International Journal of Solids and Structures 50 (2013) 2980–2994

Contents lists available at SciVerse ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Structural behavior of solid expandable tubular undergoes radial expansion process – Analytical, numerical, and experimental approaches

Omar S. Al-Abri *, Tasneem Pervez

Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University, P.O. Box 33, Al-Khoud 123, Oman

ARTICLE INFO

Article history:
Received 3 January 2013
Received in revised form 31 March 2013
Available online 28 May 2013

Keywords:
Steel
Finite element method
Metal forming
Solid Expandable Tubular Technology
Thick-wall tube
Tube expansion
Well drilling

ABSTRACT

Today's structures have to meet increasingly rigorous requirements during operation. The economic and human costs of failure during service impose a great responsibility on organizations and individuals who develop new products as well as those who select/integrate products in a final engineering design. A crucial aspect for successful product development and/or inclusion is the careful selection of the best material(s), derived from an informed awareness of the capabilities and opportunities afforded by all candidate materials, together with a design that takes full benefit of those competencies. Thick-wall tubular is an example where all these issues are playing a major role in deciding their industrial applications. Given for their desirable features of high strength and geometrical shape, they are widely used in aerospace, marine, military, automotive, oil and gas, and many other fields. This paper focuses on developing analytical solution to investigate the structural response of thick-wall tubulars undergo plastic deformation due to expanding them using a rigid mandrel of conical shape. Volume incompressible condition together with the Levy–Mises flow rule were used to develop the equations which relate the expansion ratio of the tubular to the length and thickness variations. Besides, Tresca's yield criterion was used to include the plastic behavior of the tubular material. Further to this, a numerical model of the tubular expansion process was also developed using the commercial finite element software ABAQUS. Experiments of tubular expansion have been conducted using a full-scale test-rig in the Engineering Research Laboratory at Sultan Qaboos University to validate the analytical and numerical solutions. The developed analytical and numerical models are capable of predicting the stress field in the expansion zone, the force required for expansion, as well as the length and thickness variations induced in the tubular due to the expansion process. Comparison between analytical, experimental, and simulation results showed that a good agreement has been attained for various parameters.

1. Introduction

The continuously increasing demands for petroleum products have forced the petroleum companies from all around the world to search for new reservoirs or to revitalize the existing ones, which are difficult to access and/or maintain a profitable production level. Current well drilling and operation technologies cannot provide cost effective solutions for emerging challenges in this field. The well-bore tubular technology has gained significant importance in every well with maturation in oil and gas industry. The conventional well-bore tubular technology has progressed over decades of research work including laboratory experiments and field trials that produced satisfactory results. Currently, telescoping of well size, from wellhead down to the reservoir, is a result of conventional well construction methods. This ends up in high cost of surface casing, wellheads and operating equipments. At times, the method also results in an unworkable small hole size at the target depth. This could lead to unprofitable production or in worst cases failure to reach the desired target. The conventional well-bore tubular technology is still unable to provide solutions for many problems such as deep drilling, conservation of hole size during hydraulic isolation processes, and accessing of new reservoirs that currently cannot be reached economically. These issues as well as many others are not only long-standing but have far-reaching consequences in the oil and gas industry. They involve one of the industry's most fundamental technologies: well-bore tubulars. The revolutionary new Solid Expandable Tubular (SET) Technology has successfully addressed some of the above-mentioned issues. It provides mechanical stability in situations where conventional casing strings cannot be installed due to geometrical restrictions. Further to this, larger diameters can be attained at terminal depths for enhanced production from a single well. Thus, it has gained momentum and attracted the attention of operators and researchers, and is rapidly expanding its horizon of applications.

* Corresponding author. Tel.: +968 2414 2652; fax: +968 2414 1316.
E-mail address: m053898@squ.edu.om (O.S. Al-Abri).

0020-7683/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijsolstr.2013.05.013

Nomenclature

μ	coefficient of friction
F_e	expansion force (N)
m	correction factor that may be taken between 1 and 1.15 to approximate the von Mises yield criterion
P_c	contact pressure between mandrel and tubular
r	instantaneous tubular radius along the expansion zone
r_{i1}	pre-expansion tubular inner radius (m)
r_{o1}	pre-expansion tubular outer radius (m)
r_{i2}	post-expansion tubular inner radius (m)
r_{o2}	post-expansion tubular outer radius (m)
t	instantaneous tubular thickness (m)
t_1	initial tubular thickness (m)
t_2	final tubular thickness (m)
Y	tensile yield strength (Pa)
z	instantaneous tubular length (m)
z_1	initial tubular length (m)
z_2	final tubular length (m)
α	mandrel cone angle (°)
β	$90° - \alpha$
$\sigma_{z/r/t}$	axial, radial, or hoop stress (Pa)
σ_e	equivalent stress (Pa)
OD	outer diameter
P_{cr}	collapse pressure rating
P_{Yi}	internal pressure rating at the onset of yielding

The notion of using this technology in the oil and gas industry started to take place in the late 1990s, driven by operators' aspiration to trim down the telescopic effect in casings design as the wells are drilled deeper. The basic idea was studied in several papers published during the last decade. The concept of SET Technology is simple to understand and consists of a down-hole in situ expansion of the tubular inner diameter that is attained by hydraulic and/or mechanical forces to pull/push a solid mandrel from the bottom up that permanently deforms the tubular to the required size as shown in Fig. 1. Since then, the technology has continued to grow in acceptance and use, where in a period of two years, the reliability of the technology has improved from an average of 67% in 2000 to over 95% in 2002 (Escobar et al., 2003). This has lead to the development of a collection of products that can be utilized as solutions for an ample range of drilling, completion, and production problems. Many different designs and processes have been created over the years, and as the oil industry continues to grow and change, expandables are also evolving to generate new and innovative solutions to the ever-shifting issues that operators' deal with. The ultimate goal is to realize the drilling of slim to mono-diameter oil and gas wells as opposed to the current practices of drilling telescopic wells as shown in Fig. 2. Reducing the telescopic nature of the conventional wells would allow a much smaller surface casing to be used and subsequent casings could be reduced in diameter. Additionally, with the aid of this technology, operators will be able to reduce the amount of resources required to construct the well, as well as reaching target depths with bigger diameter. Several economic evaluations have been performed to show the cost effectiveness of this new technology (Owoeye et al., 2000; Benzie et al., 2000; Dupal et al., 2001). Through field trials and case studies Dupal et al. (2001), Gusevik and Merritt (2002) and other researchers (Benzie et al., 2000) showed that open-hole solid expandable tubular have the potential to reduce the overall well construction cost. An interesting case was reported in Campo et al. (2003) showed that the mono-diameter system provides 48% cost reduction in well construction as compared to the fifth generation drillship cost and 33% cost reduction when compared with high specification semisubmersible. The environmental benefits are also substantial. Campo et al. (2003) reported a remarkable environmental impact of solid expandable tubular due to lesser requirement of consumables for well construction. The study showed 44% reduction in drilling fluid volume, 42% in cement volume and 42% in casing tonnage. These environmental impacts prove that the energy industry can fulfill world's demand for hydrocarbon products with an environmentally friendly process.

Much of the activities accompanying the introduction of SET Technology in petroleum industry were related to the effect of the expansion process on the material properties (Filippov et al., 1999; Mack et al., 1999; Stewart et al., 1999; Mack et al., 2000). Solid tubulars having adequate material properties characterized by collapse and burst strength, ductility, impact toughness, resistance to wear and environmental cracking must be carefully selected for down-hole applications. An API Grade L-80 expandable steel tubular of 5–1/2 in diameter was tested to determine the effect of expansion on the mechanical properties (Filippov et al., 1999; Mack et al., 1999). The results showed that the ultimate tensile strength increases, the elongation tends to decrease and the collapse rating decreases. The test data reveal no detrimental effect

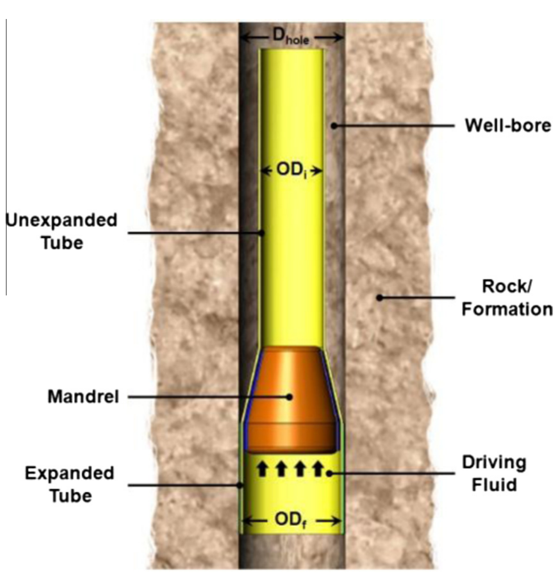

Fig. 1. Schematic diagram of tubular expansion process using conical mandrel.

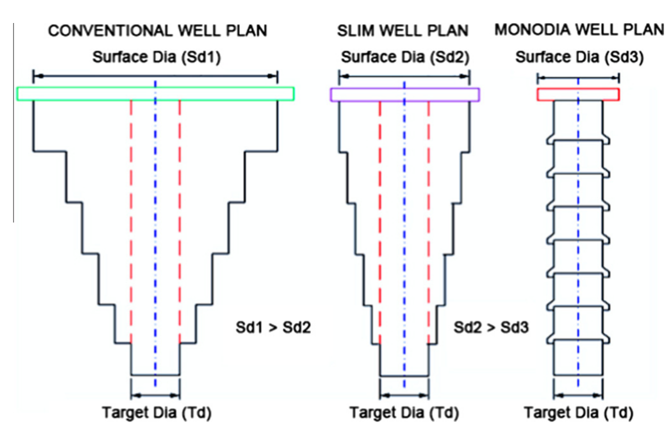

Fig. 2. Schematic sketch of conventional to mono-diameter oil-wells.