

# MICROWAVE PYROLYSIS FOR YAOJIE OIL SHALE



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# Microwave Pyrolysis Review

- **Microwave is a promising technology for oil shale processing;**
- **Previous studies in:**
  - Biomass pyrolysis;
  - Coal pyrolysis;
  - Sewage sludge pyrolysis;
  - Waste material (tires, medical plastic waste etc.)
  - Oil shale----- surface process and in-situ process;
- **Theory and findings:**
  - Microstructure and composition of feed stock,
  - Added oxides for improved thermal efficiency ;
  - Heat distribution – hot spots;

# Advantages of Microwave Pyrolysis

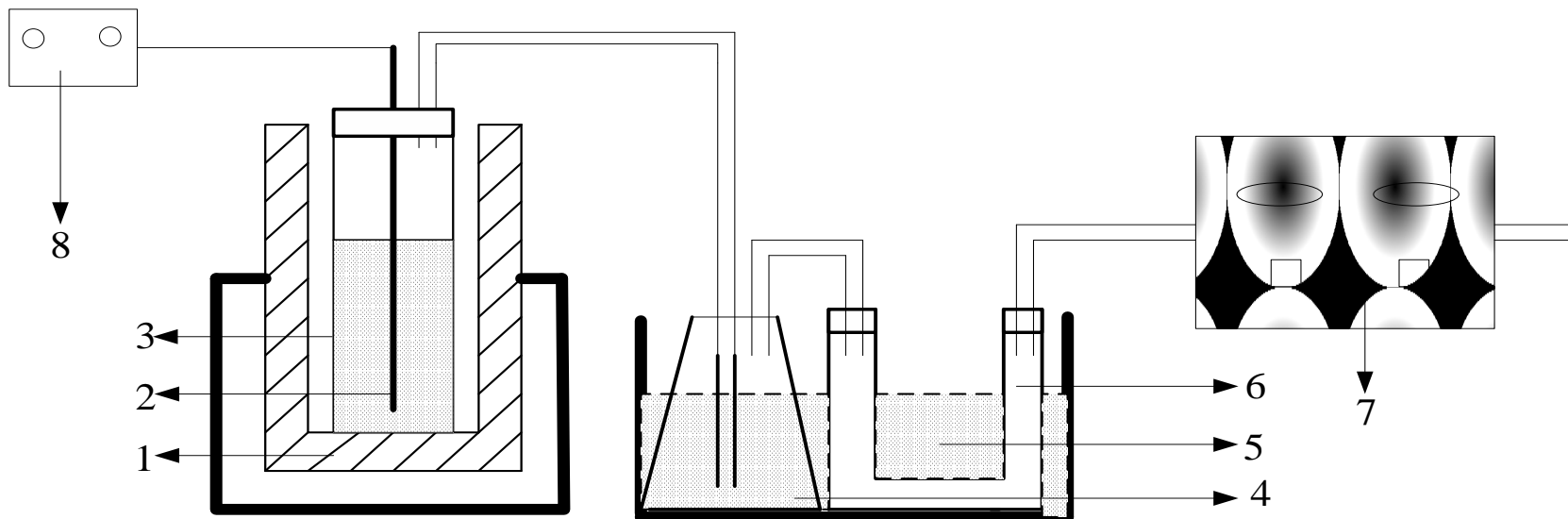
## ○ Advantages

- Short heating time--- it takes seconds to minutes to increase temperature to 1000 C;
- Heat value of retort gas is higher;
- Less water consumption;
- Less waste water production;
- Less dust in gas/oil stream;
- Potential for lower CO<sub>2</sub> emissions (use solar power/wind power);

## ○ Disadvantages

- Heat distribution – not even;
- Power consumption;
- Carbon residue utilization (low);

# EXPERIMENT SETUP



1- Microwave power generator , 2- K- thermal couple , 3- Quartz reactor , 4- Conical Flask , 5- cooling bath , 6- U tube cooler , 7- On-line GC , 8- temperature controller

Fig 1. illustration of experimental facility.

# YAOJIE LOCATION



# Yaojie Location and Resource

- **260 M ton of oil shale reserves;**
- **FA Oil yield average >10%;**
- **By-product of coal mining;**
- **Underground mining;**
  
- **Location: very dry, 100's mm rain annually – very sunny;**
- **Altitude 2100 m (elevation above sea level) – very windy;**
- **Landscape: Loess Plateau landscape;**

# Oil Shale Property

## Proximate and ultimate analyses of oil shale (%)

Proximate analysis				Ultimate analysis			
$M_{ad}$	$A_{ad}$	$V_{ad}$	$FC_{ad}$	$C_{ad}$	$H_{ad}$	$N_{ad}$	$S_{t,ad}$
0.84	64.73	22.50	11.93	23.88	2.26	0.54	0.89

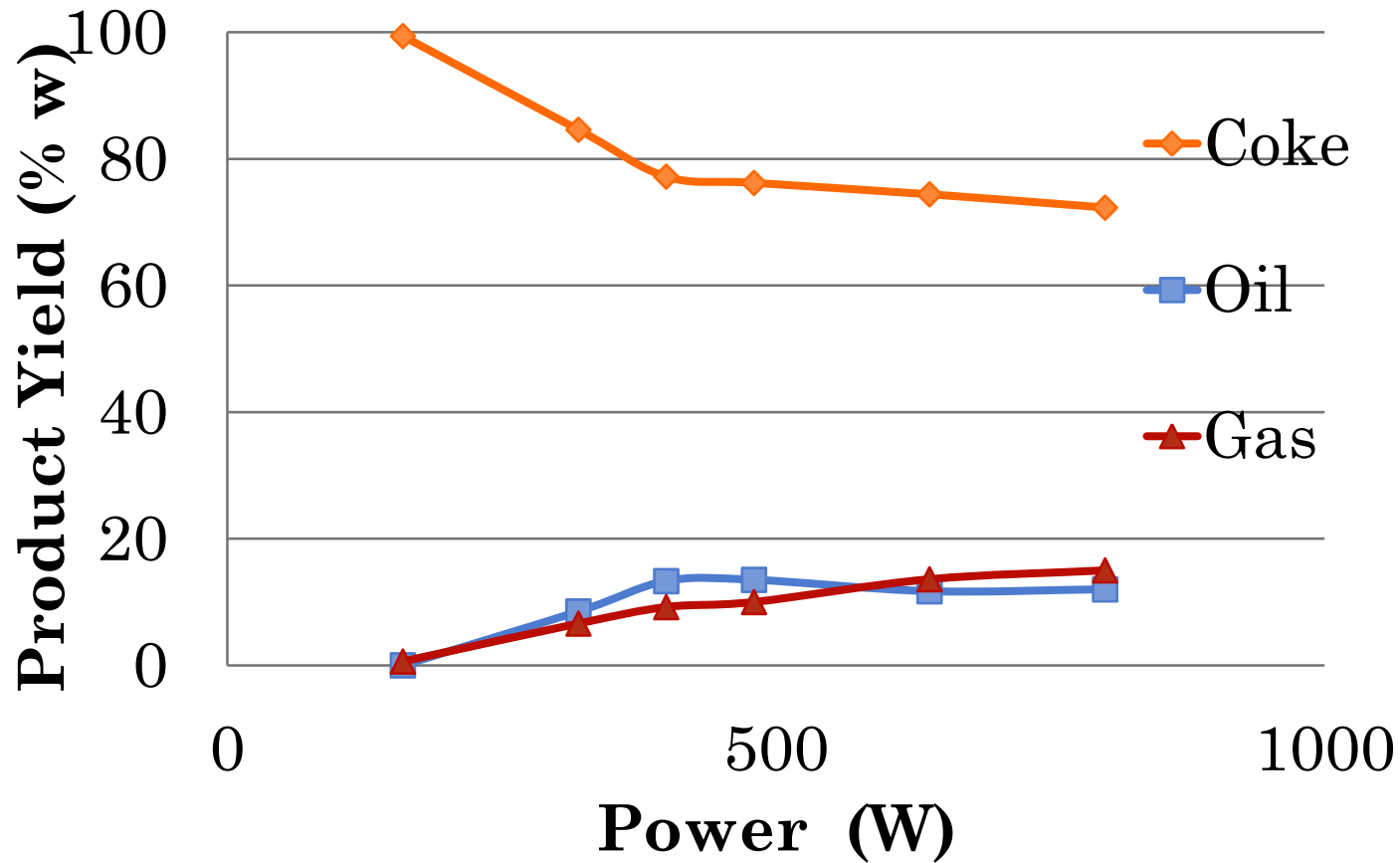
# OIL & GAS YIELD CHANGES VS MICROWAVE POWER

## Yield from Microwave pyrolysis (2450 MHz) vs. Fischer Assay

Power	Product yield / % (mass)		
	Semi-coke	Oil	Gas
/W			
160	99.4	0	0.6
320	84.6	8.5	6.6
400	77.2	13.3	9.2
480	76.2	13.5	10
640	74.4	11.7	13.6
800	72.3	12	15
FA	79.95	12.67	7.40

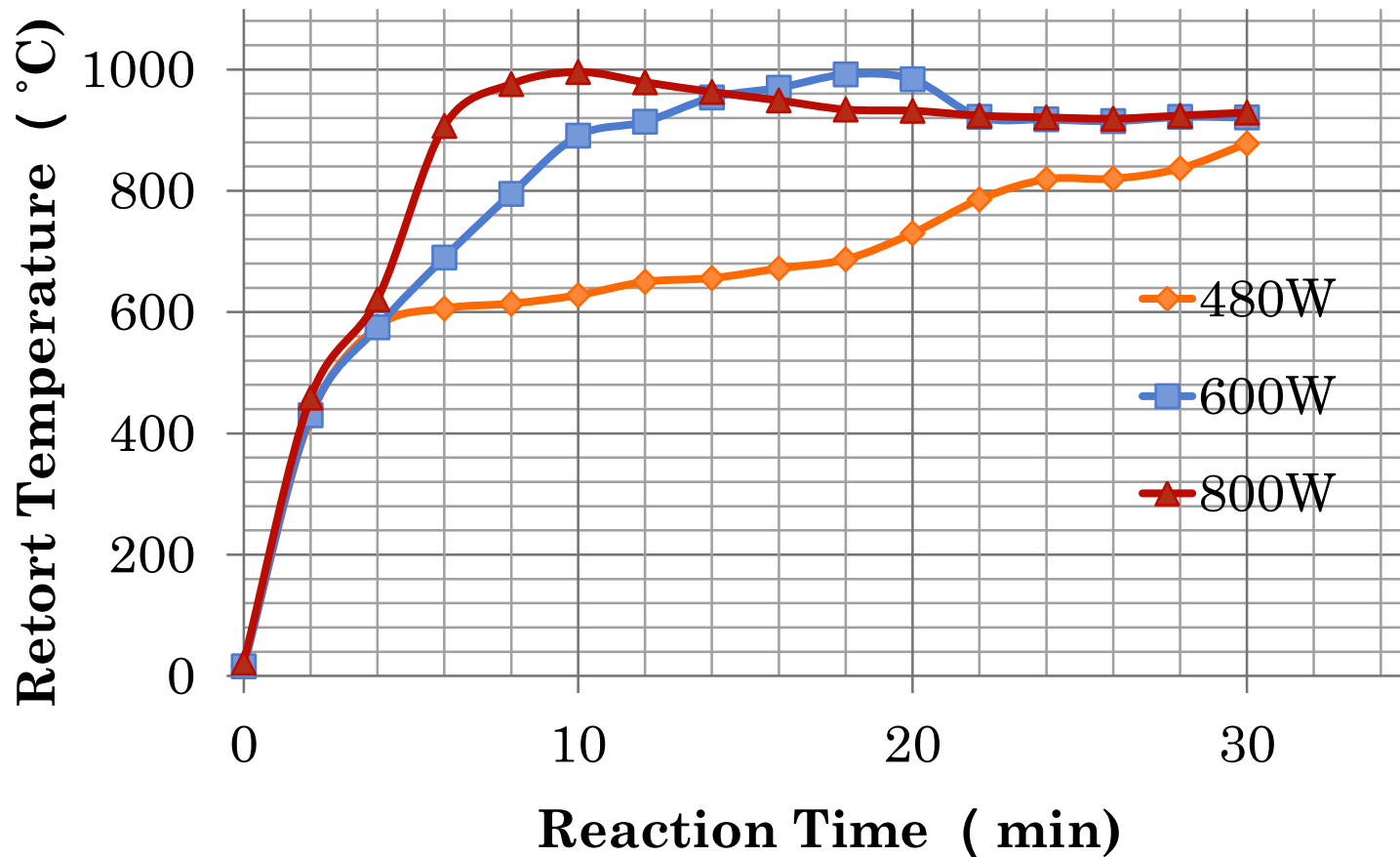


# POWER VS PRODUCT YIELD



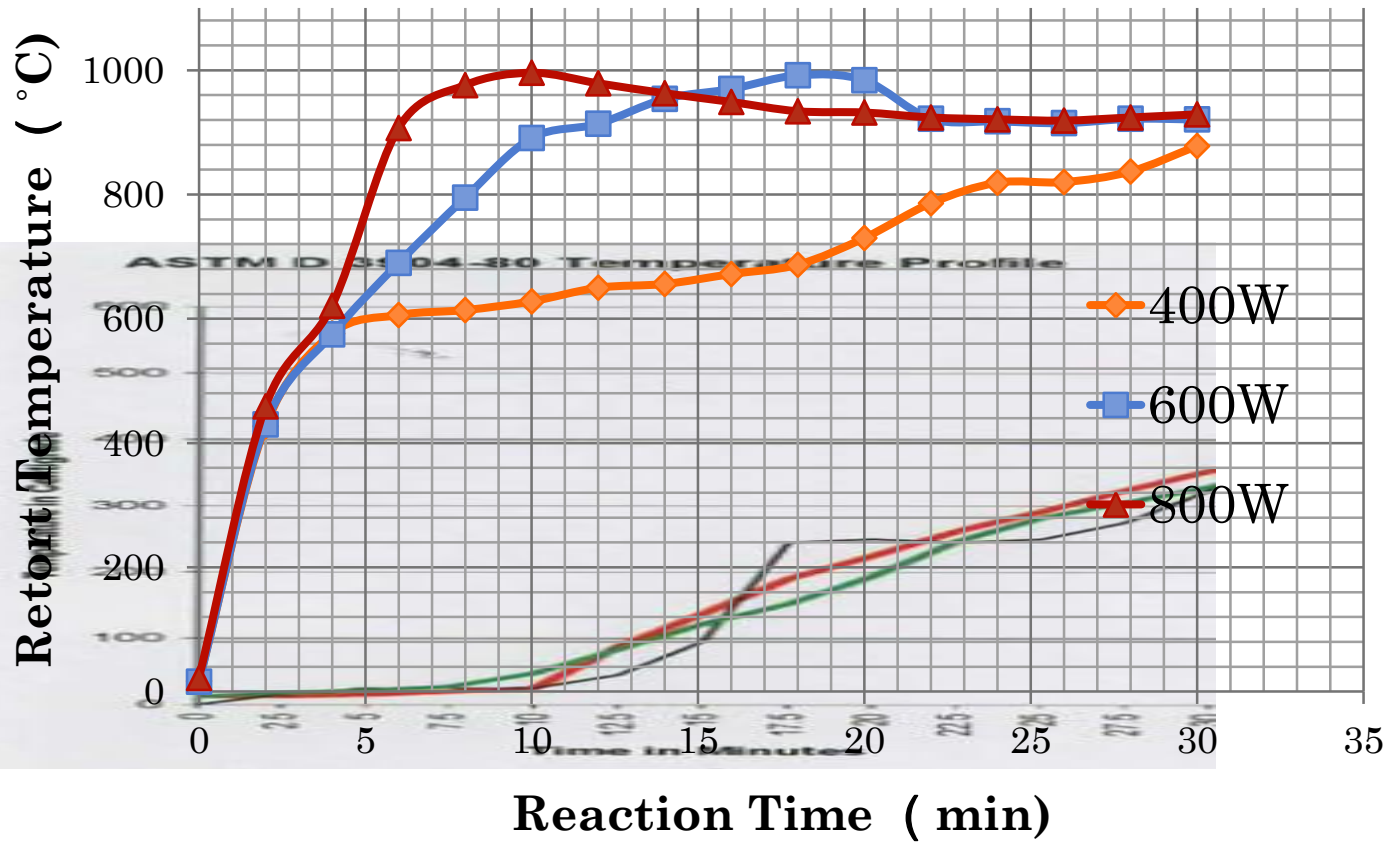
# PYROLYSIS TEMPERATURE PROFILES

## Temperature Profile with Varied Power



# PYROLYSIS TEMPERATURE PROFILES

## Temperature Profile with Varied Power



# SPENT SHALE ANALYSIS WITH DIFFERENT POWER

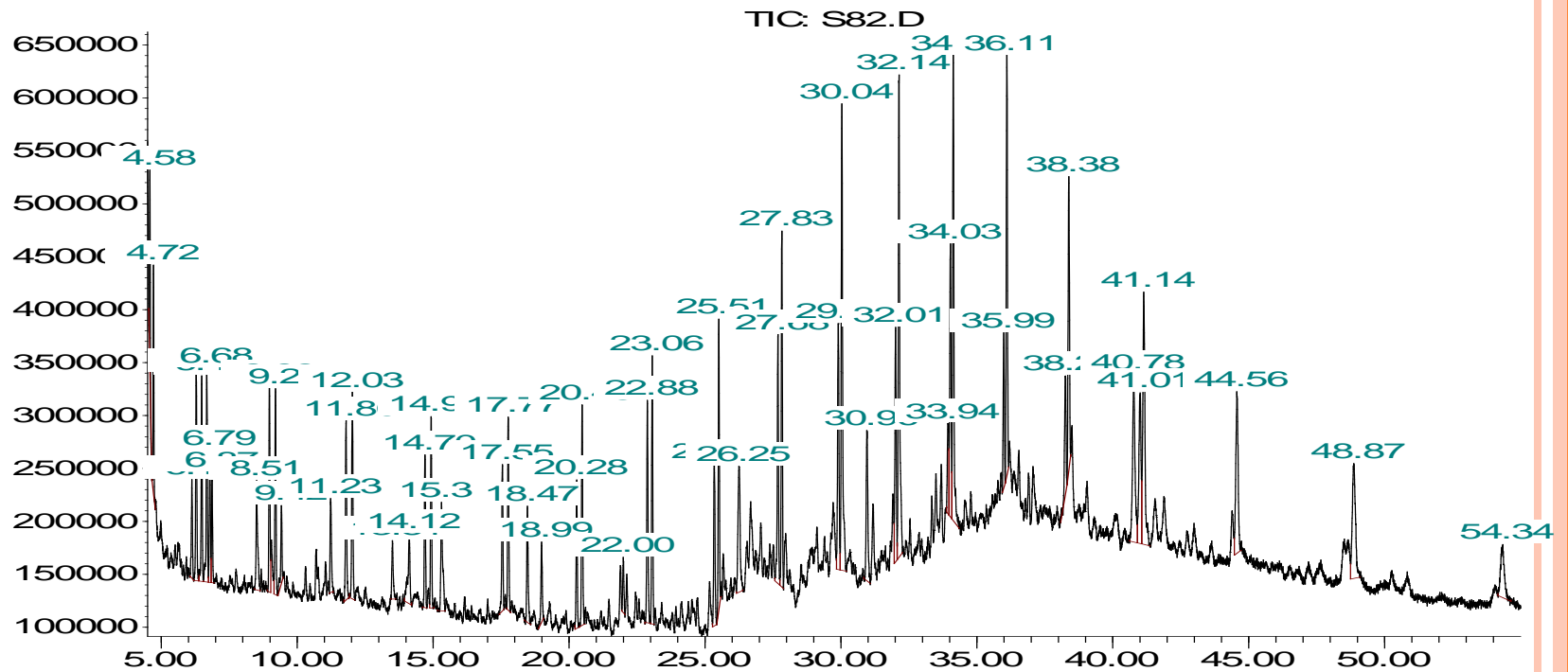
## Proximate and ultimate analyses of char under different microwave power

Power/ W	Proximate analysis/%				Ultimate analysis/%			
	M <sub>ad</sub>	A <sub>ad</sub>	V <sub>ad</sub>	FC <sub>ad</sub>	C <sub>ad</sub>	H <sub>ad</sub>	N <sub>ad</sub>	S <sub>t,ad</sub>
160	0.40	60.60	26.00	13.00	17.40	0.50	0.29	0.74
320	0.52	76.03	9.38	14.07	17.72	0.80	0.34	0.74
400	0.56	79.69	5.10	14.65	19.13	0.66	0.34	0.75
<b>480</b>	<b>0.53</b>	<b>81.07</b>	<b>1.38</b>	<b>17.02</b>	<b>18.20</b>	<b>0.82</b>	<b>0.42</b>	<b>1.03</b>
640	0.52	82.46	0.14	16.88	27.80	1.86	0.57	0.92
800	0.21	80.91	0.14	18.74	19.80	0.24	0.23	0.65



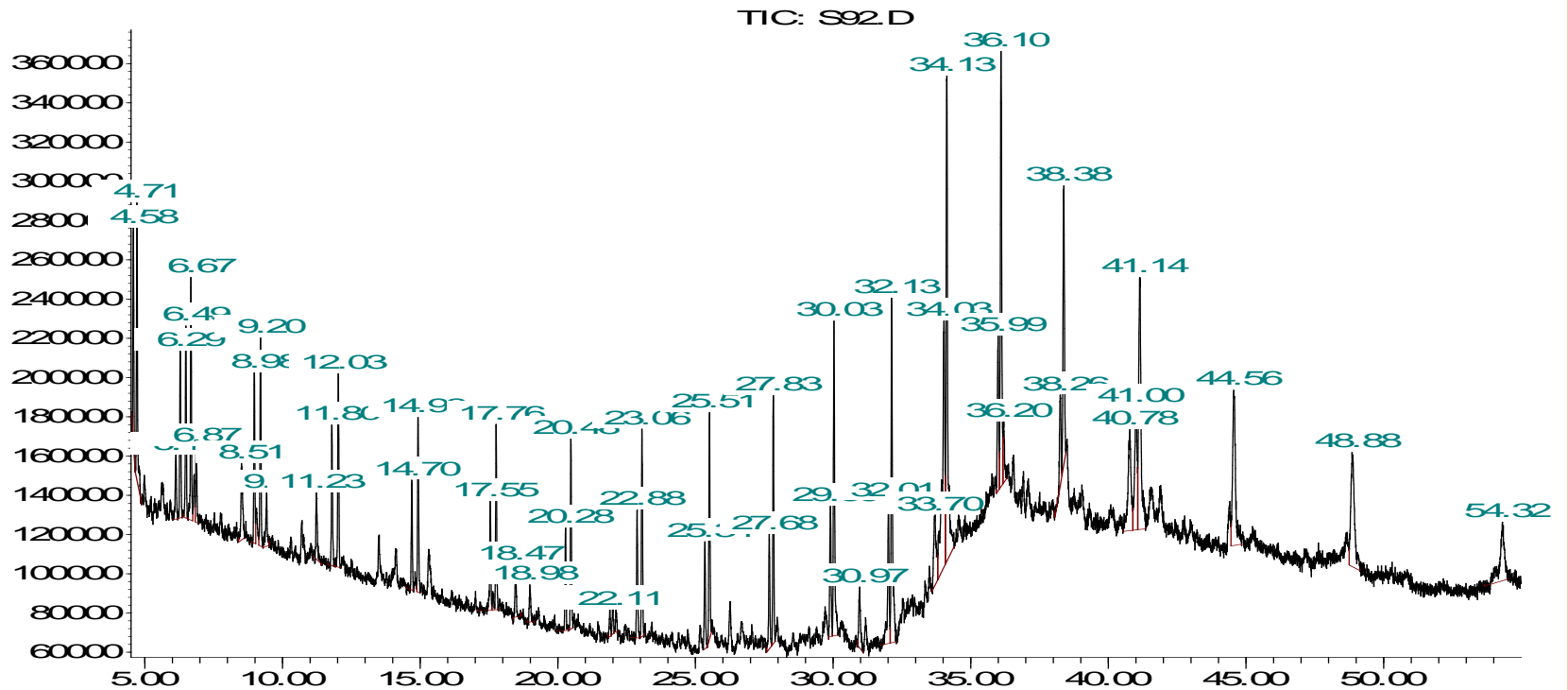
# OIL GC-MS REPORT AT 640W

Abundance



# OIL GC-MS REPORT AT 800W

Abundance



# OIL GC-MS REPORT AT 800W

Peak	Power /W								
	480 W			640 W			800 W		
	Retention /min	Compound	Concentration /%	Retention /min	Compound	Concentration /%	Retention /min	Compound	Concentration /%
1	4.354	Toluene	2.647	4.581	1-Octene	1.033	4.58	1-Octene	1.677
2	4.494	1-Octene	1.577	4.715	Octane	1.38	4.714	Octane	2.557
3	4.615	Octane	1.579	6.126	Ethylbenzene	0.785	6.13	Ethylbenzene	0.718
4	5.909	Ethylbenzene	0.651	6.285	Benzene,1,3-dimethyl-	1.777	6.285	p-xylene	1.64
5	6.054	p-Xylene	1.531	6.486	1-Nonene	1.599	6.491	1-Nonene	1.711
6	6.228	1-Nonene	1.539	6.676	Nonane	1.755	6.676	Nonane	2.319
7	6.397	Nonane	2.033	6.79	Styrene	1.064	6.867	Benzene,1,2-dimethyl-	0.771
8	6.508	Styrene	0.005	6.867	Benzene,1,2-dimethyl-	0.82	8.514	Phenol	1.172
9	6.59	Benzene , 1,3-dimethyl-	0.593	8.51	Phenol	1.242	8.978	1-Decene	1.517
10	8.078	Benzene , 1-ethyl-3-methyl-	0.628	8.978	1-Decene	1.637	9.199	Decane	1.973
11	8.507	1-Decene	1.338	9.205	Decane	1.707	9.426	Benzene,1,3,5-trimethyl-	0.688

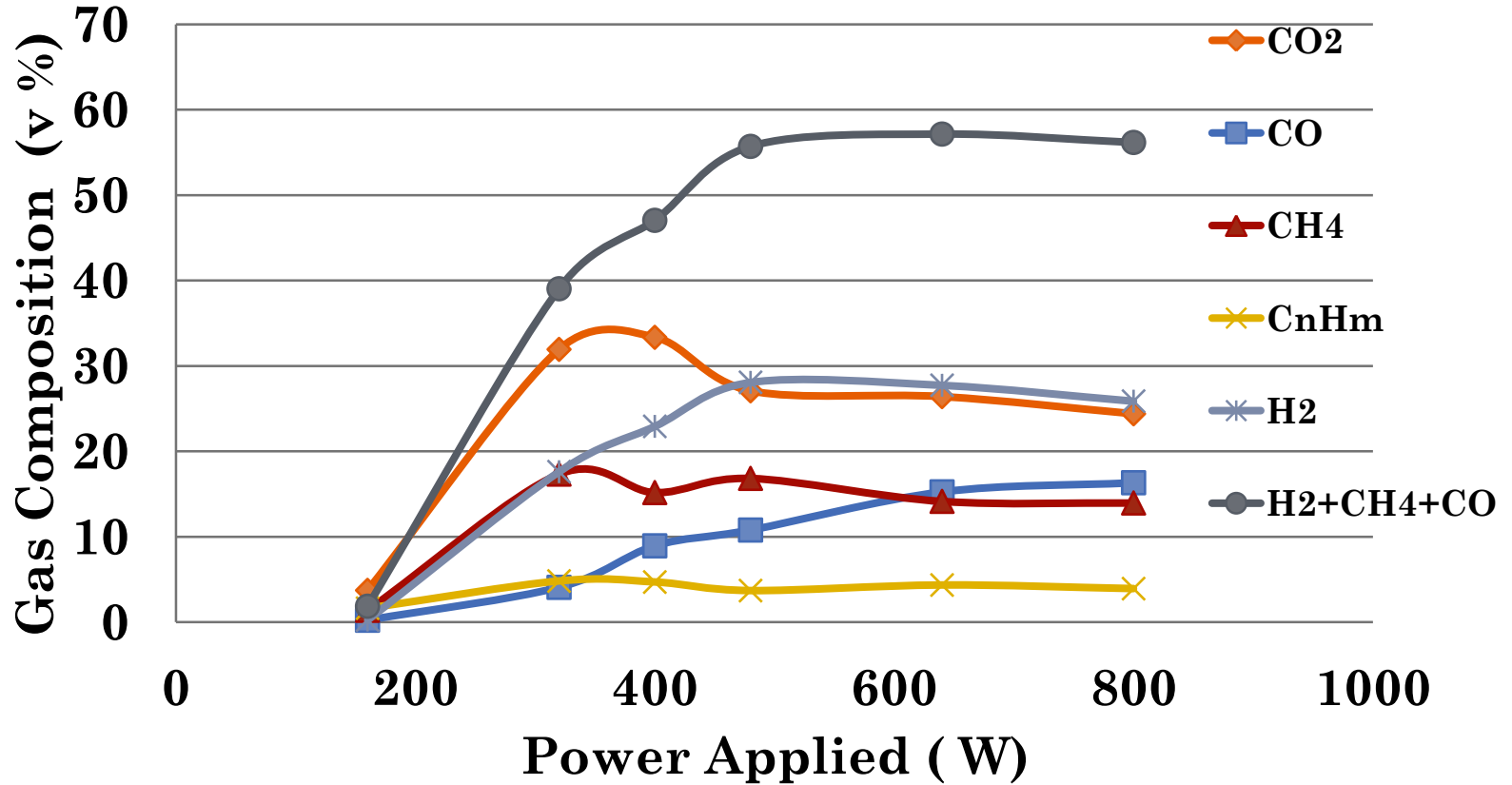


# OIL COMPOSITION VS POWER

## Oil Composition (wt %) with Varied Power

Power /W	Parafin	Aromatics	Oleffin	Phenols	Alkyl ketone
480	36.033	16.234	17.789	3.795	0.997
640	47.288	17.030	25.402	6.150	0
800	59.256	13.973	24.726	2.048	0

# GAS COMPOSITION VS POWER



## SUMMARY

- Results from Microwave Pyrolysis of oil shale:
  - Pyrolysis temperature is achieved within 3 minutes;
  - Achieved higher yield than Fischer Assay;
  - Oil & gas yield and composition is determined by microwave power applied;
  - 480W is suitable microwave power for 50 g oil shale sample to maximize oil yield;
  - At 480 W, oil yield reaches 13.5% (peak);
  - More than 36.03% of the oil is paraffinic;
  - More than 55% of gas is  $H_2+CH_4+CO$ ;

# FUTURE WORK

- A new larger pilot facility has been established;
- Continuous feed and discharge operation;
- Economical evaluation of microwave pyrolysis;

## **Challenges ahead:**

- Scale up design and economics study.
- Availability of larger Microwave power generator with even heat distribution;
- Heat recovery from spent shale;
- Utilization of remaining carbon in spent shale;
- Hybrid technology with Microwave pyrolysis

# BACKGROUND



- The company was founded in 2005, and has been profitable throughout this period.
- Our customer base is broad and we seek a close arrangements with our clients to foster long term relationships.
- Our employees come from a wide range of industries and experiences.

# THANK YOU



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- PROCOM Consultants is a niche Australian engineering company that provides process engineering and plant commissioning services in several energy industry sectors.
- PROCOM was founded in 2005 following the closure of the Stuart Shale Oil Plant in Queensland Australia. PROCOM's directors and several key employees worked on the project.
- PROCOM has provided engineering and consulting services to oil shale, UCG, CSM, Refinery in USA, Estonia, China, Jordan and Australia.