability contrast between compartments which are delimited by faults, multilateral technology can increase the total production by using horizontal branches to drain each compartment.

- **Application with enhanced oil recovery**

Conventionally, production problems due to energy loss in the system are solved by pressure maintenance. Recently, multilateral well technology has been used to revitalize the field from energy loss. Lateral branches can be drilled from an existing vertical well to enhance a marginal field, increasing well capacity and productivity, and making obsolete conventional displacement techniques in vertical wells. The multilateral technique has been successfully used in a steam flood with the aim of hydrocarbon production increment by exploiting gravitational drainage.

2.1.4 Disadvantage of Multilateral Well Technology

Although multilateral technology provides many remarkable advantages, there are some limitations which have to be considered. Problems that happen during the production phase may require well intervention that results in complexity and high cost. It should be noted that the cost of a multilateral well is more expensive than a conventional well, although recent innovations of well drilling methodology and well planning are becoming more competitive (Vij *et al.*, 1998).

2.1.5 Risk of Multilateral Technology

Multilateral well construction involves a high risk. During the evolution of multilateral technology in the past ten years, innovation of directional drilling techniques has brought a great complexity and reliability of multilateral wells as well as high cost and risk of well construction.

The risk of failure in the drilling phase has been estimated to be around 12 %, while there are not enough data to evaluate the risk of failure during production phase. Based on real applications, the risk of failure for onshore drilling is about 1.2 % while the risk is about 4.6 % for offshore drilling. (Oberkircher, 2003).

The main factors of risk that can bring failure to a multilateral well are:

- Total or partial collapse of the junction
- Entering of massive sand at the junction
- Entering of sand continuously at the junction during the production phase
- Well intervention via wireline or coiled tubing

In the multilateral well planning phase, it is very important to compare the risks between multilateral and traditional horizontal geometry evaluated for the same reservoir model.

2.1.6 Cost of Investment

According to Oberkircher (2003), the cost of multilateral well construction is about 1.2 to 1.8 times higher than the cost of a conventional well. One benefit of multilateral well is increment in oil recovery. Moreover, non-economically exploited reserves by conventional techniques can become more interesting.

A multilateral system has a high possibility of being realized in a big capitalization area. In an offshore field, where space for production facility is small, the cost is reduced drastically by decrease of the drilling activity and the space needed for drilling and production operations.

2.1.7 Comparing Multilateral and Horizontal Wells

Typically, the length of horizontal well is around 300 to 1000 meters while multilateral wells branching out from a vertical well are 30 to 200 meters long. Generally, horizontal wells are effective in thin layers, fractured reservoirs, low permeability reservoirs, and reservoirs which have a water coning problem (El Sayed *et al.*, 1999).

Disadvantages of multilateral and horizontal wells are high initial costs, sensitivity to heterogeneous and anisotropic formations, high risks of failure in the drilling, completion, and production phases, and the complexity of stimulation treatments that sometimes are very expensive. Moreover, multilateral wells have an interference phenomenon between branches causing a cross flow and difficulty in reservoir management (Retnanto *et al.*, 1996).

From a study conducted by El Sayed *et al.* (1999), it can be pointed out that

- Multilateral systems are better than horizontal wells in anisotropic formation. The best well geometry is the stacked lateral.
- The productive thickness, the number of lateral branches, and the anisotropy of formation influence the productivity of multilateral wells.
- The planar lateral well geometries are more efficient than the stacked lateral for the extended drainage and in thin layer cases.
- The optimal geometry of multilateral system is to use most three branches to avoid interference between branches.

The well productivity and reduction of coning effect are strongly influenced by the length, number, and trajectory of lateral branches as well as the distance between them. A study conducted by Vij *et al.* (1998) presented an evidence that the coning effect due to high vertical permeability zone can be reduced in multilateral well.

2.1.8 Multilateral Well Planning

According to Brister (2000), the multilateral well planning phase has to be studied in geological, completion, reservoir, and drilling aspects. The geological aspect includes optimal junction position and necessity of junction support which depends on stability, formation consolidation, and formation resistance properties. Moreover, it is important to obtain the optimal location of junction from the top structure and a well profile construction that helps reduce the risk of pipe stuck. To avoid the pipe stuck situation during multilateral well drilling, Brister suggested imposing a well inclination limit. This limit is considered from dimension of instrument used to intervene the well during the productive life of the reservoir. Moreover, the construction of a multilateral well system can minimize a potential problem of water and gas coning. The completion design has to be effective with the formation type in the production phase. The effective length of the branches has to be planned by estimating pressure loss in each branch length.

When planning a multilateral well, some aspects as shown below should be addressed:

- Sand control
- Possibility of water production
- Pressure loss due to production
- Main causes that break the junction during the production phase

The success of multilateral performance also depends on choosing an appropriate type of artificial lift, a vertical distance between lateral branches, the position of pump and the possibility of fracture treatment or stimulation.

There are many important variables that determine the well geometry and dimensions, number and optimal length of lateral branches, optimal capacity, and requirements of tubing elements. Formation type particularly influences the cost of internal system. For example, a system for consolidated sand (level 1 - 4) incurs a different cost compared to a system for non-consolidated sands (level 5 - 6). Typically, the first drilled lateral branch is the last one that is opened for production. While drilling other lateral branches, the first drilled branch should be isolated with packers in order to avoid damage in the completion interval, causing a major pressure difference at the junction of each branch.

The estimation for production has to include an exhaustive analysis for productivity of lateral branches; in particular, the estimation must be verified that it will not penalize the production in other branches. Without considering the selective production mode, a high pressure zone which may initiate cross flow is needed to verify.

In multilateral well planning, some conditions affecting to the number of branches and shape of the well are:

- Existence of compartment reservoir
- Existence of a permeability barrier or semi-permeability with clay or dolomite
- Connection between the multilateral system and fractures

The multilateral planning must be thought out when using water or gas injection to increase oil production. Different drilling methods have to be tested and examined on the stability of the junction, the detritus drilling management, the re-entry application requirements, and also the well control.

2.1.9 Examples of Multilateral Technology Application

Oberkircher *et al.* (2003) had conducted a study on multilateral system construction all over the world in the 1990's by analyzing and comparing the rate of success and outlining the potential of the technology.

In the last decade, there were about 1,000 multilateral wells drilled. The majority of them are classified as level 1, characterized by the necessity of a rig for directional drilling and by lack of completions. Nevertheless, in every large area such as an offshore field, there were about 100 multilaterals with more complex systems. Therefore, it requires special rigs during the drilling and production phases.

2.1.10 Successful Cases

The first successful case of multilateral well was in Weybourne field in Canada (Oberkircher *et al.*, 2003). The reservoir was treated as two non-communicating hydraulic zones having different pressure regimes. The field was discovered in 1954 and had been developed in a primary period from 1964 until 1985. Although during 1985 to 1992, vertical wells gave a good productivity for the field, from 1992 reservoir exploitation was slopped. The problem was caused by high oil residue, increase in water production, and the problem during well stimulation operations. From 1991 to 1992, horizontal branches were drilled from existing vertical wells using underbalanced drilling method. This solution helped to obtain an increment of oil recovery from the high-pressure attic formation. Moreover, the low pressure zone was also exploited using multilateral technology in order to increase recovery.

Initially, these wells were drilled with a single horizontal branch radiating from the vertical wells, without providing any improvement in productivity. From 1994, production from the dual lateral systems increased by about 40 % based on simulation results under the condition that the field was still exploited with only vertical wells.

Samples of successful cases of multilateral technology are offshore oil fields called Tiong and Kepong in Malaysia, which are adjacent fields discovered in 1978 and 1979, respectively (Schroeter, 1989). In the final delimitation phase of Tiong reservoir, the wells were located between two reservoirs in which the oil formations would not give economical production using conventional technology. Starting from 1993, the field was exploited with multilateral wells to gain marginal reserve. The selection was dictated by the difficulty of site location, drilling rig installation on the surface, and the need to reduce well drilling cost and time.

The objective of multilateral technology was to intersect three separated zones by drilling three branches from the same mainbore and completing the well with a double completion system that permitted selectivity. Although there were numerous problems in the drilling phase, the multilateral system was remarkably successful.

Another application of a multilateral system was reported in a heavy oil field (8.4 -10 °API) called Zuata in Venezuela (Stalder *et al.,* 2001). The reservoir composes of sandy convex layers without interconnection. The initial development project was to drill numerous extensive horizontal wells. The geometry of horizontal wells were then planned to intersect known sand deposits. Nevertheless, the project had not obtained a substantial increment of production. Then, after selecting a multilateral system called fishbone, sloped lateral branches radiating from horizontal wells were drilled to intersect sand layers. The results showed an increase in production due to longer effective length of the horizontal branches comparing with a single vertical well. In particular, the adopted geometry allowed an increment of oil production from sand layers.

The employment of a multilateral well for a thin layer reservoir in a field called Troll, located in the North Sea, increased the total drainage area and production by avoiding water and gas coning and sand problem (Rivera *et al.*, 2003). The results of such application showed an increase in oil recovery comparing with conventional well drilling technique (Berge *et al.*, 2001; Oberkircher, 2000).

Multilateral wells became important in a field called Tern, located in the North Sea. Production from this reservoir could not be economical with conventional vertical wells (Vullinghs *et al.*, 1999). To avoid constructing new platforms, multilateral well was selected.

Similarly, in an offshore oil field called Pelican, located in the North sea, a multilateral system was implemented in order to drain a non-economically exploitable reservoir using vertical wells (Vullinghs *et al.*, 1999).

An application of using multilateral systems in enhanced oil recovery was documented for a reservoir called Lagunilla Inferior in Venezuela, composed of numerous convex formations with sand, silt, and argil as rock components. At that moment, it was necessary to inject water into the reservoir in order to improve the displacement efficiency in enhanced oil recovery phase. Using dynamic performance simulation, it was shown that the recovery factor valuated for the case in which water was injected from vertical well was lower than the recovery factor obtained by injection from a multilateral system (Gutierrez *et al.*, 2002).

Another multilateral system example was an offshore field called Bonito, located in Brazil (Sotomayor *et al.*, 2001). The reservoir exploitation with this multilateral well technology had permitted an increment of oil and gas productivity in every single well. Moreover, the total number of wells is reduced resulting in saving of surface space.

An example of extended reach technology was found in applying a multilateral system in a field called Witch Farm, located in an ecologically protected area in the United Kingdom (Rocha *et al.*, 2004). Three lateral branches, radiating from an existing vertical well were drilled to improve the productivity of the field and reduce environmental impact of setting up several drilling sites.

2.1.11 Failure Cases

It is difficult to keep record of cases which did not give expected results. In some cases, low satisfaction was obtained.

The field called Statfjord, historically known as one of the most potential oil fields in Norway is one of the failure cases (Taugbøl, 2004). The implementation of multilateral well in this field was first considered as a simple project. Unfortunately, the cementation at the junction of one lateral branch was not done correctly. Consequently, the productivity of the system was compromised.

Another failure case was found a field called East Wilmington in the United States (Brister, 1998). Two lateral branches were drilled from an existing vertical well attempting to reach a marginal oil reserve. Removing the detritus from miller of a bad positioned packer resulted in the heavier drilling mud.

2.2 Intelligent Completion

In general, an intelligent system means a completion system in which the entering flux or injection control is performed in the wellbore without physical intervention and with or without a downhole monitoring system. An intelligent well is defined as a well equipped with a completion system in order to control and isolate the production from different zones or branches and equipped with downhole sensors in order to monitor actual pressure and temperature in the well (Robinson, 1997;Yeten *et al.*, 2002).

In addition, intelligent completion is a system that can acquire, transmit, and analyze data regarding completion, production, and reservoir by an intelligent system which can control the well and the production process (Konopczynski *et al.*, 2002).

The advantages of an intelligent completion include its capacity to adjust fluid production from different reservoir zones, improving flow control, and monitoring the response through the acquisition of data from downhole.

The principal elements of intelligent completion are downhole sensors that measure temperature, pressure, flow rate of different fluids and completions that allow control of the production from determinate intervals of the well or zone of reservoir.

It is very important to simulate and understand the behaviour of reservoir performance before applying an intelligent completion for a well. There are two different ideas in reservoir engineering regarding the efficiency of an intelligent well. The first approach believes that to be able to fully exploit, the potential of intelligent wells have to be characterized accurately (Thompson *et al.*, 2000) in order to understand and foresee dynamic behaviour and problems for well installations. In the second approach, downhole data are especially useful for calibrating a precise production strategy. In this case, the best strategy is to exploit an intelligent well system as an opportunity to avoid possible cases such as the intervention during the production life in case unexpected events are indicated and gas and water entering to the well.

2.2.1 Configuration

Intelligent wells can be (Yu *et al.*, 2000):

- Multilateral wells or multi drains which produce fluids from one or many reservoirs (for example, utilizing the produced gas to operate a gas lift or lifting the oil from the lower depth)

- Wells with the possibility to reduce liquid flux using downhole choke. The advantage is obtained through a monitoring system in real time and zone control using inflow control valves. In this operation, it is possible to selectively close the zones that produce undesired fluids

- Wells that can separate gas or water from oil in the well and reinject the separated fluids into the reservoir

- Wells with downhole compressors for reinjection of produced gas into the reservoir

The benefits of intelligent well are verified in some successful examples such as in the field called Oseberg in the North Sea (Rundgren, 2001). In order to manage unexpected events, wells were subdivided with isolated operation. Therefore, gas and water production was minimized while oil production was maximized.

Intelligent well studies are direct ways to obtain possible drainage of reservoir hydrocarbon by using downhole valves. The valves are applied to the system allowing the well to monitor different fluid directions entering into the well from different production zones.

Nowadays, reservoir knowledge is derived from monitoring pressure and temperature data, production data analysis, and sometimes downhole flux measurement. The flux measuring equipment has been developed in order to accurately measure the flowrate and properties of multiphase fluids. The challenges of many researches in this field are to improve the accuracy of the flowrate measurement in horizontal and directional wells. A real-time control system can provide several in horizontal and directional wells. A real-time control system can provide several benefits such as better management of unforeseen events in the well and reservoir and economically producible reserves.

2.2.2 Usefulness

The benefits achieved by intelligent completion can be listed as follows:

- High accuracy in reserve calculation and reservoir limit identification (obtainable by means of thermal monitoring, downhole flux measurement, downhole pressure measurement, and well test interpretation)
- Reduction of uncertainty effects from unknown data concerning the reservoir (through a reliable reservoir model and a history match that allows recalibration of the model in an optimal manner)
- Finding optimal positions of development wells
- Reduction in risks and operation costs by eliminating the necessity of well intervention
- Ability to control fluid flux entering the well
- Production acceleration and optimization through the analysis and interpretation of well test and production data, updating the reservoir model, and evaluation of the benefit obtained from possible injection wells
- High hydrocarbon recovery
- Reducing the intervention of reconfiguration of well completion especially in offshore fields

Moreover, intelligent wells are flexible in managing unexpected events, capable to find water and gas coning formation, possible to leave the intelligent elements to automatically optimize the production strategy, and able to control the production without the need of intervention (Tubel *et al.,* 1996). These advantages are obtained from the combination of detailed, accurate, and flexible downhole information. The flexibility of intelligent wells also provides the ability to selectively shut a high water production zone (Glandt, 2003).

The best approach is to combine an intelligent well with a reliable model which can be updated in real time by obtaining information from a highly efficient monitoring system. This system allows the re-distribution of fluids entering from different branches in order to optimize production. The objectives of this combination are to produce less undesired fluid and improve the final recovery by verifying the best drainage (Yeten *et al.,* 2002).

2.2.3 Intelligent Completion Components

The monitoring function of intelligent wells is achieved by installing permanent downhole pressure and temperature sensors and optical fiber that transmit information to the surface. Obtaining continuous data means better information can be obtained; therefore, reservoir management is better (Naevdal *et al.*, 2003). For this reason, reservoir management is a continuous process starting from the exploration phase, continuing to the development and production phase to enhance hydrocarbon recovery. The major components of intelligent completion are described as follow:

- **Flow controlling system**

The flow controlling system is carried out by means of valves. Generally, selective valves are chosen (such as sliding sleeves or ball valves) to operate in binary mode (shutting or opening), discreet mode (different fixed positions), or infinitely variable mode. The power supply in this system is generally hydraulic or electric. The most up-to-date systems have demonstrated high reliability, more resistant to erosion problem, high warrantee of better control, and better valve opening and shutting control.

- **Isolation packer**

To manage and control different zones, it is necessary to isolate each zone by packer that is equipped with flux control and transmission system inside.

- **Controller cables**

The data transmission and powering system for downhole monitoring media can be hydraulic, electric, or optical fiber. The optical fiber can be installed in a transmission line or hydraulic line. Electrical or electronic system is required if there is a presence of downhole pump such as electric submersible pump (ESP).

- **Downhole sensors**

There are many downhole sensors available in today's market such as quartz sensors with high accuracy for pressure and temperature measuring, fibre optic temperature sensors which report the temperature distribution at regular intervals along the well. fibre optic pressure sensors, and fluid phase measuring equipment whose functions are based on the Venturi system.

Other new technologies being developed are water cut sensors which detect the fraction of produced water volume respect to the total liquid volume, fluid density measuring device, flux measuring device which includes micro seismic suppliers and receiver and downhole formation resistivity detectors.

- **Surface data acquisition and controlling system**

This system is necessary to be installed because it can acquire, filtrate, examine, and memorize all the data (Konopczynski *et al.*, 2002; Nyhavn *et al.*, 2000). Accurate data analysis is the best strategy to obtain good information of the well and the reservoir.

Continuous interpretation of production data and temperature gives us more detail of permeability, shape, boundary of the reservoir, mechanism of production, and also water coning or water cresting phenomenon that may happen (Ballinas, 2002). The pressure loss analysis in a well and between reservoir and a well brings the information to optimize the production of the well.

2.2.4 Applications

The principal applications of intelligent completion are generally for:

- Wells that produce from many zones or from many reservoirs
- Multilateral wells that control the flux from a single drain
- Wells with oil-water separation systems to reuse the separated water

In many formations, sand production is a major problem. Sand and fine particle reduction is critical since it may damage separators, treatment equipment, and water reinjector. New sensors that can monitor sand and fine particle production signify a possibility of well intervention. The most recent monitoring systems are available with the level that can function in a very long horizontal well with gravel pack.

By utilizing the operating valves in order to control the downhole flux, it is possible to increase or reduce the opening to the inflow from a single branch or productive zone of the well, in case of mixed production from many laterals (commingled production).

An intelligent well with inflow control valves (ICVs) (Erlandsen, 2000) was completed in Oseberg field in the North Sea. The well was equipped with packers, hydraulic and electric control lines, inflow control valves, and a surface control unit. The packers isolated individual zones by shutting and restricting the section opening to the flux accordingly with pressure decline, water cut, and flow rates of gas and oil. The control lines were used to activate the inflow control valves and transmit downhole pressure and temperature data to the surface unit. The surface control unit worked as a data manager using the obtained data to control the remote inflow control valves.

Another example of inflow control valves application (Jackson *et al.*. 2001) was to produce oil independently from two productive zones, which can be isolated from each other and regulated by two valves.

2.3 Relevant Research

Two relevant researches on multilateral wells and intelligent completion were investigated. The main objectives were to verify the efficiency of combination of these two technologies and optimize production of non-conventional wells such as horizontal and some geometries of multilateral well. The second research involved optimizing oil recovery using intelligent completion. The descriptions of previous work are shown in the following paragraphs.

The first study was done by Ferraro (2003) with the title in Italian called "**Progettazione e Valutazione di Pozzi Multilaterali in Giacimenti ad Olio di Tipo Omogeneo**" which can be translated English as "**Design and Evaluation of Multilateral Wells in Homogeneous Oil Reservoir Model**". This study investigated multilateral well efficiency in homogeneous oil reservoir with active aquifer in term of increasing the productivity with recovery of oil. The analysis was done based on synthetic models and varying petrophysical properties, fluid properties, well geometries, and production rates. The highest and lowest increments of oil recovery were evaluated in terms of efficiency by shutting some parts of the well corresponding to the junctions between the mainbore and lateral branches. Moreover, the study also evaluated the impact inside the well, described in terms of dynamic behaviour of the reservoir. From the study, it was concluded that multilateral wells generally do not provide a significant advantage in terms of oil production in homogeneous cases.

An increment of oil recovery was clearly seen when vertical permeability increases. Nevertheless, horizontal wells always guarantee a better recovery than multilateral wells. The multilateral geometries that yield the highest oil recovery are fishbone and bilateral well geometries. Moreover, multilateral wells can reduce water cresting and water coning phenomena which cause an interference problem between lateral branches.

The second phase of the work by Ferraro studied the utilization of completion configurations, closing the connection point between lateral branches and the mainbore in order to reduce the interference problem between each lateral branch. Using appropriate completion for multilateral wells can increase recovery for a maximum of 20 %. Major benefit can be obtained especially at low flow rates. A well geometry called planar quadrilateral remarkably gives an advantage in this study by reducing the interference problem which happened when the well is completed as openhole.

In the third part of work by Ferraro, an analysis to evaluate impacts on well production by mean of discretization of reservoir geometry was performed. The adoption of discretization using small cells and equal dimensions for all reservoir model guarantees the results, avoiding an error in numerical simulation.

The second study conducted by Marescalco (2003) is also written in Italian called "**Valutazione dell' Efficienza di Pozzi Non Convenzionali in Giacimenti a Olio di Tipo Eterogeneo**" which has an equivalent name in English as "**Evaluation of Non-Conventional Wells Efficiency in Heterogeneous Oil Reservoir Models**". The study dealt with reservoir simulation concerning the efficiency of horizontal and multilateral wells. Moreover, the wells were equipped with intelligent completion in order to control downhole flux. Homogeneous and heterogeneous reservoirs were constructed using realistic size and properties. In the heterogeneous case, lacustrine and fluvial sedimentary environment models were constructed. Traditional horizontal and bilateral wells with a total effective length of 300 m were studied.

The study was divided into two parts. In the first part, two well geometries were completed with conventional completion and simulated for both sedimentary environment models. The simulation result showed that horizontal well provided better oil productivity while multilateral well had interference between the mainbore and lateral branches. In order to identify and verify the effect of the interference problem, a short part of the well near the junction between the mainbore and lateral branches was shut. The results showed that multilateral wells which were penalized from water crest problem in openhole case can be improved in term of oil production since the wells are partially closed. Moreover, the optimal results were obtained when closed zones were set up to be longer.

The second part of the study emphasized on the analysis of inflow control valve application. In this part, it can be observed that intelligent application provided productivity increment and helped delay water production

The analysis on relative plateau production period for both well geometries showed that in fluvial sedimentary model, the application of intelligent completion induced a significant improvement in term of water entrance retardation especially with multilateral well.