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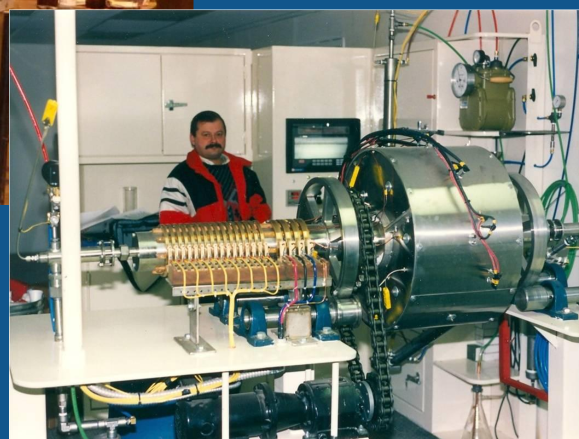
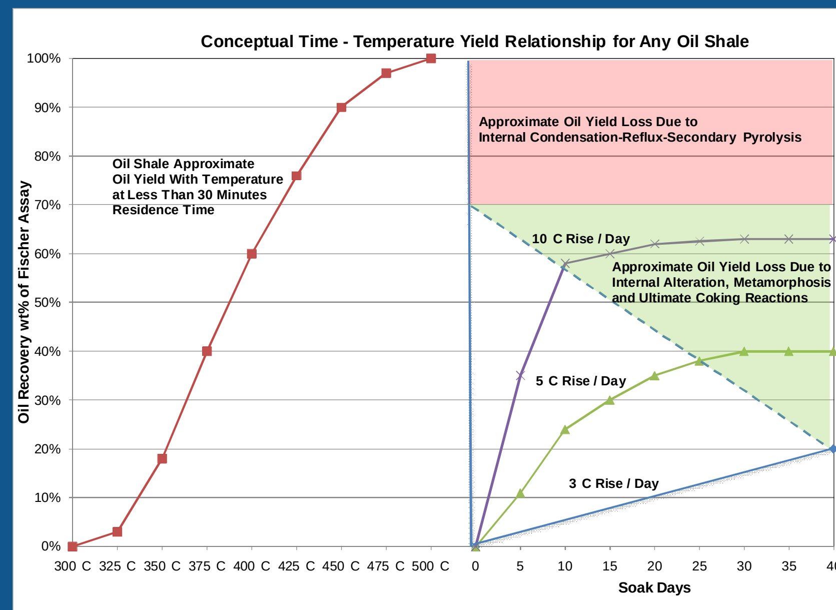
Oil Yield and Gas Compositions of Oil Shale Samples at Variable Time and Temperature





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UMATAC Industrial Processes
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Indications of Oil Shale Sensitivity to Temperature and Time

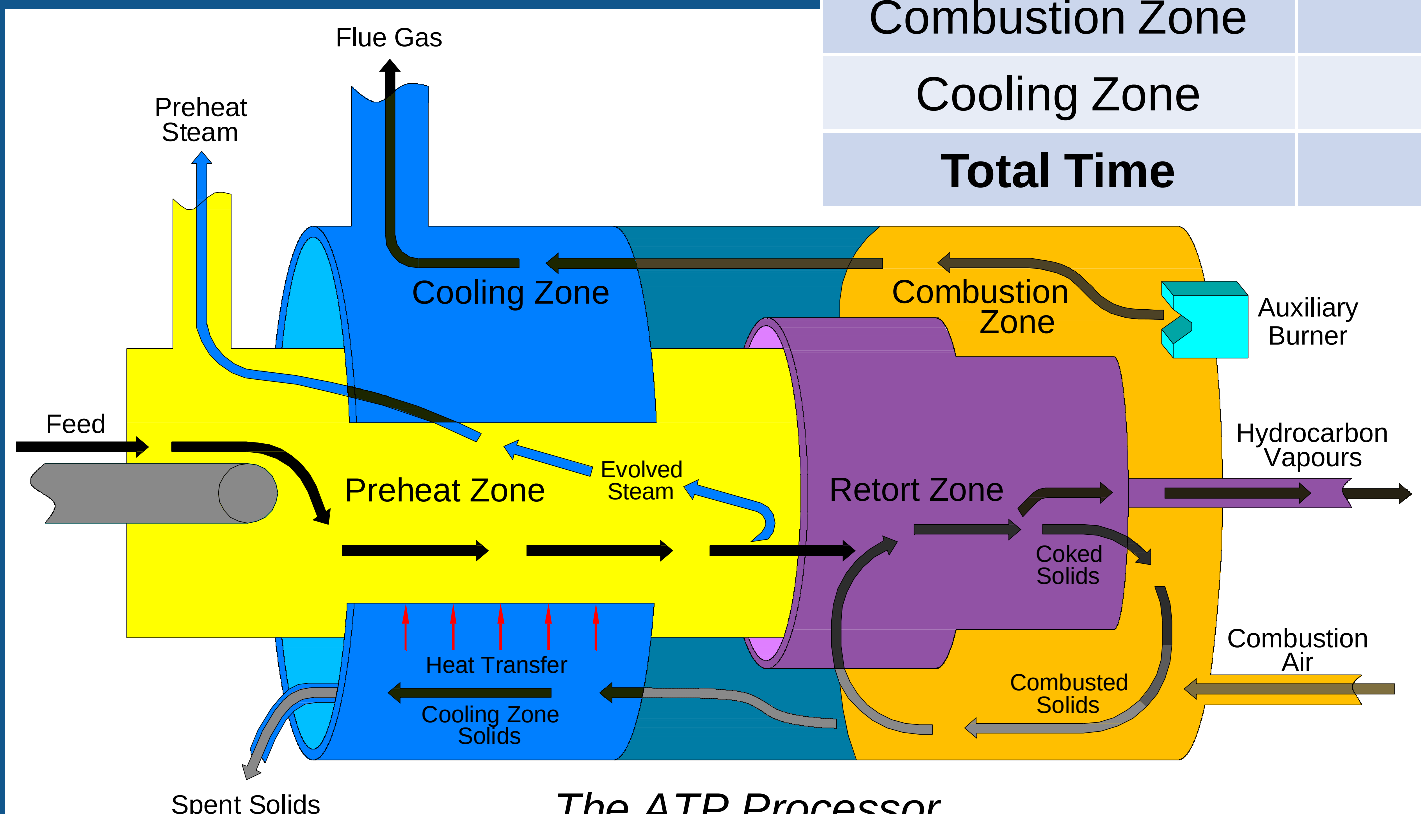
- Prolonged drying of oil shale at 150°C reduces Fischer assay oil yield.
- Prolonged drying of lignite coal at 150°C significantly reduces Fischer assay oil yield.
- Shale exposure to 200°C, as in the ATP preheat zone, results in some odorous gases.
- Shale exposure to 275°C for short periods results in condensate containing hydrocarbons.
- Certain shales have a faint bituminous smell when crushed indicating the presence of hydrocarbons.

Overall UMATAC Test Program to Evaluate Oil Shale Sensitivity to Time and Temperature

Test Series	Apparatus Used	Vapour Discharge Orientation	Duration of Test	Temperature of Test (°C)	Sample Used
A	ATP Batch Unit	Side	Various	150, 225, 300, 350, and 400	5 Oil Shales
B	Slow Soak	Top	50 – 70 days	150 – 560	5 Oil Shales
C	ATP Batch Unit	Side	Various	400	5 Oil Shales
D-1	Slow Soak	Bottom	1 day	20 – 560	Utah and Jordan Shales
D-2	Slow Soak	Bottom	5 – 20 days	20 – 560	Utah and Jordan Shales

ATP Processor Simplified Schematic

ATP Processor	Residence Time (minutes)
Preheat Zone	10 – 15
Retort Zone	5 – 8
Combustion Zone	6 – 12
Cooling Zone	10 – 20
Total Time	**31 – 55**



The ATP Processor

The ATP Processor in Gladstone, Australia

211 t/h ATP Processor at the Stuart Oil Shale Demonstration Facility

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Characteristics of the Five Oil Shales Tested

Item	Jordan	Utah	Fushun	Australia	Estonia
Sample Age (years)	11	3	5	14	8
Crushed Top Size (mm)	12	14	14	18	12
Moisture (wt%)	3-7	2-4	3-7	25-30	10-20
Modified Fischer Assay (LT0M C_4+)	135	140	90	125	110
C_6+ Oil Specific Gravity (g/mL)	0.95	0.94	0.89	0.90	0.94
Modified Fischer Assay (kg/t 0M)	125	130	80	112	103
Ultimate Analysis (dry basis)					
C (wt%)	19.60	18.90	13.60	19.24	17.14
H (wt%)	1.89	1.90	2.10	2.72	1.68
N (wt%)	0.39	0.50	0.81	0.55	0.36
S (wt%)	3.27	0.61	0.61	1.52	2.62
O (diff) (wt%)	9.85	10.9	5.76	5.27	9.75

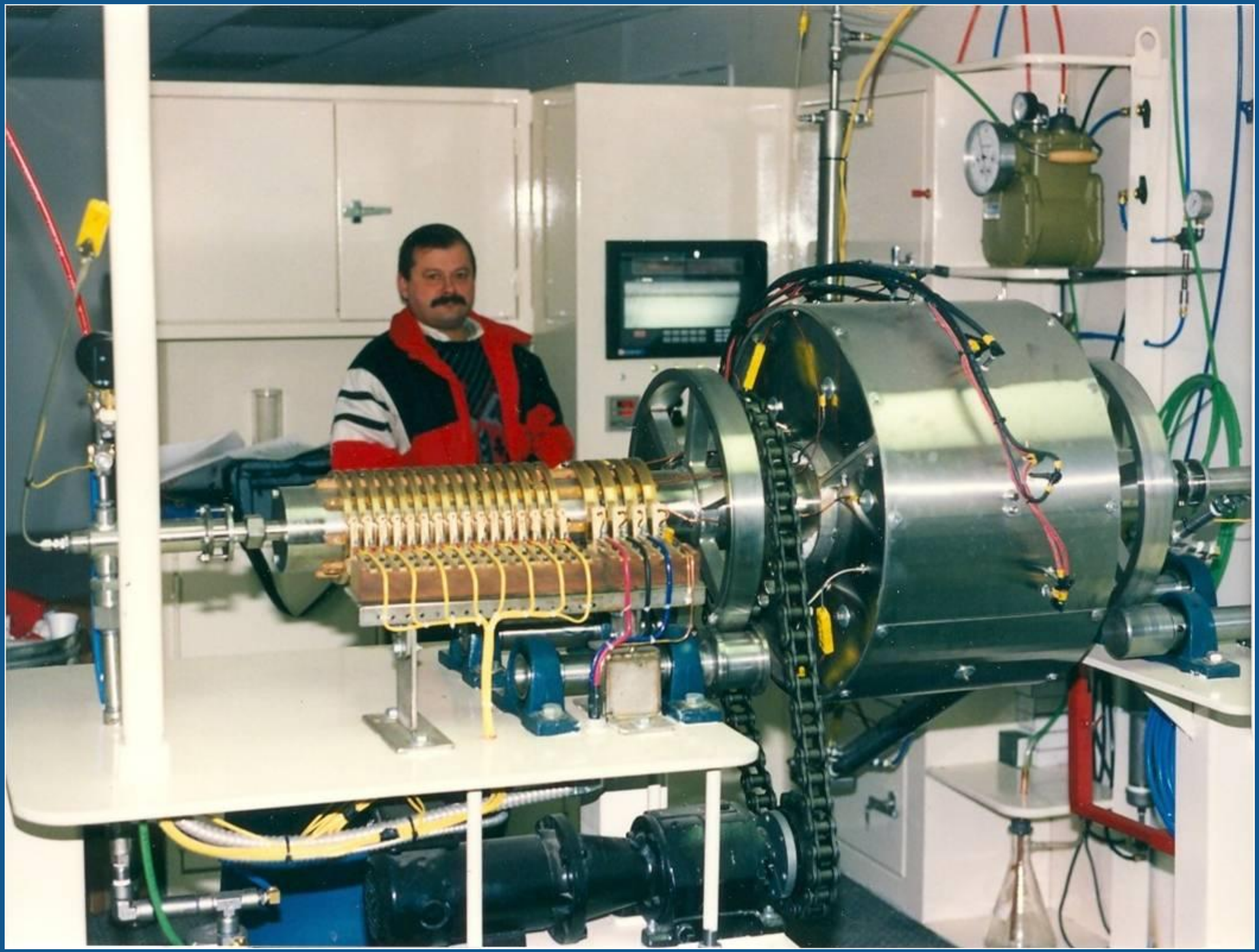
Characteristics of the Five Oil Shales Tested

Typical UMATAC – ATP Batch Unit (per 1000 kg feed)

Item	Jordan	Utah	Fushun	Australia	Estonia
C_6+ Oil (kg)	114	121	86	110	114
C_6- Gas (m^3)	36	33	37	32	36
Main Feature	High Sulfur Oil	High Limestone	Lowest Oil Content	High Moisture	Phenolic Oil

Crushed Jordan Oil Shale Sample

ATP Batch Unit – 2500 g Oil Shale Feed Capacity



Test Series A – Test Results for Jordan Oil Shale

Jordan Oil Shale Feed	150°C	225°C	300°C	350°C	400°C
Oil (mL)	0.0	0.0	0.0	4.6	30.0
Water (mL)	0.0	0.0	0.0	4.4	1.8
H_2S (vol %)	Trace	Trace	1%	30%	60%
CO_2 (vol %)	1%	2%	5%	15%	12%
C_6+ (vol %)	Present	0.5%	1.5%	2.0%	1.5%
C_1 – C_5	No Peaks	Slight	All	All	All
H_2 (vol %)	0.0	Trace	Trace	0.5%	2.0%
Odour	None	Musky	Faint HC	H_2S	Strong H_2S
Feed LOI* (wt%)					25.0
Product Solids LOI* (wt%)					19.6
LOI* Loss (wt%)					5.4

*LOI is Loss on Ignition at 600°C

Slow Soak Test Units

Pictured on the left are stainless steel containers used for the slow soak tests

Pictured on the right are the insulated and assembled stainless steel test units used for the slow soak tests

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Gas Analysis

Shown on the right is a tedlar gas bag, pump, and gas meter used during the analysis

Shown on the left are UMATAC's gas chromatographs – one is used to measure refinery gas and the other for hydrogen and methane

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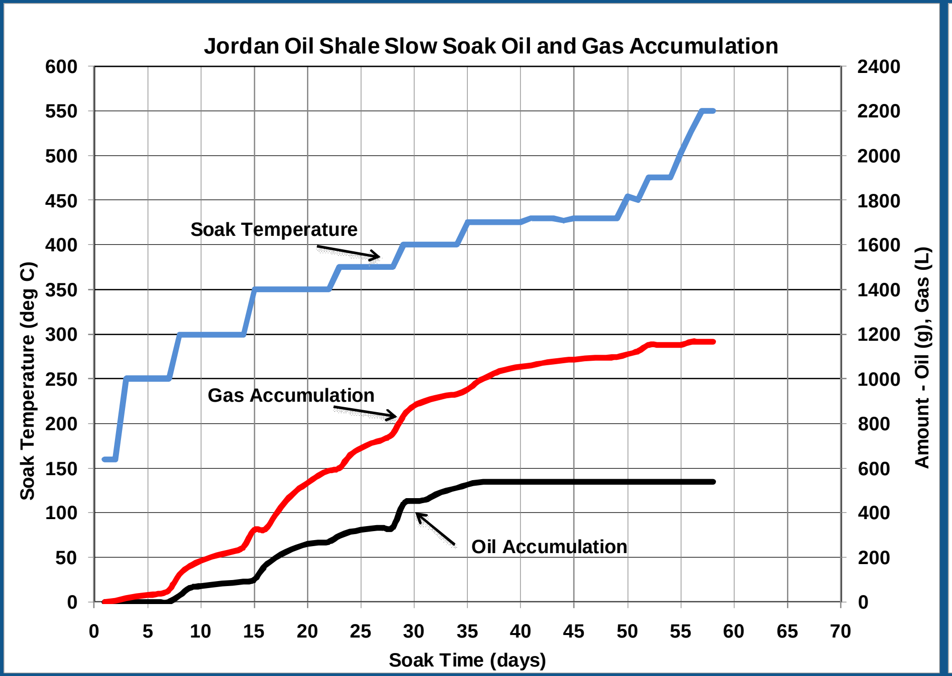
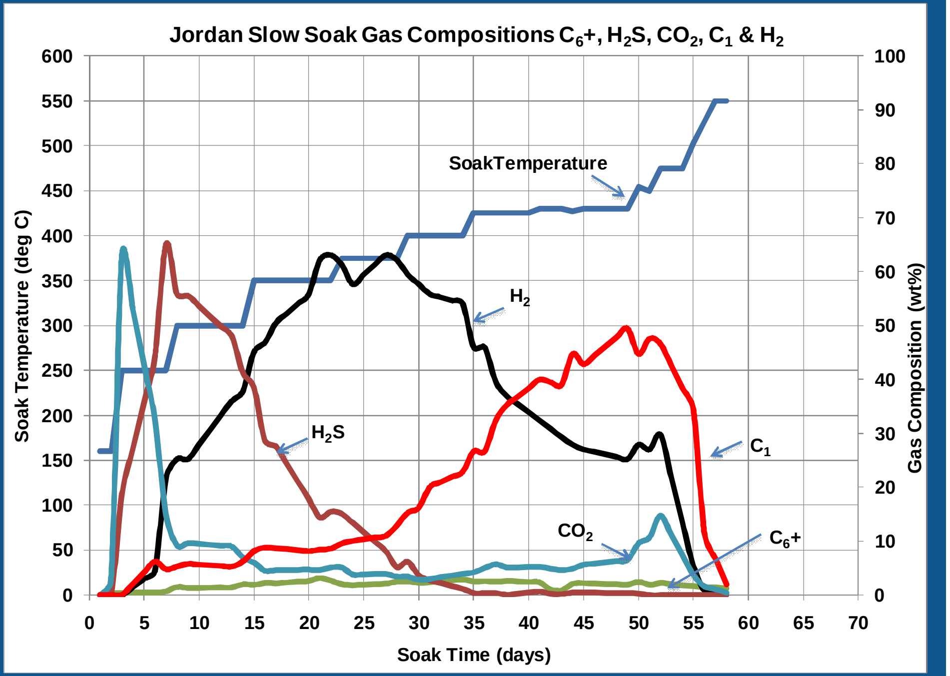
Series B – Jordan Oil Shale Slow Soak Testing

Jordan – 58 Day Soak – Oil and Gas Accumulations

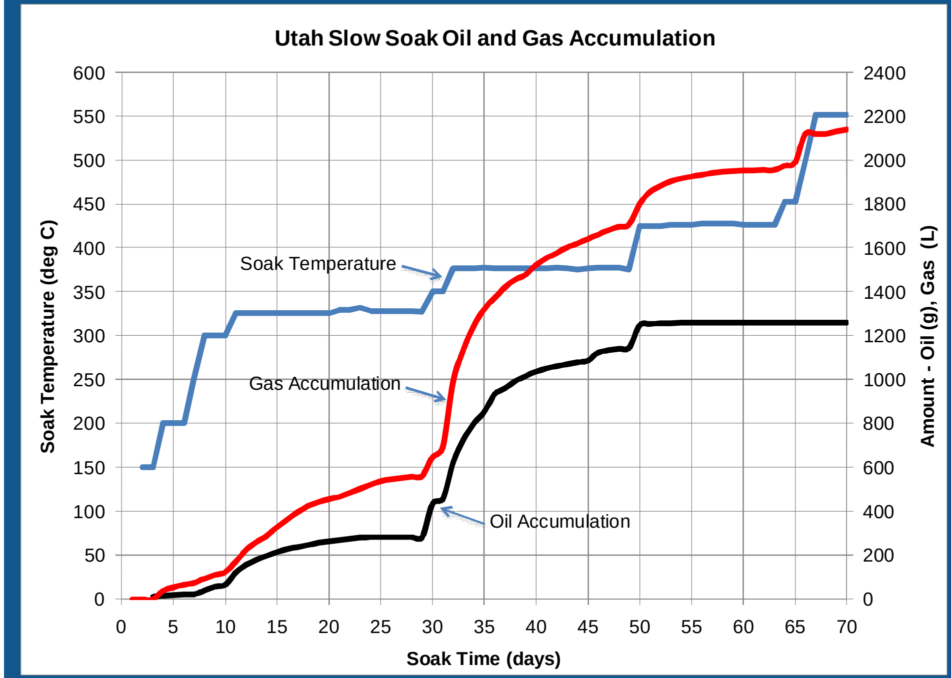


Jordan – 58 Day Soak – Off Gas Compositions

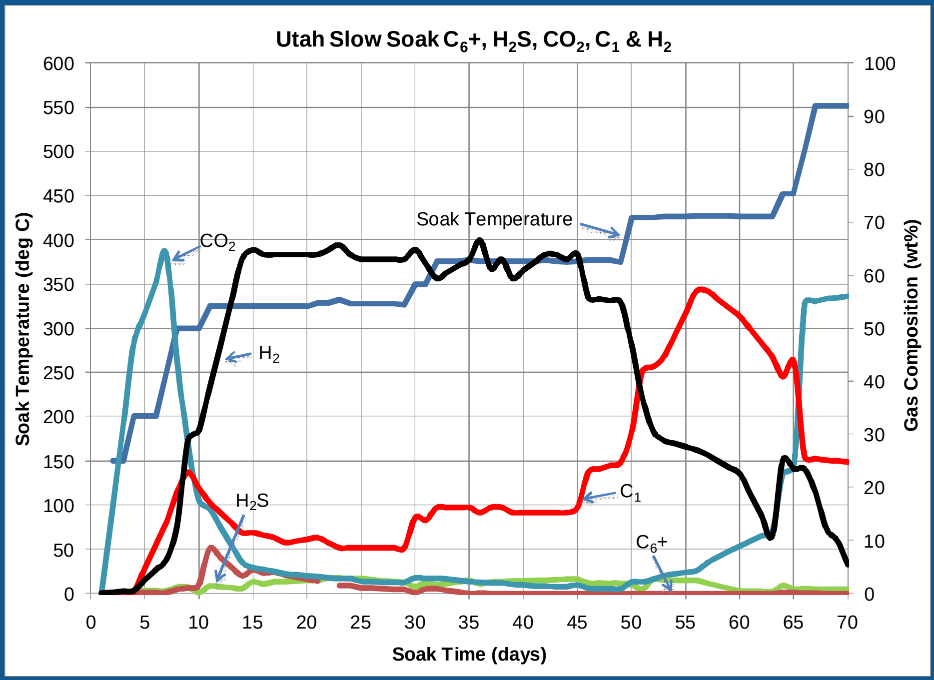


Series B – Utah Oil Shale Slow Soak Testing

Utah – 70 Day Soak – Oil and Gas Accumulations



Utah – 70 Day Soak – Off Gas Compositions



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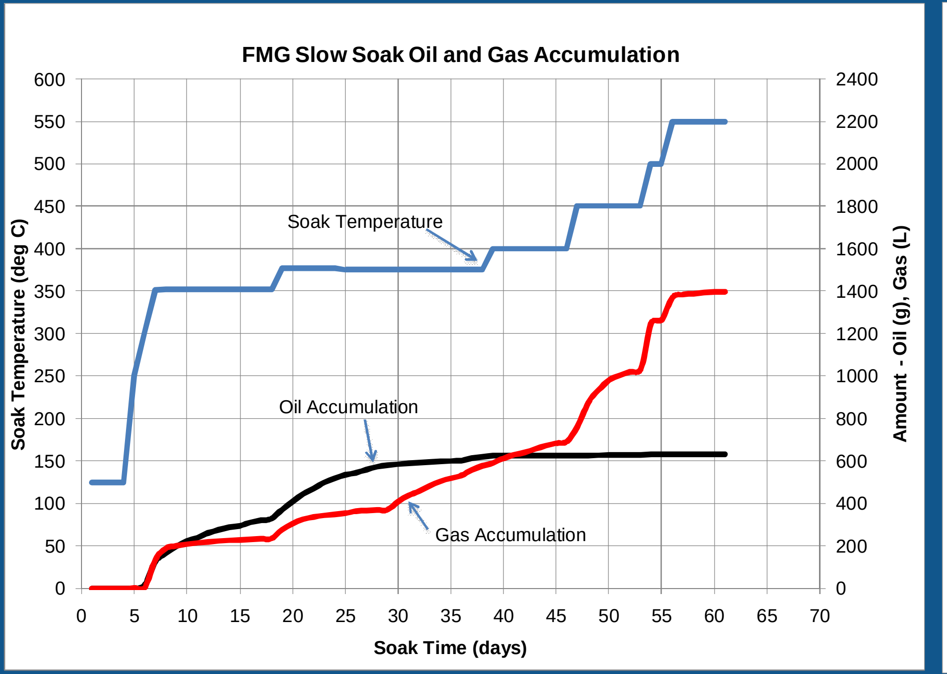
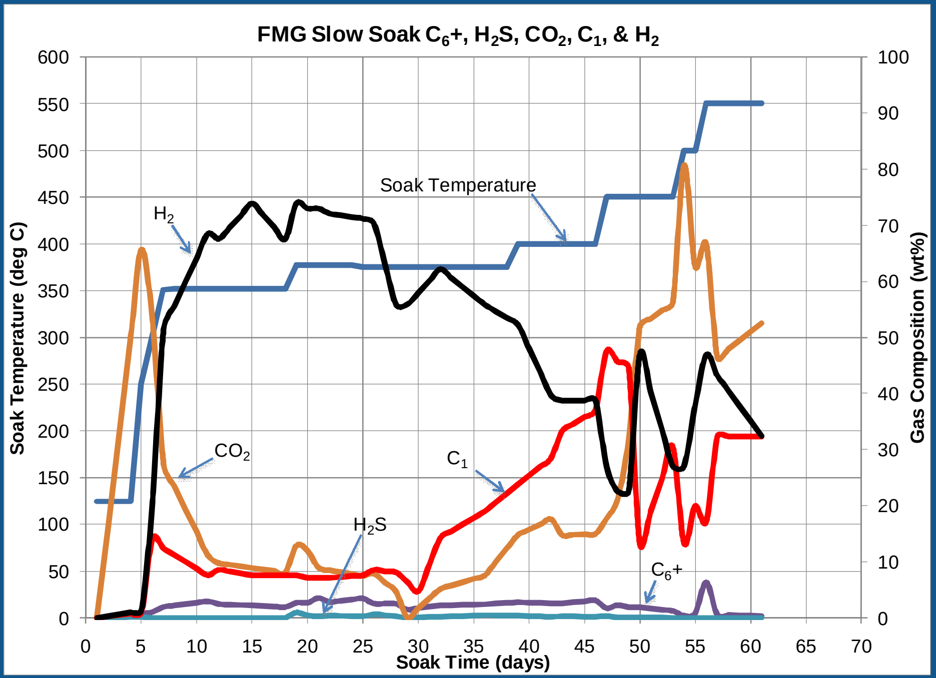
Series B – Fushun Oil Shale Slow Soak Testing

Fushun – 61 Day Soak – Oil and Gas Accumulations

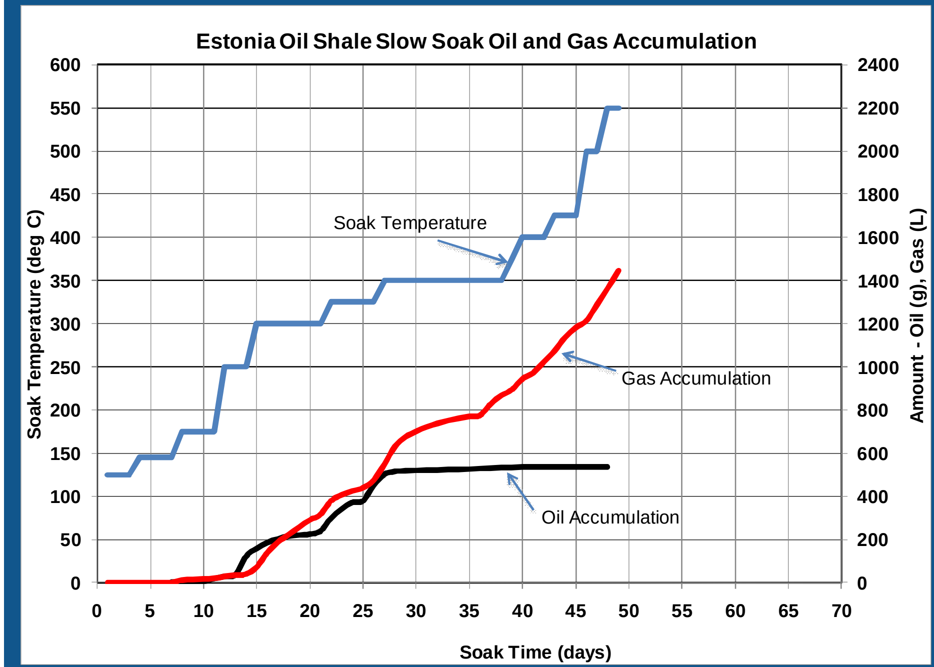


Fushun – 61 Day Soak – Off Gas Compositions

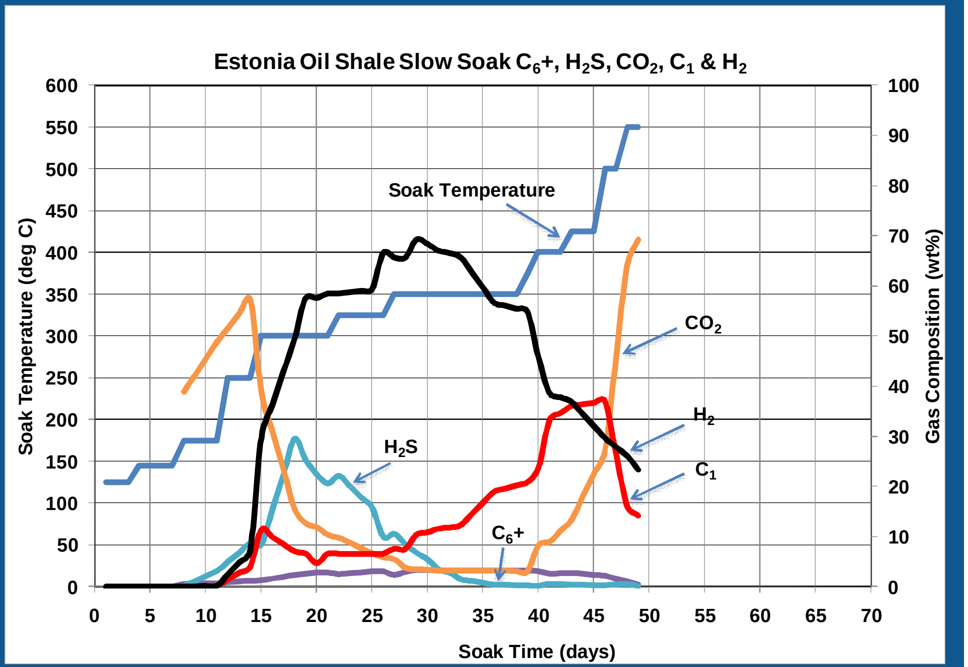


Series B – Estonia Oil Shale Slow Soak Testing

Estonia – 48 Day Soak – Oil and Gas Accumulations



Estonia – 48 Day Soak – Off Gas Compositions



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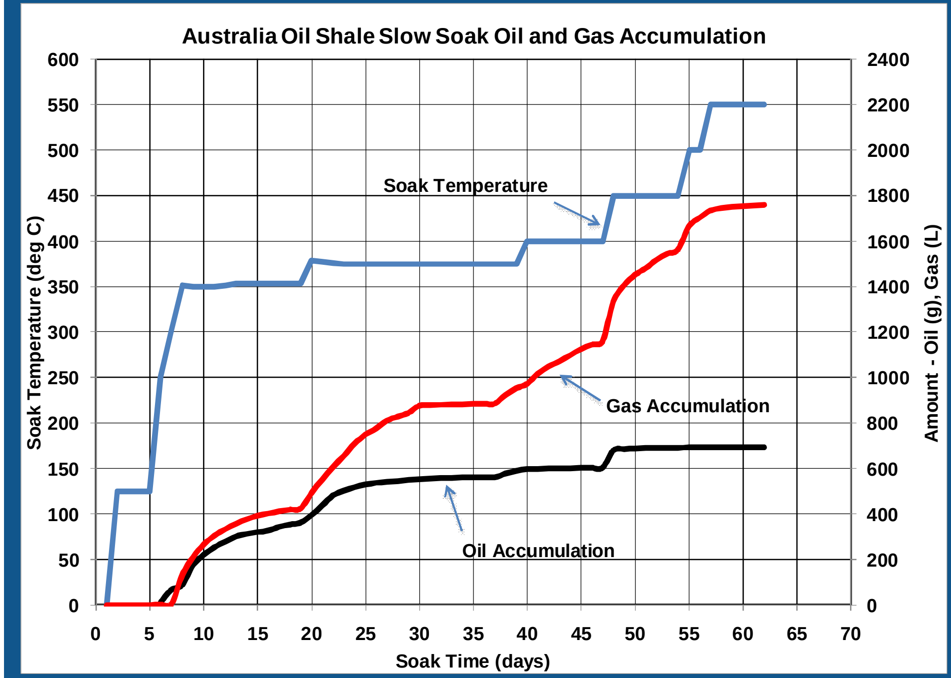
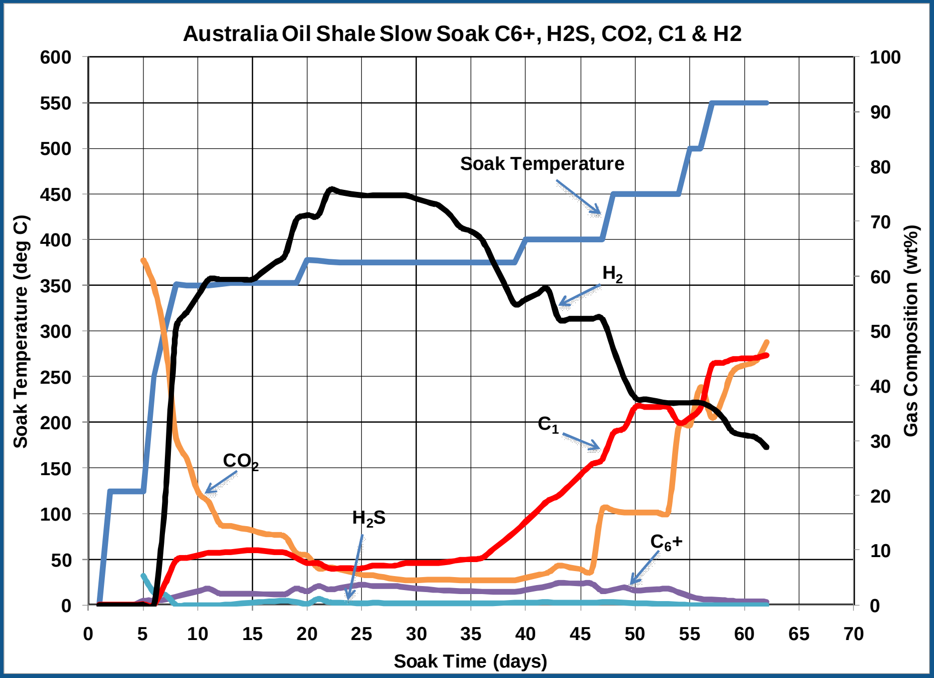
Series B – Australia Oil Shale Slow Soak Testing

Australia – 62 Day Soak – Oil and Gas Accumulations

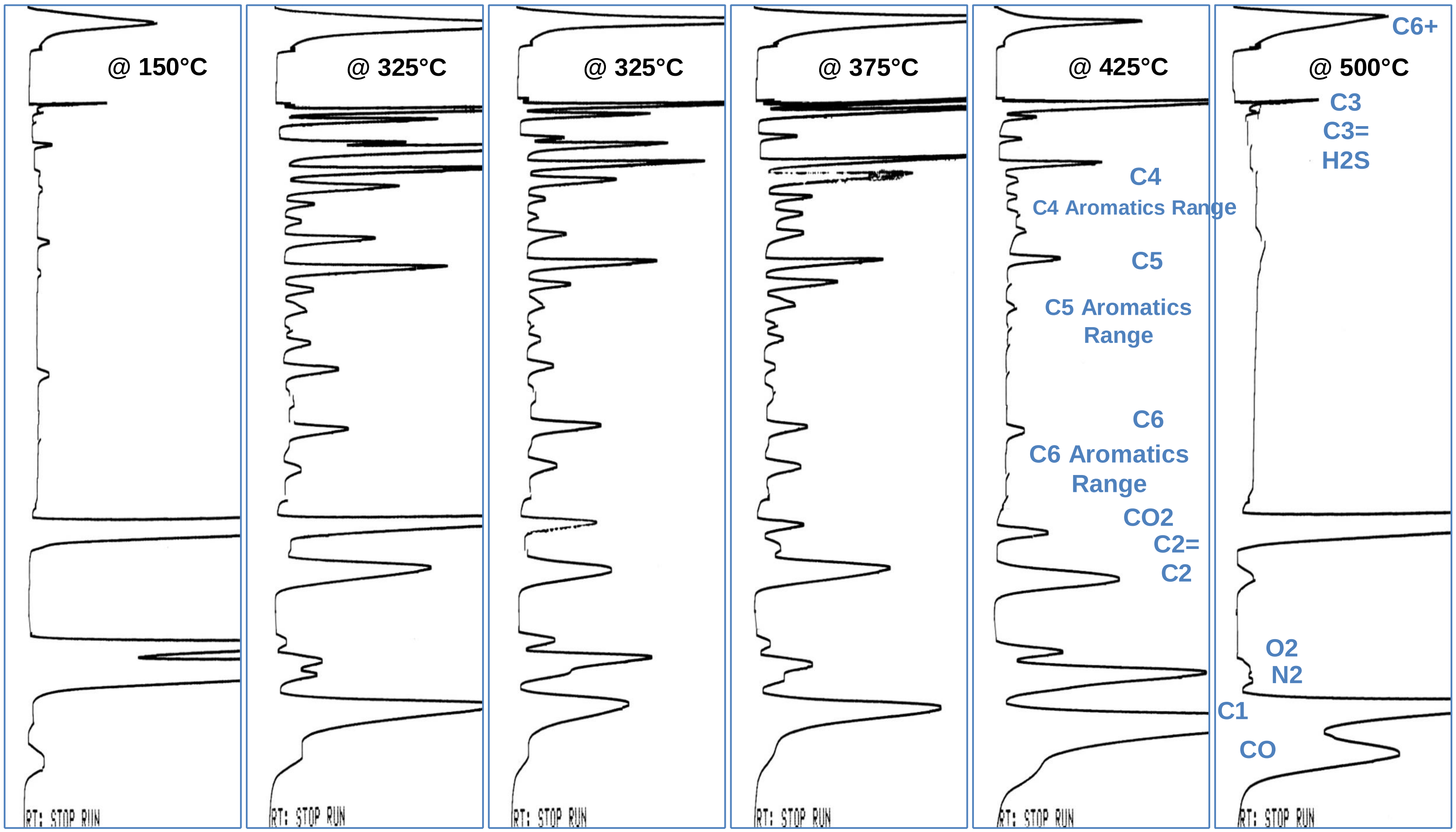


Australia – 62 Day Soak – Off Gas Compositions



Series B – Gas Chromatograph Traces

Utah Oil Shale Slow Soak Top Discharge Gas Chromatograph



Second GC:	Second GC.:	Second GC:	Second GC:	Second GC:	Second GC:
H_2 – 0.45%	H_2 – 39%	H_2 – 64%	H_2 – 67%	H_2 – 37%	H_2 – 23%
C1 – 0.29%	C1 – 17%	C1 – 9.5%	C1 – 15%	C1 – 42%	C1 – 26%

Series B – Slow Soak Tests Oil Yield Results

	C_6+ Liquid (LT0M kg/t)			% Recovery Slow Soak (referenced to Fischer)
	Fischer	ATP Batch	Slow Soak	
Jordan	125	114	21	17%
Utah	127	121	46	37%
Fushun	80	86	20	23%
Australia	112	110	24	22%
Estonia	103	114	19	17%

Series B – Slow Soak Tests Gas Yield Results

	Gas Volume (m^3/t)			
	Fischer	ATP Batch	Slow Soak	Ratio Referred to ATP Batch
Jordan	Not measured directly but included in the overall weight loss	36	72	2.0
Utah		33	108	3.3
Fushun		37	56	1.8
Australia		32	73	2.3
Estonia		36	61	1.7

Series B – Slow Soak Tests Specific Gravity of Oil Produced

	C_6+ Oil Specific Gravity (g/mL)			
	Fischer	ATP Batch	Slow Soak	
			325°C	375°C
Jordan	0.96	0.95	0.82	0.81 - 0.85
Utah	0.94	0.93	0.80 - 0.76	0.78 - 0.88
Fushun	0.89	0.87	0.77	0.78
Australia	0.90	0.89	0.78 - 0.80	0.92
Estonia	0.94	0.92	0.85	0.90

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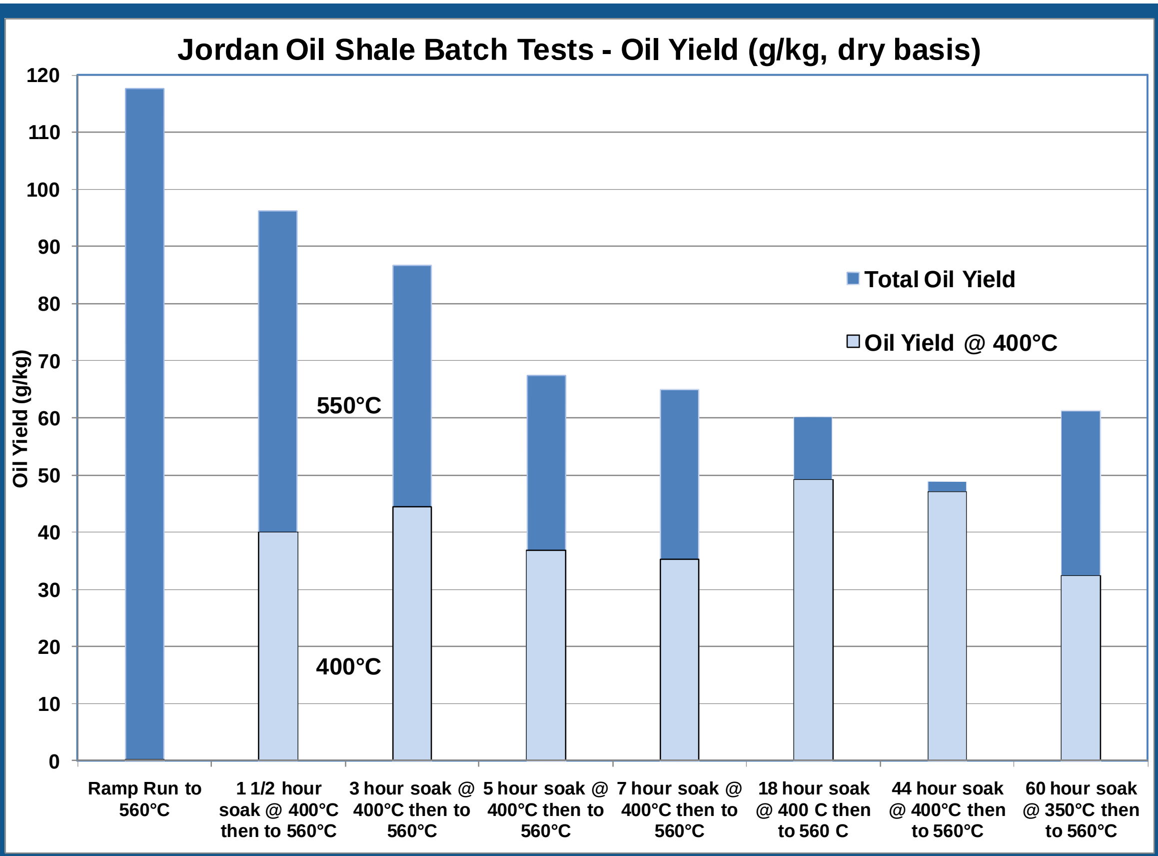
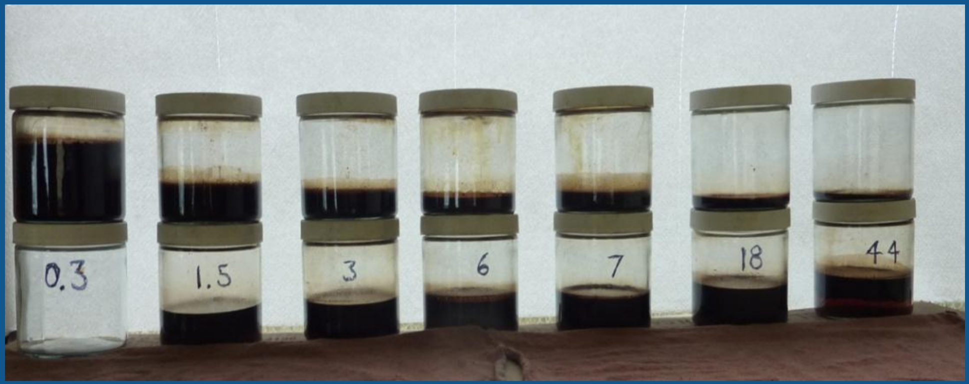
Test Series C

Jordan oil shale 400°C soak to accelerate alteration reaction on kerogen then rapid heating to 560°C to observe oil remaining.

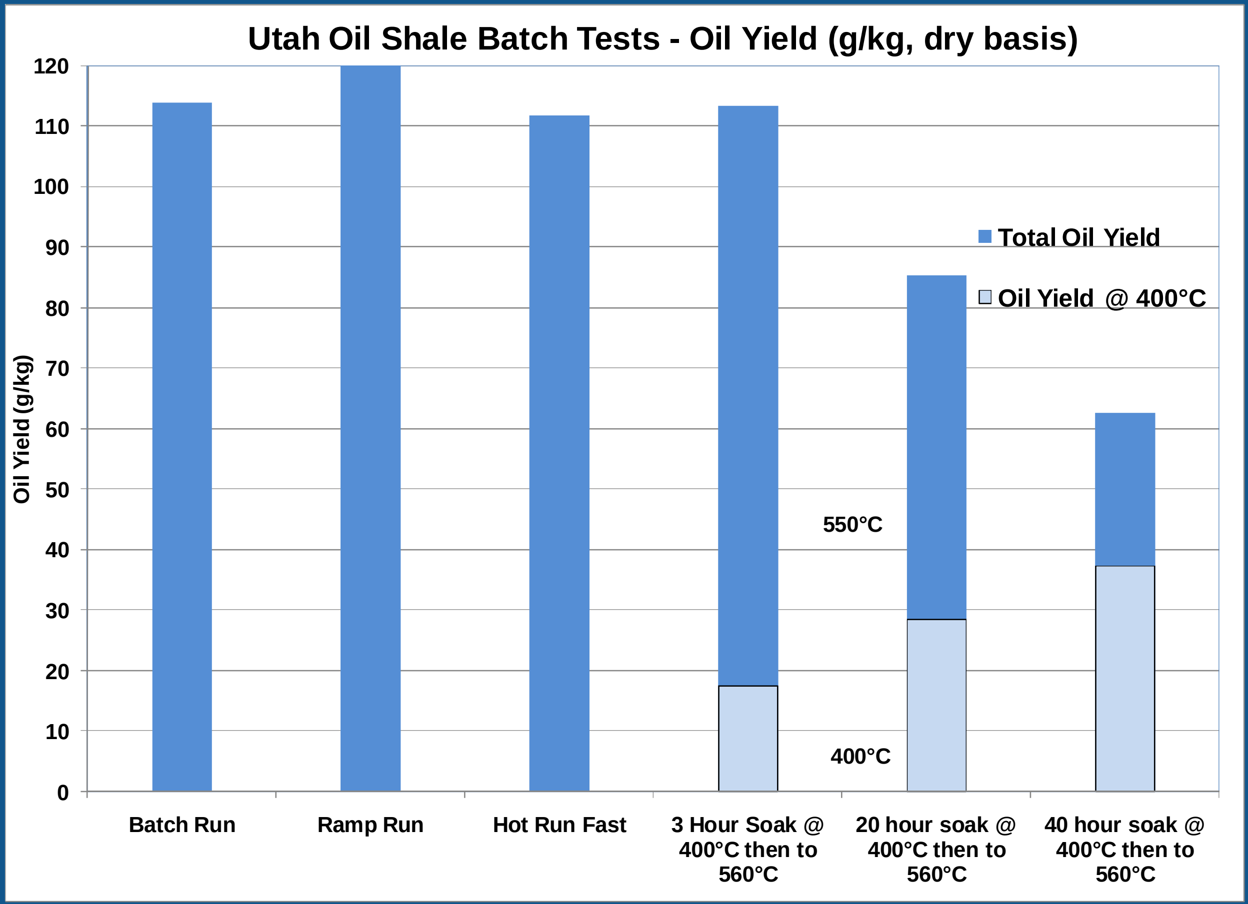




Test Series C

Utah oil shale 400°C soak to accelerate alteration reaction on kerogen then rapid heating to 560°C to observe oil remaining.

Note – Fushun, Estonia, and Australia results are similar



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Top Vapour Discharge on Slow Soak Test Units

Bottom Vapour Discharge on Slow Soak Test Units

Test Series D tests were carried but with vapour bottom discharge to eliminate effects of oil condensing and refluxing back into hot oil shale charge. Only Jordan and Utah oil shales tested to date.

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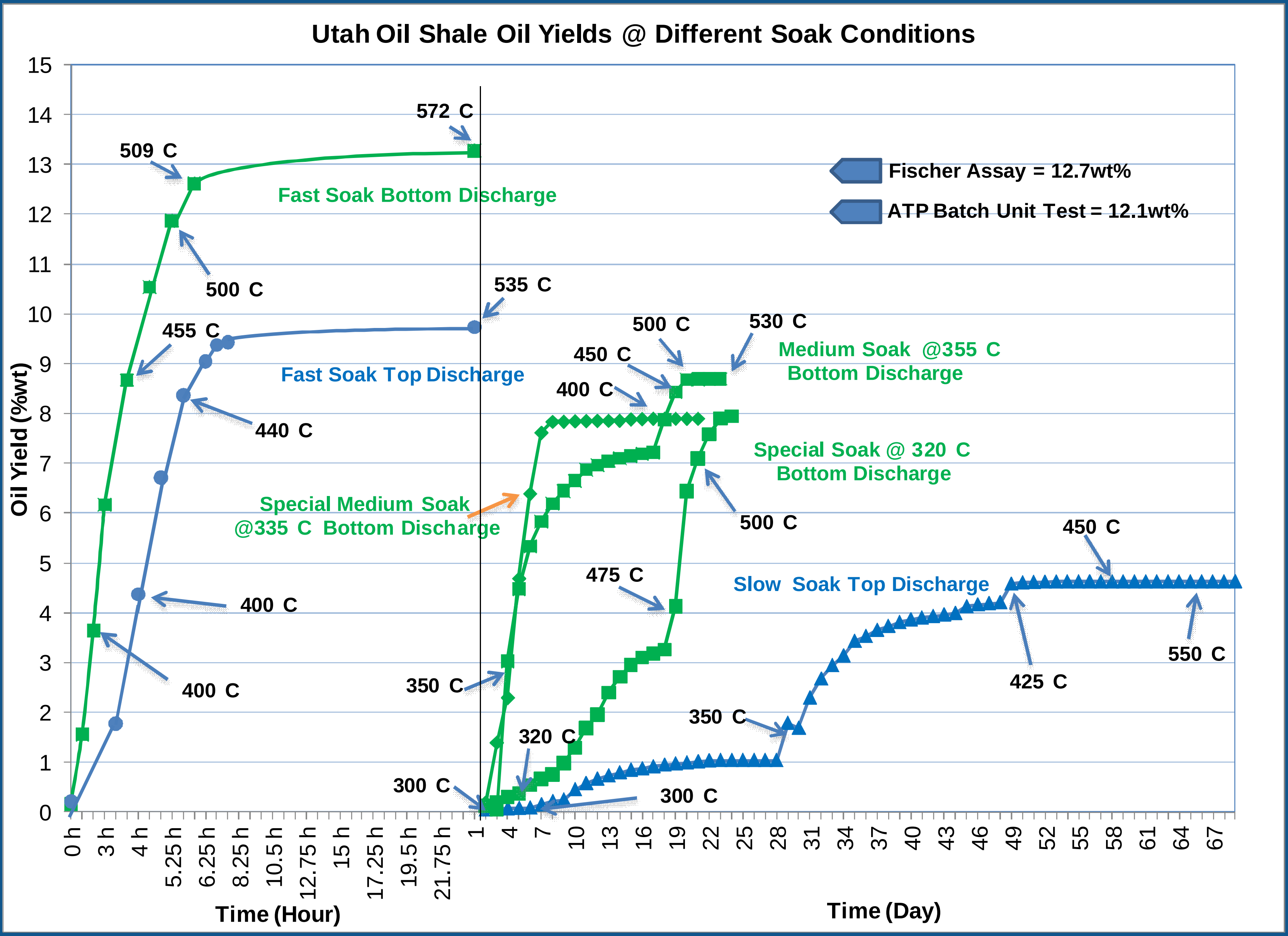

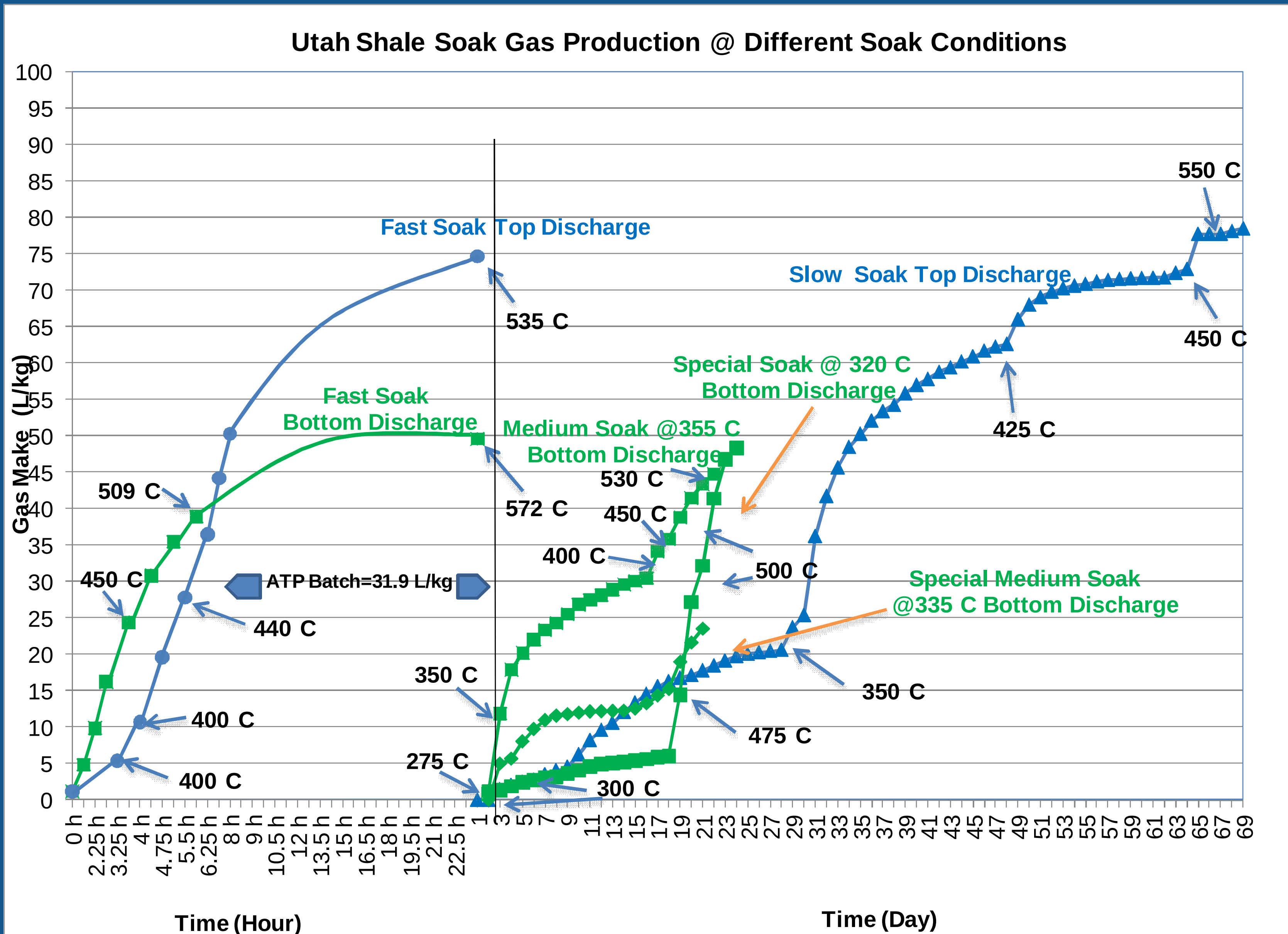
Utah Shale Soak Gas Production @ Different Soak Conditions
Gas Make (L/kg)
Time (Hour)
Time (Day)
Fast Soak Top Discharge
Fast Soak
Bottom Discharge
Slow Soak Top Discharge
Special Soak @ 320 C
Bottom Discharge
Medium Soak @355 C
Bottom Discharge
Special Medium Soak
@335 C Bottom Discharge
ATP Batch=31.9 L/kg
535 C
572 C
509 C
450 C
440 C
400 C
400 C
350 C
275 C
300 C
530 C
450 C
400 C
500 C
475 C
350 C
425 C
450 C
550 C

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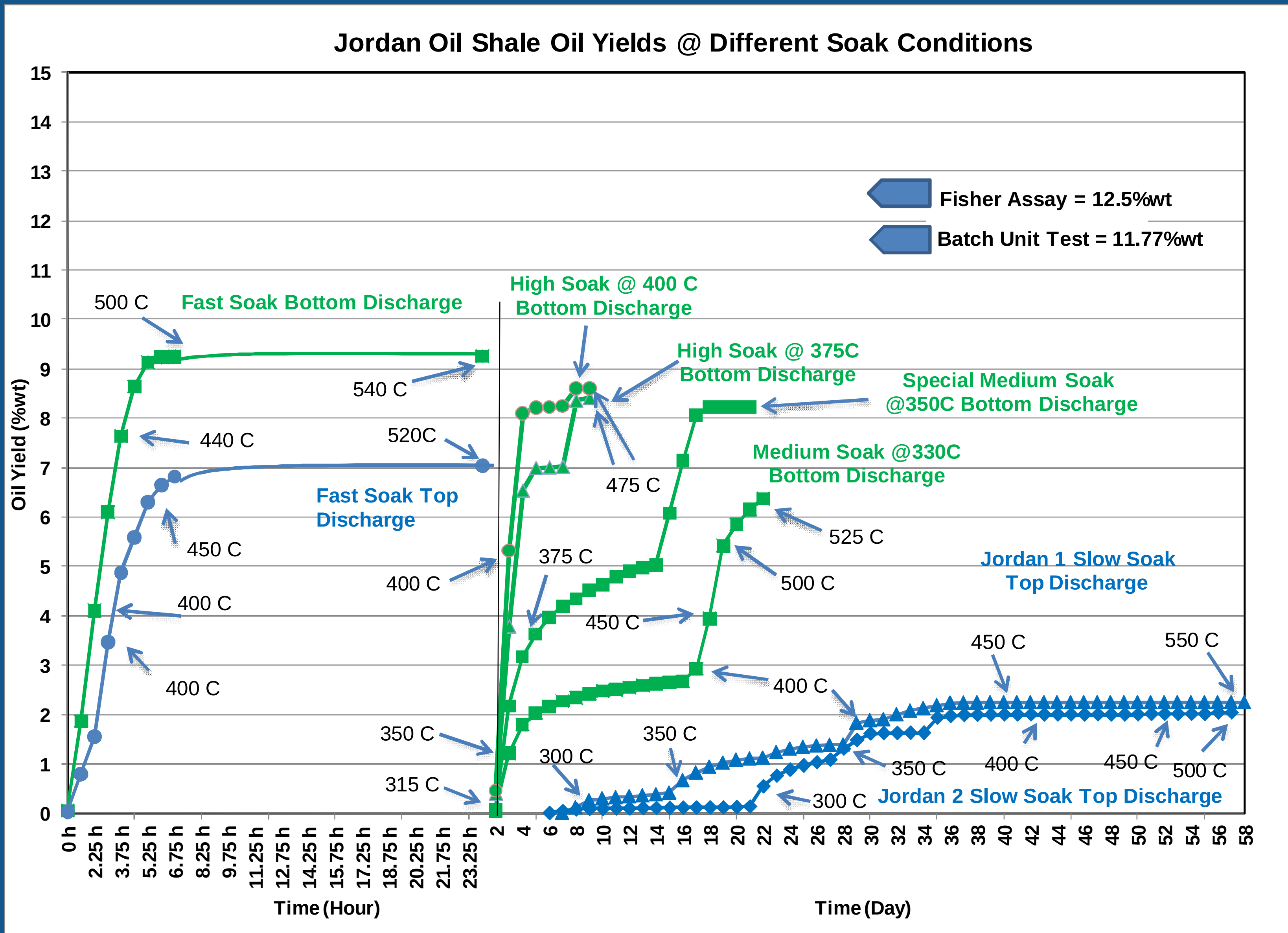

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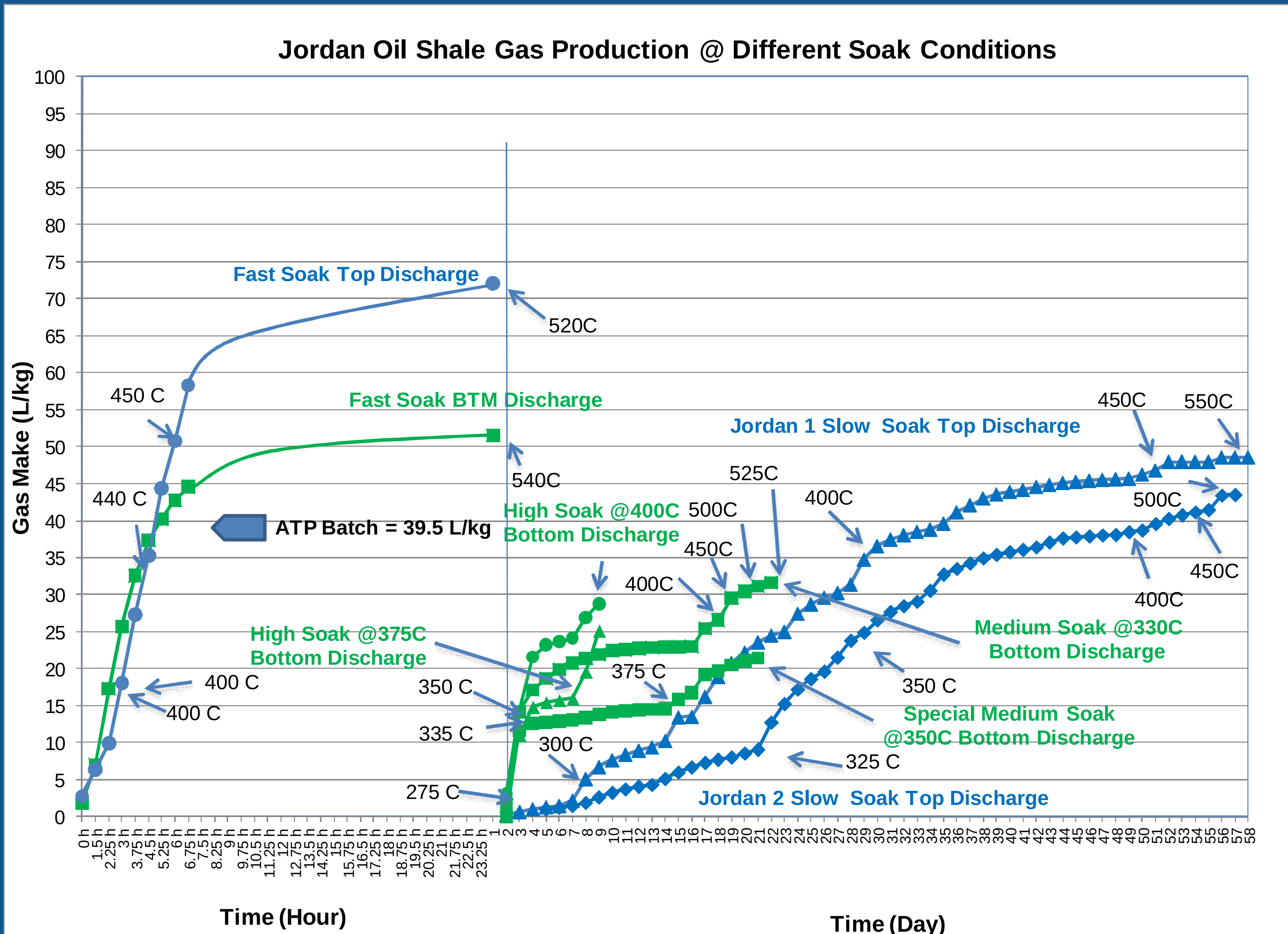

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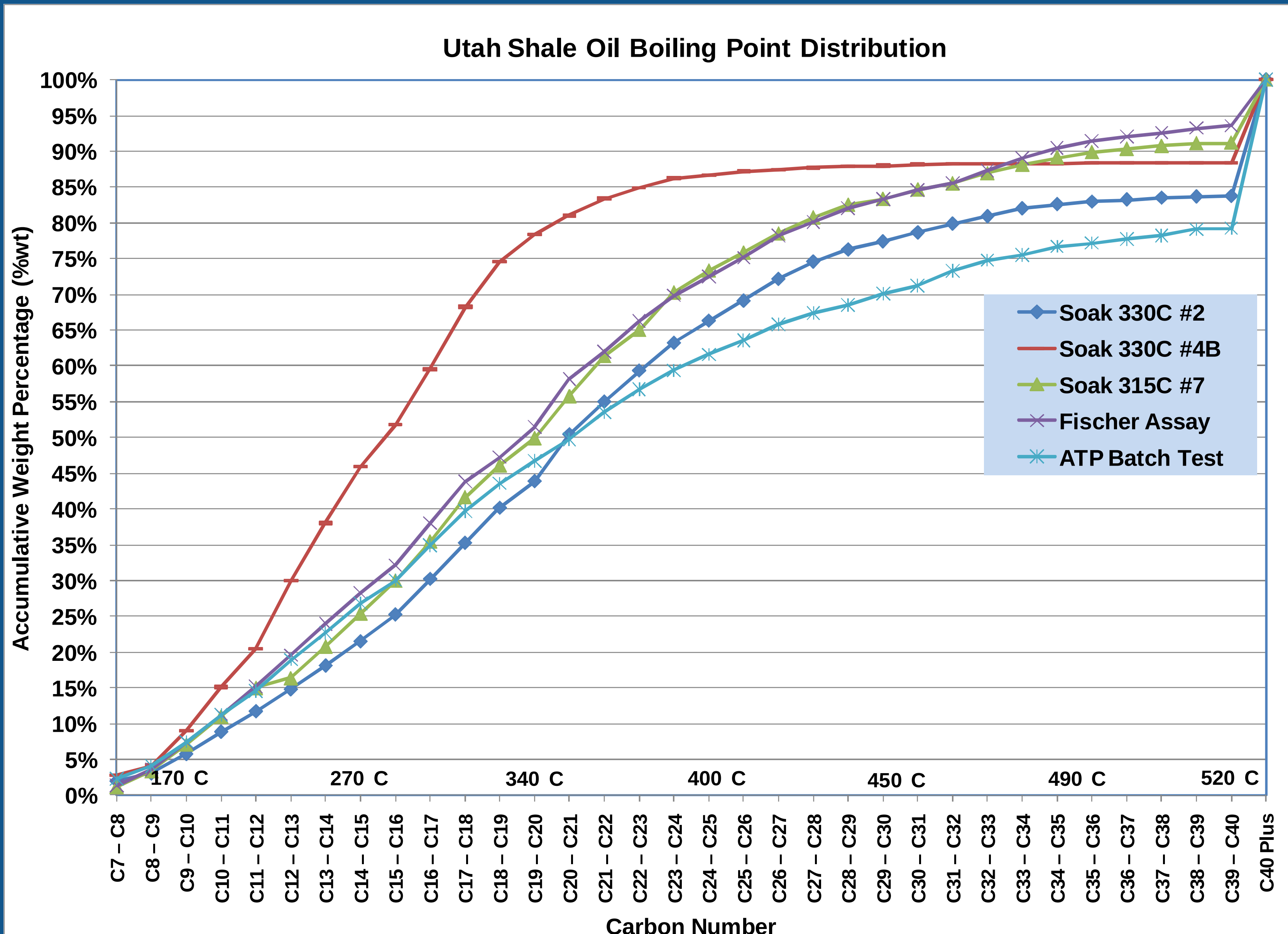

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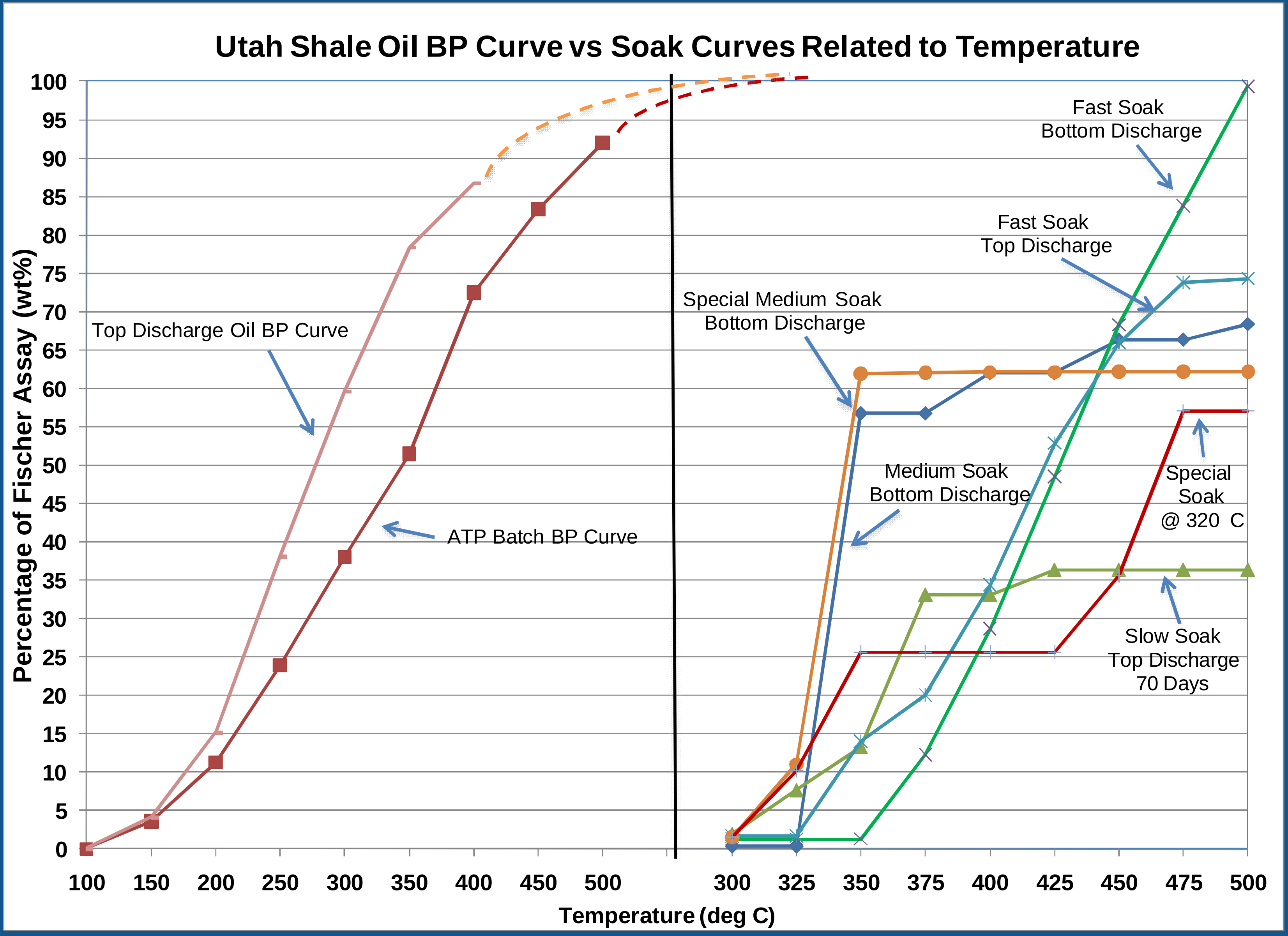
Utah Shale Oil BP Curve vs Soak Curves Related to Temperature
Percentage of Fischer Assay (wt%)
Temperature (deg C)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
100
150
200
250
300
350
400
450
500
300
325
350
375
400
425
450
475
500
Top Discharge Oil BP Curve
ATP Batch BP Curve
Special Medium Soak
Bottom Discharge
Medium Soak
Bottom Discharge
Fast Soak
Bottom Discharge
Fast Soak
Top Discharge
Special
Soak
@ 320 C
Slow Soak
Top Discharge
70 Days

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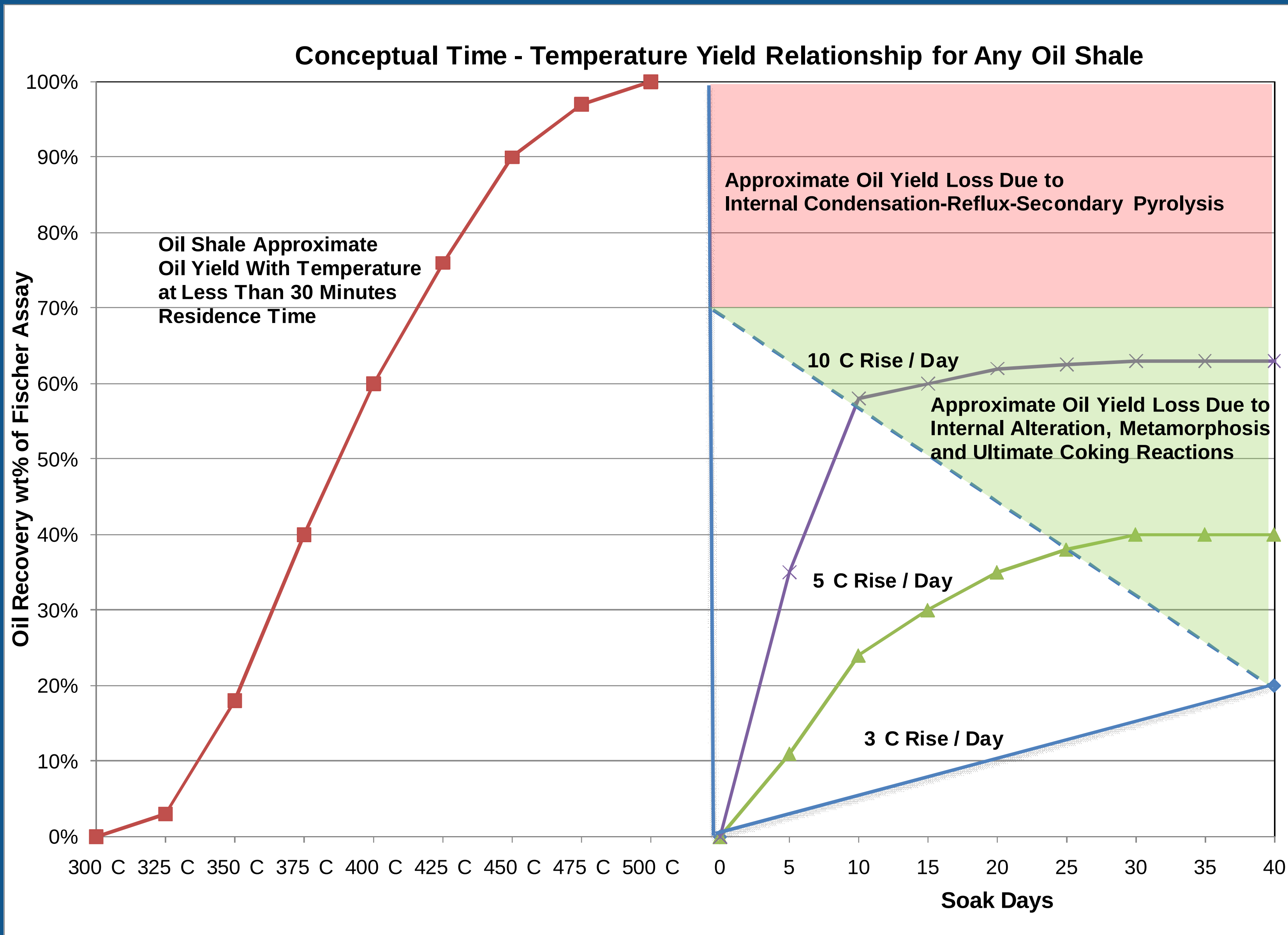

Conclusions to Date Based on Results of UMATAC Tests

1) Jordan, Utah, Estonia, China, and Australia oil shales have very similar time, temperature, product composition characteristics.
2) Measurable quantities of oil and gas released at 300°C.
3) Kerogen decomposition becomes rapid beyond 320°C.
4) Kerogen decomposition accelerates as temperature is increased.
5) Inefficient removal of oil and gas products (oil reflux) remarkably reduces oil yield.

Conclusions to Date Based on Results of UMATAC Tests

6) During kerogen decomposition the oil quality and the off gas composition trends are remarkably similar for different oil shales.
7) During soak time secondary alteration reactions occur which tend to reduce oil yield tending towards ultimate coking.
8) Long term soak periods of 60 day duration with reflux reduce oil yield by 50 to 80% referenced to Modified Fischer assay.

Comments by Author

UMATAC's technical paper searches regarding this type of slow soak research has turned up very little information on oil yields, gas yields and product comparison under our test conditions. The presentation of our test methods, our test data, and findings is to stimulate discussion with other researchers in aid of understanding the complex nature of oil shale kerogen.

Comments by Author

The author recognizes that UMATAC's test programs were performed under conditions using a prepared crushed oil shale and operating at atmospheric pressure. Based on the conclusions reached in this paper regarding kerogen alternation, reaction and the effect of reflux, the author has a much better appreciation of the complexity of modeling, designing and operating a large scale in-situ type oil shale operation where the additional factors of pressure, viscosity, bed permeability, heat transfer co-efficient, potential for multiple refluxing of oil products, catalytic action and potential for gasification are at least some of the additional considerations.

The oil resources are there in the oil shales but collectively we need to develop means to recover this oil in a safe, environmentally friendly, and economic fashion.

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