DESIGN OF OIL WELL CASINGS FOR BOURI OIL FIELD

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Abstract: The aim of this research paper is to study the design of oil wells in the Bouri field. This study depends on ensuring an appropriate selection of the casing used in all stages of the well. These designs depend on certain characteristics, including the diameter of the well, pressure and temperature inside.

Each series of casing is carefully designed in terms of the expected loads it will be exposed to during operation, including blast load, collapse load and tensile load. These loads depend on information such as: types of formations pore formation pressure and formation breaking pressure. In light of this information, a series of casings for three oil wells in the Bouri field were designed.

Casing design is an important task in oil and gas well design. Casing design involves evaluation of the factors that con tribute to the failure of the casing and proper se lection of the most suitable casing grades and weights that are both safe and economical for a specific job operation. A good knowledge of stress calculation is very essential in casing design. During casing design, various modes of casing failure must be identified and carefully handled such that the selected casing within a well segment is able to withstand all the failure modes. A safety margin, (also known as design factor).

Keywords: Types of casing; Casing grades; Design factors; Casing design; Tensile load; Burst load; Collapse load.

1. Introduction:

Bouri field is the largest oil field in Libya at the Mediterranean region, which was discovered at the end of the year 1976. Bouri field is running by National Oil Corporation (NOC) in partnership with the Italian company ENI. Bouri field is located in Libyan territorial waters and is about 130 km north-west of Tripoli.

It is generally not possible to drill a well through all of the formations from the surface (or the seabed) to the target depth in one whole section. The well is therefore drilled in sections, which each section of the well being sealed off by lining the inside of the borehole with steel pipe, known as casing and filling the annular space between the casing string and the borehole with cement, before drilling the subsequent hole section. This casing string is made up of joints of pipe, of approximately 40 ft. in length, with threaded connections. Depending on conditions encountered, three or four casing strings maybe required to reach the target depth. Great care must therefore be taken when designing a casing program, which will meet the requirements of the well installing well casing, is an important part of the drilling and completion process. Well casing consists of a series of metal tubes installed in the freshly drilled hole, Casing strengthens the sides of the well hole, and to ensures that no oil or natural gas seeps out of the well hole as it is brought to the surface, and keeps other fluids or gases from seeping into the formation through the well, A good deal of planning is necessary to ensure that the proper casing for each well is installed. The type of casing used depends on the subsurface characteristics of the well, including the diameter of the well and the pressures and temperatures experienced throughout the well. [1]

The casing is widely used as a protective conduit during all phases of drilling operations and production in the oil and gas industry. Casing design impacts greatly on how safe a well operates, and thus is one of the most important aspects of a well plan. As the casing is often designed to withstand many severe operating and production conditions, procedures for casing design must be sufficiently flexible to meet all potential requirements. Therefore, casing design requires a sound knowledge of the operating conditions imposed on the casing surface as well as a working understanding of various concepts related to the casing properties. Casing design engineers must be aware of these concepts before beginning the actual casing design. These concepts include items such as the casing manufacturing process, physical properties, and testing procedures. As the casing usually accounts for between 10% to 30% of the total cost of a well and thus represents a major capital investment, casing design will also have a significant impact on well performance, price and productivity. With the increasing need for safety awareness and cost reduction in casing design due to the competitiveness of today's market, the size and the number of investigations on how to improve the casing design criterion have been growing rapidly in recent years. The objective of a casing design is to estimate the casing strength and the possible loads during the service life, in order to make sure that they are separated by an adequate safety margin. Therefore, a casing design engineer needs to find out the casing strength and load uncertainties. Casing strength uncertainty arises due to the inherent variability of material properties of casings, workmanship, and the handling of casings during installation. While the load uncertainty is associated with, a casing designer's inability to estimate the possible loads precisely. A casing experiences a variety of loads from various operations during the service life. In particular, casings are subjected to pressure loads induced by contained moving fluids both inside and outside the casing, forces due to self-weight and end constraint, and accidental loads caused by the loss of drilling fluids. In addition, variation of temperature along the length of a casing during installation and operating conditions may induce additional loads. These loads can be reduced into a few fundamental forces such as the external and internal pressures. Analysis shows that the important casing failures include casing collapse under excessive external pressure, casing burst under excessive internal pressure and casing tensile failure under an axial tensile load. [2]

2. Function of the Casing String:

- To prevent the hole from caving in.
- To prevent contamination of freshwater sands.
- To confine production to the well pore.
- To control the pressure during drilling.
- To prevent water migration to producing formation.
- To provide acceptable environment for subsurface equipment in producing wells.
- Providing safe passage for running wire equipment.

- To provide structural support for the wellhead of Blowout preventer (BOP).

3. Types of Casing:

3.1. Conductor Casing:

The conductor is the first casing string to be run, and consequently has the largest diameter. It is generally set at approximately (100-300) ft. below the ground level or seabed. Its function is to seal off unconsolidated formations at shallow depths which. With continuous seven mud circulation, would be washed away. The surface formation may also have low fracture strengths which could easily be exceeded by the hydrostatic pressure exerted by the drilling fluid when drilling a deeper section of the hole. In areas where the surface formations are stronger and less likely to be eroded the conductor pipe may not be necessary. Where conditions are favourable the conductor may be driven into the formation and in this case the conductor is referred to as a stove piped. [3]

3.2. Surface Casing:

The surface casing is run after the conductor and is generally set at approximately 1000-1500 ft. below the ground level or the seabed. The main functions of surface casing are to seal off any fresh water sands, and support the wellhead and BOP equipment. The setting depth of this casing string is important in an area where abnormally high pressures are expected. If the casing is set too high, the formations below the casing may not have sufficient strength to allow the well to be shut in and killed if a gas influx occurs when drilling the next whole section. This can result in the formations around the casing catering and the influx flowing to surface around the outside of the casing[3].

3.3. Intermediate Casing:

Intermediate (or protection) casing strings are used to isolate troublesome formations between the surface casing setting depth and the production casing setting depth. The types of problems encountered in this interval include: unstable shale's, lost circulation zones, abnormally pressured zones and squeezing salts. The number of intermediate casing strings will depend on the number of such problems encountered.

3.4. Production Casing:

The production casing is either run through the pay zone, or set just above the pay zone (for Open hole completion or prior to running a liner). The main purpose of this casing is to isolate the production interval from other formations (e.g. water bearing sands) and/or act as a conduit for the production tubing. Since it forms the conduit for the well completion, it should be thoroughly pressure tested before running the completion. [3]

3.5. Liner:

A liner is a short (usually less than 500ft) casing string which is suspended from the inside of the pervious casing string by a device known as a liner hanger. The liner hanger is attached to the top joint of the casing in the string. The liner hanger consists of a collar which has hydraulically or mechanically set slips (teeth) which, when activated, grip the inside of the previous string of casing. These slips support the weight of the liner and therefore the liner does not have to extend back up to the wellhead. The overlap with the pervious casing (liner lap) is usually 200ft - 400 ft. liners may be used as an intermediate string or as production string. [4]

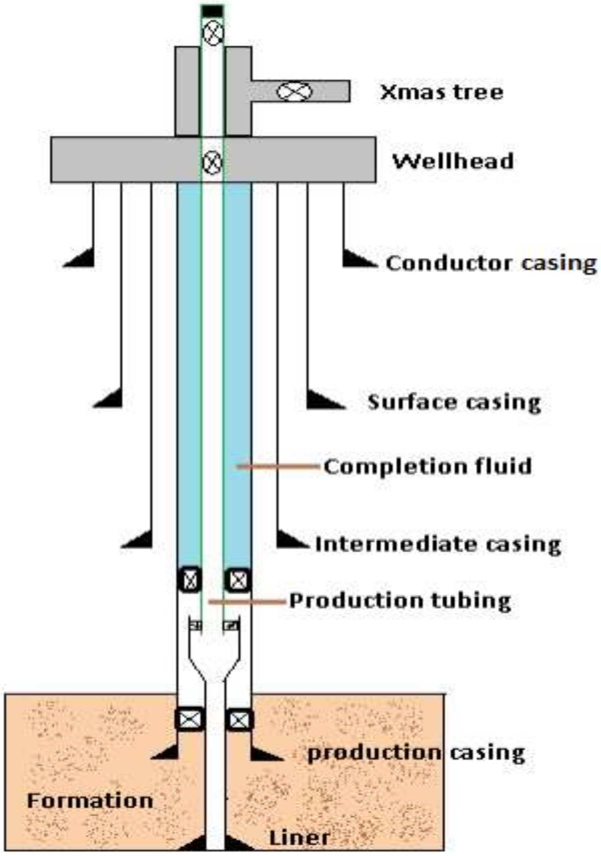

Figure (1): Illustration of a completed well.

4. Properties of Casing:

When the casing configuration (casing size and setting depth) has been selected the loads to which each string will be exposed will be computed casing of the required size, and with adequate load bearing capacity will then be selected from manufacturer's catalogues or cementing company handbooks. Casing joints are manufactured in a wide variety of size weights and material grades and a number of different types of connection are available. The detailed specification of the sizes, weights and grades of casing which are most commonly used has been standardized by the American petroleum institute API the majority of sizes, weights and grades of easing which are available can be found in manufacturer's catalogues and cementing company handbooks (e.g. Halliburton cementing tables). Casing is generally classified. In manufacturer's catalogues and handbooks, in terms of its size (OD), weights grade and connection type. [5]

5. Casing Grade:

The chemical composition of casing varies widely, and variety of compositions and treatment processes are used during the manufacturing process this means that the physical property of the steel varies widely. The materials, which result from the manufacturing process, have been classified by the API into a series of "grade" as show at table (1). Each grade is designated by a letter, and a number. The letter refers to the chemical composition of the material and the number refers to the minimum yield strength of the material. Hence, the grade of the casing provides an indication of the strength of the casing. The higher grade, higher the strength of the casing. [3]

Table (1): tensile and hardness requirements**.**

Grade	**Yield strength (psi)**		**Tensile strength (psi)**
	Min	Max	
H-44	40000	-	80000
J-55	55000	80000	100000
K-55	55000	80000	100000
C-75	75000	90000	150000
L-80	80000	95000	210000
N-80	80000	110000	280000
S-95	95000	-	310000
P-110	110000	140000	340000
V-150	150000	180000	375000

6. Setting Depths procedures:

- Start at total depth (TD) of the well.
- Calculate the formation fracture pressure at all points in the well, at different depths.
- Calculate the formation pore pressure at all point of the well, at different depths corresponding to the depths of the formation fracture pressure.
- Plot the pore pressure and fracture pressure gradient on the same axes (X-axes) versus the depth (Y-axes).

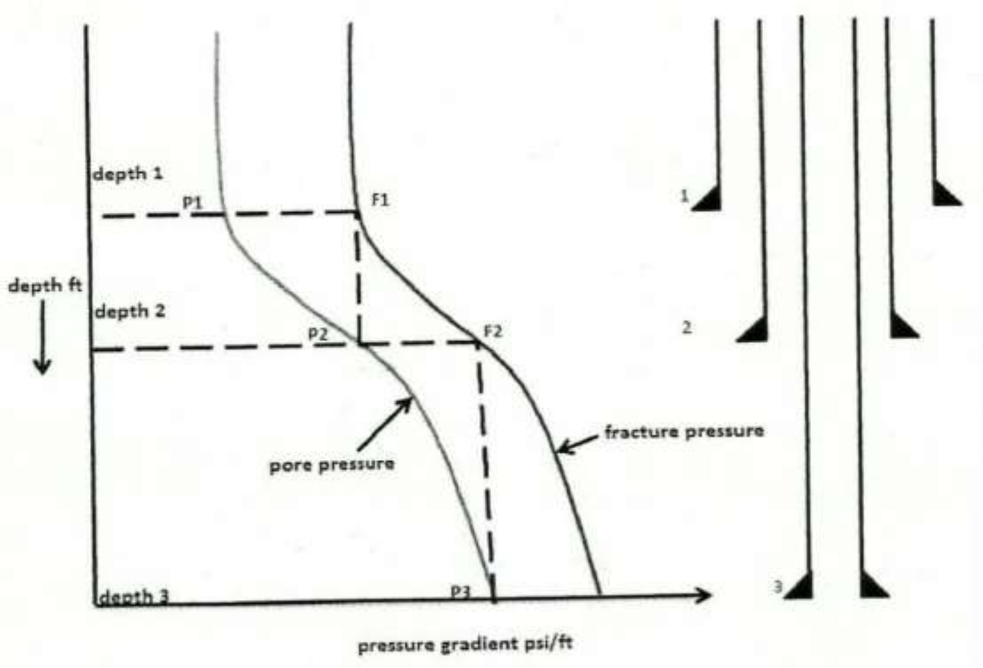

Figure (2): Graphical method to estimate casing points.

Note: casing is set at depth 1 where pore pressure is P1 and the fracture pressure is P2, then drilling continuous to depth 2, where the pore pressure P2 has risen to almost equal the fracture pressure (F1) at the casing seat, and the another casing string is set at this depth 2 with fracture pressure F2. Drilling can thus continue to depth 3, where pore pressure P3 is almost equal to the fracture pressure F2 at the previous casing seat. [6]

7. Casing Design Concept:

Having defined the size and setting depth for the casing strings, and defined the operational scenarios to be considered, the loads to which the casing will be exposed can be computed. The particular weight and grade of casing required to withstand these loads can then be determined. The uniaxial loads to which the casing is exposed:

7.1. Burst load (BL):

The casing will experience a net burst loading if the internal load exceeds the external radial. The burst load at any point along the casing can be calculated from:

$$BL = Pi - Pe$$

Where: BL = Burst load.

Pi = Internal Load.

Pe = external Load.

In designing the casing to resist burst loading the pressure rating of the wellhead and BOP stack should be considered since the casing is part of the well control system. The internal, Pi and external, Pe loads that are used in the determination the burst and collapse loads on the casing derived from an analysis of operational scenarios.

7.1.1. External loads, Pe:

The following issues are considered when deciding upon the external load to which the casing will be subjected:

- The pore pressure in the formation (pore pressure):
  If the that it will be possible to displace all of the mud from annulus between the casing and borehole during the cementing operation, and that a satisfactory cement sheath can be achieved, the formation pore pressure is generally used to determine the load acting on the casing below the top of the annulus, after the cement has hardened.
- The weight of mud in which the casing was run:
  If a poor bond between the casing and cement or cement and borehole is anticipated then the pressure due to a column of mud in the annulus is generally used to determine the load acting on the casing below the top of cement in the annulus, after the cement has hardened, if the mud has been in place for more than 1 year the weighting material will probably have settled out and therefore the pressure experienced by the casing will be due to a column of mud mix water (water or base-oil).
- The pressure from a column of cement mix water:
  The pressure due to the cement mix water is often used to determine the external load on the casing during the producing life of the well. This pressure is equal to the density of fresh or seawater in the case of water base mud and base oil in the case of oil base mud.
- The pressure due to column of cement slurry:
  The casing will experience the pressure exerted by a column of cement slurry until the cement sets. It is assumed that hardened cement dose not exert a hydrostatic pressure on the casing.
- Blockage in the annulus:
  If a blockage of the annulus occurs during a stinger, cement operation (generally performed on a conductor casing). The excess pumping pressure on the cement will be transmitted to the annulus but not to the inside of the Casing. In the case of conventional cementing operation, a blockage in the annulus will result in an equal and opposite pressures inside and outside the casing. [7]

7.1.2. Internal loads, Pi:

It is commonplace to consider the internal loads due to the following:

- Pressure due to influx:

  The worst-case scenario, which can arise, from the point of View of burst loading, is if an influx of hydrocarbon or gas occurs, that the well is completely to gas and simultaneously closed in at the BOP stack.

- Production tubing leak:

  In the case of production, casing specifically a leak in the production tubing will result in the tubing pressure being exposed on the casing. The closed in the tubing pressure is used as the basis of determining the pressure on the casing. This is calculated on the basis of a column of gas against the formation pressure.

  The pressure below surface is based on the combined effect of the tubing head pressure and hydrostatic pressure due to a Column of packer fluid. [7]

Note:

Net loading (burst or collapse load): When the internal and external loads have been quantified, the maximum net loading on the casing is determined by quantifying the difference between the internal and external load at all points along the casing .if the net loading is outward then the casing is subjected to a burst load. If the net loading is inward then the casing is subjected to a collapse load. The internal and external loads used in the determination of the net load must be operationally compatible i.e. it must be possible for them to co-exist simultaneously.

7.2. Collapse Load (CL):

The casing will experience a net collapse loading if the external radial load exceeds the internal radial load (Figure 3 - 4) the greatest collapse load on the casing will occur if the casing is evacuated (empty) for any reason the collapse load, pc at any point along the casing can be calculated from:

$$CL = Pe - Pi$$

Where: CL = Collapse load.

Pe = External Load.

Pi = Internal Load.

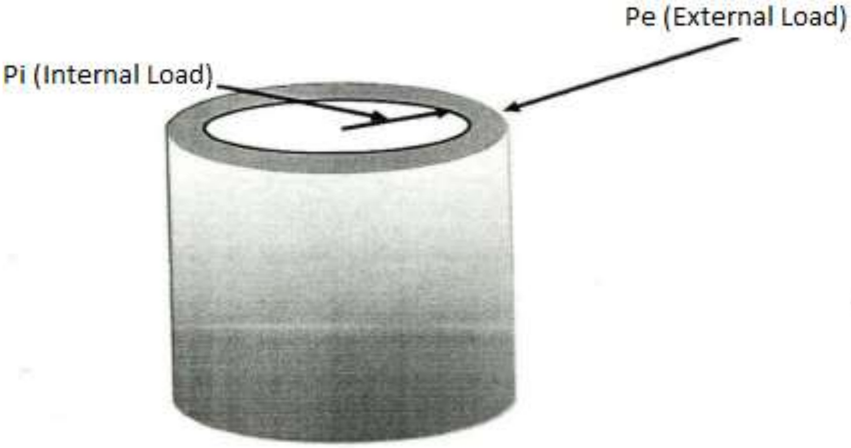

Figure (3): Radial Loads Casing.

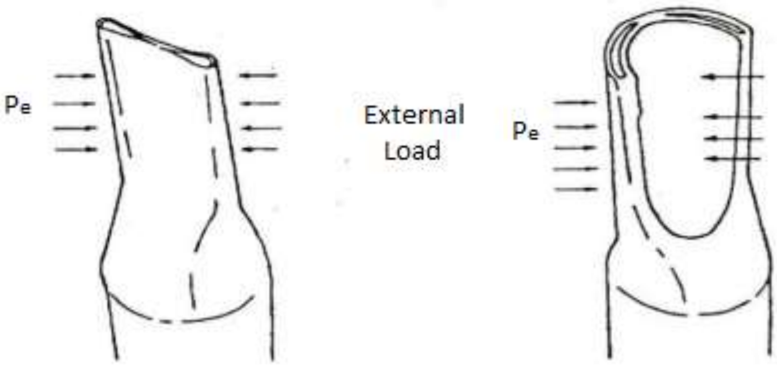

Figure (4): collapse Failure from External Load.

7. 3. Tension load (TL):

The axial load on the casing can be either tensile or compressive, depending on the operating conditions. The axial load on the casing will vary along the length of the casing. The casing is subjected to a Wide range of axial loads during Installation and subsequent drilling and production. The axial loads, which will arise during any particular, must be computed and added together to determine the total load on the casing such as figures (5 & 6).

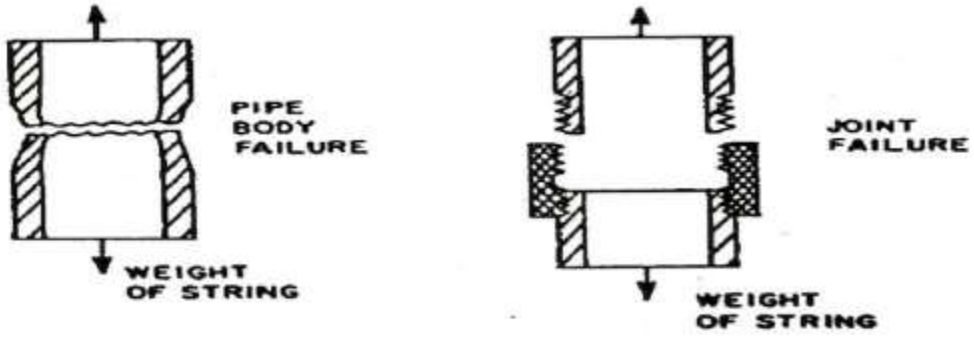

Figure (5): Casing Design Tension.

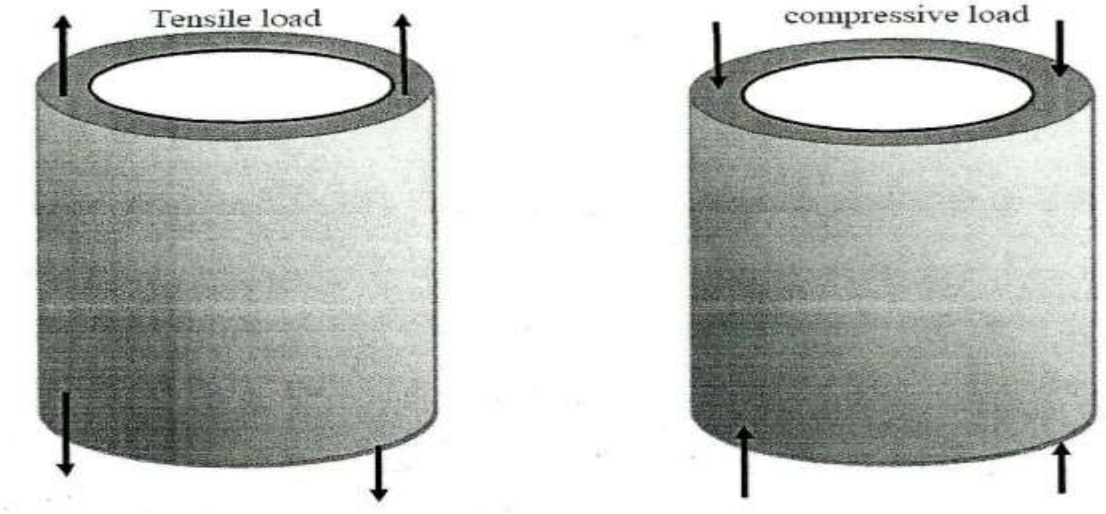

Figure (6): Axial loads on casing. [8]

8. Graphical Method:

Many oil company use graphical technique for solving casing design problems. The method is extended to include the effect of shock loading maximum load condition and gas leaks during production. In this method graph starts at zero to coincide with zero depth and zero pressure. Collapse, burst and sometimes fracture gradient lines are drawn on this graph. Strength value of available casing grades in collapse and burst are then plotted as vertical lines on this graph. Selection is made such that the casing chosen has strength properties, which are higher than the maximum existing collapse and burst pressure as show figure (7).

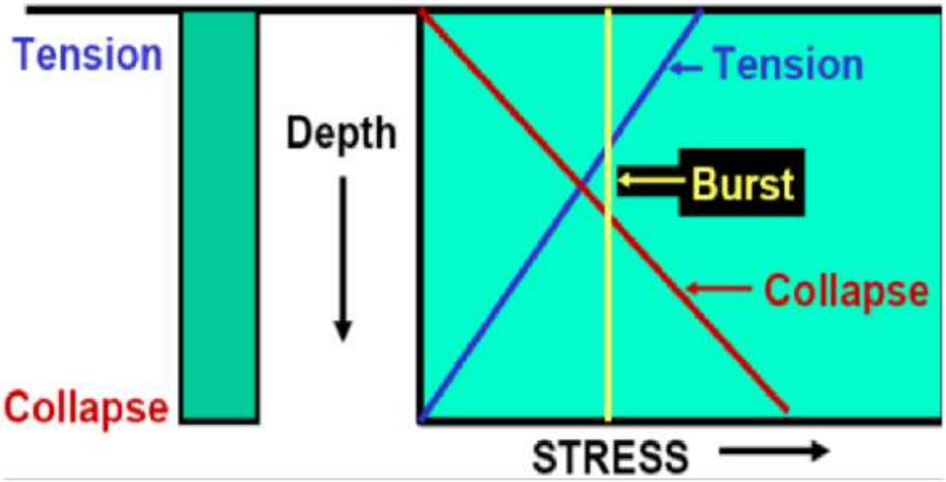

Figure (7): graphical method for casing design. [9]

9. Design factors:

The uncertainty associated with the condition used in the calculation of the external, internal, compressive and tensile loads described above is accommodated by increasing the burst collapse and axial loads by a design factor. These factors are applied to increase the actual loading figures to obtain the design loading. Design factors are determined largely through experience, and are influenced by the consequences of a casing failure. The degree of uncertainty must also be considered (e.g., an exploration well may require higher design factors than a development well), the following ranges of factors are commonly used:

1- Burst design factor (1.0 - 1.33).

2- Collapse design factors (1.0 - 1.125).

3- Tension design factors (1.0 - 2.0).

10. Casing design rules base:

The loading scenarios to be used in the design of the casing string will be dictated by the operating company, based on international and regional experience. These loading scenarios are generally classified based on the casing string classification. When the load case has been selected, the internal and external loads are calculated. These loads are then plotted in a common axis and the net loading (burst and collapse) is computed. An appropriate casing string can then be selected from the casing tables.

11. Summary of design process:

The design process can be summarized as follows:

- Select the casing setting depths and sizes based on the geological and pore pressure prognosis provided by the geologist and reservoir engineer and the production tubing requirements based on the anticipated of the formation to be penetrated.

- Define the Operational scenarios to be considered during the design of each of the casing string. This should include installation, drilling and production (as appropriate) operations.
- Calculate the burst loading on the particular casing under consideration.
- Calculate the collapse loading on the particular casing under consideration.
- Increase the calculated burst and collapse loads by the design factor, which is appropriate to the casing and load condition considered.
- Select the weight and grade of casing (from manufactures or service company tables) which meets the load conditions calculated.
- For the casing chosen, calculate the axial loading on the casing. Apply the design factor for the casing and load conditions considered and check that the pipe body yield strength of the selected casing exceeds the axial design loading. Choose a coupling whose joint strength is greater than the design loading. Select the same type of coupling throughout the entire string.

12. Sample of Calculations:

In this section, we will present the design of the surface, intermediate and Production casing series for three oil wells operating in the Bouri and Wells field:

1. Well B5-01 (Bouri Field)
2. Well B5-02 (Bouri Field)
3. Well B5-0 3 (Bouri Field)

One casing calculations from each well will be taken as sample calculations. From well B5-01, the Surface Casing was taken, well B5-02 the Intermediate Casing, and well B5-03 the Production Casing, as shown below:

12.1. Surface Casing for Well B5-01:

Diameter of casing	13 3/8 in.
Total Casing depth. (TD)	1650 ft.
Casing weight. (Cwt)	54.5 lb/ft.
Mud weight. (Mwt)	8.6 - 8.8 ppg.
Gas gradient. (PG)	0.1 psi/ft.

- **Burst Load (BL):**

  BL = Pi – Pe

Pi = 0.052 * Mwt * TD
= 0.052 * 8.6 * 1650 = 737.88 psi
Pe = PG * TD
= 0.1 * 1650 = 165 psi
BL = 737.88 – 165 = 572.88 psi
BL = 572.88 * 1.1 (Design factor)
= 630.17 psi

- **Collapse Load (CL):**

(100 % evacuated casing).
CL = 0.052 * TD * Mwt
= 0.052 * 1650 * 8.6 = 737.88 psi
CL = 737.88 * 1.1 (Design factor)
= 811.67 psi

- **Tension Load (TL):**

TL = Cwt * TD
= 54.5 * 1650 = 89925 lbs
TL = 89925 * 1.1 (Design factor)
= 98917.5 lbs

Casing depth (ft)	Weight of casing (Ib/ft)	Burst load (psi)	Collapse load (psi)	Tension load (Klbs)	Grade	Joint Threads
0 - 1650	54.5	630.17	811.67	98.9	J- 55	BTC

12.2. Intermediate Casing for Well B5-02:

Diameter of casing	9 5/8 in.
Minimum adoptable drift	8.59 in
Total Casing depth. (TD)	4285 ft.
Casing weight. (Cwt)	43.5 lb/ft.
Mud weight. (Mwt)	8.6 – 9.74 ppg.
Gas gradient. (PG)	0.1 psi/ft.
Packer fluid weight. (Pwt)	9 ppg.

Note:

Packer fluid is a critical component to the life of a producing well. The main functions of a packer fluid are to provide hydrostatic pressure to lower differential pressure across sealing elements and to lower the differential pressure on the wellbore and casing to prevent collapse.

- **Burst Load (BL):**

BL = Pi – Pe
Pi = 0.052 * Mwt * TD + 0.052 * Pwt * TD
= 0.052 * 8.6 * 4285 + 0.052 * 9 *4285
= 1916.25 + 2005.38
= 3921.63 psi
Pe = PG * TD
= 0.1 * 4285 = 428.5 psi
BL = 3921.63 – 428.5 = 3493.13 psi
BL = 3493.13 * 1.1 (Design factor)
= 3842.44 psi

- **Collapse Load (CL):**

(100 % evacuated casing).
CL = 0.052 * TD * Mwt
= 0.052 * 4285 * 8.6 = 1916.25 psi
CL = 1916.25 * 1.1 (Design factor)
= 2107.88 psi

- **Tension Load (TL):**

TL = Cwt * TD
= 43.5 * 4285 = 186397.5 lbs
TL = 186397.5 * 1.1 (Design factor)
= 205037.25 lbs

Casing depth (ft)	Weight of casing (Ib/ft)	Burst load (psi)	Collapse load (psi)	Tension load (Klbs)	Grade	Joint Threads
0 - 4285	43.5	3842.44	2107.88	205	L-80	BTC

12.3. Production Casing for Well B5-03:

Diameter of casing	7 in.
Minimum adoptable drift.	6.1 in
Total casing depth. (TD)	9729 ft.
Casing weight. (Cwt)	26 lb/ft.
Mud weight. (Mwt)	8.6 – 9.74 ppg.
Gas gradient. (PG)	0.1 psi/ft.

- **Burst Load (BL):**

BL = Pi – Pe
Pi = 0.052 * Mwt * TD
= 0.052 * 8.6 * 9729
= 4350.81 psi
Pe = PG * TD
= 0.1 * 9729 = 972.9 psi
BL = 4350.81 – 972.9 = 3377.91 psi
BL = 3377.91 * 1.1 (Design factor)
= 3715.70 psi

- **Collapse Load (CL):**

(100 % evacuated casing).
CL = 0.052 * TD * Mwt
= 0.052 * 9729 * 8.6 = 4350.81 psi
CL = 4350.81 * 1.1 (Design factor)
= 4785.89 psi

- **Tension Load (TL):**

TL = Cwt * TD
= 26 * 9729 = 252954 lbs
TL = 252954 * 1.1 (Design factor)
= 278249.4 lbs

Casing depth (ft)	Weight of casing (Ib/ft)	Burst load (psi)	Collapse load (psi)	Tension load (Klbs)	Grade	Joint Threads
0 - 9729	26	3715.70	4785.89	278.3	N-80	BTC

13. Conclusions:

Casing is one of the most important proses in the petroleum industry to prevent the collapse of the well wall so its so important to choose the right material and the right sizes of casing in this paper the casing type and design is shown.

Some data are required for casing design these data could be assumed based on experience, existing wells at the location, drilling manuals and casing property tables.

The following highlights the basic data required for the casing design: hole size, casing depth, casing size, mud weight, casing grade, burst safety factor, collapse safety factor, tension safety factor, formation fluid gradient and gradient of invading fluid (gas gradient).

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