Sustained External Pressure of Drilling Engineering Detection: under the Condition of 50 kg/cm^2

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ABSTRACT

External hydrostatic pressure or buckling pressure is an important consideration for designing and fabrication of borehole logging probes and in many other industrial applications. These tubes (probes) host wide range of electromechanical devices that are lowered into the boreholes to probe the earth and ocean layers to understand their physio-chemical properties and evaluate for natural resources. Hydrostatic pressure in the boreholes increases at 1 kg/cm2 for every 10 meter increase in the depth. Therefore depending upon the water column in the area, it is observed that in a normal 500 meters borehole, it may vary from 0 to 45 kg/cm^2. These logging probes have to withstand and safe guard all the instruments that are arranged inside. In the present study the collapse pressure for copper, brass and stainless steel tubes of 0.6mm thickness have been theoretically calculated as 18.13, 37.33 and 55.71 kg/sq.cm; for 1.6 mm thickness as 47, 98 and 146 kg/sq.cm respectively. FEA analysis on the tubes of these materials resulted in similar values. Experiments were carried out in a pressure vessel creating a uniform hydrostatic pressure up to 50kg/sq.cm simulating the borehole conditions. As anticipated the copper and brass tubes of 0.6mm thick collapsed at 20 and 23 kg/sq.cm pressure and the stainless steel tube with stood beyond 50kg/sq.cm. The thicker brass and copper tubes of 1.6mm with stood the hydrostatic pressure beyond 50kg/sq.cm. Therefore the brass tube of 1.6mm thickness and 600mm length is ideally suitable for construction of logging probes which has good engineering, physicochemical properties and cost effective and can replace the imported tubes.

KEYWORDS: Borehole logging probe, Pressure tubes, Finite Element Analysis, External pressure

INTRODUCTION

Various kinds of pressure tubes and cylinders are widely used in metallurgical, material sciences, mining, mineral, chemical, aerospace and oil and gas industries for piping, probing, storage of fluids and gases. In recent years their application in military industries as well as in nuclear power plants has increased. These tubes are usually subjected to high pressure and temperatures which may be constant or cycling in the process. During the operations in industrial applications, problems often witness ductile fracture of tube materials due to some discontinuity in geometry, external and internal pressure, material characteristics and compositions. The variations of chemical and morphological can be controlled to large extent but the pressure and temperature variations do play a major role in buckling of the tubes in industry. The conventional elastic analysis of thick walled cylinders to final radial and hoop stresses is applicable for the internal pressure up to yield strength of material where as thin-walled cylindrical tanks are prone to buckling collapse due to accidentally induced internal vacuum. Number of experiments by various workers have been carried out and established the equations that explain the internal pressure of tubes and vessels. However, very less attention has been paid to understand the external pressure on the tubes and pipes. The problem of determining the external pressure at which a thin-walled cylinder will collapse confronts the designers of boilers, vacuum tanks, borehole probe and similar units of construction. In the design of hydro-electric or water supply projects, problems of determining the collapsing pressure of thin-walled pipe and of evaluating the effect of stiffeners upon the strength of the pipe are frequently encountered. Many industries using distillation processes under partial vacuum are confronted with the problem of designing tanks to withstand external pressure. Generally empirical formulas are developed and established by researchers involved in designing the pressure tubes for some special applications. Recently, pressure cylinders subjected to external pressure have become a point of interest in the nuclear industry due to their application in advanced small and medium-sized light water reactors as they carry the nuclear fuel and also host control rods.

Borehole logging is the practice of making a detailed record of geological formations through the borehole drilled to explore the subsurface structures of the earth. The logging is generally based on visual inspection of samples brought to the surface and also on physical measurements made by instruments lowered into the hole. Well logging is performed in boreholes drilled for mineral, oil and gas, groundwater, geothermal exploration, as well as part of environmental and geotechnical studies. Logging tools developed over the years measure the natural gamma ray, electrical, acoustic, stimulated radioactive responses, electromagnetic, nuclear magnetic resonance, pressure and other properties of the rocks and their contained fluids. Imaging tools, sonic tools, mechanical tools, magnetic tools, deviation tools, Electrical tools (resistivity, IP), fluid properties tools, nuclear tools (natural gamma, alpha induced gamma, spectral gamma, thermal neutron, neutron) are generally used in probes (Figure 1). Logging probes contain sensors able to supply information on physical parameters of the rock and soil medium around the borehole, fluid column and flow parameters in the borehole, and to some extent on the character and state of individual elements of the well such as casing, filter, and sealing materials in the annulus between the casing mantel and the borehole wall (e.g. clay, cement, mud). Logging tools are equipped with a special head for connecting the tool to the cable head. The logging cable together with the winch system is used to connect the logging probe with the surface part (supplying and recording units) of the logging system, to run the tool in the borehole downwards and upwards, to power the probe and transmit data from the sensor to the recording unit.

The probes have different dimensions, i.e. diameter ranging between 32 and 60 mm, length usually not exceeding 2 m and weight between 3 and 10 kg (Figure 2). The choice of the probe depends predominantly on the physical properties of the examined geological body and their contrast to the physical properties of the surrounding medium. It is also necessary to consider the diameter of the borehole, inner diameter and material of the casing etc. These parameters can be in some cases limiting (e.g. probes measuring magnetic susceptibility or electrical conductivity of the rock medium cannot be used in boreholes equipped with steel casing). Finally, it is necessary and important to take into account the final depth of the borehole and to decide if the logging probe can withstand temperature and pressure values at the bottom of a well. These hydrostatic pressures vary as the borehole pass through various litho units. If two alternate layers of permeable and impermeable units occur at depth suddenly the hydrostatic pressure would increase. Similarly if a borehole encounters water at very shallow depth naturally the hydrostatic pressure would progressively increase as the probe is lowered. Therefore selection of the probe material is crucial in these logging operations. They need to withstand temperatures and pressures. Commercially, several probes with various sizes and designs are available in the international market. However, in India only few research institutions and Government organizations are involved in designing these probes.

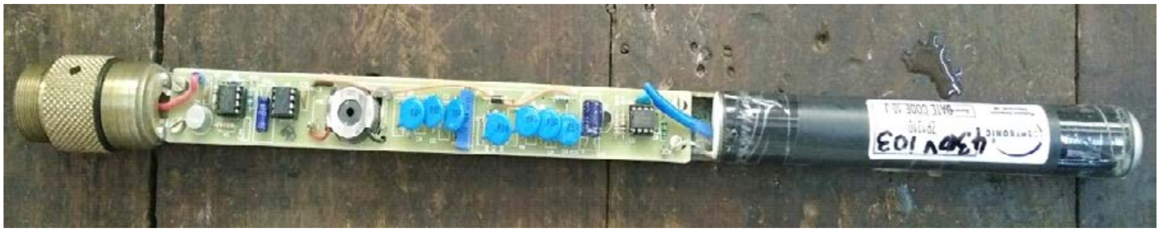

Figure 1: Logging probe hosting Geiger Muller counter and associated electronics used for gamma ray spectra in a borehole

Figure 2: Logging probes with various dimensions used in mineral and oil exploration

OBJECTIVES AND SCOPE OF THE INVESTIGATION

The objectives of the present study include:

To analyze the elastic behavior of thin circular cylindrical tubes subjected to uniform external pressure, and to determine the pressure at which they collapse for simply supported and for fixed edges

To study experimentally the behavior of thin-walled tubes under uniform external pressures, for comparison with the results of the theoretical analysis.

Finally arrive at the specifications to design an indigenous, cost effective logging probe with a uniform thickness that can host all the necessary electro mechanical devices and can be run through the borehole where it can withstand to an external pressure exerted by the water column up to 50 kg/sq.cm.

BASIC ARGUMENTS AND ASSUMPTIONS

The most important mechanical properties of the tube include burst strength, collapse resistance and tensile strength. These properties are necessary to determine the strength of the tube/ pipe and to design a logging probe. The general procedure followed in this study is to derive expressions for the collapsing pressures of round cylindrical tubes, and to treat deviations from these conditions as extensions of the first derivation. The argument used in determining the collapsing pressures is as follows:

Consider the cylindrical tubes deflected into some shape such that the differential equations of continuity and equilibrium combined together with the boundary conditions, are satisfied. If the external forces necessary to hold the tube in the deflected position are independent of the magnitude of the deflections as long as they are so small that they do not materially change the general shape of the tube, then the tube is in a state of neutral equilibrium. The lowest pressure at which neutral equilibrium may begin is the critical or collapsing pressure of the cylinder (Nimish et al 2014, Ahmed et al. 2015, Dwight et al. 1986, Chen et al. 2014, Rolland, 1941). Below the critical pressure the equilibrium is stable whereas above the critical value the equilibrium is unstable. The assumptions involved in setting up the general differential equations are as follows:

The tube is a round cylinder before buckling

The tube is of uniform thickness throughout

The material in the tube is homogeneous and isotropic, and is elastic according to Hooke's law

The thickness of the tube or pipe wall is small compared to the diameter, so that the distribution of normal stress over the thickness may be assumed as linear

As a consequence of the preceding assumption, the radial stress, a Z, is negligible compared to the circumferential and longitudinal stresses, and the radial shearing detrusions are zero

Displacements are small compared to the thickness so that certain small quantities may be neglected. These *neglections* are indicated in the development of the analysis (Ronald Sturm 1941)

PREVIOUS STUDIES

The collapse of pipes, tubes and shells in general have been extensively studied for the necessity of economical design and safety dating back to the end of the industrial revolution where the resistance of tubes to collapse was studied extensively and empirical equations were derived from numerous experiments. Number of studies has been performed on the subject to improve empirical equations of pipe collapse (Simonen and Shippell, jr., 1982; Gunnar *et al.*, 2013; Staat, 2005; Yeon-Sik Yoo *et al.* 2010; Clinedinst, 1939). In collapse experiments, imperfections like the average outside diameter, average wall thickness, eccentricity and ovality have been measured and predicted with (empirical) equations. Effects of defects on the collapse pressure of pipes and tubes have been studied with experiments and finite element models (Bulson, 1983; Netto, 2009; Niloufari *et al.*, 2014). A complete collapse of tubes is governed by uniform external to internal differential pressure. The empirical equations used in standards for collapse resistance of pipes are based on combined theoretical, numerical and statistical tools. In general, the ratio of outer diameter to thickness (*D/t*) determines whether collapse occurs in the elastic, plastic or intermediate range of the wall compressive stresses. The critical elastic buckling pressure (p_{cr}) for long tubes under uniform radial pressure is

$$p_{cr} = \frac{E}{4(1-\nu^2)}\left(\frac{t}{R}\right)^3 \qquad (1)$$

where ν is Poisson's ratio, E is Young's modulus, t is the tube thickness and R is the tube radius.

THEORY AND METHODS

Collapse of a pipe/tube origins from an unstable response to a critical load and has been extensively studied experimentally (Tohid Ghanbari et al 2013,2015, Cleaver, et al 1936, Kennedy and, Venard 1962, Menglan Duana and Chen An 2014). If external pressure exceeds internal pressure, the tubes, pipes and casing are subjected to collapse. There are many factors that have some degree of influence on the external pressure that produce the collapse of a tube, among them:

1. The relation (outside diameter/thickness) (D/t ratio)
2. The yield stress of the tube (Sy)
3. The work - hardening of the tube
4. The shape of the tube sections (outside diameter shape and thickness distribution)
5. The residual stresses locked in the tube
6. The localized imperfections introduced either in the tubes production, in the tubes handling or due to localized wear

When the tubes are subjected to internal pressure higher than external, they are exposed to burst pressure loading. The minimum internal yield pressure (MIYP) of the pipe body is determined by the internal yield pressure formula as given

$$P_B = 0.875\left[\frac{2Y_{pt}}{D}\right], \qquad .(2)$$

where

PB = minimum burst pressure (psi)
Yp = minimum yield strength (psi)
t = nominal wall thickness (inches)
D = nominal outside pipe diameter (inches)

This equation calculates the internal pressure at which the tangential (or hoop) stress at the inner wall of the pipe reaches the yield strength (YS) of the material. The expression can be derived from the Lamé equation for tangential stress by making the thin-wall assumption that D/t >> 1. A pressure at MIYP does not mean the pipe will have a burst or rupture failure which only occurs when the tangential stress exceeds the ultimate tensile strength (UTS). So using a yield strength criterion as a measure of pipe internal pressure resistance is inherently conservative. This is particularly true for lower-grade materials whose UTS/YS ratio is significantly greater than that of higher-grade materials.

Collapse strength

If external pressure exceeds internal pressure, the pipe/tube is subjected to collapse. Collapse strength is primarily a function of the material's yield strength and its slenderness ratio (D/t). The collapse strength criteria, consist of four collapse regimes determined by yield strength and D/t. Criterion of each regime is discussed below in order of increasing D/t.

Yield strength collapse is based on yield at the inner wall using the Lamé thick wall elastic solution. This criterion does not represent a "collapse" pressure at all. For thick wall pipes (D/t < 15±), the tangential stress exceeds the yield strength of the material before a collapse instability failure occurs

$$P_{Yp} = 2Y_p\left[\frac{(D/t)-1}{(D/t)^2}\right] \tag{3}$$

Plastic collapse

Empirical relation for Plastic collapse regime is generally is based on experimental data on the oil field drill casings. No analytic expression has been derived that accurately models collapse behavior in this regime. Regression analysis results in a 95% confidence level that 99.5% of all pipes manufactured to American Petroleum Institute (API) specifications will fail at a collapse pressure higher than the plastic collapse pressure. The minimum collapse pressure for the plastic range of collapse is calculated by Eq. 4.

$$P_p = Y_p\left[\frac{A}{D/t} - B\right] - C \tag{4}$$

The factors A, B, and C and applicable D/t range for the plastic collapse formula are given in API data sheets. Transition collapse is obtained by a numerical curve fit between the plastic and elastic regimes. The minimum collapse pressure for the plastic-to-elastic transition zone, PT, is calculated as

$$P_T = Y_p\left[\frac{F}{D/t} - G\right] \tag{5}$$

The factors F and G and applicable D/t range (17 to 30) for the transition collapse pressure formula, are given in API data sheets. Elastic Collapse is based on theoretical elastic instability failure; this criterion is independent of yield strength and applicable to thin-wall pipe (D/t >30). The minimum collapse pressure for the elastic range of collapse is calculated as

$$P_E = \frac{46.95 \times 10^6}{(D/t)[(D/t)-1]^2} \tag{6}$$

Most of the tubes used in drilling for mineral exploration and oil fields experience in the plastic and transition collapse regimes where Ultimate Tensile strength or Yield Strength do play a significant role. Therefore, for designing a suitable logging probes/tubes that can host sophisticated and expensive electronic equipments it was planned to consider high collapse rating tubes that can with stand the external pressure with negligible ovality, residual stress and eccentricity. In the present work a simplified equation which relates internal pressure of a pipe to the dimension and the strength of the material popularly known as Barlow's expression is used to calculate theoretically a minimum pressure at which the collapse of tube occurs. The formula is named after Peter Barlow, an English mathematician. The formula applies to design the pressure vessels.

$$\mathrm{P} = \frac{\mathrm{ST}}{\mathrm{OD(FS)}} \tag{7}$$

where

P = Pressure

T = Pipe wall thickness

OD = Outside diameter

FS = Factor of Safety
S = Material Strength (Ultimate Tensile Strength or Yield Strength)

Yield strength is used to estimate the pressure at which permanent deformation begins.

Numerous materials are available in the market in the form of tubes, rectangular bars, channels of various sizes and shapes. Importantly, they include Copper, Brass, Bronze, Aluminum, Aluminum alloys, Stainless Steel, PVC (Poly Vinyl Chloride), Acrylic, FRP (Fiber Reinforced Plastic), GRP (Glass Reinforced Plastic) etc. They are available in various lengths, diameters and thickness. As the probe material should be with acceptable engineering properties such as corrosion resistant, withstand high pressure, temperature, easy to weld, and other physicochemical properties desired by the user, accordingly materials are selected for further experimentation and analytical calculations. Generally exploration of metals is carried out that involve the drilling up to a maximum of 1500m. At this depth normally the external hydrostatic pressure would be around 50 kg/sq.cm. If the borehole encounters artesian conditions then the pressure may go beyond this limit. Therefore following materials have been selected for the present experimentation:

- Copper
- Brass
- Stainless Steel 304

Borehole's diameter varies from 2.5"-8" so probe should have a smaller diameter so Φ32 mm is chosen. In metal investigations probe should contains a camera unit, gamma ray counter, ammeter, magnetometer and gravimeter. To accommodate these instruments the probe nominal length is considered as 600 mm. Considering these requirements theoretical calculations for working pressure and burst pressure are carried out and then obtained values are shown in Table 1.

Table 1: Physical and mechanical properties of copper, brass and stainless steel

Material	Thickness (mm)	Ultimate Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)	Working Pressure (kg/cm^2)	Burst Pressure (kg/cm^2)
Copper	0.6	1500	70	18.13	26.76
	1.6	1500	70	47.59	71.37
Brass	0.6	370	145	37.33	55.36
	1.6	370	145	98.43	147.63
S Steel 304	0.6	505	215	55.71	82.25
	1.6	505	215	146.24	219.33

Generally collapse of a pipe occurs when the value of external pressure applied on the pipe is higher than the internal pressure of the pipe whereas a pipe bursts when the internal pressure is higher than the external pressure. In this case, bursting of the pipe does not occur as the internal pressure in this case is negligibly low as both ends are closed.

FINITE ELEMENTS ANALYSIS (FEA)

Finite Elements Analysis (FEA) is a method for solving complex mechanical problems using the power of modern computers. Choosing sound boundary conditions and loads, the engineer is actually able to simulate reality whatever the situation or complexity. The mechanical behavior of products and constructions can be analyzed and optimized without the necessity of prototyping. Direct results are profits in the field of time and cost in the design phase. It also adds to the reliability of the product. Finite Element Analysis is numerical method of solving engineering problems. This technique may be applied in a) Structural, b) Heat transfer, and c) Fluid flow analysis.

The basic principle of the finite element method is the creation of a computer model which is built up from a finite number of elements. The elements all have a mathematical defined relationship between force and displacement. This relationship of each element can be used to estimate the stiffness distribution of the whole structure. By applying a matrix solution technique, the response of the entire structure to the prescribed loads and boundary conditions can be determined. In the present case, the collapse pressure is to be determined. The input elements are Young's modulus of elasticity, Poisson's ratio, diameter, length and thickness of the tubes. The closed tubes/pipes are modeled according to the considered dimensions. Then a uniform hydrostatic pressure is applied on the outer surface of the pipe. The applied hydrostatic pressure is varied and the structural changes are noted. At a particular pressure the pipe starts collapsing and the pressures are recorded.

In this Section we discuss the 3D finite element models that we have implemented to simulate the external pressure collapse test. Similar results are obtained from ANSYS:

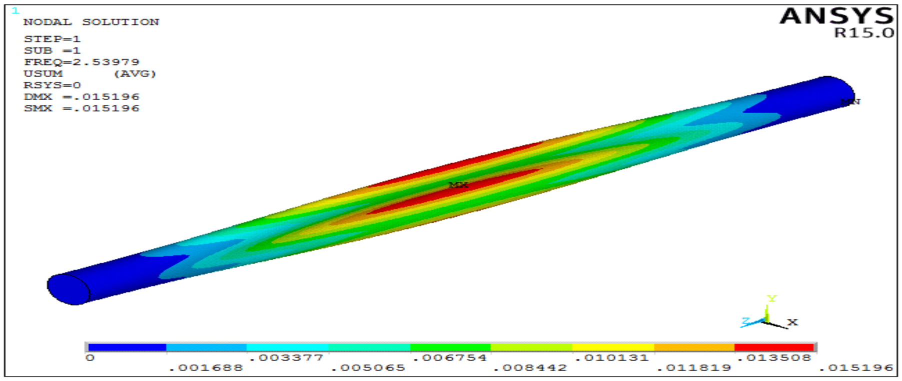

Figure 3a: Copper pipe of thickness of 0.6 mm, the collapse pressure is observed to be 25.397 kg/cm^2

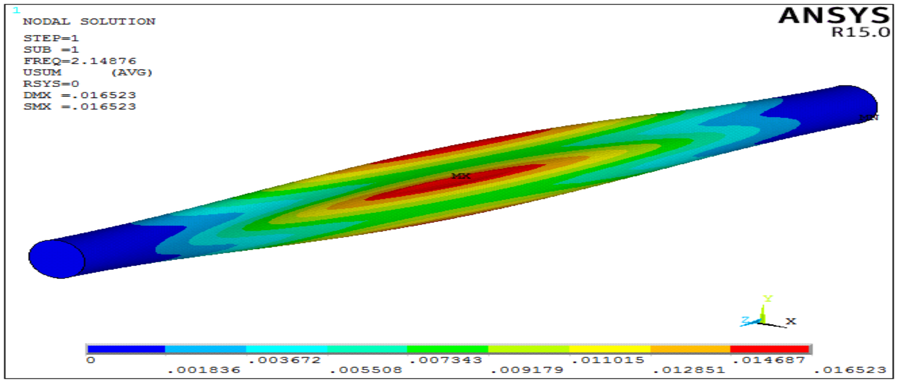

Figure 3b: Brass pipe of thickness 0.6 mm, collapse pressure is observed to be 21.4876 kg/cm2

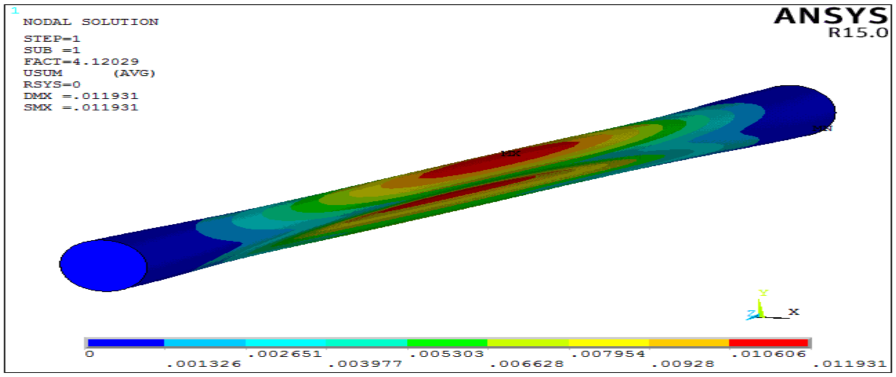

Figure 3 c: Stainless Steel pipe of thickness 0.6 mm Collapses pressure is 41.203 kg/cm2

EXPERIMENTAL SETUP

Indigenously designed pressure vessel by the Department of Atomic Energy is used for the present study (Figure 4). In the test apparatus the full specimen length is exposed to the test pressure. It does not impose radial or axial restraint or axial load on the specimen, either mechanically or hydraulically, and does not apply pressure to the inside surface of the specimen. To ensure that the specimen is not axially restrained during testing, the initial clearance between the end of the specimen and the end of the test chamber must be at least 0.06 inch for a test specimen 28 inches or less in length and proportionately greater for a longer test specimen. The test chamber is equipped with a maximum reading pressure measuring device that is open to the test chamber during the test. The pressure measuring device is equipped with a dampening system to bleed pressure slowly from the device at the time of specimen collapse. The pressure measuring device is calibrated at intervals of six months by means of a dead weight tester or more frequently if there is reason to doubt its accuracy. The percentage of error within the working range of the pressure measuring device does not exceed 1.0 percent.

The hydrostatic test facility consists of a custom made pressure vessel with an internal arrangement (Figure 4) for keeping the probes, a high pressure triplex reciprocating pump driven by a 3 phase 3 hp electric motor, which can deliver at 70 kg/cm^2 pressure head, and an electrical panel for reading indications of leakage. A saddle stand is made for the vessel to rest on, with a water tank at the bottom of the stand. The vessel has nozzle openings for the electric wires to pass through and an air vent. A pressure gauge 0-120 kg/cm^2 is also attached on top of the vessel. Water inlet and drain connections are made using suitable material. A weld neck flange of ASME standard SA 105 ,class 300 on the nozzle side of the pipe and a standard ellipsoidal end cap of SA214 as per ASME 16.9 on the other side are welded to the pipe. A blind flange head of SA 105, class 300 is bolted to the weld neck flange with 7/8" High tensile 10.5 grade (Boltsman) bolts for loading and unloading of the vessel. A cotton reinforced rubber gasket is used between the flanges. A small brass cylinder with perforated Teflon shield is placed inside the probe attached to the probe head so that it gets contacted with the leaked water immediately after entering the probe. The brass cylinder is connected to an electrical circuit through ammeters and dc power supply. Water leaked into the probe gets in contact with the brass cylinder and acts as a switch. Electric current then passes through the circuit and ammeters which shows deflection indicating the leakage. There is an audio buzzer and LED indications also. Buzzer and light indicate leakage in any of probes and ammeters identifies the failed probe. Color code is used for identification.

Probes to be tested are placed inside the vessel three at a time in any combination of sizes and closed with the blind flange head. Water is then pumped to the vessel, opening the vent screw. Once water is filled pressure builds up in the vessel which is shown by the pressure gauge. Pressure can be regulated through the bypass valve of the pump.Once required pressure is attained the delivery valve of the pump may be closed and pump may bypass the discharge to the tank. The pressure in the system is maintained even the pump is stopped, as long as there is no leakage in any form.

Now the probes inside the vessel are subjected to the external pressure of water as they do in actual borehole with water column of ~ 600 meters. If any leakage is there in the probes the water leaked into the probes first get in touch with the brass cylinder and the electric circuit is closed as body of the probe is earthed. Deflection in the Individual ammeters attached to each probe identifies which probe is faulty. There is an audio and visual indication for attention drawl of the operator. After test is completed the vessel may be drained by opening the outlet valve, and second lot of probes may be loaded and cycle continues.

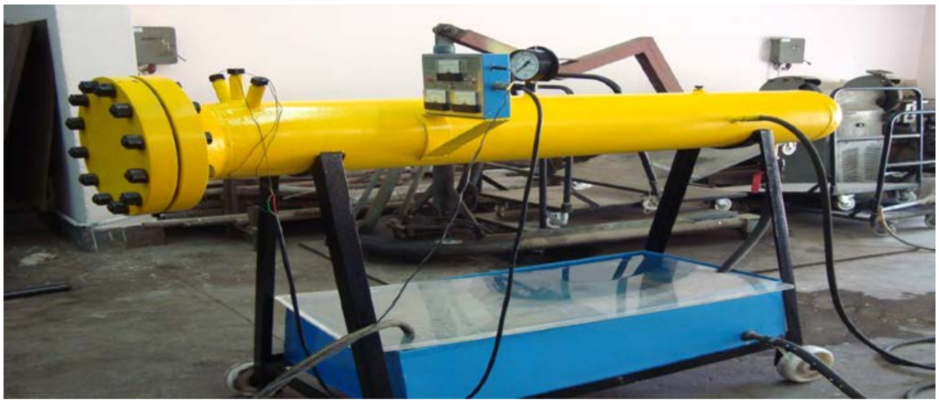

Figure 4: Pressure vessel that can withstand an internal pressure of 70 kg/sq.cm.(vessel can with stand a pressure of 97 kg/cm^2, but it is limited by the flanges that can withstand only 70 kg/cm^2.)

Detailed Specifications of the Pressure vessel Setup:

MAWP and DP : 55 kg/cm2
(Maximum Allowable working Pressure and Design Pressure)
Operating Pressure: 50 kg/cm2
Relief valve Set Pressure: 55 kg/cm2
Vessel Standards
Material Specification: SA 106 B ANSI/ASME B31.1 8"NPS SCH.40 SEAMLESS
Pressure Heads:
WLRF & BLRF FLANGES: SA 105, ANSI/ASME B31.1 CLASS 300
END CAP: Ellipsoidal, SA 234 WPB ANSI/ASME B 16.9
LENGTH: 1500 mm
VOLUME: 50 lt.
CONTENT USED: Clear water
SAFETY VALVES: 2 no.s Spring loaded, Reclosing type
DURATION OF HYDRO-TEST: Once in 2 years
RADIOGRAPHY: Full radiography done to WLRF & ENDCAP weld joints(with Ir 192 Gamma Source)
PUMP DETAILS: High pressure triplex 13 LPM, P.Max-90 kg/cm2 MWP- 70 kg/cm2
PROBE TESTING CYCLE: 3 at a time

RESULTS AND DISCUSSION

Initially one stainless steel tube of 0.6mm diameter, one copper tube of 0.6mm diameter and one imported thick walled tube of the experiment were loaded in the pressure vessel. The operating flanges were closed tightly and slowly the water had been pumped. Regular monitoring of the pressure gauge continued during the experiment. When the pressure vessel reached 20 kg/sq.cm. there had been a sound followed by buzzer sound alarm, glow on LED indicating a collapse of one of the tube. Further, continued the experiment by increasing the hydrostatic pressure. At around 48kg/sq.cm. the experiment had been stopped and maintained the same pressure for ten minutes. Slowly, pressure was released and vessel was opened and found that copper tube had collapsed. It is concluded that copper tube of 0.6mm diameter collapsed at 20kg/sq.cm. (Figure 5.a) The other two tubes viz. stainless steel (Fig 5.d) and imported thick walled tube did not show any signs of deformation. Similarly, in the second experiment Brass metal 0.6mm thick was loaded along with the tube of Brass with 1.6mm thickness and an imported thick walled tube. The Brass tube with 0.6mm thickness collapsed(Fig 5.b) at 25 kg/cm^2 whereas there was no change in the other two tubes i.e. 1.6 mm thick Brass tube (Fig 5.c) and the imported thick walled tube even beyond 50 kg/cm^2.

Table 2: Experimental values for working pressure obtained, theoretically calculated and derived by FEA values for copper, brass and stain less steel material with varying thickness.

Material	Thickness (mm)	Collapse Pressure (kg/cm^2)		
		Experiment	Theoretical	FEA
Copper	0.6	20	18.13	25.39
	1.6	48	47.59	
Brass	0.6	25	37.33	21.46
	1.6	NA	59	59
S.Steel 304	0.6	55	55.71	41.20

Among the selected materials Brass and Stainless Steel 304 pipe with 1.6 mm as thickness withstand the pressure of 50 kg/cm^2. One of the important physical aspects measured in the exploration of minerals magnetic susceptibility. The probe includes magnetic compass while logging and the magnetic material might produce a deflection in it. Therefore, Stainless Steel 304 is not considered for using as a probe material. The Brass material of 1.6mm thickness is selected as it is comparatively cheaper and non-magnetic material and can with stand to the pressures above 50kg/sq.cm.

Figure 5a: Collapse of copper tube of 0.6 mm thickness buckled at 20 kg/sq.cm.
Brass

Figure 5b: Collapse of brass tube of 0.6 mm thickness buckled at 25 kg/sq.cm.

Figure 5c: Non Collapse of brass tube of 1.6 mm thickness that buckles at ~ 98 kg/sq.cm.

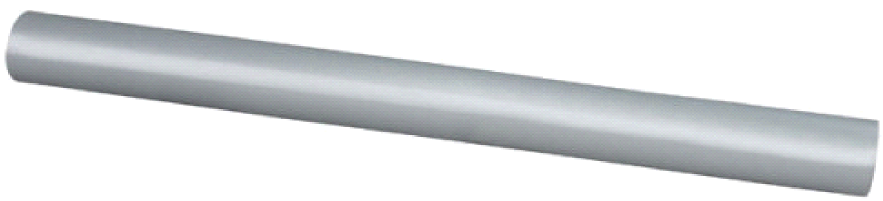

Figure 5d: Non Collapse of stainless steel tube of 0.6 mm thickness that buckles at 55 kg/sq.cm.

CONCLUSIONS

The theoretical and experimental studies on copper, brass and stainless steel tubes to be used as borehole logging probe that can with stand to the desired external pressure have give corroborative results as follows.

1. Theoretical values for Collapse pressure for Copper tube with thickness 0.6mm and 1.6mm are 18.129 kg/cm^2 and 47.588 kg/cm^2, Brass metal with thickness 0.6mm and 1.6mm are 37.33 kg/cm^2 and 98.43 kg/cm^2, Stainless Steel with thickness 0.6mm and 1.6mm are 55.709 kg/cm^2 and 146.29 kg/cm^2 respectively.

2. FEA results on the simulated models for Copper with thickness 0.6mm is 25.3979 kg/cm2, Brass metal with thicknesses 0.6mm and 1.6mm are 21.4876 kg/cm^2 and 246.85 kg/cm^2, Stainless Steel with thickness 0.6mm is 41.203 kg/cm^2 respectively.

3. Experimental values for Copper of 0.6mm thick is 20 kg/cm^2, Brass metal of 0.6mm and 1.6mm thick are 25 kg/cm^2 and beyond 50kg/cm^2, Stainless Steel 0.6mm thick did not collapse even at 50 kg/cm^2.

4. Logging probe made of Brass is found to be ideal as it can withstand external pressure beyond 98 kg/cm^2 , it is non-magnetic in nature, possess good engineering properties and also a cost effective material and can replace the imported probes.

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Unit clarification by the editor:
Kilogram (kg) is a mass unit in the International System of Units "SI" adopted by United Nations. In the old metric system it was often used as if it were a force unit, thus kg/cm^3 (kg/cu.cm) was often used, as in this paper, as a pressure unit. Since the atmospheric pressure on earth is approximately 1.0 in that unit, it is useful to remember that it is 100 kPa in the SI stress/pressure unit of kPa. It is useful to remember this simple conversion factor when reading this paper.

Editor's note. This paper may be referred to, in other articles, as:
Yang Wu: "Sustained External Pressure of Drilling Engineering Detection: under the Condition of 50 kg/cm^2" *Electronic Journal of Geotechnical Engineering*, 2017 (22.08), pp 3087-3100. Available at ejge.com.