PET 535 MODERN WELL DESIGN - SEPTEMBER 2015

1. WE WILL DESIGN THE PRODUCTION CASING OF A WELL. THE FOLLOWING DATA APPLIES:

9 5/8" 47 # P110	
WEIGHT	68.73 kg/m
BURST STRENGTH	651 bar
COLLAPSE	366 bar
TENSION	6590 kN
MW	1.60 sg IN/OUTSIDE OF CASING
D_i	220.5 mm
SETTING DEPTH	2909 MMD, 2350 M TVD
DEPTH NEXT HOLE	3341 MMD, 2655 M TVD
CEMENTED INTERVAL	2131 - 2909 MMD, 1800 - 2350 MTVD
PRODUCTION PACKER	2414 MMD, 2000 MTVD
GAS DENSITY NEGLIGIBLE	

* bar x CM^2 = daN

THE WELL IS VERTICAL DOWN TO 1000 M, FOLLOWED BY A SHARP BUILD UP. FROM 1000 M TO TD ASSUME CONSTANT 45° INCLINATION. ASSUME THAT THE WELL IS DRILLED FROM A JACK-UP WITH 25 M AIRGAP. USE THE ENCLOSED PROGNOSIS.

ASSUMED DATA SINCE THE CURVE IS MISSING IN THE PDF FILE:

PORE PRESSURE GRADIENT @ 2655 M TVD	1.55 sg
MW OF NEXT SECTION	
PACKER FLUID DENSITY	1.10 sg
FRACTURE PRESSURE @ 2350 M TVD	1.85 sg
WATER DEPTH	120 M

a) PREPARE A FIGURE OF THE WELL AND DEFINE TWO CRITERIA FOR BURST OF THE PRODUCTION CASING, AND DETERMINE THE DESIGN FACTOR

* GAS FILLED CASING CRITERIA

- PRESSURE OUTSIDE
  1. AT WELLHEAD $P_o = (0.0981)(1.60)(145) = 23$ bar * ASSUMING MUD OUTSIDE CSG.
  2. AT SHOE $P_o = (0.0981)(1.60)(1800) + (0.0981)(1.03)(550) = 338$ bar * ASSUME WATER IN THE CEMENT

- PRESSURE INSIDE
  1. PORE PRESSURE $= (0.0981)(1.55)(2655) = 404$ bar
  2. AT WELL HEAD = 404 bar
  3. AT SHOE = 404 bar * ASSUME WEIGHTLESS GAS

- BURST LOAD
  1. AT WELLHEAD $= P_i - P_o = 404 - 23 = 381$ bar
  2. AT SHOE $= P_i - P_o = 404 - 338 = 66$ bar

- DESIGN FACTOR
  $DF = \frac{651 \text{ bar}}{381 \text{ bar}} = 1.71$

* TUBING LEAKING CRITERIA

- PRESSURE OUTSIDE
  1. AT WELLHEAD = 23 bar * SEE ABOVE
  2. AT PACKER $= (0.0981)(1.60)(1800) + (0.0981)(1.03)(200) = 303$ bar

- PRESSURE INSIDE
  1. AT WELLHEAD = 404 bar
  2. AT PACKER $= 404 + (0.0981)(1.10)(2000) = 620$ bar

- BURST LOAD
  1. AT WELLHEAD = 381 bar
  2. AT PACKER $= 620 - 303 = 317$ bar

  DF = 1.71

b.) DECIDE A CRITERION FOR COLLAPSE AND DETERMINE THE DESIGN FACTOR

* LOSSES TO A THIEF ZONE : THE ASSUMPTION IS THAT THE MUD LEVEL WILL DROP UNTIL THE COLUMN ESTABLISHES WITH THAT OF A NORMAL PRESSURE PORE GRADIENT

$$(0.0981)(1.03)(2350-25) = (0.0981)(1.60)(2350-h)$$

$$h = 853\ M$$

- PRESSURE OUTSIDE
  1. AT WELL HEAD $P_o = 23$ bar * SEE BEFORE
  2. AT h $P_o = (0.0981)(1.60)(853) = 134$ bar

- PRESSURE INSIDE
  1. AT WELL HEAD $P_i = 0$
  2. AT h $P_i = 0$

- COLLAPSE LOAD
  1. AT WELL HEAD = $P_o - P_i = 23$ bar
  2. AT h = 134 bar

- DESIGN FACTOR

$$DF = \frac{366\ bar}{134\ bar} = 2.73$$

c.) DETERMINE THE TOTAL WEIGHT ON AIR OF THE CASING STRING, AND THE BUOYED WEIGHT IN THE WELL. DETERMINE THE DESIGN FACTOR FOR TENSION. BENDING MAY BE NEGLECTED

- WEIGHT ON AIR

$$W = (68.73)(9.81)(2350\ M) = 158 \times 10^3\ daN$$

* PROJECTED HEIGHT PRINCIPLE

- BUOYED WEIGHT

$$W_b = \left(1 - \frac{1.60}{7.85}\right)(158 \times 10^3) = 126 \times 10^3\ daN$$

- PRESSURE TEST

ASSUMING PRESSURE TEST IS DONE TO WELLHEAD PRESSURE RATING = 10 000 psi

$$F_t = P_t \cdot A = (690\ bar)\left(\frac{\pi}{4}(22.05)^2\right) = 263 \times 10^3\ daN$$

- TOTAL TENSION

$$T_{TOTAL} = W_b + F_t = (126 + 263) \times 10^3 = 389 \times 10^3\ daN$$

* NEGLECTING BENDING

- DESIGN FACTOR

$$DF = \frac{659 \times 10^3\ daN}{389 \times 10^3\ daN} = 1.69$$

d) THE RESERVOIR HAS A VERTICAL EXTENT OF 50M. PROPOSE A DRILLED LENGTH BELOW THE RESERVOIR. EXPLAIN WHY.

THERE IS LITTLE INFORMATION TO GIVE AN ASSESSMENT OF THIS SITUATION SO HERE ARE A FEW CONSIDERATIONS. IF THE WELL IS TO BE COMPLETED IN SAND-FACED COMPLETION LIKE SCREENS / SLOTTED LINER, ETC, THERE SHOULD BE ENOUGH DEPTH BELOW BOTTOM TO INSTALL A SUMP PACKER SO PERHAPS 5M FROM THE BOTTOM OF THE RESERVOIR. THIS IS OBVIOUSLY CONSIDERING THAT THE PROPER ANALYSIS OF OWC HAS BEEN DONE. IF THE WELL IS TO BE COMPLETED AS C&P, WE HAVE TO DRILL DOWN TO A COMPETENT SHALE WHERE WE CAN SET THE SHOE, IN MANY OF THESE WELLS, A LENGTH OF A FEW METERS IS DESIRED BELOW THE BOTTOM OF THE RESERVOIR TO ACCOUNT FOR ANY POTENTIAL DEBRIS FROM THE PERFORATION GUNS OR POSSIBLE SANDING DURING THE PERFORATIONS.

2. THE FOLLOWING CASING TYPES ARE AVAILABLE

SIZE (in)	GRADE	WEIGHT (lb/ft)	D_o (mm)	D_i (mm)
20	P 110	133	508	475.7
13 3/8	K-55	88.2	346.1	314.3
10 3/4	N80	60.7	273	245.4
7	L80	20	177.8	164

a) COMPUTE THE BURST STRENGTH OF EACH CASING. LIST THE CASINGS FROM WEAKEST TO STRONGEST IN BURST

FIRST $P_{burst} = 2\,\sigma_{tensile}\left(\frac{t}{D_o}\right)$

HENCE

SIZE (in)	$\sigma_{tensile}$ (psi)	t (mm)	D_o (mm)	P_{burst} (psi)
20	110 000	16.15	508	6994
13 3/8	55 000	15.90	346.1	5053
10 3/4	80 000	13.80	273	8088
7	80 000	6.90	177.8	6209

FROM STRONGEST TO WEAKEST

SIZE (in)	P_{burst} (psi)
10 3/4	8088
20	6994
7"	6209
13 3/8"	5053

b) ARE THESE CASINGS SUITABLE FOR USE IN THE SAME WELL? EXPLAIN WHICH OF THE CASINGS COULD BE REPLACED, AND IF IT SHOULD BE STRONGER OR WEAKER.

ASSUMING THAT THERE IS NORMAL PRESSURE GRADIENT TO THE TOP OF THE RESERVOIR, WE COULD ARGUE THAT EVEN THOUGH WE WOULD EXPECT A HIGHER RESISTANCE OF THE 13 3/8" INTERMEDIATE CASING, IT MIGHT BE POSSIBLE TO USE THIS CASING WITH NO FURTHER ISSUES. ON THE OTHER HAND, ASSUMING THAT THIS WELL IS A CASED HOLE COMPLETION WITH A 7" LINER, WE WOULD NEED A LINER OF THE SAME RESISTANCE AT LEAST AS THE PRODUCTION CASING AS IT SEEMS CLEAR THAT THE 10 3/4" PRODUCTION CASING HAS BEEN DESIGNED FOR A HIGHER MAXIMUM EXPECTED BURST LOAD, SO THE 7" NEEDS A STRONGER CASING TYPE.

c) A CLOSED PIPE IS PRESSURIZED FROM THE INSIDE. DEFINE TWO FAILURE MODES, AND SHOW WHICH FAILURE MODE IS DOMINATING

THERE ARE TWO TYPES OF FAILURE MECHANISMS: AXIALLY AND TANGENTIALLY.

- AXIALLY $\sigma_a = \frac{1}{4} P \left(\frac{D_i}{t}\right)$

- TANGENTIALLY $\sigma_t = \frac{1}{2} P \left(\frac{D_i}{t}\right)$

THEREAFTER $\sigma_t = 2\sigma_a$ SO THE DOMINATING FAILURE MECHANISM IS TANGENTIALLY

3. HYDRAULICS

a) IN THE HYDRAULIC SYSTEM OF THE DRILLING RIG, IS THE FLOW MOSTLY LAMINAR OR MOSTLY TURBULENT. PROVIDE AN EXAMPLE

PROVIDING THAT WE ARE PUMPING AT A NORMAL PUMPING RATE AND WITH A CONVENTIONAL DRILLING FLUID IN THE HOLE, THIS IS NORMALLY WHAT THE SECTIONS LOOK LIKE THROUGHOUT THE WELLBORE:

SURFACE LINES	TURBULENT
DP, HWDP	TURBULENT
DC, BHA	TURBULENT
ANNULUS - BHA	TURBULENT
ANNULUS - DP	LAMINAR
RISER	LAMINAR
BIT	TURBULENT

BASED ON THIS WE COULD STATE THAT LOOKING REGIMES ON EACH SECTION, THE FLOW IS MOSTLY TURBULENT THROUGHOUT THE CIRCULATING SYSTEM

b) WHICH PARAMETER CONTRIBUTES MOSTLY TO THE PRESSURE DROP, VISCOSITY OR DENSITY OF THE DRILLING FLUID? EXPLAIN

VISCOSITY HAS A GREATER IMPACT ON THE FRICTIONAL PRESSURE LOSSES IN THE WELL. THIS IS SEEN FOR EXAMPLE IN THE INCREASE OF SPP WHEN THE PLASTIC VISCOSITY OF THE MUD INCREASES, AND ONE OF THE REASONS WHY FLAT-RHEOLOGY MUDS ARE USED FOR ECD MANAGEMENT IN DEEP WATER WELLS. VISCOSITY IS DIRECTLY RELATED TO SHEAR STRESS WHICH IN TURN IS CONNECTED TO A FRICTIONAL PRESSURE GRADIENT, AS FOLLOWING

$$\frac{\Delta P}{\Delta L} = F \cdot \frac{\rho \cdot V^2}{2D}$$ FOR LAMINAR NEWTONIAN FLOW $$F = \frac{64}{Re} = \frac{64\mu}{\rho V \cdot D}$$

COMBINING BOTH EQUATIONS WE OBTAIN

$$\frac{\Delta P}{\Delta L} = \left(\frac{64\mu}{\rho \cdot V \cdot D}\right)\left(\frac{\rho V^2}{2D}\right) = \frac{32 \cdot \mu \cdot V}{D^2}$$ INDEPENDENT OF ρ

c) COMPARING ORDINARY ROTARY DRILLING WITH DRILLING WITH A MOTOR, ARE THERE ANY DIFFERENCES? IF YES, IDENTIFY THE IMPORTANT

FROM THE HYDRAULICS POINT OF VIEW, THE MAIN DIFFERENCE IS RELATED TO THE ROTATION OF THE PIPE. DRILLING WITH A MUD MOTOR IMPLIES THAT ONLY THE SECTION BENEATH THE MUD MOTOR ROTATES (SLIDING); WHEREAS ORDINARY ROTARY DRILLING ROTATES THE ENTIRE STRING WHICH AIDS SIGNIFICANTLY TO IMPROVE HOLE CLEANING PARTICULARLY IN HIGHLY DEVIATED WELLS.

d) THE DRILLSTRING STRING IS CHANGED FROM 3½" TO 5" IN A WELL. IDENTIFY 3 IMPROVEMENTS IN THE HYDRAULIC SYSTEM

1. LOWER FRICTIONAL LOSSES INSIDE THE STRING, ALTHOUGH THEY MIGHT INCREASE IN THE ANNULUS, THERE IS AN OVERALL REDUCTION OF THE SPP. NEED TO BE CAREFUL WITH THE ECD INCREASE
2. IMPROVED HOLE CLEANING SINCE THE ANNULAR VELOCITY INCREASES DUE TO SMALLER CROSS SECTIONAL AREA
3. REDUCTION OF THE ECCENTRICITY OF THE PIPE WHICH COMBINED WITH ROTATION CONTRIBUTES TO THE PREVENTION OF BED CUTTINGS DEPOSITS

e) DEFINE AN EQUATION FOR MECHANICAL POWER AND ONE FOR HYDRAULIC POWER.

- HYDRAULIC POWER $$HP = \Delta P_{HYD} \cdot q = \rho_{FLUID} \cdot g \cdot h \cdot q$$
- MECHANICAL POWER $$P = \frac{W}{t} = \frac{F \cdot d}{t} = F \cdot V = m \cdot a \cdot V = m \cdot V \cdot \frac{dV}{dt}$$

4. MUD WEIGHT OPTIMIZATION

a) DEFINE THE TWO CLASSICAL LIMITS FOR THE MUD WEIGHT. WHAT ARE THE FAILURE MECHANISMS

- LOWER LIMIT — COLLAPSE PRESSURE — COLLAPSE IS A SHEAR FAILURE
- UPPER LIMIT — FRACTURE PRESSURE — FRACTURE IS A TENSILE FAILURE

NOTE THAT THE LOWER LIMIT IS DEFINED FROM WELLBORE STABILITY PERSPECTIVE, ANOTHER EQUALLY IMPORTANT PARAMETER IS THE PORE PRESSURE.

b) USING A SIMPLE FRACTURING EQUATION, DEFINE THE NEW OPTIMIZATION CRITERION PRESENTED IN THIS COURSE. WHAT IS THIS CRITERION CALLED?

$$\sigma_a = \frac{1}{2}(P_{wf} + P_o)$$

THIS IS CALLED THE MEDIAN LINE PRINCIPLE AND STATES THAT THE MID-POINT BETWEEN THE FRACTURE AND THE PORE PRESSURE DEFINES THE WELL PRESSURE THAT IS CLOSEST TO THE IDEAL IN-SITU STRESS.

c) DEFINE TWO ADVANTAGES OF USING THIS CRITERION. ALSO DEFINE TWO CONCERNS

ADVANTAGES:
1. LEAST DISTURBANCE OF THE IMMEDIATE SURROUNDING BOREHOLE
2. HOLE DIAMETER WILL REMAIN CONSTANT.

CONCERNS:
1. RELIABILITY OF THE PORE AND FRACTURE PRESSURE PROGNOSIS
2. INABILITY TO MONITOR THE PORE PRESSURE IN PERMEABLE INTERVALS
3. LOW MW IS PREFERRED TO PERFORM LOT.
4. IN THE FIELD APPLICATION WEIGHING UP THE MUD IN SHORT INTERVALS MIGHT BE CHALLENGING

5. ONE PROBLEM WITH SUBSEA WELLHEADS IS THE POTENTIAL OF TRAPPED PRESSURES. THE PRESSURE INSIDE THE B-ANNULUS MAY INCREASE DUE TO THERMAL EFFECTS. IN THE FOLLOWING YOU ARE ASKED TO INVESTIGATE THIS:

a) SHOW THE RELATIONSHIP BETWEEN PRESSURE INCREASE AND TEMPERATURE INCREASE. EXPLAIN THE CONDITIONS FOR THE EQUATION

FIRST $\frac{\Delta V}{V} = \frac{1}{2}\alpha \Delta T$ AND $\Delta P = \left(\frac{-1}{c}\right) \cdot \frac{\Delta V}{V}$

COMBINING BOTH EXPRESSIONS $\Delta P = -\frac{1}{2} \cdot \frac{\alpha}{c} \Delta T$ WHERE α: HEAT EXPANSION COEFFICIENT
c: COMPRESSIBILITY OF FLUID

THE ASSUMPTIONS OF THIS EXPRESSION ARE:
- MASS OF FLUID REMAINS CONSTANT
- EXPANSION OF PIPE AND ROCK ARE NEGLECTED
- CLOSED ANNULUS
- ANNULUS IS CONSIDERED THERMALLY ISOLATED.

b) ASSUME THAT THE COEFFICIENT OF THERMAL EXPANSION IS 3×10^{-4} (1/°C), AND THE COMPRESSIBILITY COEFFICIENT IS -3×10^{-5} (1/bar). COMPUTE THE PRESSURE INCREASE IF BHT REMAINS CONSTANT BUT THE SURFACE TEMPERATURE HAS INCREASED 100 °C

FROM THE ABOVE EQUATION $\Delta P = -\frac{1}{2}\left(\frac{3 \times 10^{-4}\ \text{bar}}{-3 \times 10^{-5}\ °C}\right)(100\ °C) = 500\ \text{bar}$