Chapter

Swelling Elastomer Applications in Petroleum Drilling and Development

Sayyad Zahid Qamar, Maaz Akhtar and Tasneem Pervez

My powers are ordinary. Only my application brings me success.

Sir Isaac Newton.

Abstract

Oil and gas drilling and development is witnessing new and inventive techniques targeted at increased production from difficult and aging wells. As depth of an oil or gas well increases, higher temperatures and harsher environments are encountered. Suitable elastomers can provide good sealing as they possess good resistance to heat and chemical attack, and as they are widely availability at low cost. In comparison with metals, elastomers are lighter in weight and lesser in stiffness and hardness, swell more with increasing temperature, and are usually better in corrosion resistance. Other reasons for their preference include excellent damping and energy absorption, more flexibility and longer life; good sealing even with moisture, heat, and pressure; negligible toxicity; good moldability; and flexible stiffness. As mentioned in chapter-1, swelling elastomers or gels have found extensive use in different applications including drug delivery, microfluidics, biomedical devices, scaffolds for tissue engineering, biosensors, etc. As the main focus of this book is the oil and gas industry, implementation of swelling elastomer technology and deployment in different petroleum applications are discussed below.

Keywords: Swelling elastomers, field applications, oil and gas, drilling and development

1. Introduction

Oil and gas drilling and development is witnessing new and inventive techniques targeted at increased production from difficult and aging wells. As depth of an oil or gas well increases, higher temperatures and harsher environments are encountered. Suitable elastomers can provide good sealing as they possess good resistance to heat and chemical attack, and as they are widely availability at low cost. In comparison with metals, elastomers are lighter in weight and lesser in stiffness and hardness, swell more with increasing temperature, and are usually better in corrosion resistance. Other reasons for their preference include excellent damping and energy absorption, more flexibility and longer life; good sealing even with moisture, heat, and pressure; negligible toxicity; good moldability; and flexible stiffness [1, 2].

As mentioned in chapter-1, swelling elastomers or gels have found extensive use in different applications including drug delivery, microfluidics, biomedical devices, scaffolds for tissue engineering, biosensors, etc. [3–8]. As the main focus of this book is the oil and gas industry, implementation of swelling elastomer technology and deployment in different petroleum applications are discussed below.

2. Swelling elastomer

Elastomers are increasingly being used for sealing and other applications in the oil and gas industry. Specifically developed elastomers possess durable properties and have the ability to withstand detrimental effects of heat, chemicals, and harsh environments. Of special interest is the class known as swelling elastomers. Swelling elastomers are advanced polymers that swell naturally by absorption when exposed to the appropriate swelling agent (oil and/or water). They can be mounted as seals/gaskets directly on to the steel pipe for petroleum piping applications. When in contact with well fluids, they exhibit significant swelling, providing improved sealing against outer tubulars or borehole wall [9, 10].

In conventional drilling, the initial hole has a large diameter, and casing pipe (steel) is run into this hole. Cement is poured in the borehole-casing gap, known as the annulus, to act as a structural support for the well, and to prevent any flow from the formation into the wellbore. Each new pipe should pass through the previous one. Each new casing string thus causes an approximately 20% reduction in the borehole diameter. Any deep well requires multiple casing strings. Because of the "telescoping effect," the well has to begin with a very large-diameter surface casing and finish with a substantially small-diameter production casing. This not only leads to very high costs, but also restricts the exploration and production of oil and gas [11, 12].

Solid expandable tubular (SET) technology has been successfully employed to overcome some of these problems. In SET technology, a conical mandrel is pushed (or pulled) through a solid steel tubular, expanding it to a predetermined size. The most common and valuable application of SET is zonal isolation and water shutoff, preventing fluid cross-flow between geological layers, and reducing the amount of produced water. Together with SET technology, swelling elastomers seals have been used successfully in both open and cased holes. These seals contain several sections of swelling elastomer material mounted on steel pipes or joints. Connecting these joints together can yield seals of any required length. Over time (few days to several weeks), the rubber elements swell considerably, providing a very good sealing. This extremely useful application is also quite low-cost [13]. A crucial brown field was successfully redeveloped in Oman, requiring difficult drilling across fractured carbonate sections, through the use of swelling elastomer seals for zonal isolation [14].

Swellable elastomer is a novel type of unconventional polymer; it increases in volume when exposed to water, oil, or acid. This swelling causes changes in geometry, together with variations in density, hardness and other material properties [15–18]. The mechanism of osmosis is the basis for swelling in water-swell elastomers. On the other hand, volume-change in oil-swell elastomers occurs due to a diffusion action, resulting in the absorption of hydrocarbons into the elastomer material [19, 20]. Rate of swelling is a function of temperature, pressure, elastomer type, and composition of the fluid medium. For applications such as zonal isolation and water shutoff, swelling elastomers are now the inevitable choice. **Figure 1** schematically illustrates the construction of a standard swell packer. There are many applications of swelling elastomers, including

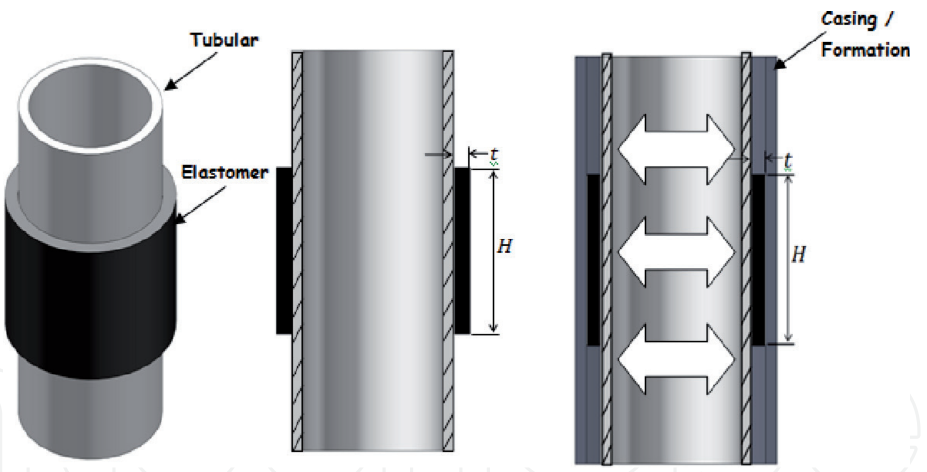

Figure 1.
Arrangement of inner steel tubular, elastomer, and outer casing or rock formation in a typical swellable packer.

profitable production from old wells, restarting of production from discarded wells, and production from difficult-to-access new reservoirs [21, 22].

One of the earliest uses of swelling elastomers in conjunction with an SET system was by Shell in July 2002, known as an open-hole clad (OHC). This was followed by various successful deployments of swell packers in fields requiring zonal isolation in Brunei, Malaysia, Gabon, Nigeria, and the United Kingdom [23]. X-ZIP and E-ZIP solutions (swellable elastomer sections mounted on expandable and standard pipes, respectively) have been success stories in open-hole clads and liners in Oman. Addressing the problems of water shutoff and fracture, these techniques provide new methods for increased oil recovery [24]. Expandable sand screen technology is another good example of the use of swelling elastomers [25, 26]. In recent years, swelling elastomers have become an essential element in many oil well completions since they provide new solutions for zonal isolation and inflow control in horizontal and vertical wells.

3. Applications of swellable elastomers

Many published case studies about swell packers discuss only a few of the related applications. This chapter adopts a more holistic approach, describing most of the key applications of swelling elastomers in the oil and gas industry. For instance, zonal isolation techniques are used to separate undesirable zones from production zones. Safeguarding production lines from water incursion is known as water shutoff [27]. Protection of the wellbore from sand invasion is known as sand control: sand screens provide protection against plugging and wear of well equipment. A well becomes ready to produce through a series of steps collectively known as well completion, cementing being the most critical stage. When existing passages are enlarged or new ones are formed to improve the production the process is called well stimulation [28]. Swelling elastomers have been effectively used in all of these applications, as an integral part of improved oil recovery (IOR) or enhanced oil recovery (EOR), providing low-cost manner and long-term solutions.

Swelling elastomers are generally self-healing, paving the way for easy installation and execution of swell packers, and saving a large amount of rig time and related costs. More relevant case studies about deployment of swell packers and seals in the development of oil and gas fields are presented in the following sections. This brief overview can be beneficial for petroleum students, field practitioners, researchers, and application designers.

3.1 Zonal isolation

Techniques used to stop or reduce the mixing of redundant fluids (from undesirable regions) with production fluids are known as zonal isolation. Conventionally, zonal isolation in a well bore is carried out by cementing the production string in place, and by appropriate use of casing plugs and packers. Swelling elastomer seals used for active zonal isolation are shown in **Figure 2**. Asab field in Abu Dhabi is a mature carbonate reservoir and was drilled in 1985 and horizontally sidetracked in 1999. By the year 2005, water cut increased from 14–25%, considerably reducing the oil production [29]. Water was coming from the fractures due to the failure in the placement of cement plugs at the toe. Deployment of swell packers successfully isolated the unwanted zones, bringing down water cut from 25% to 0.3%. By using swelling elastomers in Malaysia South Furious field, water cut was significantly reduced, and production started within a day, even before complete swelling of the elastomer [23]. Other valuable applications of swelling elastomers for zonal isolation include water production management, reservoir compartmentalization, sand control, inflow profile control, production separation, and control of condensate banking.

3.2 Well completion

As mentioned above, all tasks that are carried out to make the well ready for production are jointly known as *well completion*. These operations include drilling of the hole, running of the casing and cementing, further drilling of the hole until reaching the desired depth, perforation of the steel casing, and stimulation of the cement and formation. Cementing is a critical stage, hydraulically sealing the casing from the formation, thereby isolating individual zones and preventing annular flow. Swellable packers offer cost-effective and more efficient alternatives to traditional cementing and mechanical packer methods. As described above, they consist of polymer segments that swell proportionally when immersed in well fluids. They contain no mechanical parts, and are easy to operate, thereby minimizing cost and time requirements. Swell packers used in well completion are shown in **Figure 3**.

Intelligent well is a unique well type targeting maximum hydrocarbon recovery. Special completion and monitoring tools are installed that can be adjusted either automatically or through human intervention. Use of swelling elastomers in intelligent well completions significantly reduces the development costs and improves the production. Such an optimum zonal isolation cannot be realized in conventional perforating and cementing methods. The offshore Al-Khalij field in Qatar is a success story where corroded and damaged tubulars were remediated by using the intelligent well approach [30]. Using an alternative packer design was tried out before attempting the recompletion. This dependable hydraulic sealing mechanism makes the

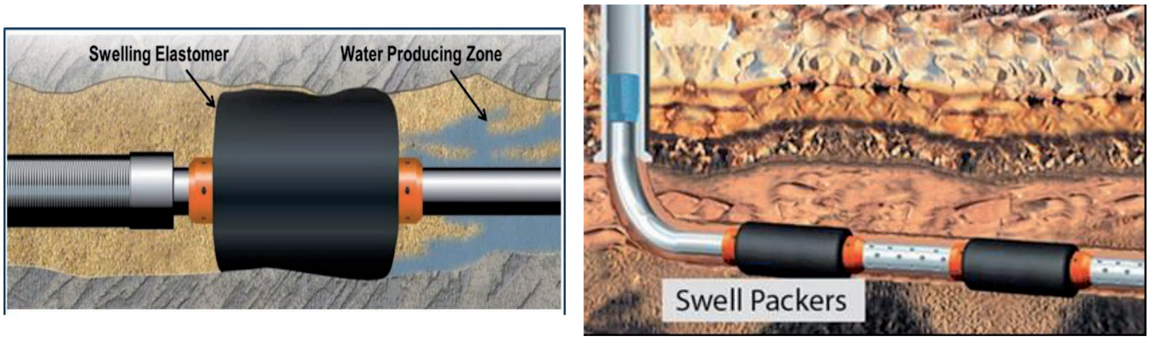

Figure 2.
Schematic of a typical swellable packer used for isolation of water producing zone (left); use of swell packers for zonal isolation in a horizontal well (right).

DOI: http://dx.doi.org/10.5772/intechopen.94721

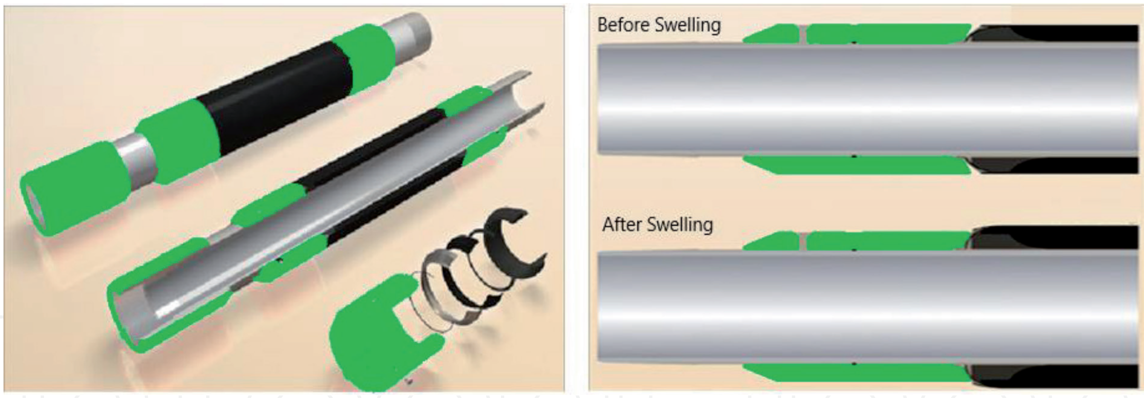

Figure 3.
Elements (and working principle) of a typical swell packer used in well completion operations.

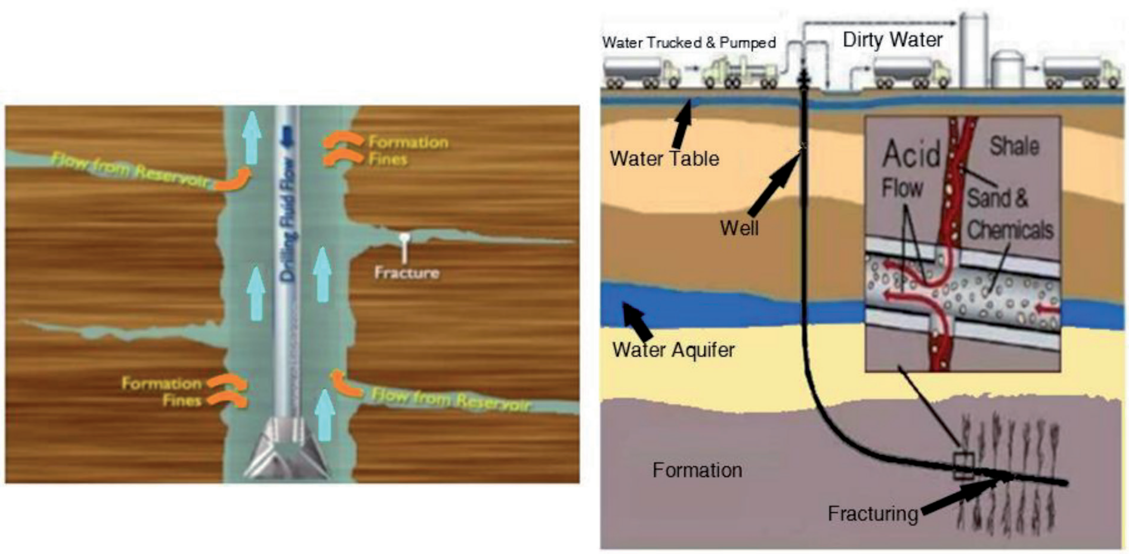

Figure 4.
Two of the more common stimulation operations: Hydraulic fractruring (left), and well acidizing (right).

work-over task technically and economically feasible, especially in the case of mature reservoirs. Use of swell packers guarantees the extension of well life and enhances the oil recovery. Swelling elastomers can also be used as a completion tool in conjunction with open and cased holes, horizontal wells, and SET technology [9, 31].

3.3 Stimulation operations

It is sometimes required to enlarge old channels or create new ones in the production zone of a well. This is accomplished by the methods of acidizing, formation fracturing, etc. and the process is called *stimulation* [32]; **Figure 4**. The stimulation technique of fracturing consists of opening of new flow channels in the rock formation surrounding a producing well. This increases the surface area through which formation fluids can flow into the well, and also extends beyond possible fractures close to the wellbore. The in-situ well conditions can pose challenges in the use of swell packers in stimulation operations. These include local temperature and pressure, and shrinkage forces of the tubular. Moreover, certain thermal effects can result in contraction of the seal: owing to temperature drop because of contact with stimulation fluid. Successful results were reported by an operator in USA in stimulation efforts in horizontal open-hole completions. Technologies used were expandable liner hanger, swelling elastomer packers, and ball drop sleeves [33]. Some other successful applications of swellables in stimulation operations are hydraulic fracturing, multi-stage fracturing, and matrix acidization.

3.4 Underbalanced drilling

It is a conventional practice to go for overbalancing in well drilling. In this method, a column of fluid of preselected density is maintained in the hole to serve as the primary well-control mechanism. By design, pressure at well bottom is kept higher than the formation pressure. During *underbalanced drilling* (UBD) of oil and gas wells, a lighter fluid replaces the fluid column, and the pressure on the bottom of the well is designed on-purpose to be lower than the pressure in the formation; **Figure 5**. This is done to allow formation fluids to rise to the surface while drilling, preventing damage to the formation being drilled. The hydrostatic head of the fluid may naturally be less than the formation pressure, or it can be induced by adding different substances to the liquid phase of the drilling fluid, such as natural gas, nitrogen, or air [34].

One use of underbalanced drilling is to find out probable thief zones for proper placement of swell packers [35]. Effective zonal isolation can be achieved through a judicious combination of UBD and swellable elastomers. This can lead to maximization of well performance and significantly improved hydrocarbon recovery. In the case of underbalanced drilling in Nimr reservoir in Oman [36], it was concluded from data extracted by UBD that rogue fractures and thief zones are important factors in the movement of water. Swell packers were then deployed for water shutoff in zones detected by UBD.

3.5 Enhanced oil recovery

Any technique used to increase the amount of oil that can be recovered from a reservoir is known as enhanced oil recovery (EOR). This is generally achieved by injecting a suitable material into an existing well, increasing the pressure and reducing the oil viscosity. EOR is a thermal or compositional transformation of either the hydrocarbons or reservoir rock to aid in the recovery of additional volumes. EOR helps to maximize the oil reserves recovered, extend the life of fields, and increase the recovery factor. EOR techniques can be used for higher recovery from dwindling old reservoirs or difficult new ones. An openhole packer system is shown in **Figure 6**, for effective zonal isolation in complex offshore deep water wells, unconventional completions, and mature oil field locations.

By combining swellable elastomers and primary cementing, it is possible to successfully isolate oil (or gas) and water. Employing miscible gas injection, the

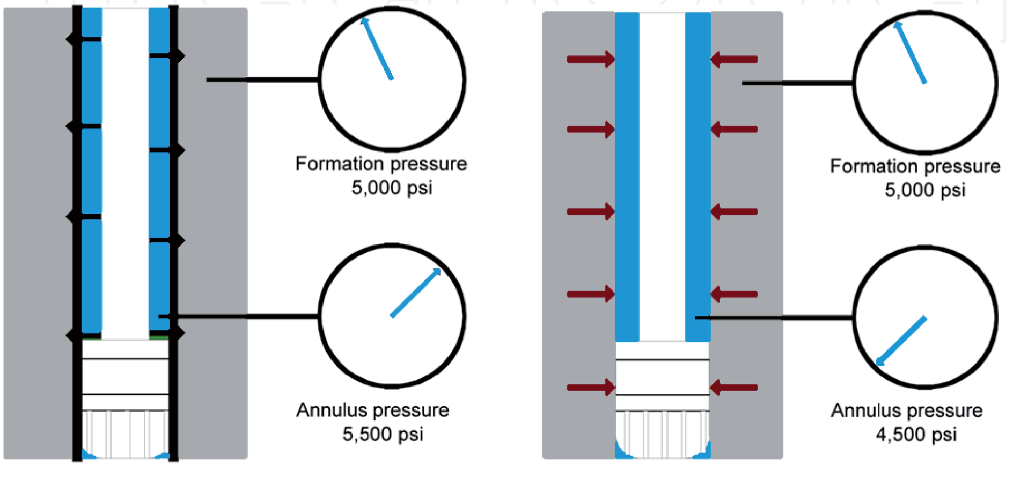

Figure 5.
Schematic illustration of conventional overbalanced drilling (left), and an underbalanced drilled well (right).

Figure 6.
Openhole packer system for EOR applications requiring maximum isolation efficiency in difficult wells.

first EOR scheme in southern Oman was implemented by Petroleum Development Oman (PDO) in the Harweel Cluster. Efficient zonal isolation was a prerequisite for enhanced hydrocarbon recovery. As cementing was unsuccessful in many cases, swellable elastomers were used and produced very positive results [37]. Durongwattana et al. [38] declare that quite a few EOR based well technologies have matured to a level that they can be considered to be field proven and cost effective. They particularly mention the use of expandable clads and swellable elastomers in applications such as shutoff of high permeable zones and fractures, and well segmentation as a remediation action after breakthrough of water or gas in the segment.

3.6 Evaluation of swellable packers

As swelling elastomer seals are relatively new in the oil and gas industry, reliable performance assessment is critical. One method used to evaluate if swell packers have effectively achieved zonal isolation is wireline ultrasonic measurements. Herold et al. [19] describe conventional and new ultrasonic tools for the evaluation of zonal isolation through swelling elastomers. Perhaps the most promising ultrasonic technique is the third interface echo (TIE) method, ensuring good hydraulic seal and isolation of zones through swellable elastomers [39]. Some other studies have been carried out for performance assessment of swellable packers and seals in petroleum drilling using experimental, analytical, and numerical methods [40–42].

4. Future trends

Already showing major successes, new swelling elastomers and applications are still being developed. As with every new technology, there are many challenges that need to be addressed. Use of swell packers in the extreme conditions of high-pressure and high-temperature (HPHT) wells is uncertain. Reservoirs that are more chemically aggressive (highly acidic, for instance) are also uncharted waters. Controlling the speed and amount of swelling, and activation of swelling in especially targeted settings, are also areas where more work is required. Development of new swelling-elastomer materials and designing of improved and innovative applications is a need of the moment for the working envelope of HPHT and aggressive reservoirs [43, 44].

5. Chapter summary

Swelling packers and seals offer promising unconventional solutions in well completion, repair of damaged wells, water shutoff and zonal isolation, and other downhole applications. Apart from functional performance, swellables are also more cost effective and economical in terms of rig time. As they offer improved production volume and higher rate of hydrocarbon recovery, they are further attractive due to lower environmental impact. In the case of failure of tubular or cementing, or in situations of high water-cut, swelling elastomers have been successfully and efficiently used for well remediation and recompletion. However, the technology has great potential, and should be introduced (if expedient) during the well design phase rather than as only a remediation method. This can save a lot of time and cost spent in firefighting after well damage or shutoff. The review presented above can assist field engineers in the selection of suitable swellable elastomer devices, and can be useful to research and development (R&D) engineers in the design of new downhole applications.

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