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EXPANDABLE TUBULAR TECHNOLOGIES TECHNOLOGY GAPS AND THE WAY FORWARD

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I. Introduction

The concept of expandable tubing is not particularly regarded as a new one. In fact it is said to have been used for many years in the boiler industry as a core technology, (Benzie et al, 2000). The use of expandable tubing in downhole applications back to the late 1800's (Benzie et al, 2000).Expandable tubing nevertheless became more prominent in the oil and gas industry due to the increasing pressure to provide reasonably priced oil from mature fields such as the north sea and in high cost areas such as deepwater in order to meet the increasing demand for hydrocarbons which has continuously been upward over the years.

It is interesting to note that despite the rapidly evolving technologies, important issues that challenge the oil and gas industry include conservation of hole size, economic feasibility of crude production and maximisation of well life. It seems therefore that the development of expandable tubular technologies (ETT) which is although short but fast paced and commenced by Shell, in the 1980's so as to overcome the telescopic nature of well designs which has been a limitation since wells were first drilled in the mid-nineteenth century was envisioned by Shell engineers as a technology that would eventually result in a single-diameter wellbore that would deliver well cost savings in the order of 30% to 50% long term, (Wright 2003). ETT was initiated by the need to reduce the cost of drilling wells, to enable operators to access reservoirs that could otherwise not be reached economically without the use of expandable wellbore tubulars and to increase the production of tubing constrained wells. Furthermore, the significant losses of internal diameter experienced by operators in the course of normal drilling process, during re-entry and deepening of existing wells, or during installation of additional casing string to remediate well problems are largely curtailed through ETT. Other reasoning underpinning the development of ETT includes its proven ability to improve safety; and minimise environmental cuttings handling and drilling rig footprints.

Since the development of expandable tubular technologies, its application has moved rapidly from a deepwater technology to a technology that has been embraced by operators in many basins. As at present only 22% of the installations have been in deepwater whilst more than 65% of its utilisation been on land. (Wright 2003)

In comparison to conventional well construction which requires telescoping of the well size from the well head down to the reservoir thereby resulting into large expensive surface casing, wellhead trees and other operating equipment, this method can result in an unworkable small hole size at the required depth. Expandable tubular technology has the potential of reducing the cost of well construction significantly and to give life to existing wellbores through capabilities for selective water shut-off, damaged casing and tubular repair by cladding. ETT therefore allow operators to explore in remote geologic regions and exploit reserves once considered unprofitable if drilled with conventional technology.

A common practice in the process of ETT is the use of "specially designed pigs or mandrels" to expand tubular diameter in order to reduce well tapering while preserving borehole sizes. This way the life of mature field is increased by internally cladding existing wellbores to isolate troublesome zones. Expandable pipe or tubulars therefore shares the ability for expansion after downhole installation. In simple terms,

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the process involves expanding the steel by cold working it downhole to the desired diameter. Expandable technologies refer to both **slotted and solid expandable tubular**, associated tools and accessories, and systems used to expand the specially manufactured pipe.

In summary, the technological development of expandable was driven from a business perspective by offshore high-pressure/high temperature activities (Stewart 1999) and initiated by a need to:

- Increase depth and reach capability of well designs to access reservoirs, which are impossible or difficult to reach (e.g. high pressure zones, deepwater environments and troublesome subsalt zone) with the use of conventional well design.
- Reduce the cost of drilling by a large percent.
- Increase the production capability of tubing constrained wells.

II. Fundamentals of Expandable Tubing

The five major components of the expandable solid tubing system are the expansion cone, threads, material, annular seal and expansion mechanisms. Each one of them affects the performance of the other components. The basic principle is such that when expanded tubing is forced over the expansion cone during expansion process, the expansion cone radius and angle as well as the material characteristics would determine the amount of surplus expansion and the amount of the subsequent relaxation of the material expanded. Combination of expansion cone radius, materials, guage tolerance of the openhole or casing within which the tubing is to be expanded all determine the expansion forces and tolerances, or fit of the final expanded product in the wellbore.

The two major types of expandable tubular are expandable slotted tubular and expandable solid tubular.

Expandable slotted tubulars (EST) are usually made from steel; they have slots which are in an overlapping periodic pattern, cut in axial direction. Unlike expandable solid tubular (SET), EST require a much lower expansion force , the slots open and the plastic deformation is concentrated around the fingers at the end of the slots. EST technology has been made available to the industry through conventional service companies like Petroline. The expansion principle is based on bending the metal strips between 2 overlapping slots, and expansion forces are consequently low (approximately 10 tonnes). Bending the strip allows the slots to open into diamond shape resulting in an increased pipe diameter while wall thickness remains the same; the length is reduced by about 2%. Expandable slotted tubular technologies are a metal - to –rock expansion which has 3 major applications i.e. expandable sand screen system; alternative borehole liners and expandable completion liners.

Expandable solid tubulars are wellbore tubulars that are produced from ductile steel of conventional strength. Its ductility is as such that its diameter can be increased by tens of percent downhole. Expandable solid tubulars (SET) can also be made of titanium or aluminium because of their ductile nature.

III. Principles of Solid Tubular Expansion

For a solid tubular to expand, a conventional material selection criteria like corrosion resistance and strength is required. The ductility of the material from which it is made should be able to sustain tens of percent of plastic deformation and should be able to strike a balance with regards to expansion and post expansion processes. It is worth noting that the metallurgical process that increases strength in the solid tubulars tends to reduce its ductility. As a result a suitable alloy compositions and heat treatment procedures have to be chosen to ensure a combination of high ductility and strength of the expandable well bore tubular. The basic piece of equipment that underlies solid expansion technology is a mechanical expansion device known as an expansion cone (Stewart et al) which is propagated through downhole tubulars using hydraulic pressure. Cone movement expands the tubulars to the desired internal and external diameters in a plastic-deformation process known as cold-forming. To ease the expansion process, the inside diameter of the tubing must be lubricated to allow the expansion cone to move smoothly through the tubing thus minimising the chance of galling and reducing frictional force. Below are some expected capabilities of downhole expansion:

- Expand long section of tubulars at high rates.
- Maintains integrity of expanding tubulars connections.
- Achieve constant diameter and wall thickness of the expanded tubular over whole length of expanded section.
- Expansion of tubular to desired diameter without damaging or bursting the tubular.
- Maintaining hydraulic capabilities of the expanded tubular to provide sufficient resistance to burst and collapse loads in service.

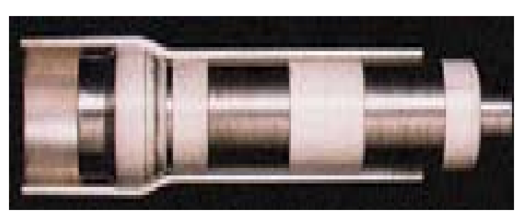

Fig 1 : Early expansion cone used to expand solid expandable tubulars (Fillipov et al 1999)

Table 1: illustrates the differences between expandable solid tubular and expandable slotted tubular

	Expandable slotted tubular	Expandable solid tubulars
Slots	Consists of periodic overlapping slots cut in axial direction	No Slots present
Expansion force	Less force	Higher expansion force
Wall thickness after expansion	reduces	constant
Tubular length after expansion	Reduces	constant
Concentration of plastic deformation	Finger at the end of the slots	Entire wall thickness

IV. Well Design with Expandable Tubular

Because the production capacities of most wells are halved through the use of production tubular, the constructions of large wells are therefore design to install relatively small production casings which results in pronounced telescopic profile of conventional well designs and thereby offering limited scope for major reductions in the cost of well construction.

It is obvious that in order to reduce well construction costs by tens of percent the implementation of radically new well designs are required. Expandable wellbore tubulars forms the basis of one such concept.

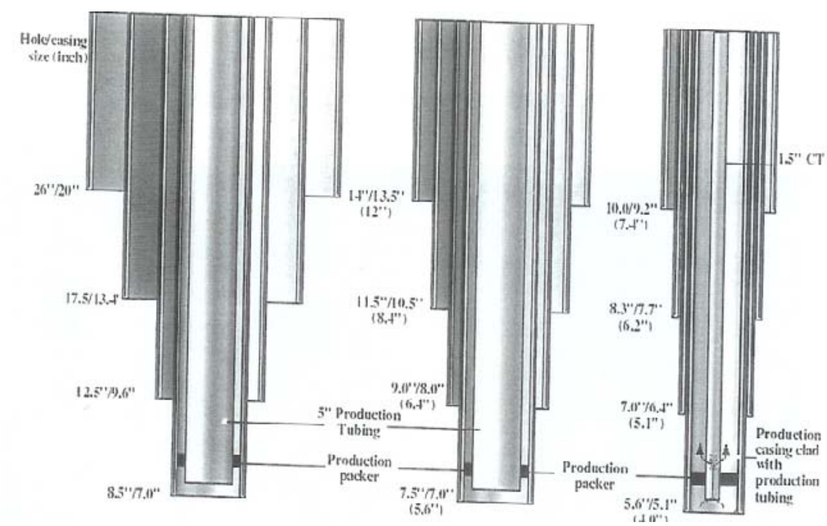

Fig 2 : a comparison of well designs with the same production capability.(Stewart et al 1999)
Left: Conventional telescopic well design
middle: Well design with casing expanded by 25% in outer diameter.
Right: Well design with expanded casing and clad production

V. Applications of Expandables

There are various applications for expandable tubing. Some of these applications include casings, liners sand screens etc. Even though expandable products are unique and very interesting in their concept and installation, they have little value if cost effective applications are not the end result of the development of this technology. The application of the technology in the subsurface environment has the potential of significantly reducing surface and subsurface costs and increasing the return on investments of the operating companies. Probably the most important advantage of expandable technology is that it is an "enabling" technology considering the fact that currently certain wells cannot be drilled to their objectives without solid expandable tubular technology. Expandable tubular technology can be applied in these three main application segments. (i) Well bore construction; (ii) Remediation and (iii) Completions

Well bore construction: Expandable tubing can be used in the open liner hole as a temporary drilling liner or as permanent liner tied back to the previous casing string. Where a contingency liner is required, temporary liners can be used. A good example of these may include deepwater and high pressure wells where there is very low tolerance between the formation pressure and fracture pressure. In this case the temporary liner used allows the operator to reach total depth without losing hole size. Expandable tubing can thus be used as a permanent liner and include a tie back into the previous liner or casing thereby replacing the conventional liner hanger.

Remediation: Application of ETT for remediation purposes deals with the repairing of casing, production tubing or sand screens, it can also be used for sealing off perforations. In which case the solid tubing are expanded inside the casing to seal leaks or in the repair of corroded or eroded sections of casing or tubing. In remediation process, "clads" whether light weight or heavy weight can be used to shut off perforations in cased hole and also used to shut off non-producing zones in the sand screens or to repair damaged sand screens.

Completions: Sand exclusion mechanism was one of the first commercial usages of expandable tubing well completions. In sand exclusion mechanism, the slotted tubing is expanded against the sand face, this mechanism is an improvement over the conventional sand exclusion mechanism because of the higher productivity and this is possible because of the larger effective in-flow area provided by the expandable screen, and the reduced chance of premature screen failure given the close tolerance between the expanded screen and the sand face.

VI. Gap Analysis

In order to reveal the weakness and strength of expandable tubular technologies, a gap analysis is conducted so as to have a better understanding of the dynamics of the exploration and production competitive environment and to develop ways of staying ahead in the area of technological development. The gap between the conventional technology and the already existing expandable tubular technologies would be identified, after which suggestions would be provided to close the existing gap by developing a process of change and ways of managing the process of change from the already existing technologies to the improved technologies. Thereafter, the process of change is monitored so as to ensure that the same gap does not appear again and, if possible to open a favourable gap with the competition. (Ambrosini et al 1998)

Some pertinent issues arising from the literature, practical application of expandable tubular technologies which can be considered as a gap and therefore worth analysing are as follows:

a) Connections

Most connections available are not gas tight connections i.e. there are always gas leakages from the connection and would therefore be a worthwhile issue to analyse in order to find suitable solution to this apparent set of expandable tubular technologies.

b) Collapse

This is a very important issue in the oil and gas industry. Although expandable tubulars are made of highly ductile material to enable it expand however, its main problem is the post expansion characteristics of the expandable tubular i.e. the strength and wall thickness, the collapse of tubular increases after expansion, this make it weak to withstand pressure exerted on it. The material used to make the tubular can also be altered so as to reduce the collapse of the post expanded tubular.

c) Expansion force

The fact that very high pressures are required to expand the tubulars and the cost of generating the required pressure can be very high and therefore makes it imperative to find a good solution and one such good solution that can be applied is the use of pressure intensifiers to increase the applied pressure. By so doing only the pressure applied to the pressure intensifier will be needed and this pressure is in turned increased. This method can help cut cost in the oil and gas sector.

d) Corrosion

Since the oil and gas industry place so much emphasis on safeguarding exploration and production equipment from quick and immediate corrosion, the implication of expandable tubulars during expansion as the cone rubs against the tubular is such that metal is been removed and deposited. This phenomenon is known as galling. The exposed surface where metal removal has taken place now becomes susceptible to corrosion. Corrosion can be very expensive and cost the oil and gas industry millions of dollars. A way of saving cost and combating this problem is to electroplate the metal surface with chrome in order to prevent galling and consequently preventing corrosion to takes place.

e) High temp high pressure well

Unfavourable conditions like high temperature and high pressure can pose a lot of problems like tubular collapse, corrosion amongst others.

f) Multilateral wells junction stability

Expandable tubular technology can be applied successfully in well completion but there are a few issues that can complicate the process. A very crucial issue to be considered is sealing of the multilateral junction. Depending on the construction method, the junction can offer either or both mechanical integrity (a barrier between formation and well bore pressure)(Ohmer et al 2001). The ultimate goal is a junction with full mechanical and hydraulic integrity provided by the casing itself, without the aid of cement. Multilateral junction connectivity failures have been identified as a recurring risk when deploying junctions featuring casing windows in unstable formations. When a junction experiences a connectivity problem, usually because unstable formations induce mechanical loads, solids can intrude and expected junction geometry can deteriorate. Borehole stability has been the subject of study for more than two decades now because of a great number of problems associated with the construction of petroleum boreholes and the subsequent production or injection of fluids, (Fuentes, J.A et al 1999). If two cylindrical bodies intersect at a very shallow angle, the junction geometry amplifies pre-existing mechanical stresses that are generated in the course of drilling and production operations. This

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phenomenon suggests that the geo-mechanical forces at a junction may be a root cause of junction collapse.

VII. Conclusions and Recommendations

The foregoing analysis indicates that the development of expandable tubular technology was in part driven from a business perspective and also initiated by a need to increase depth and reach capability of well designs to access reservoirs, which are impossible or difficult to reach (e.g. high pressure zones, deepwater environments and troublesome subsalt zone) with the use of conventional well design; to reduce the cost of drilling by a large percent and to increase the production capability of tubing constrained wells. The potential benefits of expandable tubing extend far beyond the advantages outlined above. In practice this technology has replaced the conventional technology in wellbore construction and this may not be unconnected to its advantages.

Whilst expandable tubular technology promises to be an enabling technology that leads to standardised well and allows the concept of disposable exploration well to be realised, it is however associated with varied problems. Nevertheless, the technology could be advanced further and improved upon.

There are various areas in which the technology of expandable tubular technology can be improved and they include the following;

a) Annular sealing

The use of expanding cements for improving the sealing efficiency of annulus cementing has been considered for a long time as a possible solution to the existing problem of leakages and fluid loss. This is important because environmentally compatible, safe and economical production from oil and gas wells depends in an essential manner on flawless cementation of the installed casing string whose function is the prevention of fluid and gas flow through the annuli among other items. The requirements of annulus cementing can be satisfied only if the cement ensures an impermeable bond between the casing string and the surrounding rock and exhibits sufficient compressive and shear bond strength until the ultimate plugging of the well. Gas and fluid motions in the annulus are continual but often slow processes which are consequently detected late or not at all. It is not uncommon for migration from the payzone to build-up at the wellhead. In practice, definite effects of leakage can occur in comparatively short liner cementation in gas wells and in combination with insufficient sealing of the liner hanger, the gas often can easily penetrate into the production tubing. The formation of voluminous Ca $(OH)_2$ and Mg $(OH)_2$ crystals on the surface of the cement particles which resulted in matrix expansion by more than 10% even under a hydrostatic pressure of 120Mpa and at borehole temperatures up to 175^{o}C. Calcium oxide(CaO) and magnesium oxide(MgO) additives exhibit effective matrix expansion, even under hydrostatic pressures up to 120Mpa. The improved shear bond strength values of such cements indicate effective bonding of the cement at the interfaces with the casing and formation, and that superior sealing action can thus be achieved. The permeability studies on the system comprising the hardened cement paste and steel pipe essentially confirm this conclusion (Ghofrani and Plack 1993).

b) Swelling elastomers

Swelling elastomers are used extensively throughout the industry (Braas et al 2003). A swelling elastomer has been identified as a potential method of increasing the sealing OD range of openhole clad. The swelling is based on contact between the elastomer and has the potential of doubling the seal thickness after downhole deployment. The swelling rate downhole is determined by pressure and temperature as well as the composition of wellbore fluids. Fast rates of swelling are preferred, to reduce waiting time to a minimum before the seal becomes effective. Swelling rates should however not be too fast, as this might prevent running the OHC to depth.

Fig 3 : Swelling elastomers. Original thickness: steel 4mm, rubber 3.6mm (left); 66% swelling (middle); 118% swelling (right), (Braas et al 2003).

Better annular sealing can also be achieved chemically by the use of production chemistry processes which affect the formation. A good example of this is the use of permeability modifier to modify the permeability of the formation in order to prevent fluid loss.

c) Galling prevention

This can be done by thin dense chrome plating. It is achieved by chrome plating the tubular in thickness ranging from 0.000025 to 0.0005 (0.000635-0.0127 mm). The electro-alloy thin dense plating process is an alternative to standard chrome plating, which may develop tiny cracks and thereby allow a corrosive liquid or gas to penetrate to the base metal and attack it. Thin dense chrome is hard chrome which is so thin and it has not yet built up enough stress to cause cracking and therefore has good corrosion resistance. It uniformly deposits dense, high chromium, non-magnetic alloy on the surface of any metal without measurably changing the micro-inch value of the base metal. This process of chrome plating offers design engineers an efficient means of improving the performance of the expansion process of expandable tubulars. In addition to preventing galling it perform the following functions.

- Lengthens service life
- Increases lubricity
- Permits use of similar opposing surface
- Results in significant savings in time, labour and replacement parts.

Among other things it is characterised by:

- Remarkable wear resistance
- Extremely low coefficient of friction
- Smooth sliding properties
- Excellent anti-seizure characteristics
- Beneficial corrosion resistance.

The plating can be applied in thickness ranges from 0.000025 to 0.0005 inch with a tolerance of (+/_) 10%. The precision electro-chemical deposition takes place in a special fluoride bath to assure a positive, lasting bond between the base metal and the surface. The minimum deposition thickness prevents hydrogen build-up that often plagues plating. This deposition takes place at low temperatures, generally less than 140ºF, and is applicable to all ferrous and non-ferrous metals without causing distortion. A uniform electro-alloy can be applied to the internal and external surfaces of metal parts having varied configurations. The plating's main attribute in wear resistance is its low coefficient of friction which means less drag and therefore less heat is generated as the expansion cone rubs against the expandable tubular. It is applicable to virtually any environment ranging from –425ºF to greater than 1150ºF ambient. It can be used to treat base metal for improved performance, or it may be combined with a less expensive base metal as a substitute for corrosion resistant steel, thereby generating considerable savings in material cost. The three important advantages which are put to use in a wear situation are that it is very hard; it is very slippery; and it is resistant to most industrially corrosive environment.

d) Pressure intensifiers

In this case the hydraulic pressure intensifiers can be used to increase the pressure applied to the expansion cone in order to expand the expandable tubular, they are used for creating pressures up to 100,000psi. Since generation of such high pressure onshore or offshore will involve the use of very special pumps which are very expensive. A very good way to reduce cost is to use pressure intensifiers during the deployment of the expansion cone down the expandable tubular. This way a lower pressure can be easily generated by the pumps and in turn could be multiplied by the pressure intensifier. Pressure intensifiers are used for creating pressure greater than those ordinarily obtained directly from either hand operated pumps or motor driven pumps, while it is unintended for high volumetric capacity, their simplicity of design makes them an economic means of obtaining high pressure

e) Material selection

Material selection is a very important factor for solid tubular expansion. A low yield material with high ductility is selected to ease the expansion process. The required energy use to expand a solid tube is approximately proportional to its yield strength. Similarly, the expansion ratio, which is the ratio of the post expansion outside diameter of the pre-expanded outside diameter, is also approximately proportional to the expansion force for a given material. The preferred range of yield strengths is between 40,000psi and 70,000 psi. It is important that the manufacturing quality of the material needs to be of a higher specification than conventional API tubing, particularly with respect to allowable defects, wall thickness, yield strength, ductility and uniformity along the length and the circumference of the tubing. During the expansion process, the material strength increases since the expansion process is a cold working of the material. However, the collapse strength of post expanded material is less than that of the pre-expanded material. This is due to a combination of factors which includes the increase in diameter, reduction in wall thickness and material changes due to the cyclic working e.g. expansion decreases the collapse rating of tubular goods, probably as a result of Baushinger effect. The Baushinger phenomenon occurs when the plastic flow in one direction (expansion) lowers the applied stress at which plastic flow begins in the reverse direction (collapse) (Choi H.J. 2009). The test data for grade L-80 indicate that, if the pre-expansion and post-expansion dimensions are the same, collapse resistance should decrease by about 30% as a result of the expansion process. Collapse test data on 5 ½ inch x 17lb/ft grade L-80 show that post-expansion collapse resistance was near or slightly below the minimum required by API Bulletin 503. Fortunately, studies have shown that a significant portion of material's initial collapse resistance can be recovered in situ through a special process under development. For example, application of this process to 20% expanded L-80 casing resulted in a 48% increase in post expansion collapse resistance. The expansion process appears to have no detrimental effects on burst strength. Burst pressure of expanded L-80 casing meets or exceeds general formulae expectations, and the fracture surface of all samples tested has shown ductile fracture behaviour. (Choi H.J.2009).

Since the collapse strength of the post expanded material is less than the collapse strength of the pre-expanded material, it implies that the low collapse strength of the post expanded material will constitute a major problem. A very good way to increase the collapse strength of the post expanded material is to increase the wall thickness of the pre-expanded solid tubular. By so doing, after expansion, the post expanded material will have a higher collapse strength and therefore prevents the solid expandable tubular from collapse.

Selection of the proper materials for the mandrel or pig assembly is very crucial. The working piece, the cone is subjected to high interfacial stresses as it expands the pipe. The shape of the cone and lubrication of the cone that interface with the tubular product are also critical to successful performance.

Materials for the components of the expansion assembly are chosen for sufficient strength, ductility, impact toughness, and resistance to galling, wear, and environmental cracking.

The performance of standard grades of steel tubulars after its subjection to permanent expansion (up to 20%) was previously unknown. Initial laboratory experiments included flaring tests, much more meaningful than tensile tests for determining the suitability of the various API 5CT grades for expansion. Seam-Welded products were the initial expansion studies because their wall thickness is more easily controlled.The knowledge of post expansion mechanical properties is imperative for the accurate service rating of the tubular product under evaluation. Post expansion strength, ductility, impact toughness, collapse, and burst have been studied for selected sizes of pipe and compared to the same values for the pipe as received. The data show that the expansion process does, indeed affect the mechanical properties of the material. Ultimate tensile strength tends to increase, and elongations tend to decrease, with expansion- natural results of cold-working the metal.

The convergence of a number of technologies will further advance the technology and application of expandable tubing, an example of this convergence is the use of formed metal technology in multilateral wells, this in turn create the desire to begin the process of designing fit for purpose wells using expandables as the enabling technology. The continued use of expandable products and the rapid development of a broader range of solutions will lead to the use of expandables more and more on a well design basis rather than on a contingency basis.

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