Homework 6 Solutions

Problem 1

The following data corresponds to a leak-off test in an offshore well in the Gulf of Mexico.

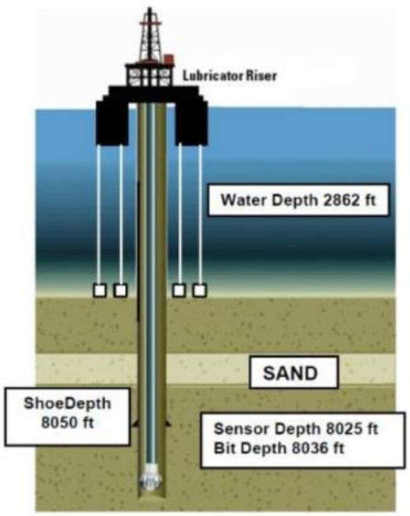
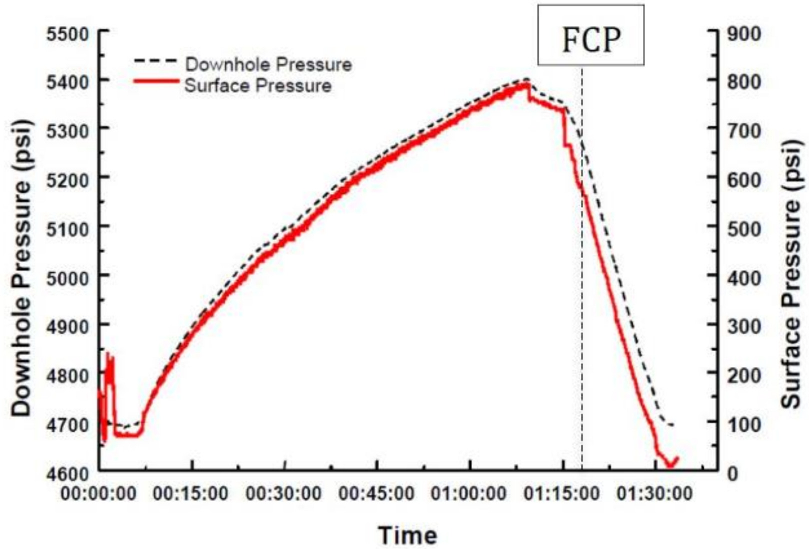


Fig. 5 – Schematic of Auger TLP Well Configuration



a) Estimate S_v at the shoe depth (TVDSS = 8050 ft).

We assume the pore pressure gradient is 0.44 psi/ft and the overburden gradient is 1 psi/ft.

S_v at 8050 ft is the summation of the overlying hydrostatic head of water and the remaining pressure head to that depth:

$$S_v = 2862 \times 0.44 + (8050 - 2862) \times 1 = 6447psi$$

b) Assuming the pore pressure is P_p = 4700 psi, and fracture closure occurs at time 1:18:00, calculate effective vertical stress σ_v and minimum effective stress σ_3.

At 1:18:00, the downhole pressure is approximately 5270 psi and the surface pressure is 550 psi.

$$\sigma_V = S_v - P_p = 6447 - 4700 = 1747psi$$

$$\sigma_{hmin} = P_{FCP} - P_p = 5270 - 4700 = 570psi$$

c) What is the faulting regime? Calculate the effective stress anisotropy ratio σ_v/σ_{hmin}.

Faulting regime is normal since $\sigma_v > \sigma_{hmin}$

$$\frac{\sigma_v}{\sigma_{hmin}} = \frac{1747}{570} = 3.06$$

d) What is the density of the drilling mud?

$BHP = 4600psi$ since downhole pressure reading at time 00:00:00 is 4700 psi and the surface pressure is approximately 100 psi

$$\rho_m = \frac{BHP}{8050ft} \times \frac{8.33ppg}{0.44psi/ft} = 10.81ppg$$

Problem 2

Download the file "MicrofracData.xls" which corresponds to a minifrac field test. The pressure reading corresponds to surface pressure.

a) Plot surface pressure and injection rate in a double y-axis plot as a function of time. Plot the entire interval and make a zoom from 70 to 90 min. TVD is 7503 ft

In [1]:
```
import pandas as pd

excel_file = 'HW6.xlsx'
DataQ2Summary = pd.read_excel(excel_file, sheet_name="Q2")
DataQ2Summary.head(721)
```

Out[1]:

	Time (minutes)	Sqrt(Time)	Pressure(psi)	Rate (gpm)
0	70.2900	8.383913	1332.848	0.000
1	70.3626	8.388242	1342.264	0.000
2	70.4220	8.391782	1353.660	0.000
3	70.4946	8.396106	1362.405	0.000
4	70.5474	8.399250	1369.632	0.000
5	70.6002	8.402393	1377.376	0.000
6	70.6596	8.405926	1467.873	0.000
7	70.7124	8.409067	1632.455	0.000
8	70.7652	8.412205	1867.525	0.000
9	70.8246	8.415735	2142.580	0.000
10	70.8972	8.420048	2213.464	0.000
11	70.9500	8.423182	2216.214	0.000
12	71.0028	8.426316	2228.248	0.165
13	71.0622	8.429840	2203.894	9.647
14	71.1150	8.432971	2229.238	14.729
15	71.1678	8.436101	2221.307	19.349
16	71.2470	8.440794	2213.090	20.988
17	71.2998	8.443921	2205.423	21.208
18	71.3526	8.447047	2207.029	23.078
19	71.4120	8.450562	2224.453	25.839
20	71.4120	8.450562	2229.337	29.392
21	71.5176	8.456808	2206.853	29.843
22	71.5176	8.456808	2203.124	27.929
23	71.6496	8.464609	2222.077	29.612
24	71.7024	8.467727	2207.315	29.557
25	71.7552	8.470844	2210.626	28.831
26	71.8146	8.474350	2210.582	30.294
27	71.8674	8.477464	2196.315	30.745
28	71.9202	8.480578	2202.893	30.800
29	71.9796	8.484079	2194.852	31.251

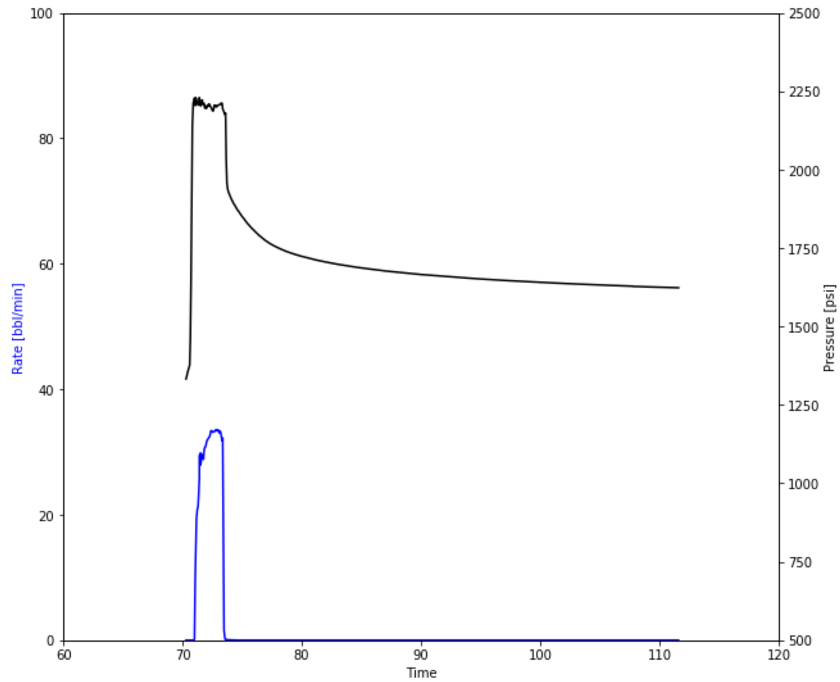
...	...	...	...	...
689	109.9098	10.483787	1625.371	0.000
690	109.9626	10.486305	1625.349	0.000
691	110.0220	10.489137	1625.250	0.000
692	110.0748	10.491654	1625.195	0.000
693	110.1474	10.495113	1625.096	0.000
694	110.2002	10.497628	1625.030	0.000
695	110.2596	10.500457	1624.975	0.000
696	110.3124	10.502971	1624.920	0.000
697	110.3652	10.505484	1624.843	0.000
698	110.4378	10.508939	1624.788	0.000
699	110.4972	10.511765	1624.722	0.000
700	110.5500	10.514276	1624.667	0.000
701	110.6028	10.516787	1624.590	0.000
702	110.6622	10.519610	1624.502	0.000
703	110.7150	10.522120	1624.458	0.000
704	110.7678	10.524628	1624.392	0.000
705	110.8470	10.528390	1624.315	0.000
706	110.8998	10.530897	1624.249	0.000
707	110.9526	10.533404	1624.172	0.000
708	111.0120	10.536223	1624.117	0.000
709	111.0648	10.538729	1624.040	0.000
710	111.1176	10.541233	1623.974	0.000
711	111.1902	10.544676	1623.897	0.000
712	111.2496	10.547493	1623.842	0.000
713	111.3024	10.549995	1623.765	0.000
714	111.3552	10.552497	1623.699	0.000
715	111.4146	10.555311	1623.644	0.000
716	111.4674	10.557812	1623.567	0.000
717	111.5400	10.561250	1623.501	0.000
718	111.5928	10.563749	1623.424	0.000

In [4]:

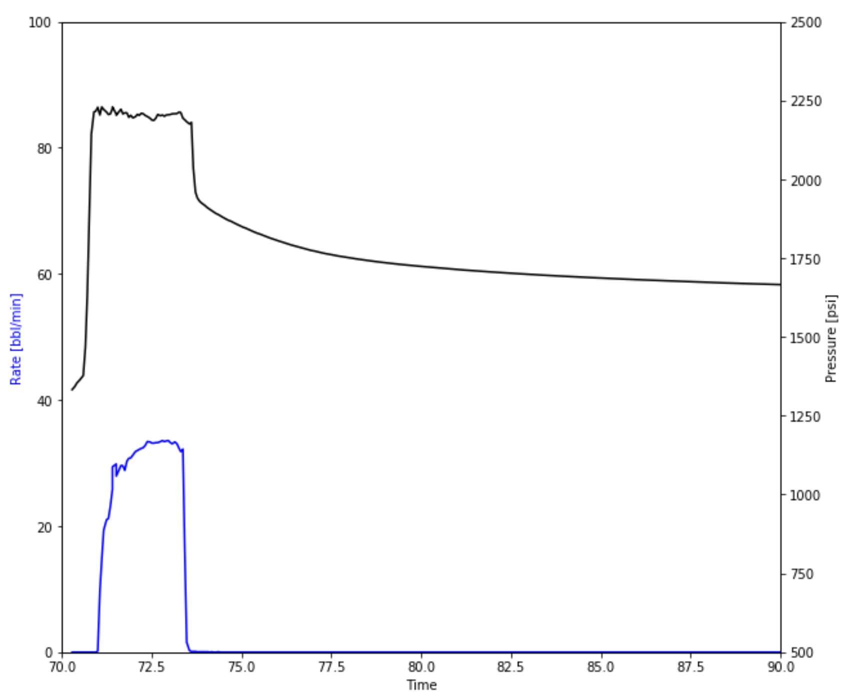
```
import numpy as np
import matplotlib.pyplot as plt

Time = DataQ2Summary['Time (minutes)']
SQRT_Time = DataQ2Summary['Sqrt(Time)']
Pressure = DataQ2Summary['Pressure(psi)']
Rate = DataQ2Summary['Rate (gpm)']

# Plot data
fig, ax1 = plt.subplots()
ax2 = ax1.twinx()
ax1.plot(Time, Rate, 'b-')
ax2.plot(Time, Pressure, 'k-')
# Plot labels
ax1.set_xlabel('Time')
ax1.set_ylabel('Rate [bbl/min]', color='b')
ax2.set_ylabel('Pressure [psi]', color='k')
# Axis range
plt.xlim([60, 120])
ax1.set_ylim(0, 100)
ax2.set_ylim(500, 2500)
plt.show()
# Change plot size
plt.rcParams["figure.figsize"] = (10,9)
```



In [5]:
```
# Plot data
fig, ax1 = plt.subplots()
ax2 = ax1.twinx()
ax1.plot(Time, Rate, 'b-')
ax2.plot(Time, Pressure, 'k-')
# Plot labels
ax1.set_xlabel('Time')
ax1.set_ylabel('Rate [bbl/min]', color='b')
ax2.set_ylabel('Pressure [psi]', color='k')
# Axis range
plt.xlim([70, 90])
ax1.set_ylim(0, 100)
ax2.set_ylim(500, 2500)
plt.show()
# Change plot size
plt.rcParams["figure.figsize"] = (10,9)
```



b) Find the instantaneous shut-in pressure (ISIP) and make a plot of surface pressure as a function of square root of time. Find the fracture closure pressure (FCP) [surface pressure].

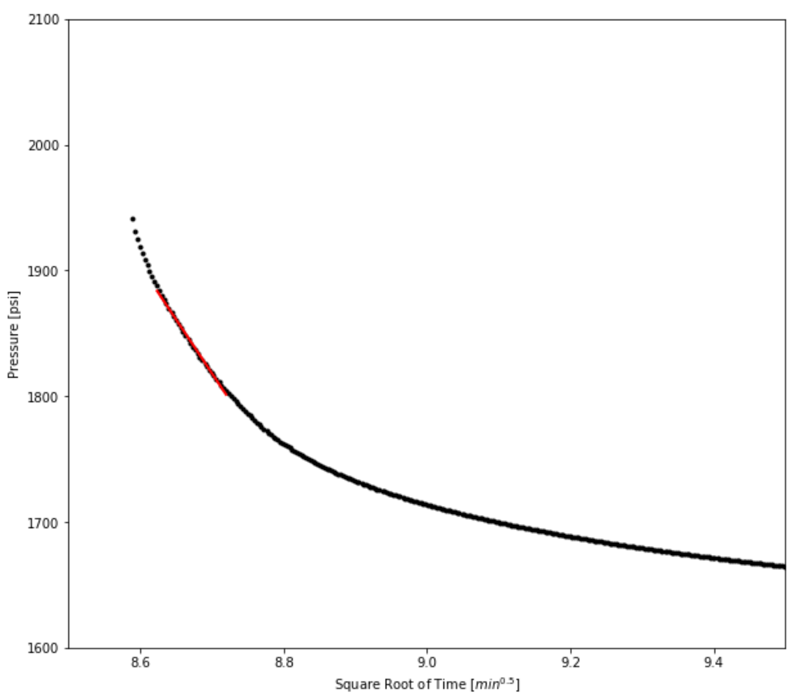
ISIP is 2035 psi

From the below figure, FCP is approximately 1800 psi (pressure at which pressure departs from linear portion)

In [4]:
```
import numpy as np
import matplotlib.pyplot as plt

# Segment of the data set to plot
SQRT_Time1 = SQRT_Time.iloc[60:720]
Pressure1 = Pressure.iloc[60:720]
# Segment of the data set for calculating FCP
SQRT_Time2 = SQRT_Time.iloc[70:100]
Pressure2 = Pressure.iloc[70:100]

# Plot data
plt.plot(SQRT_Time1, Pressure1, 'ok',markersize=3)
# Calculate the simple linear regression fit to find loading strain rate
coefficients = np.polyfit(SQRT_Time2, Pressure2, 1)
yy = np.poly1d(coefficients)
# plot trendline
plt.plot(SQRT_Time2,yy(SQRT_Time2),"-r",linewidth=2)
# Plot labels
plt.xlabel('Square Root of Time [$min^{0.5}$]')
plt.ylabel('Pressure [psi]', color='k')
# Axis range
plt.xlim([8.5, 9.5])
plt.ylim([1600, 2100])
plt.show()
# Change plot size
plt.rcParams["figure.figsize"] = (10,9)
```

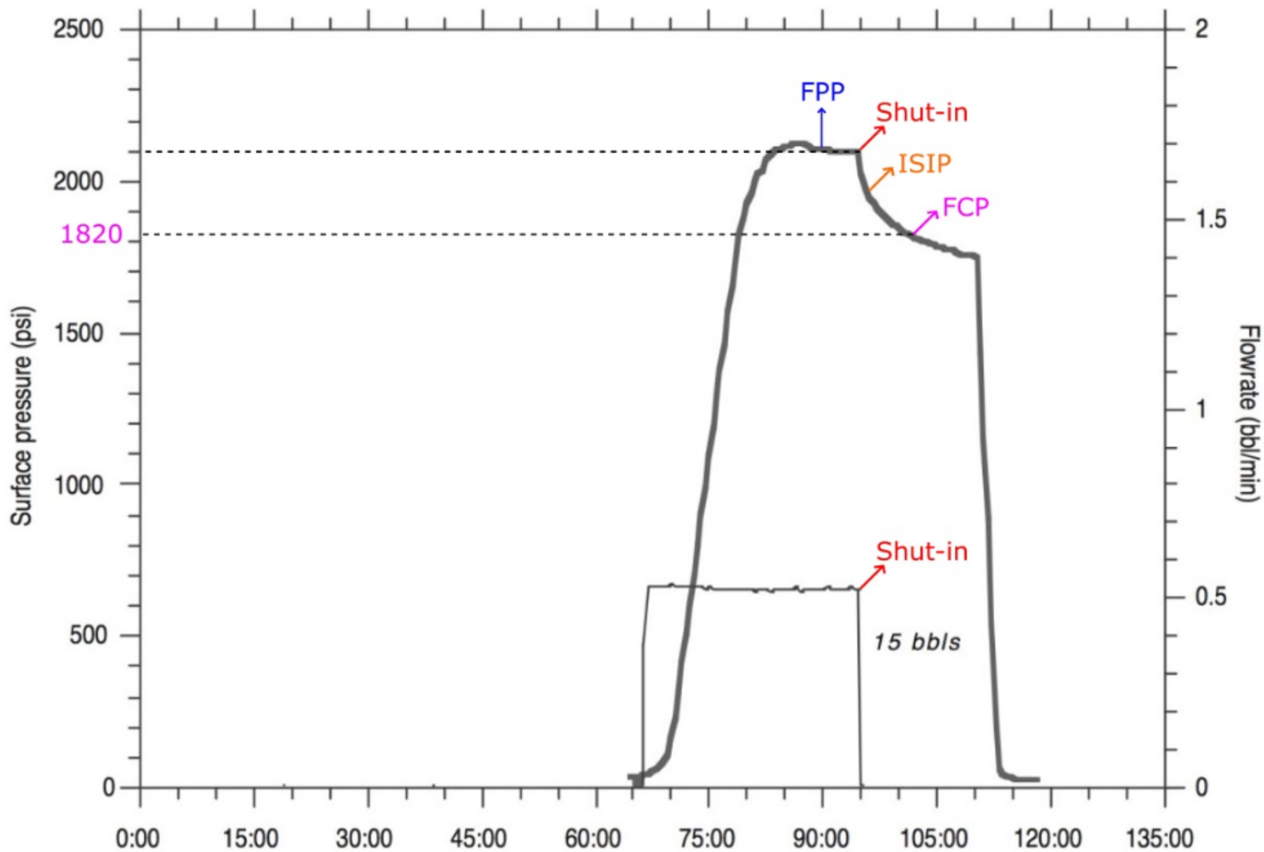


c) The true depth is 7,503 ft. Assuming a hydrostatic pressure gradient inside the wellbore of 0.44 psi/ft, calculate the minimum total principal stress S_3 in this place.

$$S_3 = FCP + P_W = 1800 + 0.44 \times 7503 = 5100psi$$

Problem 3

The figure below shows the results of a DFIT test (data from Zoback 2007).



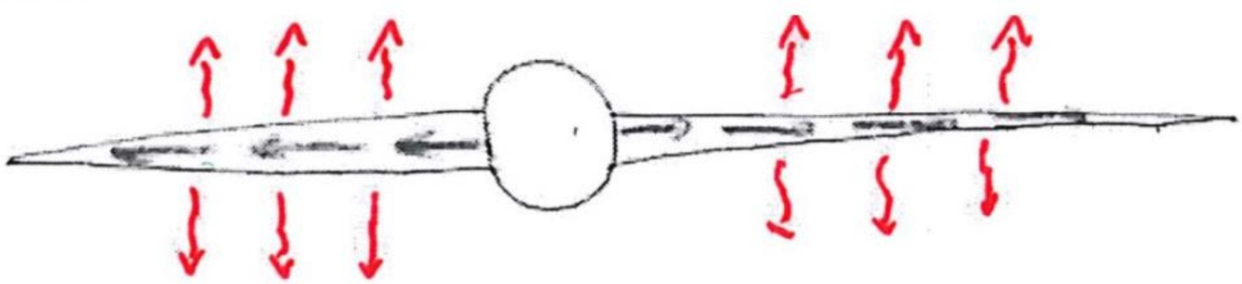
a) How many barrels of fracturing fluid were used in this test?

15 barrels of fracturing fluid

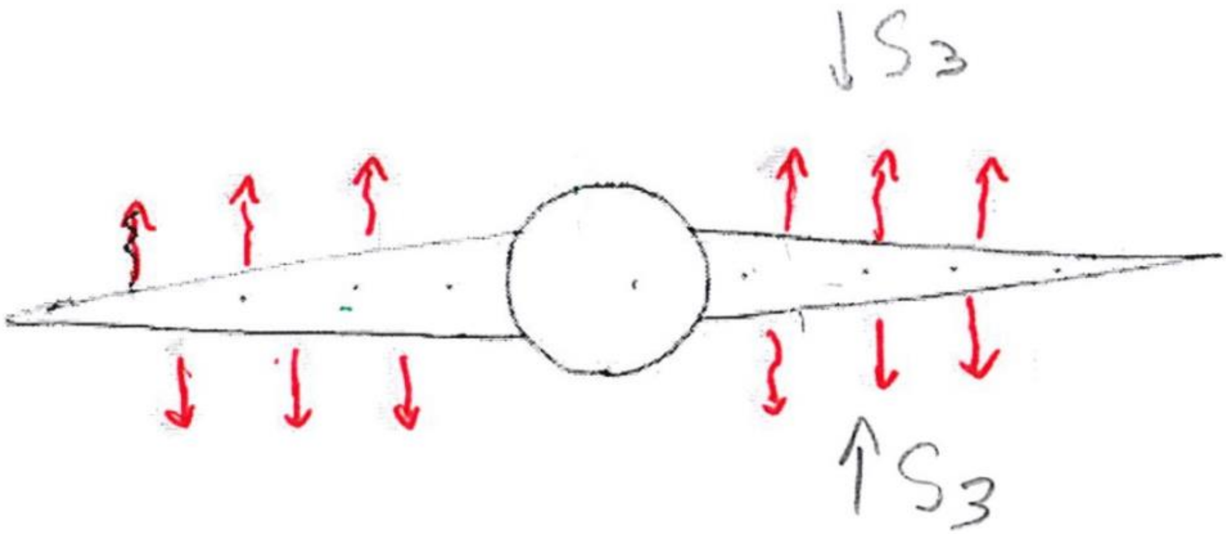
b) Indicate fracture propagation pressure (FPP), instantaneous shut-in pressure (ISIP) and fracture closure pressure (FCP) (as well as you can without analyzing the data in detail).

c) Describe and sketch the flow behavior around the wellbore before and after shut-in. ¶

Before shut-in,



After shut-in,



d) At surface pressure of 0 psi the bottom-hole pressure is 5,500 psi. What is the minimum principal stress in this formation?

Minimum principal stress is $S_3 = FCP + P_W = 1820 + 5500 = 7320psi$. Notice that the pressure needed for fracture propagation is a few hundred psi higher.

Problem 4

Interpret the following step-rate test data (i.e., find the formation parting pressure). Plot pressure vs. time for all steps.

In [5]:
```
import pandas as pd

excel_file = 'HW6.xlsx'
DataQ4Summary = pd.read_excel(excel_file, sheet_name="Q4_Data")
DataQ4Summary.head(14)
```

Out[5]:

	Step #	Test Rate [bbl/min]	Test Rate (% of Max Rate)	-	-.1	-.2	-.3	-.4	-.5	-.6	-.7
0	1	0.2	5	Time [min]	0	5	10	15	20	25	30
1	-	-	-	Pressure [psi]	0	99	105	108	109	110	110
2	2	0.4	10	Time [min]	0	5	10	15	20	25	30
3	-	-	-	Pressure [psi]	88	187	204	215	219	220	220
4	3	0.8	20	Time [min]	0	5	10	15	20	25	30
5	-	-	-	Pressure [psi]	209	358	424	431	438	439	440
6	4	1.6	40	Time [min]	0	5	10	15	20	25	30
7	-	-	-	Pressure [psi]	418	770	869	871	875	878	882
8	5	2.4	60	Time [min]	0	5	10	15	20	25	30
9	-	-	-	Pressure [psi]	825	1089	1133	1199	1265	1298	1321
10	6	3.2	80	Time [min]	0	5	10	15	20	25	30
11	-	-	-	Pressure [psi]	1210	1375	1459	1507	1529	1535	1540
12	7	4	100	Time [min]	0	5	10	15	20	25	30
13	-	-	-	Pressure [psi]	1485	1595	1650	1683	1727	1749	1760

In [6]:
```
import pandas as pd

excel_file = 'HW6.xlsx'
DataQ4Summary = pd.read_excel(excel_file, sheet_name="Q4_Plot1")
DataQ4Summary.head(55)
```

Out[6]:

	Step	Cumulative Time [min]	Time [min]	Pressure [psi]	Rate [bbl/min]
0	1	0	0.0	0.0	0.2
1	-	5	5.0	99.0	0.2
2	-	10	10.0	105.0	0.2
3	-	15	15.0	108.0	0.2
4	-	20	20.0	109.0	0.2
5	-	25	25.0	110.0	0.2
6	-	30	30.0	110.0	0.2
7	Pseudo	30	NaN	NaN	0.4
8	2	30	0.0	88.0	0.4
9	-	35	5.0	187.0	0.4
10	-	40	10.0	204.0	0.4
11	-	45	15.0	215.0	0.4
12	-	50	20.0	219.0	0.4
13	-	55	25.0	220.0	0.4
14	-	60	30.0	220.0	0.4
15	Pseudo	60	NaN	NaN	0.8
16	3	60	0.0	209.0	0.8
17	-	65	5.0	358.0	0.8
18	-	70	10.0	424.0	0.8
19	-	75	15.0	431.0	0.8
20	-	80	20.0	438.0	0.8
21	-	85	25.0	439.0	0.8
22	-	90	30.0	440.0	0.8
23	Pseudo	90	NaN	NaN	1.6

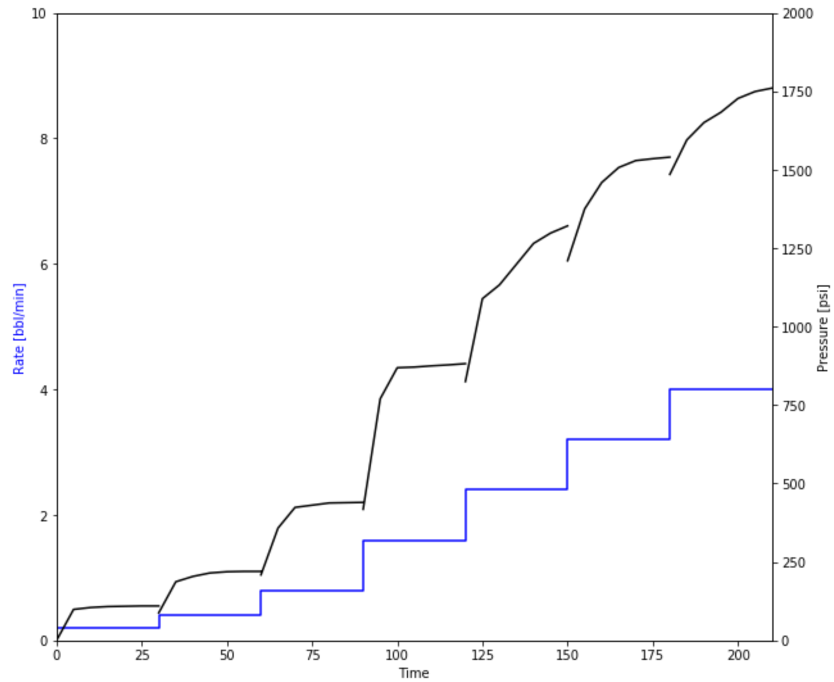
24	4	90	0.0	418.0	1.6
25	-	95	5.0	770.0	1.6
26	-	100	10.0	869.0	1.6
27	-	105	15.0	871.0	1.6
28	-	110	20.0	875.0	1.6
29	-	115	25.0	878.0	1.6
30	-	120	30.0	882.0	1.6
31	Pseudo	120	NaN	NaN	2.4
32	5	120	0.0	825.0	2.4
33	-	125	5.0	1089.0	2.4
34	-	130	10.0	1133.0	2.4
35	-	135	15.0	1199.0	2.4
36	-	140	20.0	1265.0	2.4
37	-	145	25.0	1298.0	2.4
38	-	150	30.0	1321.0	2.4
39	Pseudo	150	NaN	NaN	3.2
40	6	150	0.0	1210.0	3.2
41	-	155	5.0	1375.0	3.2
42	-	160	10.0	1459.0	3.2
43	-	165	15.0	1507.0	3.2
44	-	170	20.0	1529.0	3.2
45	-	175	25.0	1535.0	3.2
46	-	180	30.0	1540.0	3.2
47	Pseudo	180	NaN	NaN	4.0
48	7	180	0.0	1485.0	4.0
49	-	185	5.0	1595.0	4.0
50	-	190	10.0	1650.0	4.0
51	-	195	15.0	1683.0	4.0
52	-	200	20.0	1727.0	4.0
53	-	205	25.0	1749.0	4.0
54	-	210	30.0	1760.0	4.0

From the following plot, we can pick the maximum pressure at steady-state conditions

In [7]:
```
import numpy as np
import matplotlib.pyplot as plt

Time = DataQ4Summary['Cumulative Time [min]']
Pressure = DataQ4Summary['Pressure [psi]']
Rate = DataQ4Summary['Rate [bbl/min]']

# Plot data
fig, ax1 = plt.subplots()
ax2 = ax1.twinx()
ax1.plot(Time, Rate, 'b-')
ax2.plot(Time, Pressure, 'k-')
# Plot labels
ax1.set_xlabel('Time')
ax1.set_ylabel('Rate [bbl/min]', color='b')
ax2.set_ylabel('Pressure [psi]', color='k')
# Axis range
plt.xlim([0, 210])
ax1.set_ylim(0, 10)
ax2.set_ylim(0, 2000)
plt.show()
# Change plot size
plt.rcParams["figure.figsize"] = (10,9)
```



In [8]:
```
import pandas as pd

excel_file = 'HW6.xlsx'
DataQ4Summary = pd.read_excel(excel_file, sheet_name="Q4_Plot2")
DataQ4Summary.head(10)
```

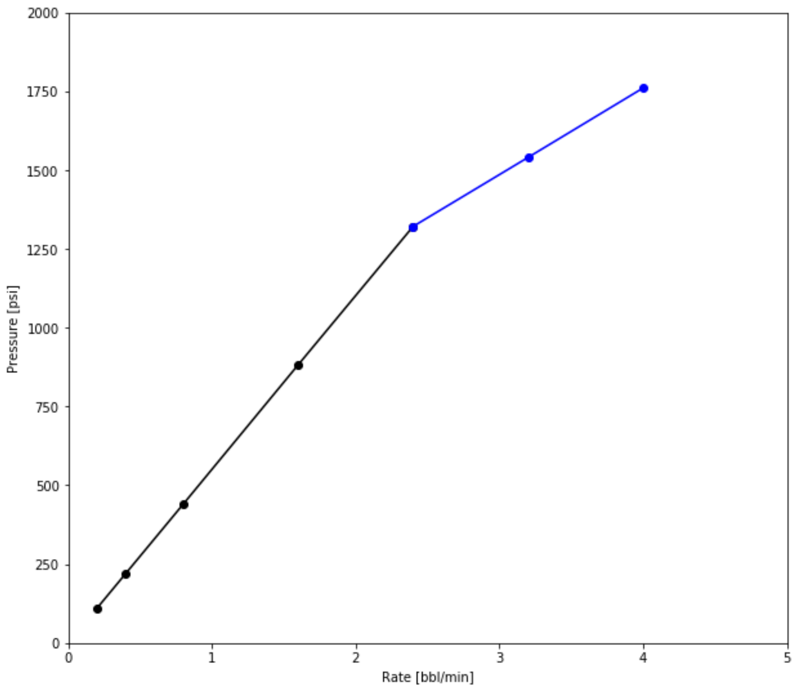
Out[8]:

	Rate [bbl/min]	Max Pressure [psi]
0	0.2	110
1	0.4	220
2	0.8	440
3	1.6	882
4	2.4	1321
5	3.2	1540
6	4	1760
7	-	-
8	Formation Parting Pressure [psi]	1318.75

In [9]:
```
import numpy as np
import matplotlib.pyplot as plt

Rate = DataQ4Summary['Rate [bbl/min]']
Pressure = DataQ4Summary['Max Pressure [psi]']
Rate1 = Rate.iloc[0:5]
Pressure1 = Pressure.iloc[0:5]
Rate2 = Rate.iloc[4:7]
Pressure2 = Pressure.iloc[4:7]

# Plot data
plt.plot(Rate1,Pressure1,'o-k')
plt.plot(Rate2,Pressure2,'o-b')
# Plot labels
plt.xlabel('Rate [bbl/min]')
plt.ylabel('Pressure [psi]')
# Axis range
plt.xlim([0, 5])
plt.ylim([0, 2000])
plt.show()
# Change plot size
plt.rcParams["figure.figsize"] = (10,3)
```



From above graph, the formation parting pressure is 1320 [psi], the intersection between the two trends.