Lecture 5:
Oil Well Casing Design-Principles and Application

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Instructor: Mohammed Ariwan Jamal

Email: mohammed.ariwan@tiu.edu.iq
OIL WELL CASING DESIGN—PRINCIPLES AND APPLICATIONS

2. https://youtu.be/iMUsMOopwpU
What is casing? Why casing should be run?

Primary objective of casing is to keep cylindrical shape of wells by withstanding external and internal forces
What is casing? Why casing should be considered?

Casing

Casing is defined as tubular steel pipe. It is run into the wellbore and cemented in place. **Casing serves several important functions in drilling and completing a well:**

- Prevents collapse of the borehole during drilling
- Prevents cave-in of unconsolidated, weaker, near-surface sediments
- Protects the shallow, freshwater sands from contamination
- Isolates the wellbore fluids from the subsurface formations and formation fluids
- Provides a high-strength flow conduit for the drilling fluid to the surface
- Permits safe control of formation pressure
- Confines production to the wellbore
Typical oil/gas well configuration

Lecture Contents

- Why? Required Information?
- Casing design criteria
  - PPFG curve
  - Selection of casing setting depths
- Selection of casing sizes
- Class activity 1
- Selection of casing weight, grade
- Class activity 2
- Types and functions of casing strings
- Additional casing string components
Why? Required Information?

- Formation pore pressure ($P_o$)

$$H_p(\text{psi}) = 0.052 \times \rho(\text{ppg}) \times D(\text{ft})$$

Hydrostatic pressure
Fluid density

- Normal pore pressure
- Abnormal pore pressure

Surface
Why? Required Information?

- Formation pore pressure ($P_o$)
- Formation fracture pressure ($F_p$)
- Surface location and geologic target
- Minimum hole size

$$H_p(\text{psi}) = 0.052 \times \rho(\text{ppg}) \times D(\text{ft})$$

- Hydrostatic pressure
- Fluid density
- Depth
- Target
Why? Required Information?

- Formation pore pressure ($P_o$)
- Formation fracture pressure ($F_p$)
- Surface location and geologic target
- Minimum hole size

\[ H_p(\text{psi}) = 0.052 \times \rho(\text{ppg}) \times D(\text{ft}) \]

Surface

- $P_o = 13260$ psi
- $F_p = 14664$ psi

Hydrostatic pressure

Fluid density

Depth

Target

- $P_o = 1872$ psi
- $F_p = 2953$ psi
Why? Required Information?

- Formation pore pressure ($P_o$)
- Formation fracture pressure ($F_p$)
- Surface location and geologic target
- Minimum hole size

$$H_p(\text{psi}) = 0.052 \times \rho(\text{ppg}) \times D(\text{ft})$$

- Hydrostatic pressure
- Fluid density
- Depth

Surface

$P_o = 1872 \text{ psi}$
$F_p = 2953 \text{ psi}$

$\rho = 9 \text{ ppg}$

Target

$P_o = 13260 \text{ psi}$
$F_p = 14664 \text{ psi}$
Why? Required Information?

- Formation pore pressure \( (P_o) \)
- Formation fracture pressure \( (F_p) \)
- Surface location and geologic target
- Minimum hole size

\[
H_p(\text{psi}) = 0.052 \times \rho(\text{ppg}) \times D(\text{ft})
\]

Hydrostatic pressure \( \rightarrow \) Depth

Fluid density \( \rightarrow \) Target

\[
\begin{align*}
P_o &= 1872 \text{ psi} \\
F_p &= 2953 \text{ psi} \\
\rho &= 9 \text{ ppg} \\
H_p &= 15000 \text{ ft} \\
\end{align*}
\]

\[
\begin{align*}
P_o &= 13260 \text{ psi} \\
F_p &= 14664 \text{ psi} \\
H_p &\approx 10000 \text{ psi} \\
\end{align*}
\]
Why? Required Information?

Information

- Formation pore pressure \( (P_o) \)
- Formation fracture pressure \( (F_p) \)
- Surface location and geologic target
- Minimum hole size

\[
H_p(\text{psi}) = 0.052 \times \rho (\text{ppg}) \times D (\text{ft})
\]

Hydrostatic pressure

Depth

Fluid density

Target

Surface

\( P_o = 1872 \text{ psi} \)
\( F_p = 2953 \text{ psi} \)

\( H_p = 36 \text{ psi} \)

\( P_o = 13260 \text{ psi} \)
\( F_p = 14664 \text{ psi} \)

\( \rho = 17 \text{ ppg} \)
Why? Required Information?

Information

- Formation pore pressure \( (P_o) \)
- Formation fracture pressure \( (F_p) \)
- Surface location and geologic target
- Minimum hole size

You need 17 ppg mud to control a lower zone, but this will cause fracture in an upper zone.

What do you do?
Casing design criteria

- Depth vs. Pore pressure and fracture gradient (PPFG) plot
  Casing has become one of the most expensive parts of a drilling program, so selection of casing
  - Setting depth
  - Size
  - Grade
  - And connectors
  is a primary engineering and economic consideration.

Studies have shown that the average cost of tubulars is about 18% of the average cost of a completed well.
Casing design criteria

Class activity: PPFG plot
Casing design criteria

- **Casing sizes**

- **20 in**
- **14 in**
- **9.875 in**
- **7 in**

- Conductor
- Surface
- Intermediate
- Production
Casing design criteria: Class activity 1
Casing design criteria: Class activity 1

Class activity 1

A well is being planned for x-location. The intended well completion requires the use of 5-in production casing set at 15000 ft. Pore Pressure, fracture gradient and lithology data from logs of nearby wells are given in Fig. Allow a 0.5-lbm/gal trip margin and a 0.5-lbm/gal kick margin when making the casing-seat selections. The minimum length of surface casing required to protect the freshwater aquifers is 2000 ft. Approximately 180 ft of conductor casing generally is required to prevent washout on the outside of the conductor.

(a) Determine the number of casing strings needed to reach this depth objective safely and select the casing setting depth of each string.
(b) Select casing sizes OD for each casing string and bit size to drill each section.
Casing design criteria

- Selection of casing weight, grade, ...

Classification and Properties of Casing:

Casing is generally classified in manufacturer catalogues and handbooks in terms of

1) size (outside diameter, OD, vary from 4.5” to 36”).

2) range of length (the most common is 25–34 ft).

3) casing grade.

4) casing weight in wt/ft (within each grade of casing various wall thicknesses are available for a given OD).

5) type of coupling (connections).

Table: Grades of casing recognized by the API

<table>
<thead>
<tr>
<th>API Grade</th>
<th>Yield strength (Psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>H-40</td>
<td>40 000</td>
</tr>
<tr>
<td>J-55</td>
<td>55 000</td>
</tr>
<tr>
<td>K-55</td>
<td>55 000</td>
</tr>
<tr>
<td>C-75</td>
<td>75 000</td>
</tr>
<tr>
<td>L-80</td>
<td>80 000</td>
</tr>
<tr>
<td>N-80</td>
<td>80 000</td>
</tr>
<tr>
<td>C-90</td>
<td>90 000</td>
</tr>
<tr>
<td>C-95</td>
<td>95 000</td>
</tr>
<tr>
<td>P-110</td>
<td>110 000</td>
</tr>
</tbody>
</table>
Casing design criteria

- Selection of casing weight, grade, ...

Casing Connections:

- Different types of joints

- Pin
- Field end
- Coupling
- Mill end
- Box
- Box OD same as pipe OD
- Box OD expanded

- Threaded and coupled
- Integral joint
- Flush joint
Casing design criteria

- Selection of casing weight, grade, ...

In general each casing string is designed to withstand the most severe loading conditions anticipated during casing placement and the life of the well. The loading conditions which are always considered are:

- Collapse
- Burst
- Tension

To achieve minimum cost casing design, the most economical casing and coupling that will meet the design loading conditions must be used for all depths.
Casing design criteria

- Selection of casing weight, grade, ...

- Collapse

Collapse pressure originates from the column of mud used to drill the hole, and acts on the outside of the casing.

\[ HP \text{ (psi)} = 0.052 \times \rho_f \text{ (ppg)} \times D \text{ (ft)} \]

where:
- \( HP \) = hydrostatic pressure (psi)
- \( \rho_f \) = average fluid density (ppg)
- \( D \) = true vertical depth or height of the column (ft)

Since the hydrostatic pressure of a column of mud increases with depth, collapse pressure is highest at the bottom and zero at the top.
Casing design criteria

- Selection of casing weight, grade, ...

Burst

Burst pressures occur when formation fluids enter the casing while drilling next hole section.

In most cases the maximum formation pressure will be encountered when reaching the total depth of the next hole section.

BURST FAILURE FROM INTERNAL PRESSURE
Casing design criteria

- Selection of casing weight, grade, ..

Tension

Most axial tension arises from the weight of the casing itself. Other tension loadings can arise due to, for example bending of casing.

In casing design, the uppermost joint of the string is considered the weakest in tension, as it has to carry the total weight of the casing string.

Tensile forces are determined as follows:
- calculate weight of casing in air using true vertical depth.

Tension failure in pipe body or joint

Pipe body failure

Joint failure

Weight of string

Weight of string
Casing design criteria

- Selection of casing weight, grade, ..

- Design factor

The uncertainty associated with the conditions used in the calculation of the external, internal, compressive and tensile loads described is accommodated by increasing the burst collapse and axial loads by a design factor.

Ranges of typical API design factors

<table>
<thead>
<tr>
<th>Forces</th>
<th>Ranges of design factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collapse</td>
<td>1.0 – 1.125</td>
</tr>
<tr>
<td>Tension</td>
<td>1.0 – 2.0</td>
</tr>
<tr>
<td>Burst</td>
<td>1.0 – 1.33</td>
</tr>
</tbody>
</table>
Casing design criteria

- Selection of casing weight, grade, ..

- Design factor
  
  \[
  \text{Design factor} = \frac{\text{calculated load}}{\text{actual load}}
  \]

  Design factor for joint strength (Nj) = Joint strength of casing (Fj) in lb / weight (w)

  Design factor for casing pipes (Na) = Strength of casing (Fa) in lb / weight (w)
  \[
  \text{Fa} = \text{Minimum yield strength in psi (Ym)} \times \text{Root thread area in sq. in (Aj)}
  \]

  Design factor collapse (Nc) = Collapse resistance (Pc) / External pressure of mud

  Design factor burst (Ni) = Internal yield (Pi) / Reservoir pressure
Casing design criteria

Casing design process (Ford, 2005)

- Design Casing Configuration
  - Select casing setting depth
  - Define load cases for each string
  - Select casing sizes
  - Formation, strength, pore pressure, mud weights, geological considerations, directional well plan, drilling fluid selection etc.
  - Calculation of internal/external, and axial loads on each string
  - Calculation of net collapse, and burst loads
  - Select casing weight and grade
  - Calculation of net axial loads
  - Derate collapse rating of casing based on axial loads
  - API ratings of casing and design factors
  - Confirm casing selection
  - Well objectives, logging tools, testing equipment, production equipment contingency
Casing design criteria: Class activity 2
Casing design criteria: Class activity 2

Class activity: Problem solving

Design a 7 in casing for borehole with length of 8000 ft. The well is filled with drilling mud of 12 ppg density and the formation pressure gradient is 0.5 psi/ft. Use the worst possible case assumption for design the casing, assuming that only J-55 and N-80 casing pipes, all weights according to API are available. Apply the following design factor $N_i = 1$, $N_c = 1.125$, $N_j = 2$, and $N_a = 1.25$
Types and functions of casing strings

➤ Drilling cellar
Types and functions of casing strings

- **Auxiliary conductor pipe / conductor pipe**
  - **Purpose**
    - Security of the rig foundations
    - Isolate unconsolidated formations and water sands
    - Enable circulation of drilling fluid
    - If necessary, diverter (shallow gas)

- **Surface casing**
  - **Purpose**
    - Provide blowout protection
    - Isolate water sands and prevent lost circulation
    - Protection against any problem arising by further drilling
Types and functions of casing strings

- Intermediate casing
  - Purpose
    - Isolate unstable hole sections, lost-circulation zones, low-pressure zones, abnormal zones …..
    - Provide integrity to withstand the high mud weights necessary to reach true depth (TD) or next casing

- Production casing
  - Purpose
    - Connection between reservoir and well head
    - Separation of reservoirs from each other
    - Provide the environment to install subsurface completion equipments
Types and functions of casing strings

- **Liner**
  - **Purpose**
    - Not extend back to the wellhead
    - Reduce cost
    - Allow the use of larger tubing above the liner top
    - Can be either an intermediate or a production string
      - Intermediate liners: Same as Intermediate casing
      - Production liners: Same as production casing
  - Conductor
  - Surface
  - Intermediate
  - Liner
Additional casing string components

- Casing shoe
  - Smooth run
  - Non-return valve
  - Drillable

- Scraper
  - Cleaning of the drilling hole wall
  - Purpose: Uniform annulus for the cementing
Additional casing string components

- **Centralizer**
  - Creation of a uniform annulus for the cementing

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TU Freiberg: Prof. Dr. Matthias Reich lecture notes