

# Annular Pressure

Where did it come from?

How can you control it?

Annular pressure is not always associated with leaks, malfunctions or problems – The highest pressures are often generated with little more than heat transfer.

North Slope wellhead with surface safety valve.

The annular access ports are below the master valve. Each spool usually indicates access to a different annulus.

These annular areas are most often monitored by gauges.



# What Creates Annular Pressure?

## Many Sources

- 1. Major source is heat from produced fluids expanding fluids in inner and outer annuli.**
- 2. Gas (and liquids) may leak from tubing or inner annulus into outer annulus. May be trapped or equalize (quickly or slowly)**
  - Leak sources – threaded connections, wellhead, corrosion, corrosion, packer, seal assembly, etc.**
- 3. Gas may leak into annulus from a “non” producing formation.**

# Questions Around Annular Pressure

- Simple and Complex:
  1. How can gas (and liquids) leak into the annulus?
  2. How do wells develop annular pressure?
  3. Why does the annular pressure rise during startup?
  4. Why does annular pressure continue to rise in some wells even in stable flow?
  5. Why does annular pressure not rise in some wells?
  6. Can a gas column in the annulus reduce annular pressuring?

# How do well fluids leak into the outer annulus on some wells?

- No, it's not supposed to happen. However:
  - Thread leaks in inside tubulars
  - Wellhead seal leaks
  - Corrosion holes in inside tubulars
  - Packer seal leaks
  - Mechanical damage
  - Shallow zone charging of annulus (rare!)

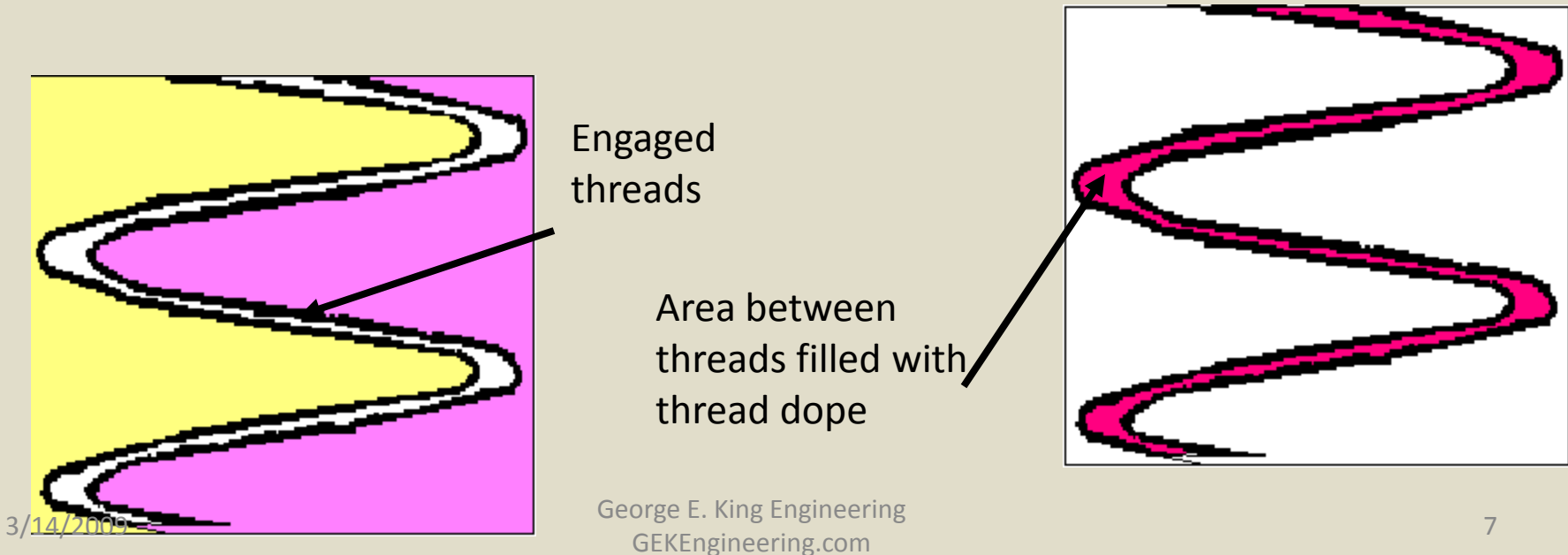
All of these may contribute to annular pressure.

# Thread Leaks

- Many different types of threads – can rely on mechanical seal(s) or thread dope, depending on the pipe thread type.
  - Many older connections, such as API and buttress threads were selected for availability or strength, but are difficult to seal gas tight. These threads can be subject to very small leaks if the pipe dope seal deteriorates.
  - Patented threads, with much better elastomer and metal-to-metal seals, are available for situations requiring seals.

# Thread Dope

- If gaps between threads are larger than particles in the dope, a long lasting seal may not be created. Dope must maintain elasticity



Patented Thread - A flush connection (not upset) with two-step thread, metal-to-metal seal and a torque shoulder at the base of the thread. This thread uses dope or make up grease to prevent galling





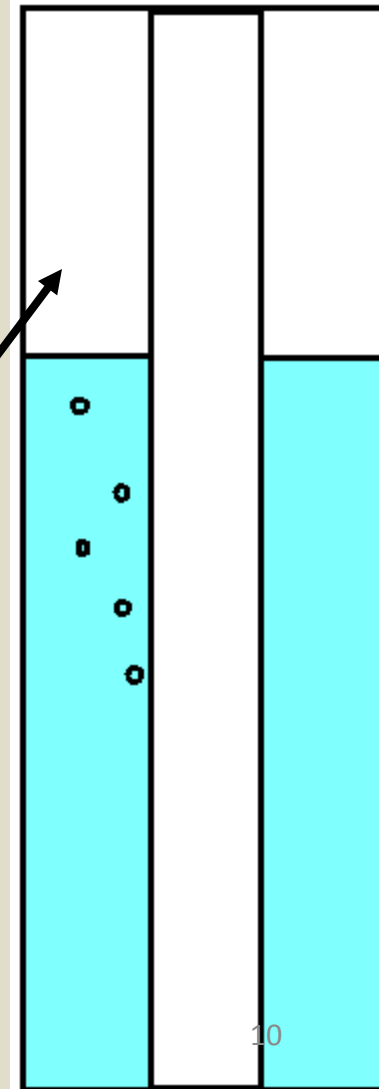
# One-Way Leaks?

- Yes – one-way leaks are very common.
- The liquid level height is one of the keys
  - Some leaks will allow gas to pass, but are too small for liquids. If the leak is below liquid level, the gas comes through and is trapped in the annulus because the liquid can't be forced back through the leak.
- Also, annular debris can act as a check valve for some leaks.

# One-Way Leaks?

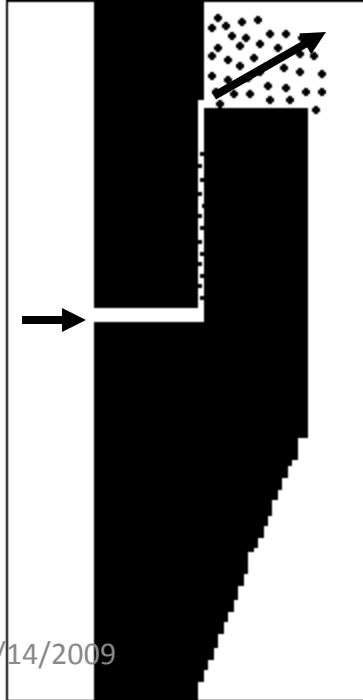
- Liquid level as a one-way leak path:
  - Gas permeates the leak, rising through the liquid to gas cap
  - Liquid is much slower to travel back to inner tubular when the tubing pressure is lowered. Gas is trapped.

*Accumulated Gas  
in Annulus*

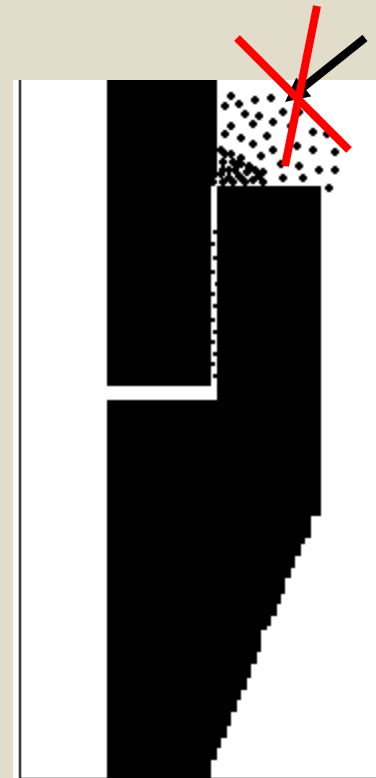


# One-Way Leaks?

- Annular particle-containing fluid as a check valve:



Any particle containing fluid may seal the leaks – NOTE – this is often an intermittent problem.



# One-Way Leaks?

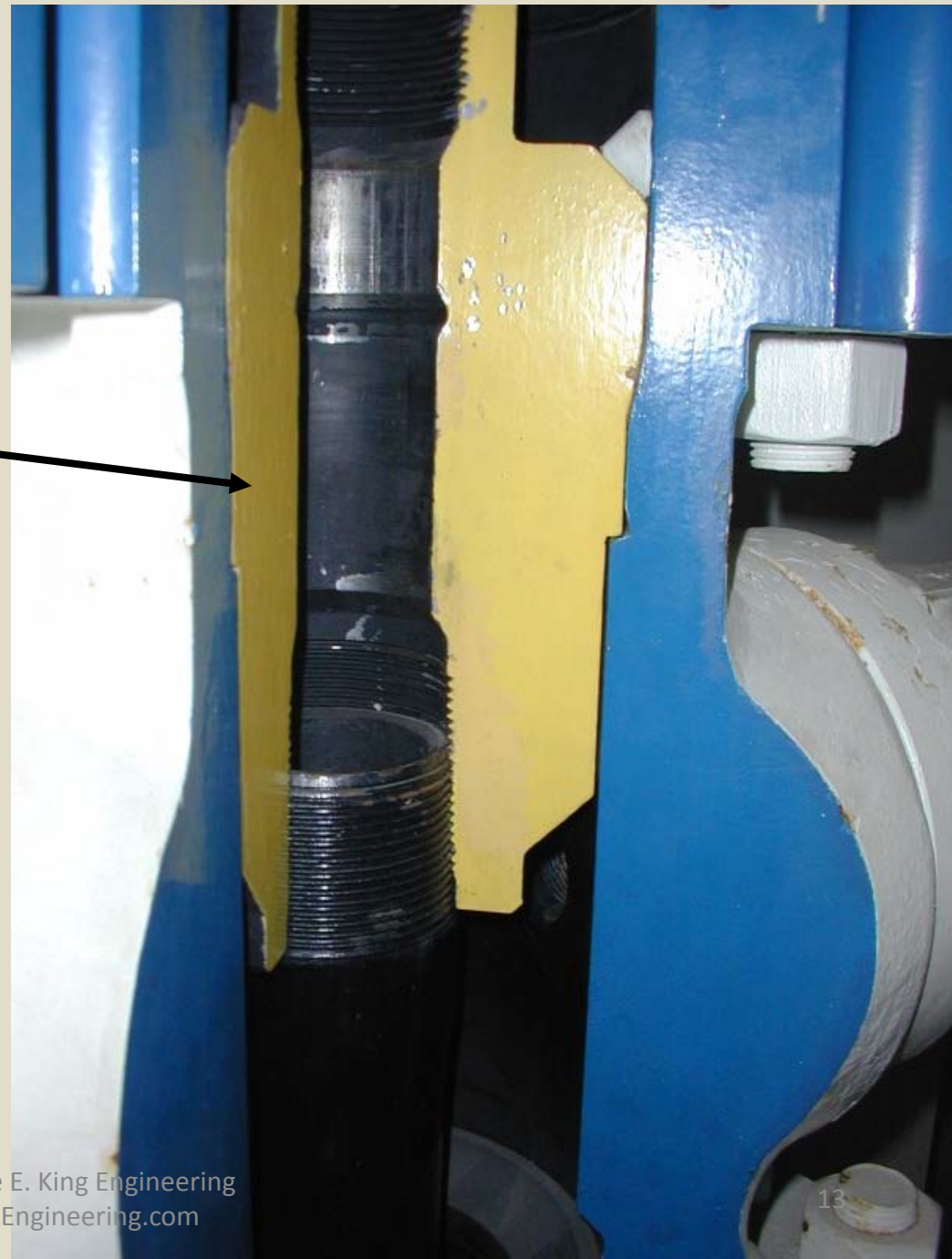
- If well head seal leak is created when the pipe is heated (and expanded – length increases), gas may leak into the annulus.
- When the pipe cools, the seal may re-engage, trapping the gas.

Tubing hanger.

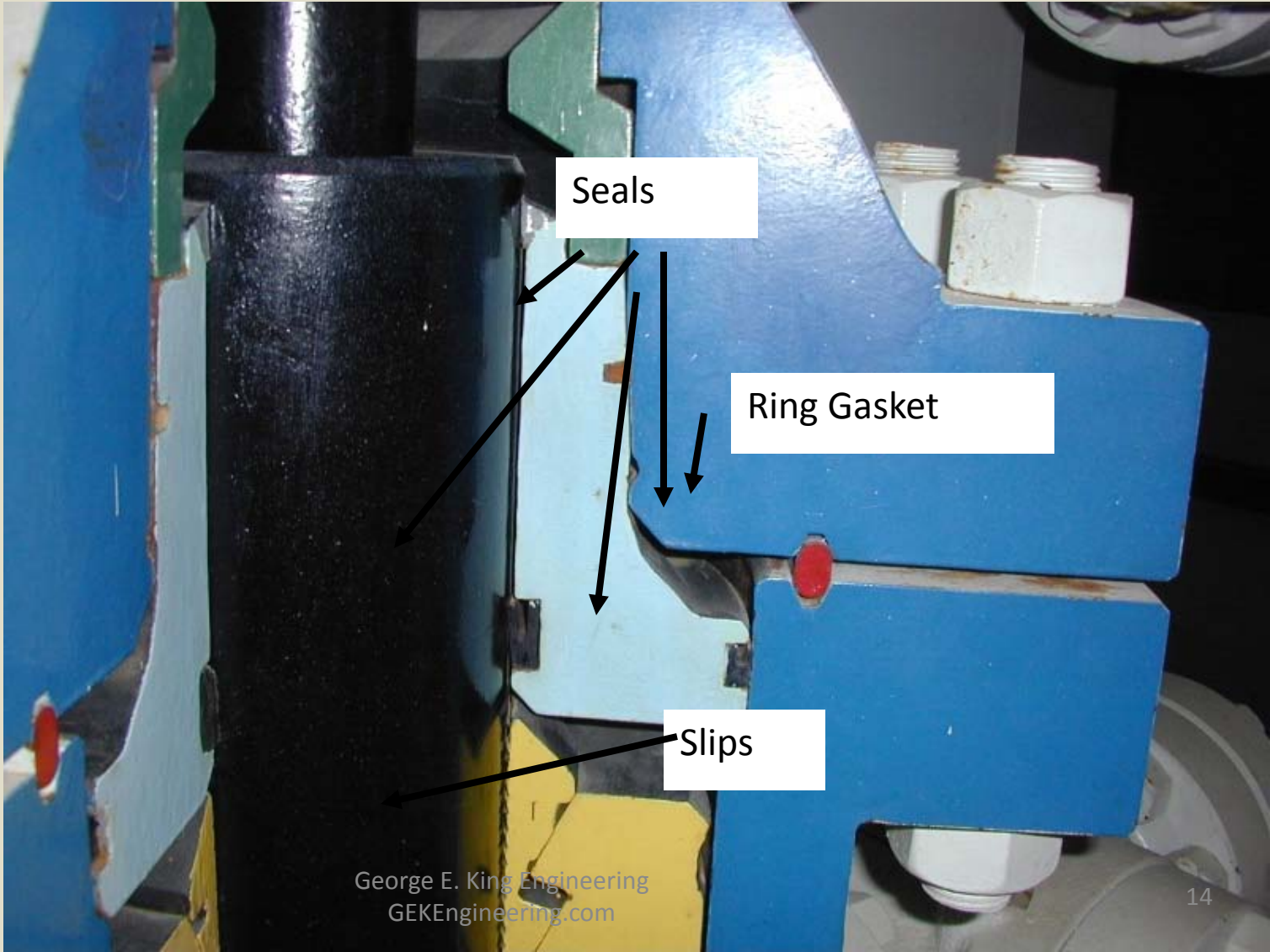
Note the lockdown screw and small seal isolating the tubing from the annulus. Other seals are above the hanger.

This is one of many types of wellheads.

Note that the top part of the hanger is threaded to allow pickup of the tubing string.



Seal assembly on an outer casing string in the wellhead. The seal stacks in most wellheads depend on a smooth pipe contact with the seal body. A small amount of upward pipe movement does not generally cause a problem.



# Why Do Some Annular Leaks Equalize?

- Depends on the size of the leak path.
  - Small or one way leaks don't easily equalize or may equalize only slowly.
  - Larger leaks can more easily equalize – may still take some time.
- Depends on the location of the leak path.
  - Leaks in the upper tubing or wellhead (above the liquid) may equalize more easily and quickly.

Lockdown  
screw

Basic adapter

TC-1A-EN  
hanger

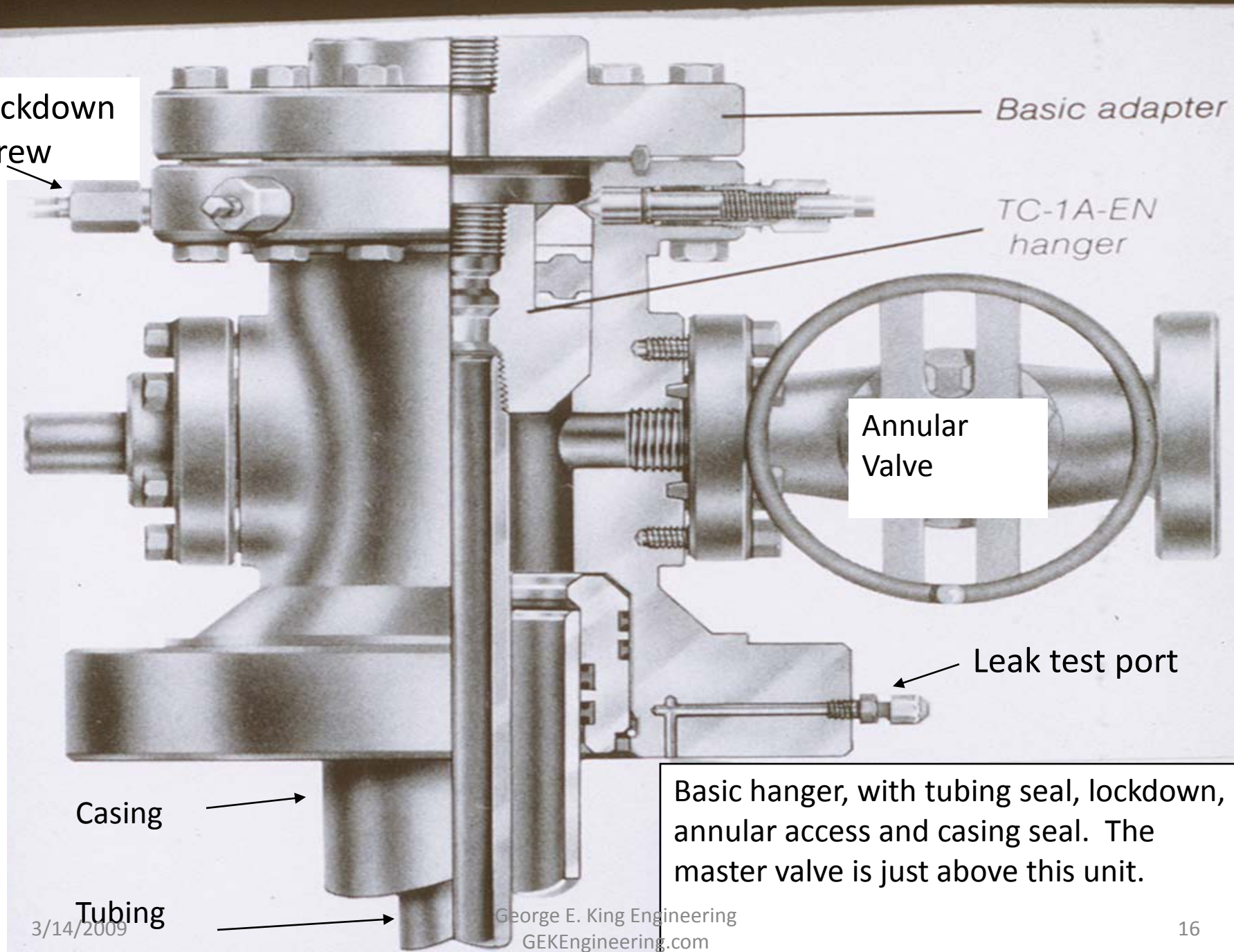
Annular  
Valve

Leak test port

Casing

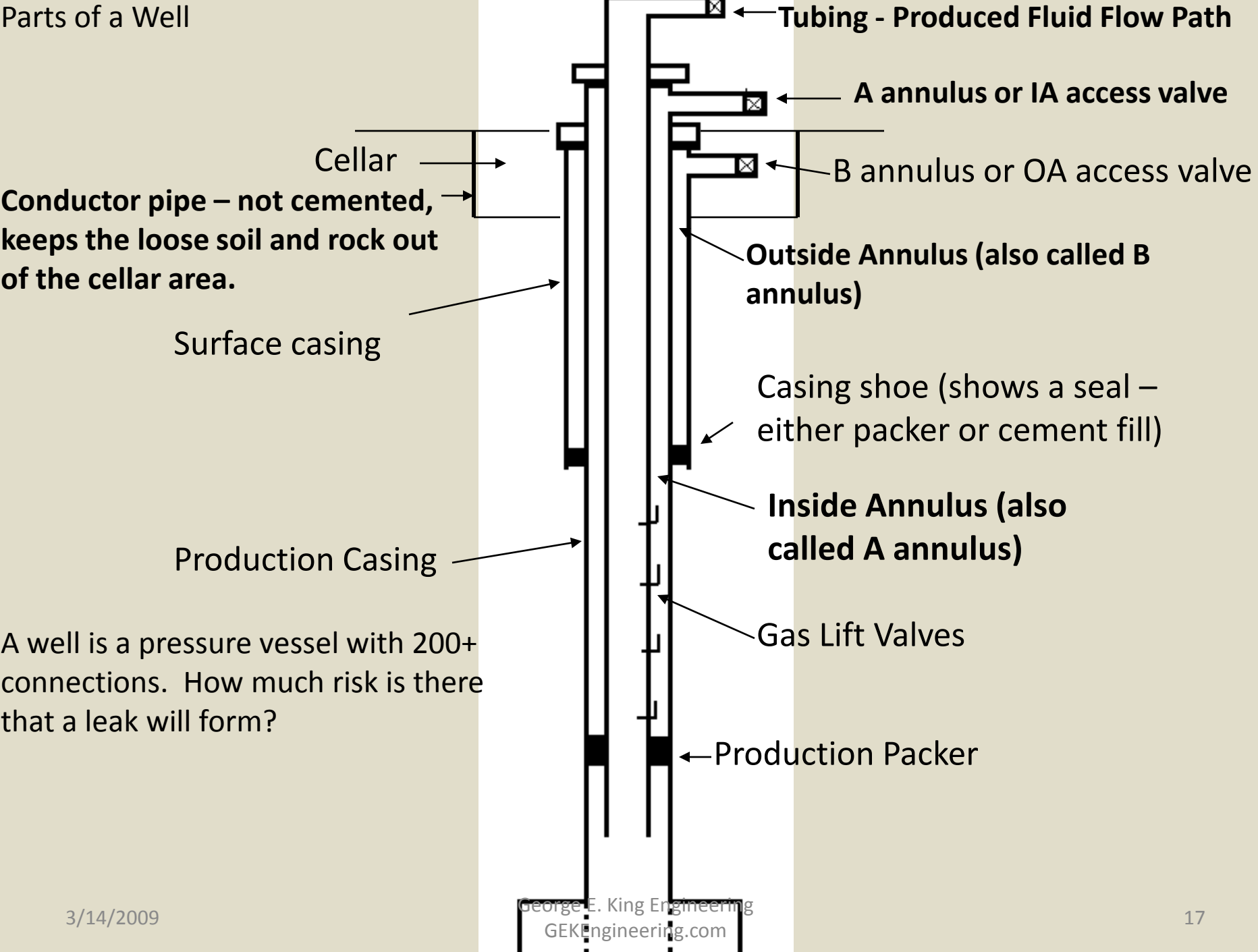
Tubing

Basic hanger, with tubing seal, lockdown, annular access and casing seal. The master valve is just above this unit.





# Parts of a Well



Conductor pipe – not cemented, keeps the loose soil and rock out of the cellar area.

Surface casing

Production Casing

A well is a pressure vessel with 200+ connections. How much risk is there that a leak will form?

Tubing - Produced Fluid Flow Path

A annulus or IA access valve

B annulus or OA access valve

Outside Annulus (also called B annulus)

Casing shoe (shows a seal – either packer or cement fill)

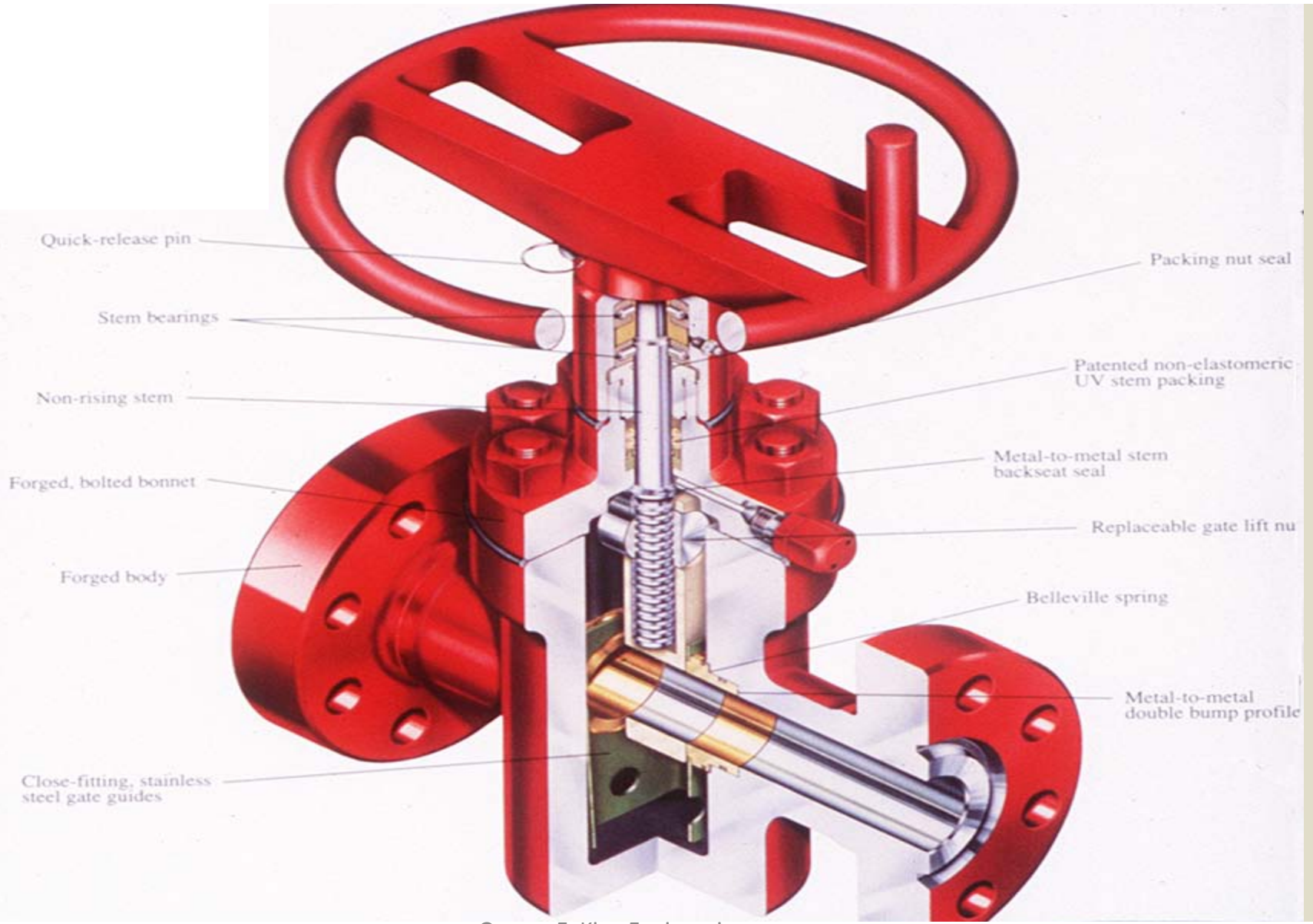
Inside Annulus (also called A annulus)

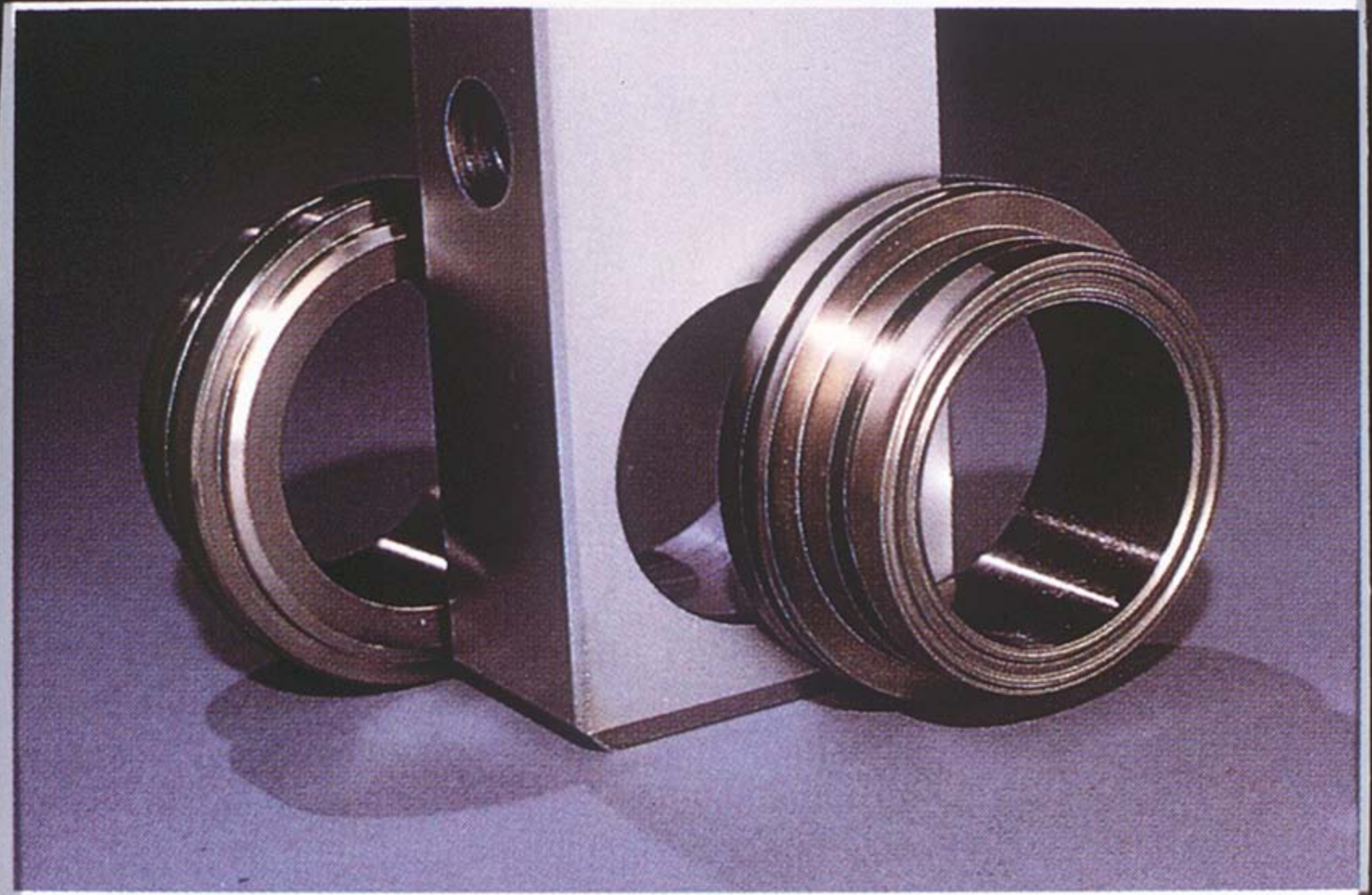
Gas Lift Valves

Production Packer

Cellar

One type of annular valve. The valves come in many pressure ratings –2,000 psi, 3,000 psi and 5,000 psi are the most typical rating. Sizes range from 2-1/16" to over 7-1/8".





**Never throttle with a gate valve! - washouts will ruin seal ability. Valves in series give repair opportunities.**

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# Wellhead Construction

- Most wellheads are made up of flanged spools and valves.
- The flange contains a metal-to-metal seal that is very reliable if properly made-up and routinely inspected.

A gasket sealing area in a flange, prior to cleaning, lubrication and assembly. The seal depends on a metal-to-metal seal that is accomplished by deforming a new seal ring during flange make-up.



The type of flange and gasket determine how the seal is made.

# Flanges with Ring Grooves, API Type 6B, for 5000 psi working pressure

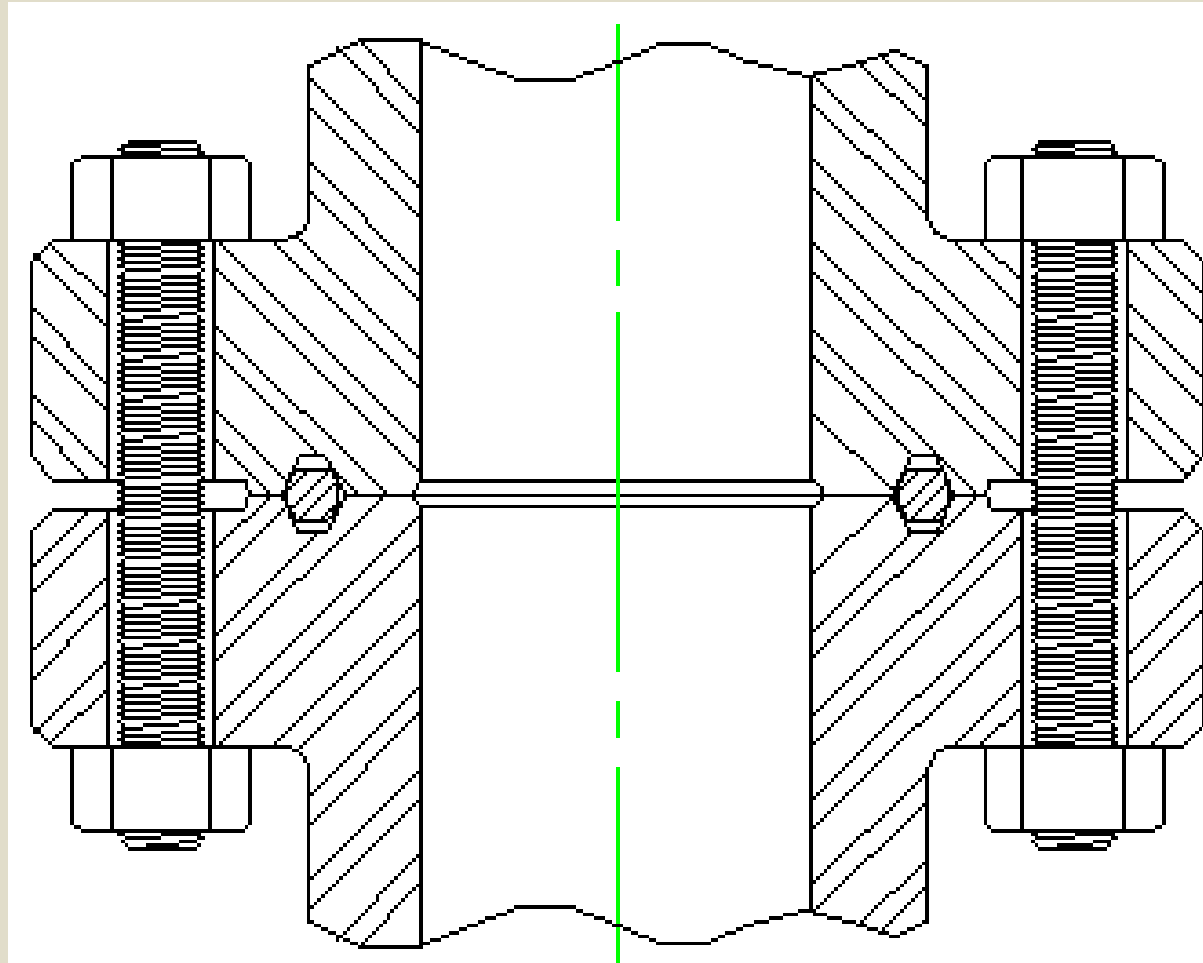
Nominal Size of Flange	Casing Size	Diameter of Flange	Diameter of Bolt Circle	Number of Bolts	Ring Type
2-1/16	2-3/8	8-1/2	5-1/2	8	R-24
2-9/16	2-7/8	9-5/8	7-1/2	8	R-27
3-1/8	3-1/2	11	8-1/2	8	R-37
4-1/16	4-1/2	12-1/4	9-1/2	8	R-38
5-1/8	5-1/2	14-3/4	11-1/2	8	R-44
7-1/16	7	15-1/2	12-1/2	12	R-46
11	9-5/8	23	19	12	R-54
13-5/8	16	30-3/8	26-5/8	16	BX-160

## 6 BX Flanges

Those flanges for which API Spec. 6A specifies BX Ring Gaskets.

### Made-up 6 BX Flanges -

6 BX flange raised faces shown in contact after assembly. In actual field situations any small gap present after achieving specified torque should appear uniform all around.



These flanges have raised faces that the design permits to meet or touch when the connecting bolts have reached the required torque.



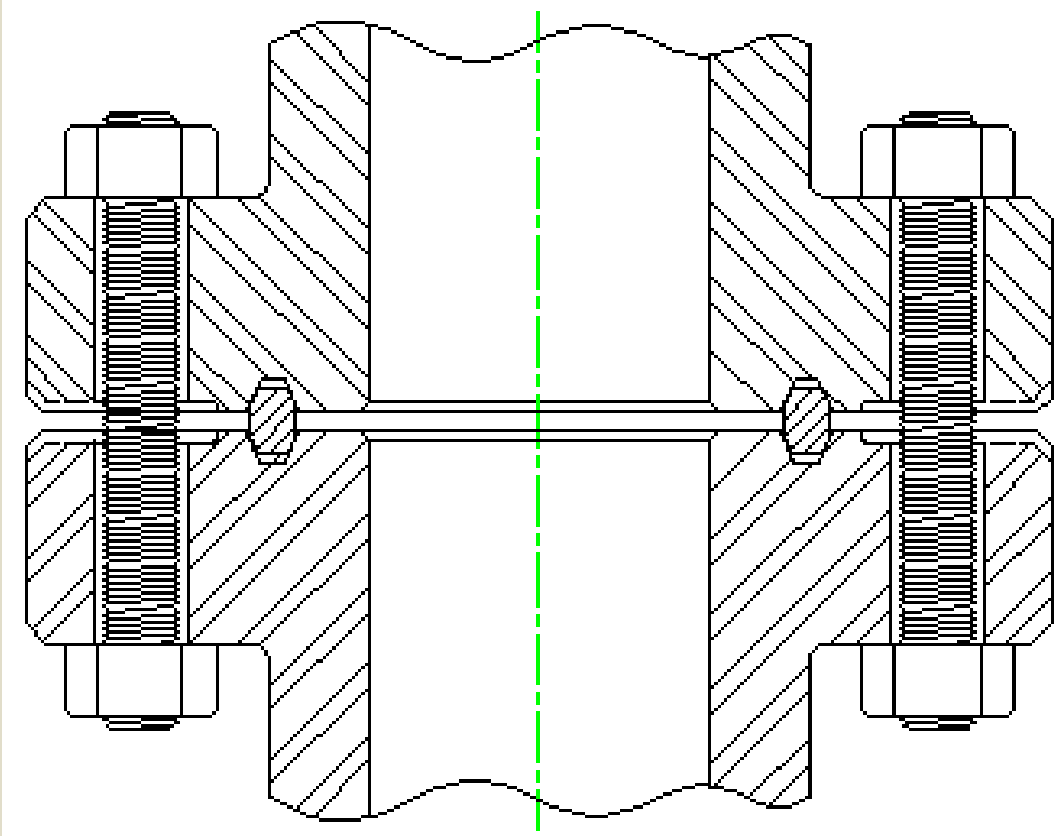
# 6 B Flanges

- Those flanges for which API Spec. 6A specifies R or RX Ring Gaskets
- These flanges (usually without raised faces) have designs that leave a stand-off (gap) between the flanges after bolts have reached the required torque. See illustration.
- Select flange size to display stand-off between flanges using **R** and **RX** Gaskets in standard Ring Grooves.

6 B flanges must always stand apart after assembly.

Raised faces on 6 B flanges make the stand-off (gap) space difficult to measure accurately but field construction of a simple feeler gage will usually give a satisfactory approximation of the measurement.

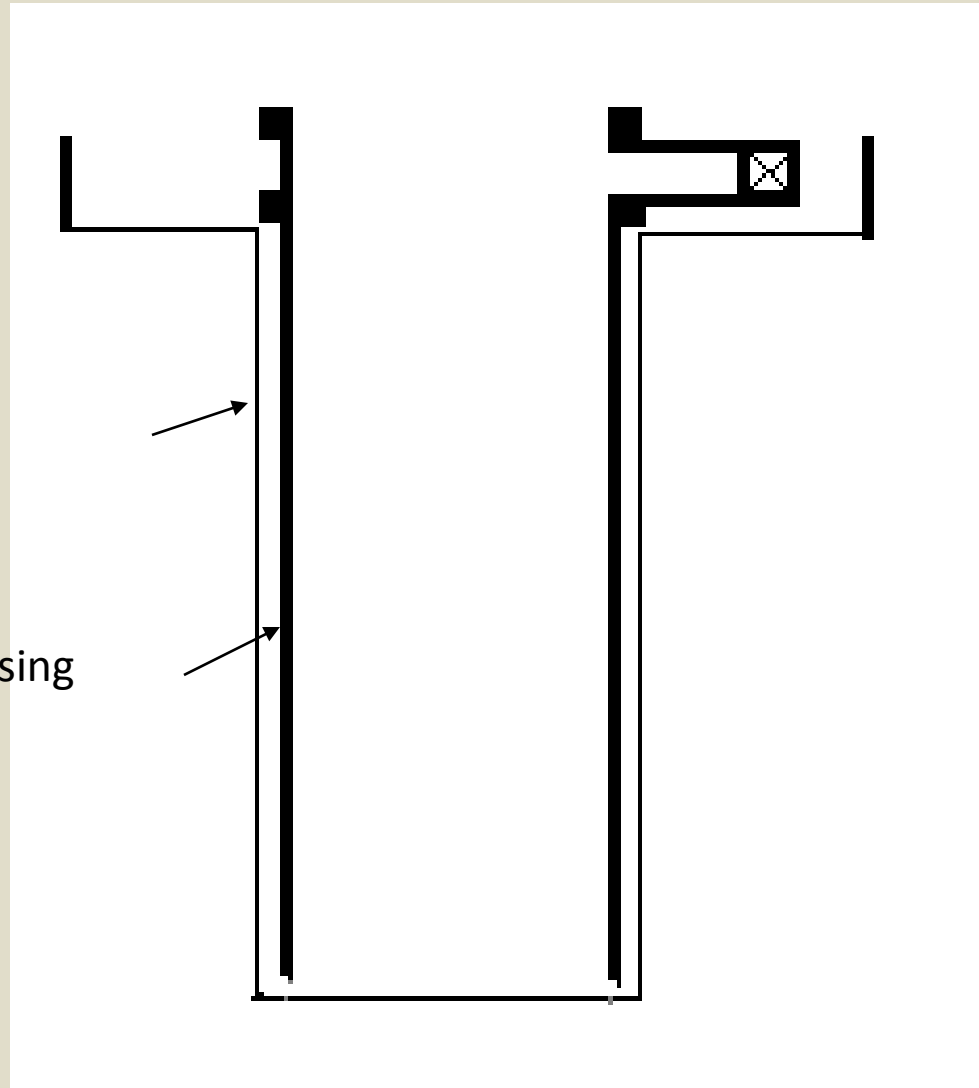
This stand-off should appear uniform all around



# Well Construction

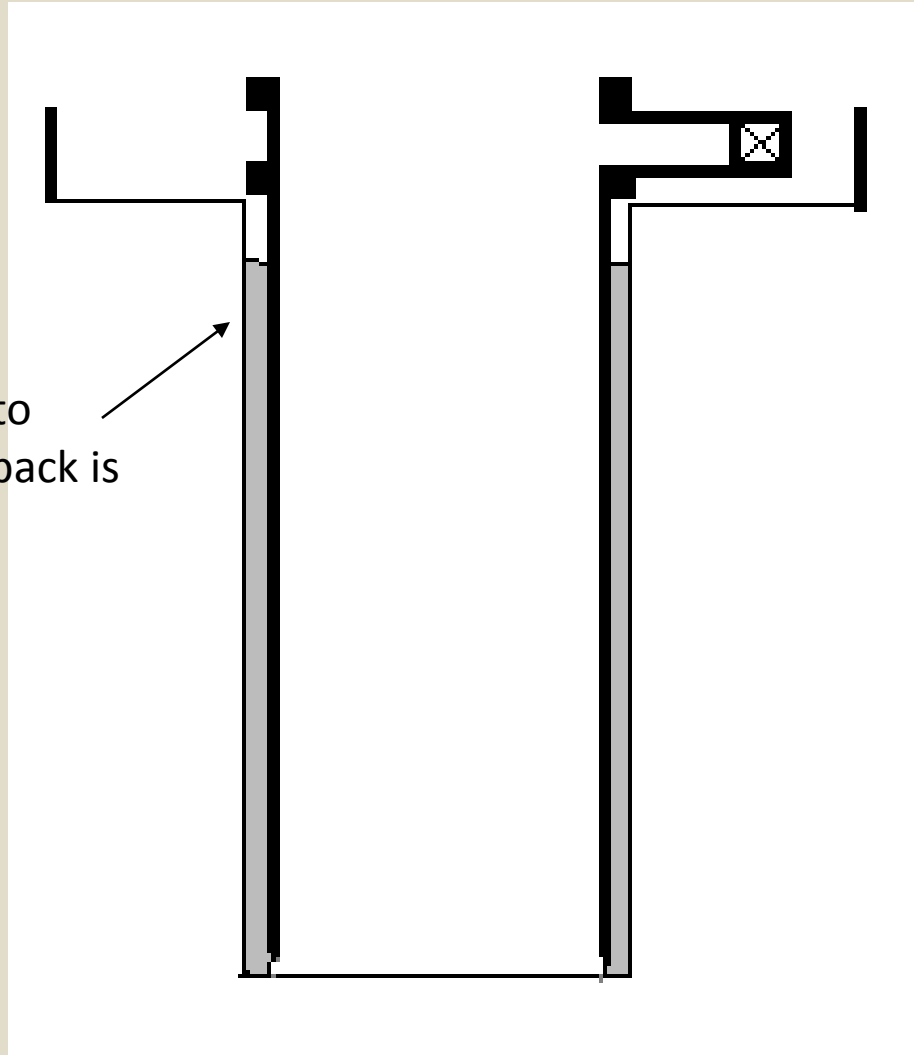
- Each part of a well is built to establish pressure isolation adequate to control any pressure that the well will see during further drilling, completion, production, intervention, stimulation, or abandonment.
- The pressure containment depends on long-term pipe, cement and seal integrity.
- Every well segment where trapped fluids have accumulated can build pressure as well conditions change.

Wells are drilled in stages with casing strings run and cemented to control formation pressures, to seal off unwanted fluids and to isolate sections of the formation.

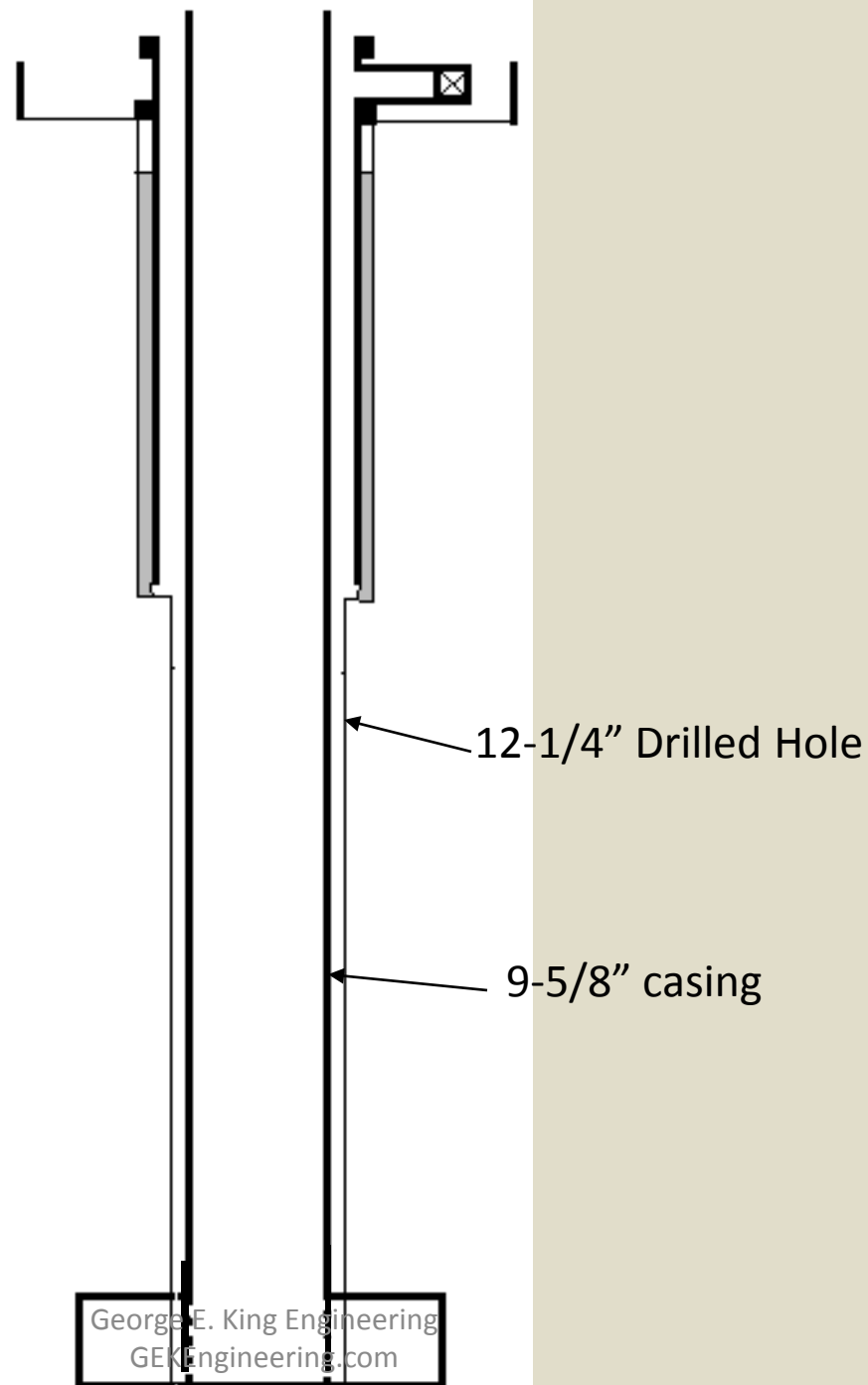


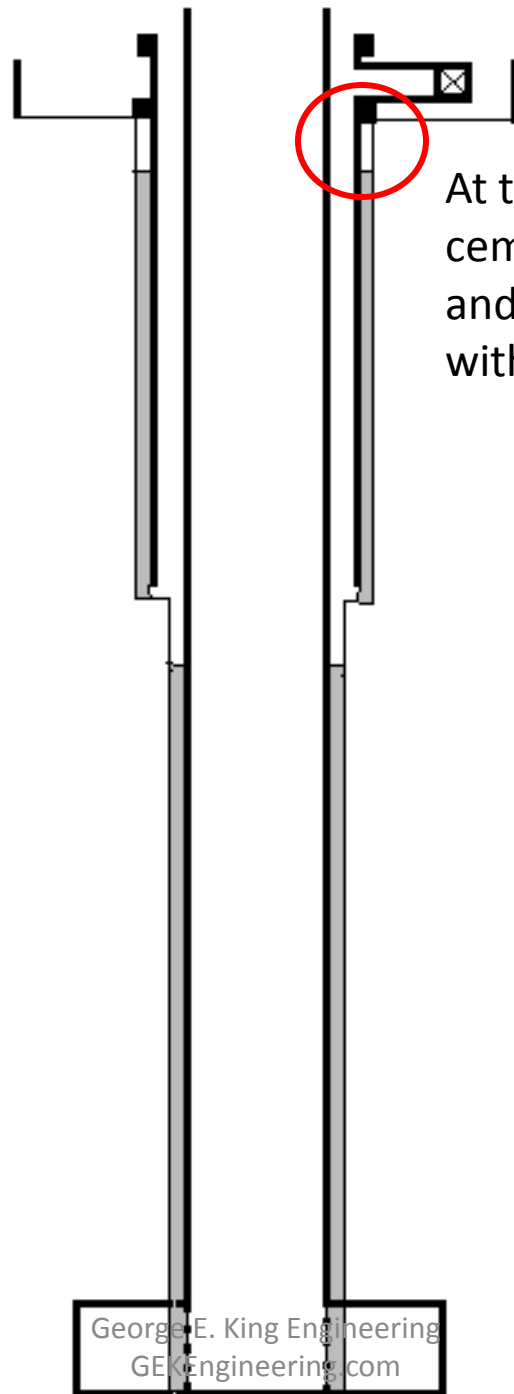
While the steel casing provides the initial strength, the cement provides the seal between zones. It also supports and protects the casing.

Cement circulated to surface – some fallback is normal.



The deeper parts of the well are drilled and the deeper casing string (the production casing in this example) is run through the upper strings (the surface casing) after the upper casing is cemented and tested to the maximum pressures expected in drilling the lower sections.

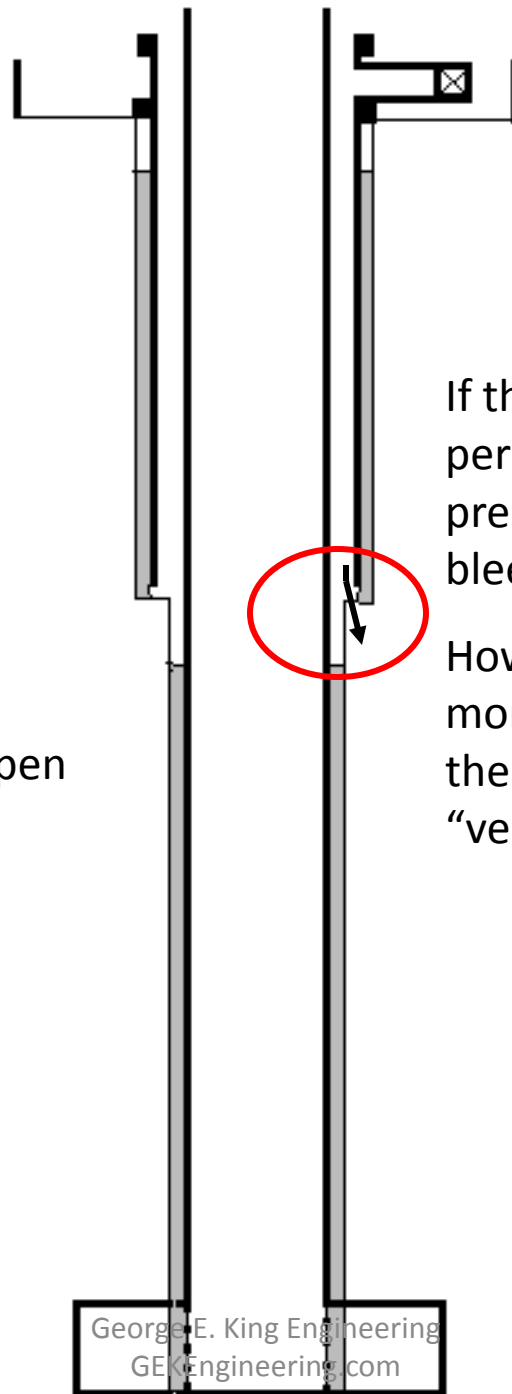




At the surface the small amount of cement fallback due to gravity, leakoff and other factors may leave a few feet with poor cement coverage.

Regardless of intent – cement is never perfect. And – it only extends to ground level.

9-5/8" cemented, but open area left below 13-3/8" overlap.



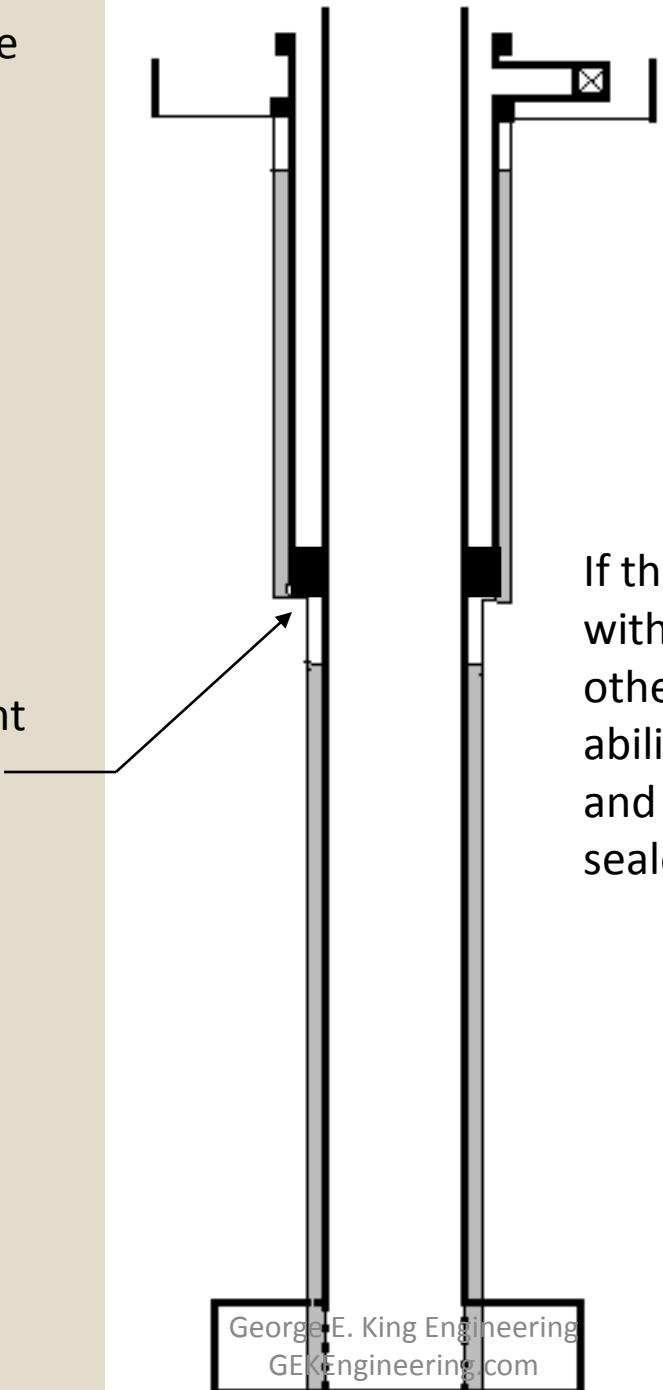
If the uncemented section is in a permeable formation, any annular pressure in the outside annulus can bleed off to the formation.

However, unless the active annulus is monitored for fluid height, a leak in the tubing will go undetected and the "vent" zone can be pressured up.



Consequences of sealing the annulus at the bottom.

Packer or cement seal



If the open lap is cemented sealed with cement or covered with mud or other fluid loss control material, the ability is lost to bleed off the pressure and the outside annulus becomes a sealed pressure chamber.

# The Source of the Temperature Increase in the Annulus:

- Produced fluids change the well temperature from the earth temperature near the wellhead (varies from about 5°F (-15°C) to 80°F (27°C)) to the produced fluid flowing surface temperature (varies from 50°F (10°C) to over 200°F (93°C)).

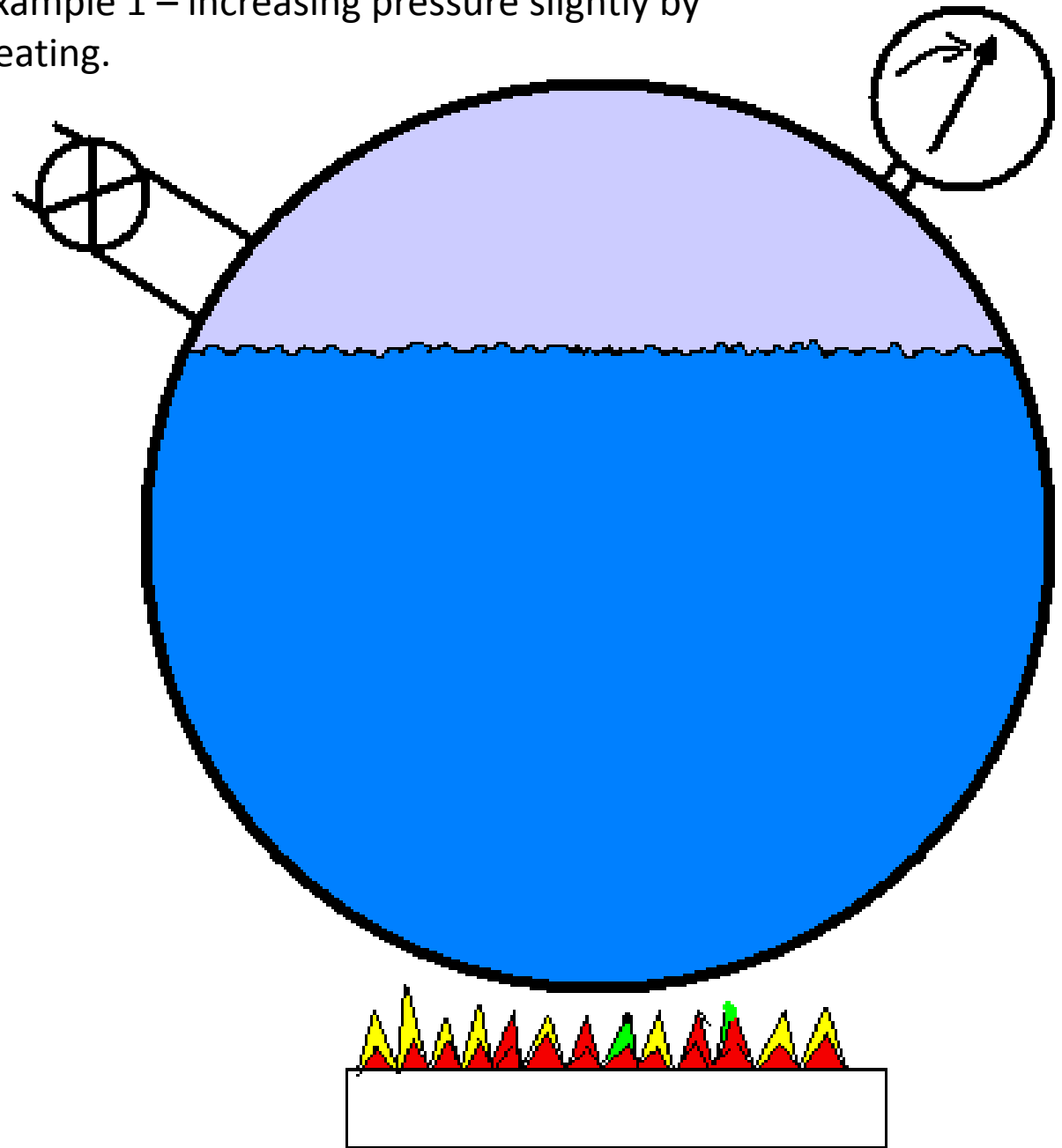
# Pressurization by Trapped Fluids

- Fluids (either liquid or gas) expand when heated.
- Fluids in a confined volume can only expand to fit the maximum space, then they increase the pressure.
- Gas, when heated, compresses easily - pressure builds very slowly.
- Liquids also expand when heated, but when the volume has been filled with liquid, they can rapidly exert very high forces on the confinement vessel.

A sealed fluid filled chamber builds up pressure as it is heated by the heat from the produced fluids.

There is a very big difference in the rate of pressure build up when the chamber is all liquid filled compared to a gas filled chamber.

Example 1 – increasing pressure slightly by heating.

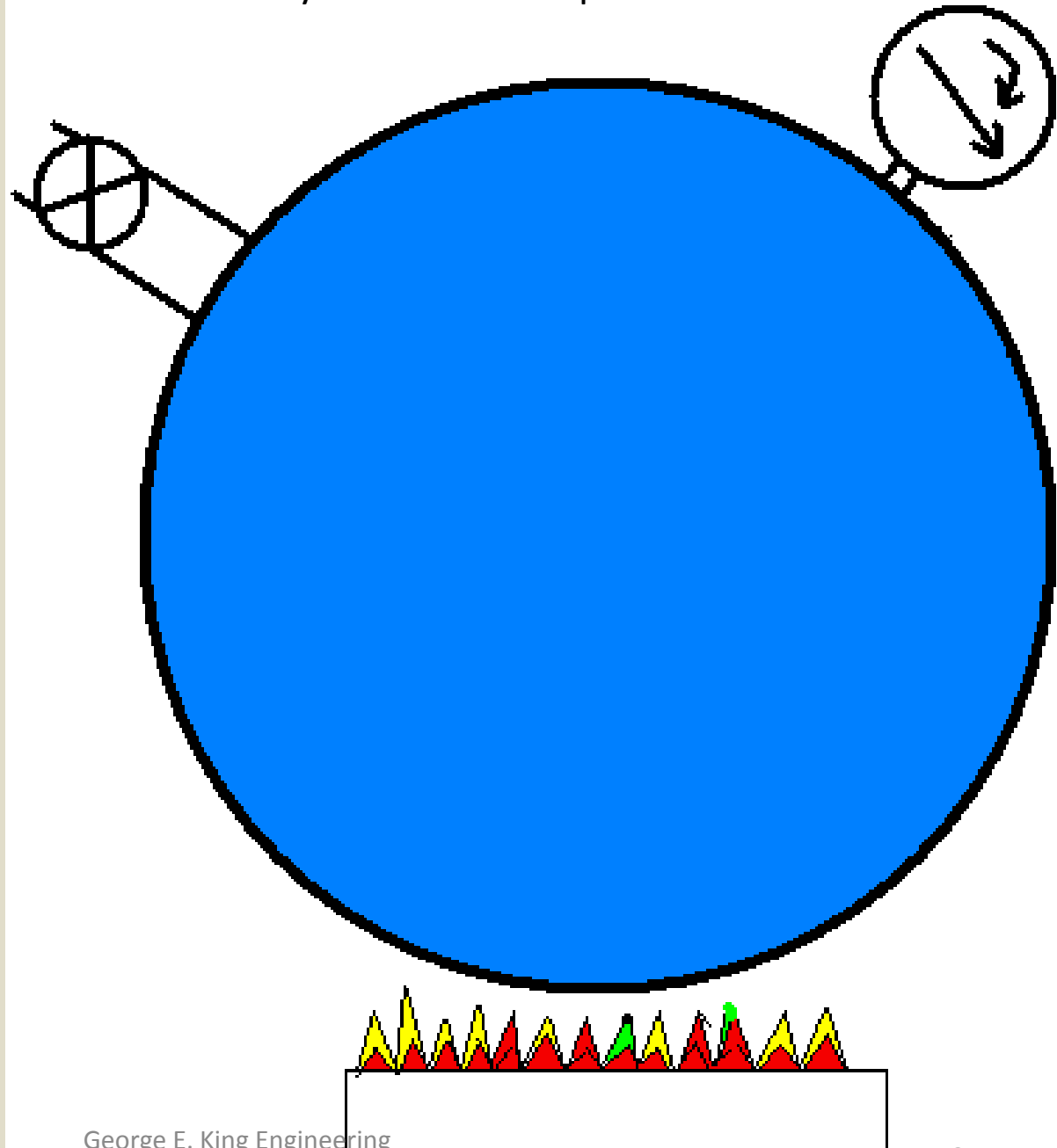


Example 2 – heating an all liquid closed chamber system increases pressure rapidly.

Pressure buildup as a liquid filled or nearly liquid filled system is heated will be very rapid.

Diesel, for example, increases volume at 0.0004 vol % increase per 1°F temperature rise (0.00072 vol% increase per 1°C).

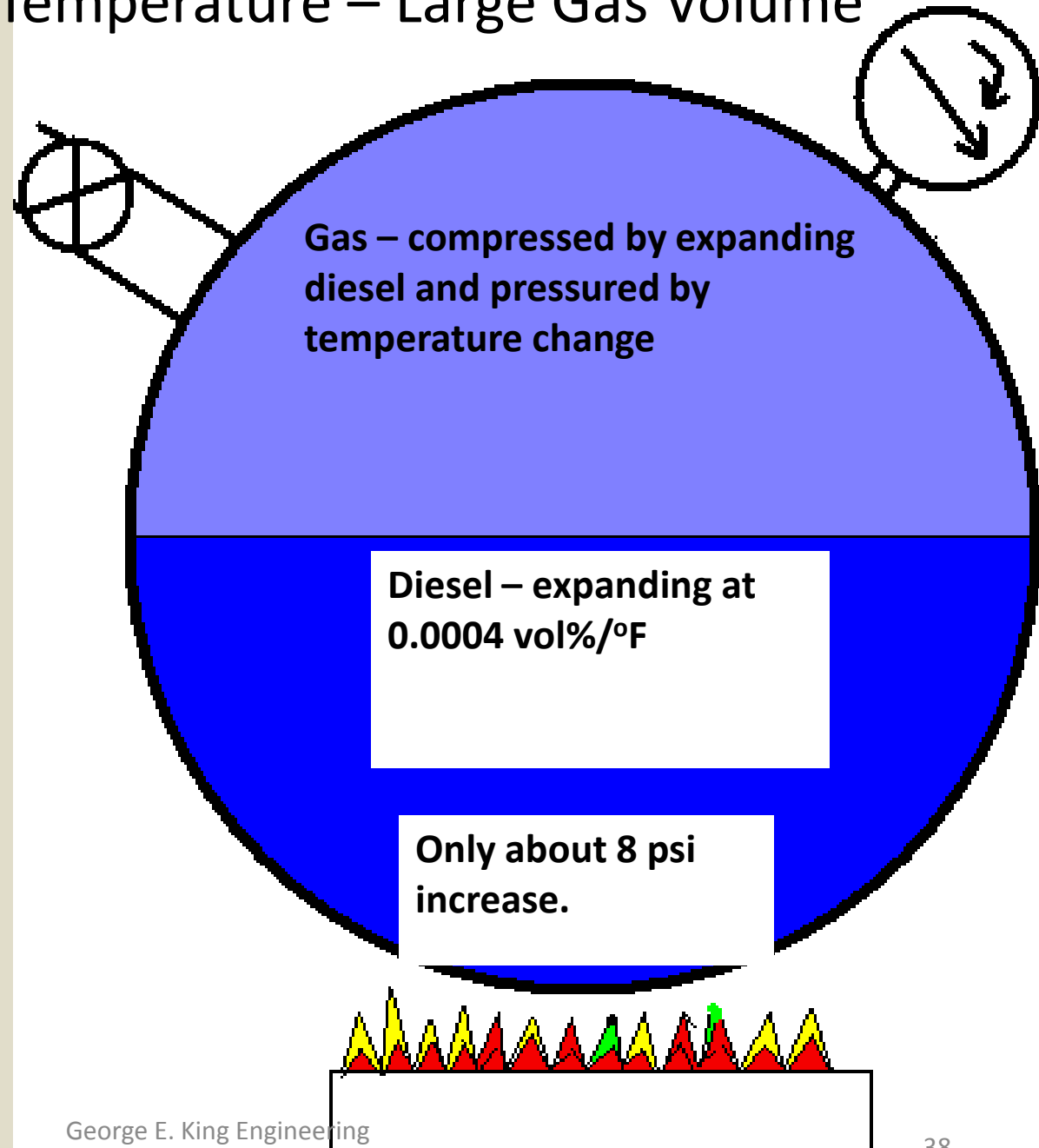
Pressure rise to very high levels is almost immediate when heated even a small amount.



# Example 1a – Effect of Temperature – Large Gas Volume

10 bbl chamber, 5 bbl gas and 5 bbl diesel, initial pressure 0 psig (1 bar) and initial temperature is 32°F (0°C).

What is the pressure when the fluids are heated to 212°F (100°C)?



# Approximate Solution

Initial Temperature =  $460 + 32 = 492^{\circ}\text{R}$

Final Temperature =  $460 + 212 = 672^{\circ}\text{R}$

Diesel volume increase =  $(212-32) * (0.0004) * (5) = 0.36$  bbl., Total final volume of diesel is 5.36 bbl

Ideal gas law pressure rise:  $P_1V_1/T_1 = P_2V_2/T_2$

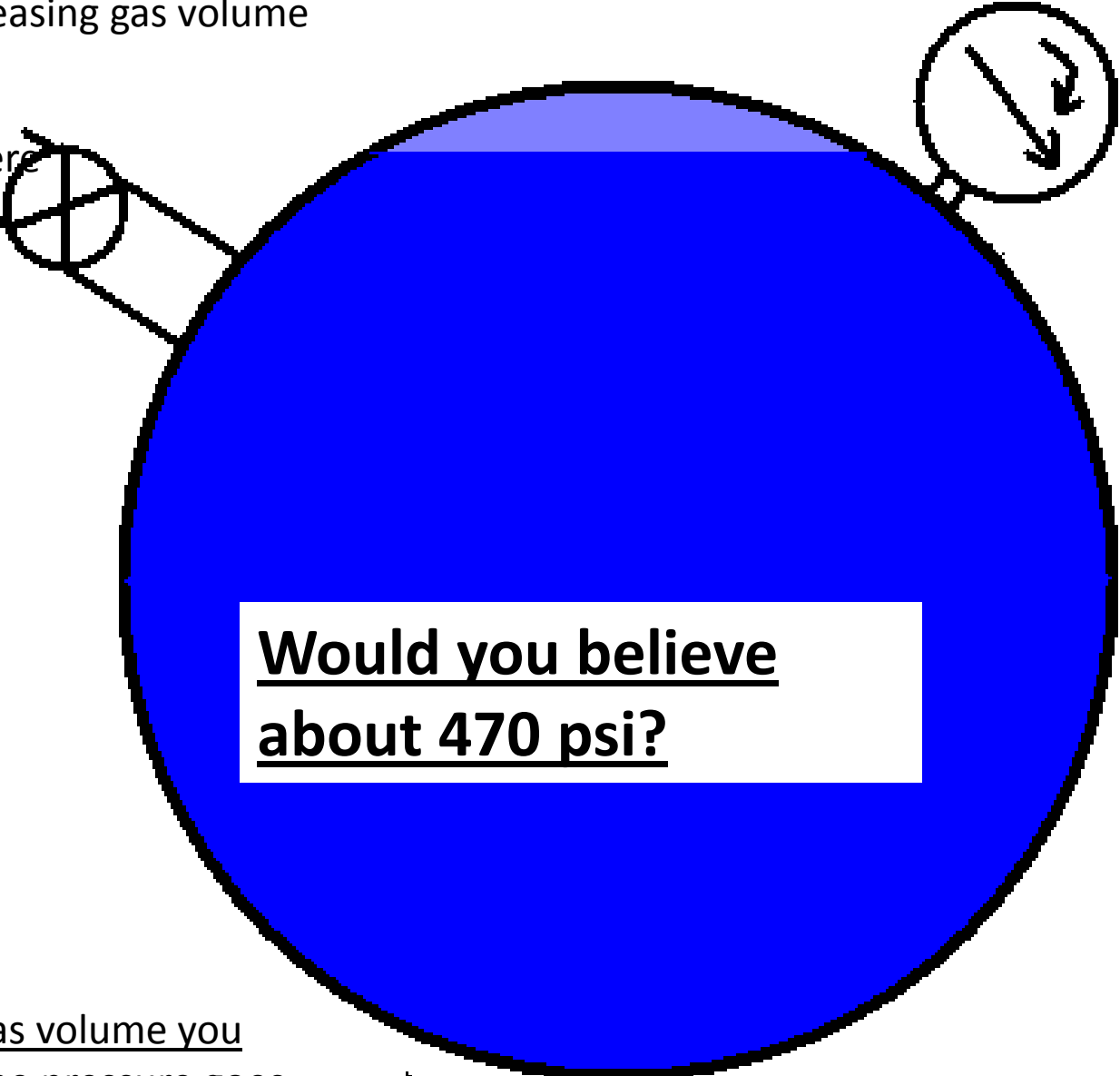
$\underline{P_2} = [(1) * (5) * (672)] / [(5-0.36) * 492] = 1.47$  bar or 22 psia or 8 psig.

Assumption: gas compression is a minor influence in opposing diesel expansion.

## Example 1b – The effect of decreasing gas volume

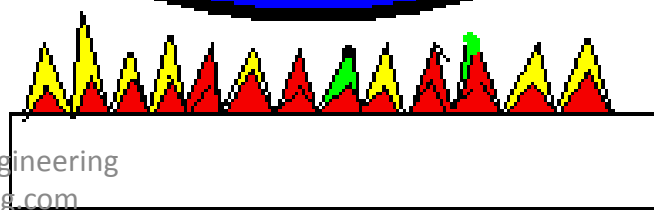
Consider the same problem where the starting condition is 9.3 bbl diesel and 0.7 bbl gas.

Same starting pressure (0 psig).  
Same temperature rise from 32°F (0°C) to 212°F (100°C)?



Would you believe  
about 470 psi?

Consequence? The less initial gas volume you have in the system, the higher the pressure goes and the faster it increases.





# Approximate Solution

Initial Temperature =  $460 + 32 = 492^{\circ}\text{R}$

Final Temperature =  $460 + 212 = 672^{\circ}\text{R}$

Diesel volume increase =  $(212-32)*(0.0004)*(9.3) = 0.67 \text{ bbl.}$ ,

Total final volume of diesel is 9.97 bbl

Ideal gas law pressure rise:  $P_1V_1/T_1 = P_2V_2/T_2$

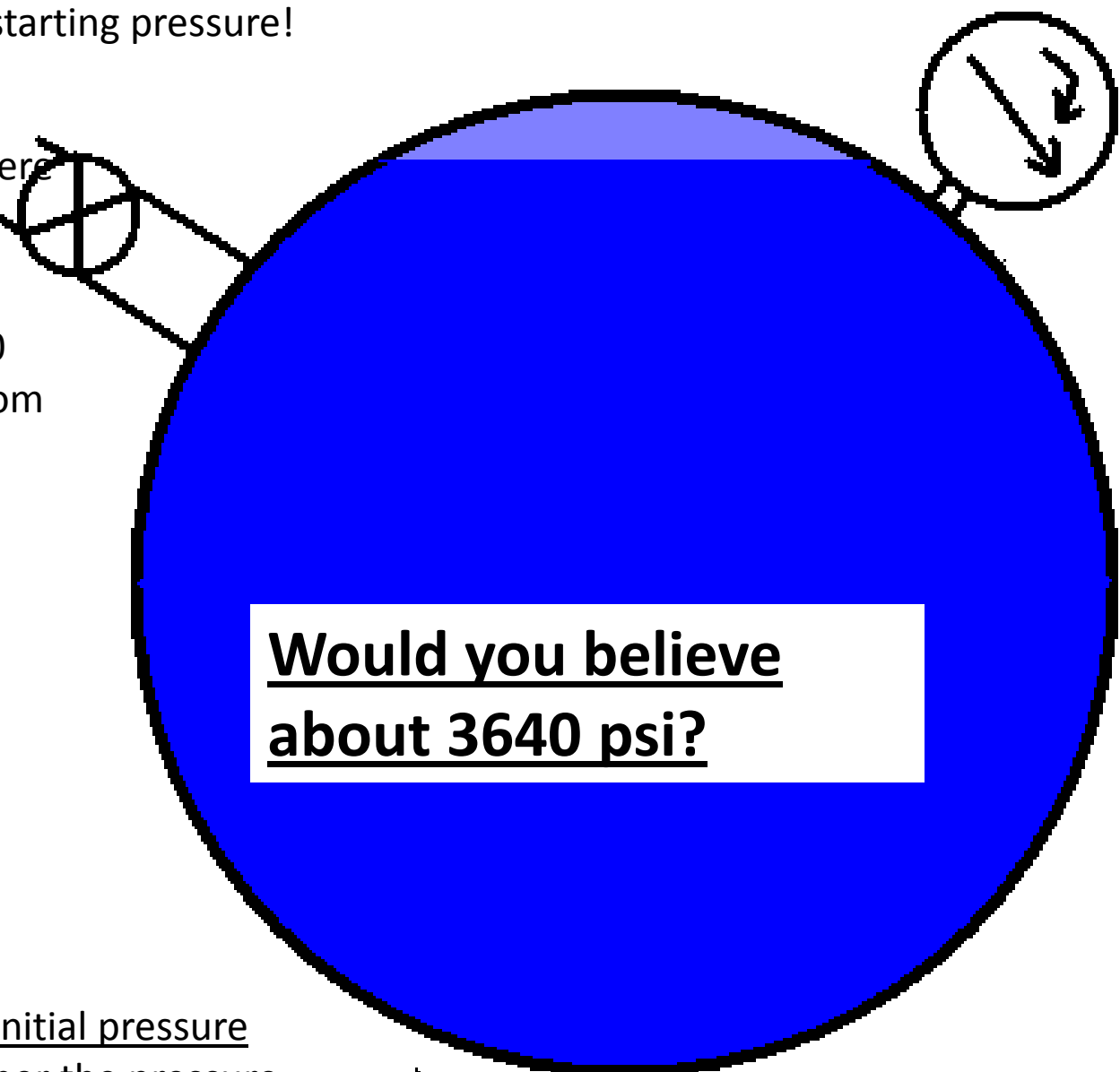
$\underline{P_2} = [(1)*(0.7)*(672)] / [(0.03)*492] = 31.9 \text{ bar or } 469 \text{ psia or } \underline{454}$   
psig.

Assumption: gas compression is a minor influence in opposing diesel expansion.

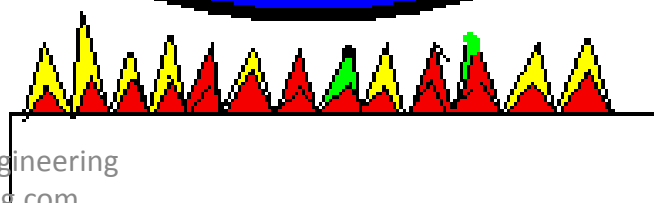
### Example 3 - importance of the starting pressure!

Consider the same problem where the starting condition is 9.3 bbl diesel and 0.7 bbl gas.

**But**, the starting pressure is 100 psig. Same temperature rise from 32°F (0°C) to 212°F (100°C)?



Consequence? The higher the initial pressure you have in the system, the higher the pressure goes and the faster it increases.



# Approximate Solution

Initial Temperature =  $460 + 32 = 492^{\circ}\text{R}$

Final Temperature =  $460 + 212 = 672^{\circ}\text{R}$

Starting Pressure = 100 psig = 114.7 psia or 7.8 bar

Diesel volume increase =  $(212-32) * (0.0004) * (9.3) = 0.67 \text{ bbl.}$ ,

Total final volume of diesel is 9.97 bbl

Ideal gas law pressure rise:  $P_1 V_1 / T_1 = P_2 V_2 / T_2$

$P_2 = [(7.8) * (0.7) * (672)] / [(0.03) * 492] = 248.6 \text{ bar or } 3654 \text{ psia or } 3640 \text{ psig.}$

Assumption: gas compression is a minor influence in opposing diesel expansion.

# So, how do we control the annular pressure rise?

Four ways:

1. Bleed the pressure off as it accumulates.
2. Vent the pressure at the shoe to a lower formation through a gap in the cement at the casing shoe
3. Use enough compressible material to absorb the maximum expansion of the liquid plus give a safety factor.
4. Use pipe with a high enough pressure rating to contain any pressure encountered in any extreme! (EXTREMELY heavy wall casing).

# What are the requirements with each method?

1. Bleed the pressure off – requires a timely, reliable pressure bleed down procedure. All liquid systems must be bled quickly. Note – very high efficiency control systems can be build around human control or mechanical control. Both approaches require timely backup checking.
2. Vent the pressure at the shoe – requires an open path from the annulus to a permeable formation.
3. Compressible material – requires that the compressible material levels for the particular well be preserved (not filled with liquid or solids).
4. Extremely heavy wall pipe – requires that you know what the highest pressure in any situation will be.

# Bleeding Pressure Off

- This is the most typical approach and a good one as long as the monitoring process works as planned.
- Liquid filled annuli pressure up quickly and bleed off quickly.
- Gas filled annuli pressure up slower (depending on total gas volume) and bleed down slower.
- Repeated bleed-offs may enlarge the leak under some conditions.

# Vent the Pressure Through an Open Shoe

- Also a good approach if adequately monitored, however:
  - Debris settling from liquids and scale/mud may block the vent path.
  - The open shoe ceases to be a barrier to flow and well control.
  - Allowing large gas volumes to vent through the shoe may charge up a shallow zone over time and transfer the problem to another well via a shallow formation (the outside pressure charging consideration).
  - An open shoe may prevent annular pressure testing.

# Compressible Materials

- One of the approaches taken for subsea wells where venting is difficult.
- The problem is maintaining the gas cap from being displaced (preventing filling the annulus with liquid).
- Compressible, closed cell foams are good but are usually an option only for new wells.
- Annular pressure testing is very difficult when any part of the annulus is filled with gas.



# Extremely Heavy Wall Casing

- Some very thick wall and high alloy pipes that will tolerate higher pressures are available.
- Higher alloy pipes are more susceptible to some forms of corrosion.
- Heavier pipes (thicker walls) are harder to handle and harder to gain a good cement job (centralization problems).
- Even the heaviest wall and highest alloy pipes still have pressure limits. Remember, liquid filled annuli build very high pressures when heated.

# What do the pipe strength ratings mean?

- Rated pressures, loads and forces are the minimum performance expected from new, round pipe within specification.
- Collapse, burst, joint tensile and body tensile strengths depend on:
  - Pipe diameter and ovality,
  - Pipe connection type and quality,
  - Pipe alloy,
  - Pipe weight,
  - Pipe condition (this is often the toughest to judge).
- The pipe values also heavily depend on the quality of cement filling the annulus.

# Consider Two Pipes – 5-1/2" and 9-5/8"

- Strength from pipe tables

<b>Pipe Diameter in.</b>	<b>Grade</b>	<b>Weight lb per ft</b>	<b>Collapse Resistance psi</b>	<b>Yield or Burst psi</b>
<b>5-1/2"</b>	<b>N-80</b>	<b>17</b>	<b>6,280</b>	<b>7,740</b>
<b>5-1/2"</b>	<b>N-80</b>	<b>26</b>	<b>12,650</b>	<b>9,880</b>
<b>5-1/2"</b>	<b>P-110</b>	<b>17</b>	<b>7,460</b>	<b>10,640</b>
<b>9-5/8"</b>	<b>N-80</b>	<b>43.5</b>	<b>3,810</b>	<b>6,330</b>
<b>9-5/8"</b>	<b>N-80</b>	<b>53.5</b>	<b>6,620</b>	<b>7,930</b>
<b>9-5/8"</b>	<b>P-110</b>	<b>43.5</b>	<b>4,430</b>	<b>8,700</b>

Note that both increases in grade (alloy) and weight per foot (wall thickness) increase collapse and burst, but in different proportion.

Also note that a larger pipe diameter, although with a thicker wall, has less collapse and burst strength.

# The Pressure Gauge

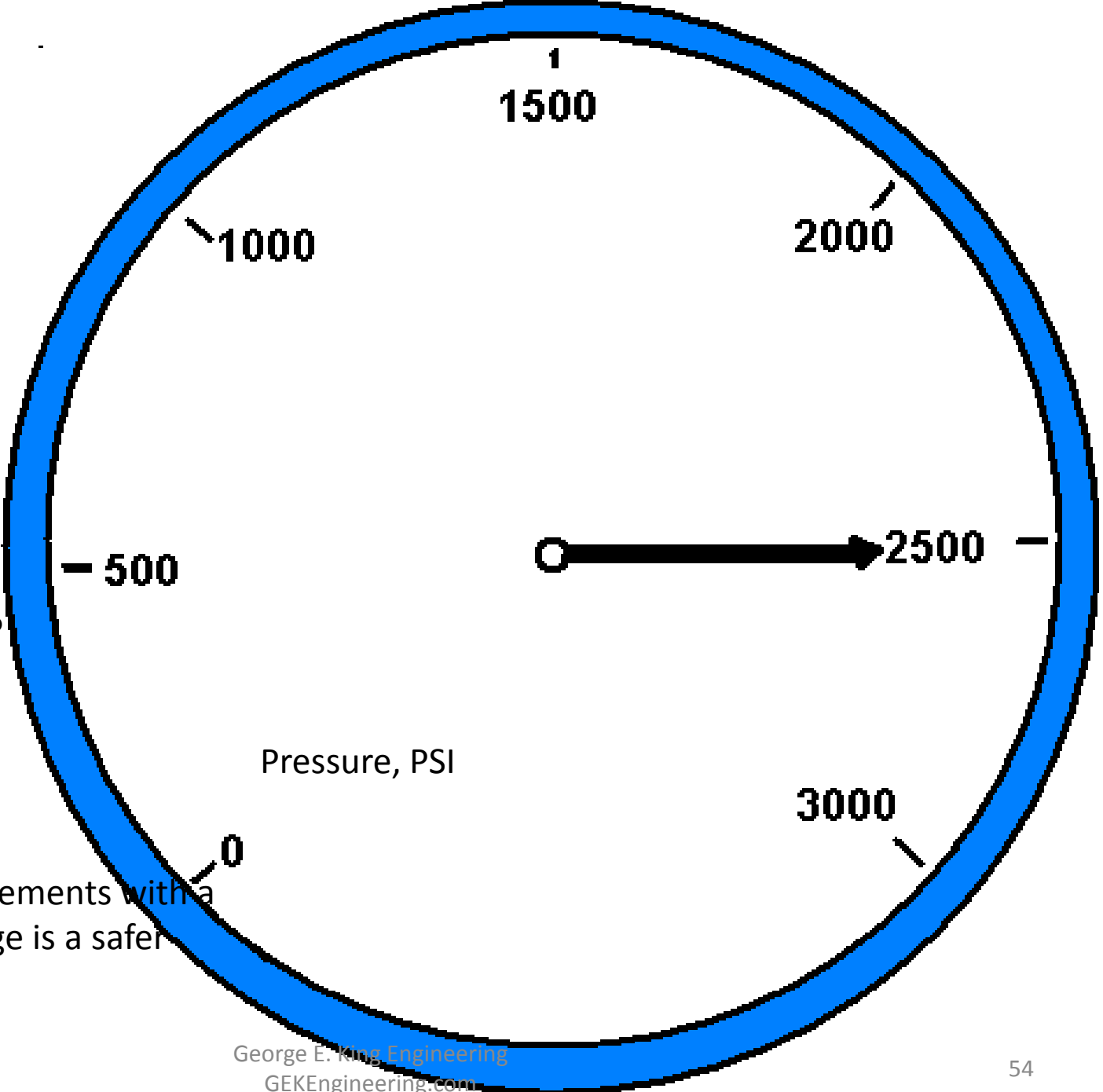
- Each pressure measurement device is set for a particular range.
  - The gauge is most accurate at mid range
  - The lack of a stop at maximum pressure can lead to false readings
  - Over pressuring a gauge (even one with a stop) destroys its accuracy and may make it read very high or very low.



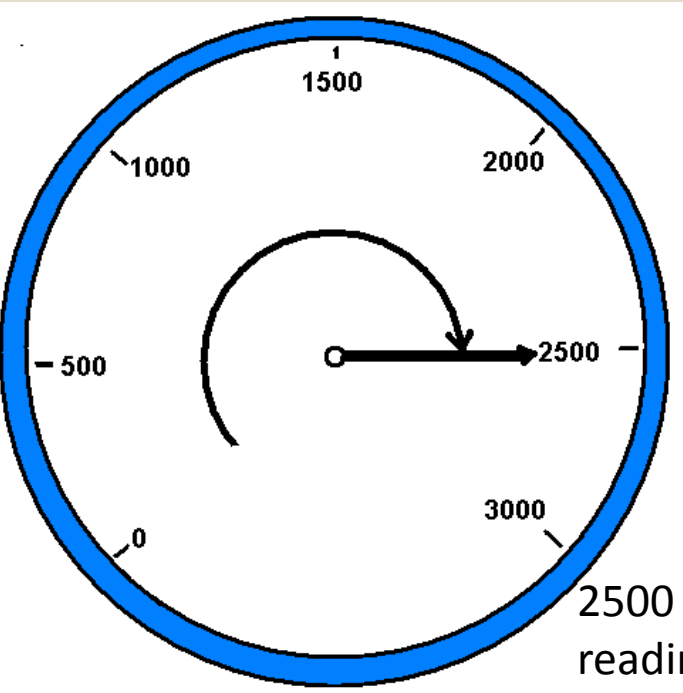
What is the pressure on this annulus?

2500 psi???? Or has the gauge wrapped around?

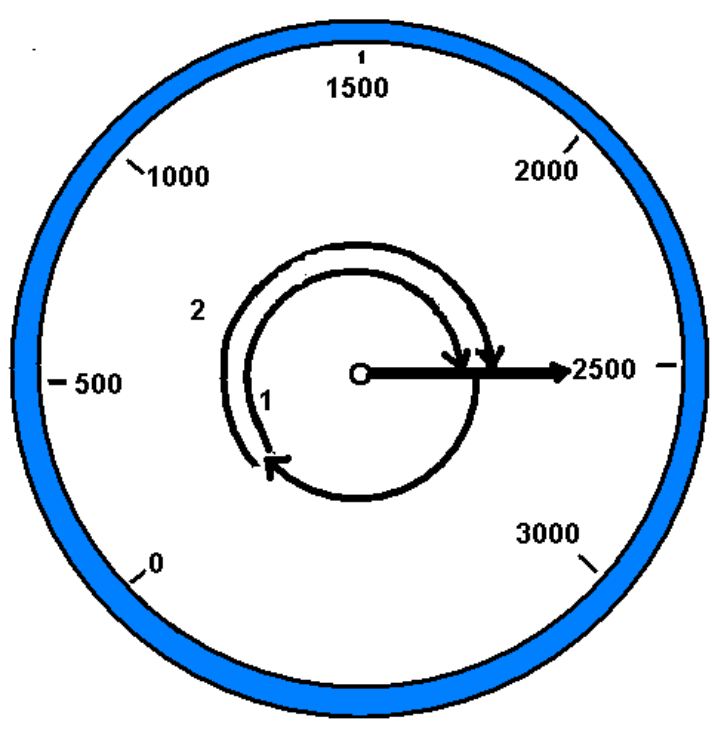
Remote sensing measurements with a wide measurement range is a safer way.



Without a stop pin at maximum gauge reading, the indicator hand can sweep around, showing one dial reading and really measuring twice (or more) the indicated pressure.



2500 psi reading



6500 psi actual?

# Annular Pressure Control Summary

- Fluids can reach the annulus by several different mechanisms.
- No control method is perfect:
  - Gas caps in the annulus can be a way to control annular pressures but only if there is sufficient gas as a cushion.
  - Shoe venting techniques are only of value so long as the path at the shoe stays open.
  - Liquid filled or nearly liquid filled annuli build pressure very quickly when the well heats up.