

Figures to accompany IACC14 paper

Note that pictures have been deleted due to file size

# **Low Temperature Regeneration of Spent Activated Carbon Theory and Applications**

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TC	days/bed	yrs/bed
375	4.7	
350	14.3	
300	70.5	
250	501.7	1.4
200	5.07E+03	13.9
150	9.03E+04	2.5E+02
100	3.47E+06	9.5E+03
50	4.14E+08	1.1E+06
25	8.25E+09	2.3E+07
0	2.84E+11	7.8E+08

Figure 1

# The Criterion for Gas Adsorption

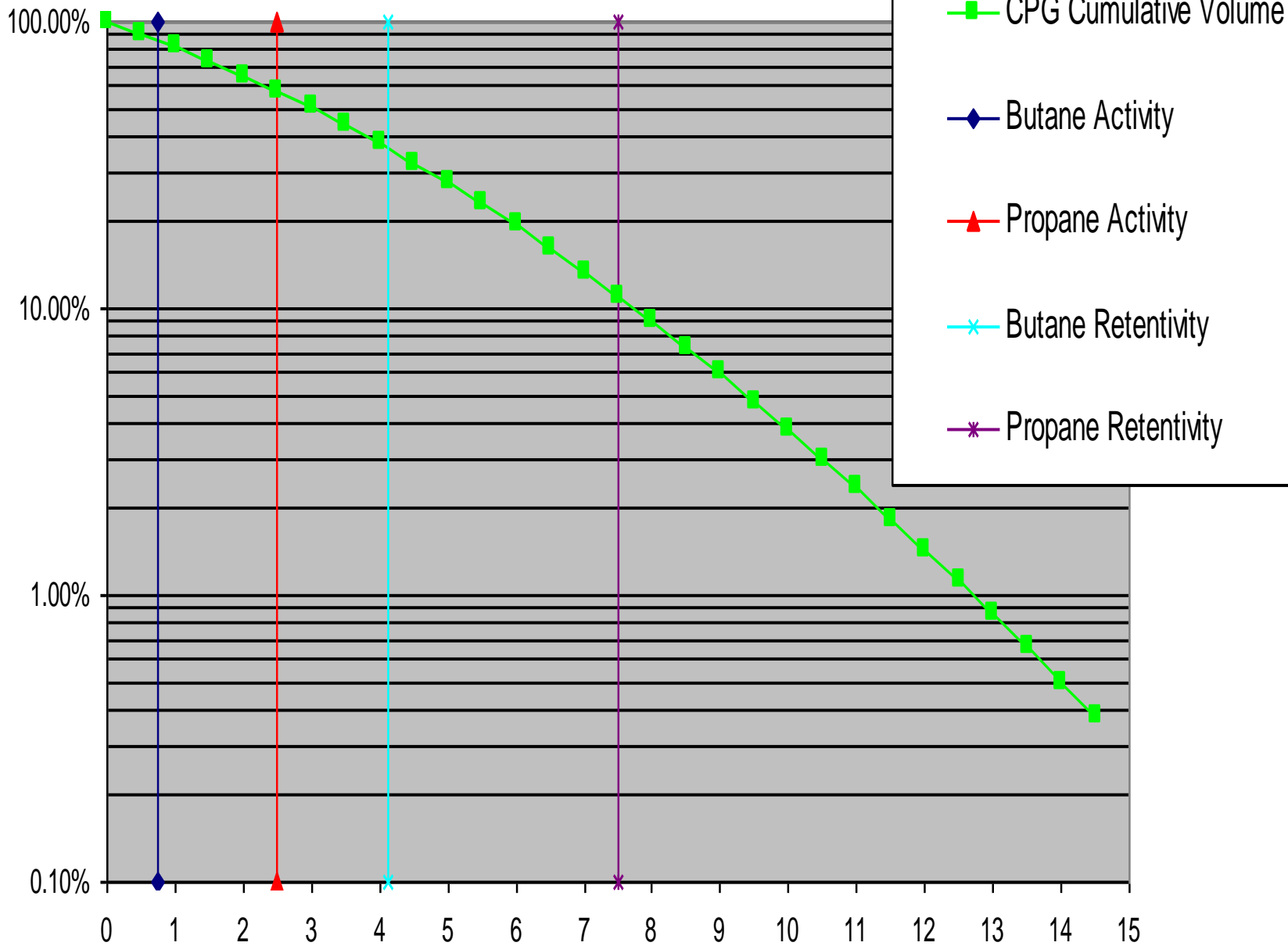
For Spontaneous adsorption to occur at a specific site,  $\epsilon$ , the potential energy of the adsorption site must satisfy:

$$\epsilon_{\text{Ads.}}(\text{at site}) \geq RT \ln \{P_{\text{sat}}/P\}$$

Therefore, every adsorption site within the carbon structure with an adsorption potential equal to or greater than the above criterion will be occupied by an adsorbate molecule, condensed from the gas phase.

Figure 2

Cumulative Adsorption Capacity in percent of maximum



Adsorption potential in Kcals per mole of Butane adsorbed

Figure 3

# Activated Carbon Temperature Profiles w/o Air, with Air and with Air & Butane

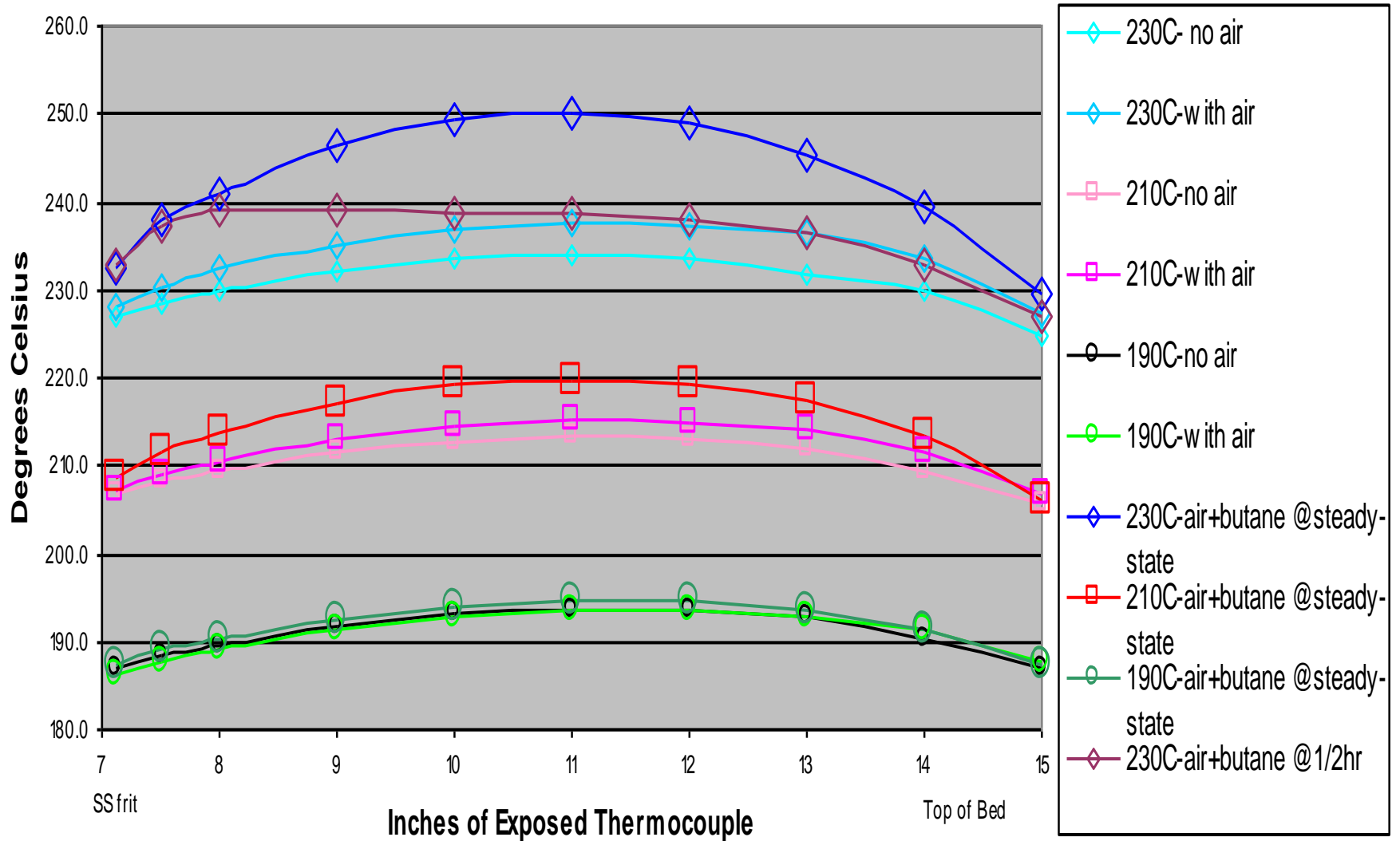


Figure 4

# Activated Carbon Temperature Profiles with Butane versus Propane

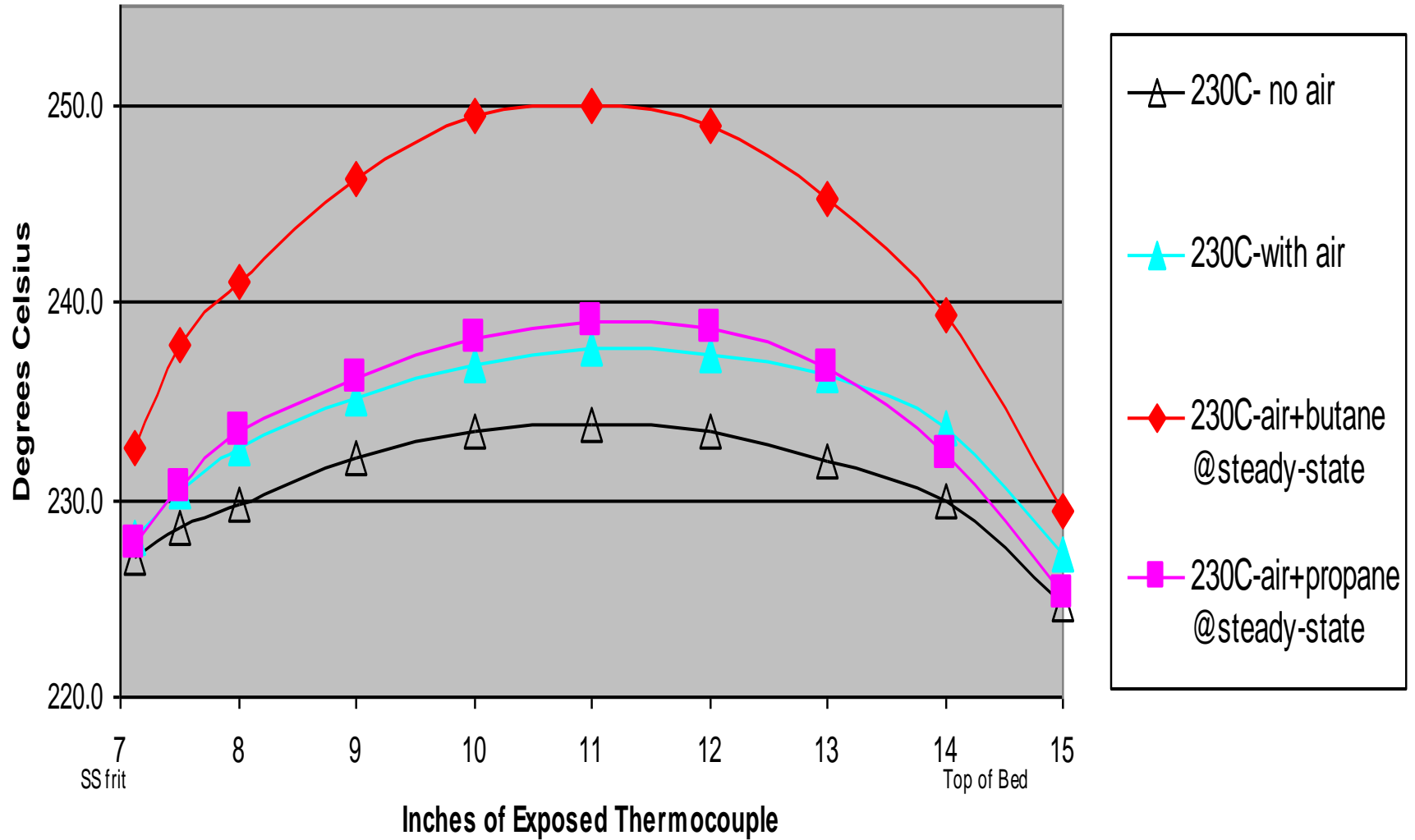


Figure 5

## Pyrolyzation of Spent Carbon

### Desorption/charring : As a function of the adsorbate

#### Simple Desorption - No char formed

Alkanes( $< C_{10}$ ), Aromatics( $< C_4$  side chain), Acids and Alcohols( $< C_6$ ),

Ethers, Polynuclear aromatics ( $< 4$  fused rings)

#### Adsorbate bonds break - pieces desorb below 1000F

Alkanes( $> C_{10}$ ), Aromatics( $> C_4$  side chain), Aliphatic Alcohols,

Alkenes and Alkynes( $< C_{10}$ ), Esters, Organic Halides, Aldehydes, Ketones

#### Adsorbate destroyed low level of (2-5%) char formed

Aliphatic Alcohols( $> C_{10}$ ), Alkenes and Alkynes( $> C_{10}$ ), Aromatic acids,

any large molecule ( $> C_{20}$ )

Figure 6

#### Adsorbate destroyed high levels of ( $> 5\%$ ) char formed

Amines, Aromatic alcohols, Aliphatic acids, Conjugated Alkenes and Alkynes

Figures 7, 8 & 9 deleted due to file size (jpg's)



# TGA trends in Nitrogen

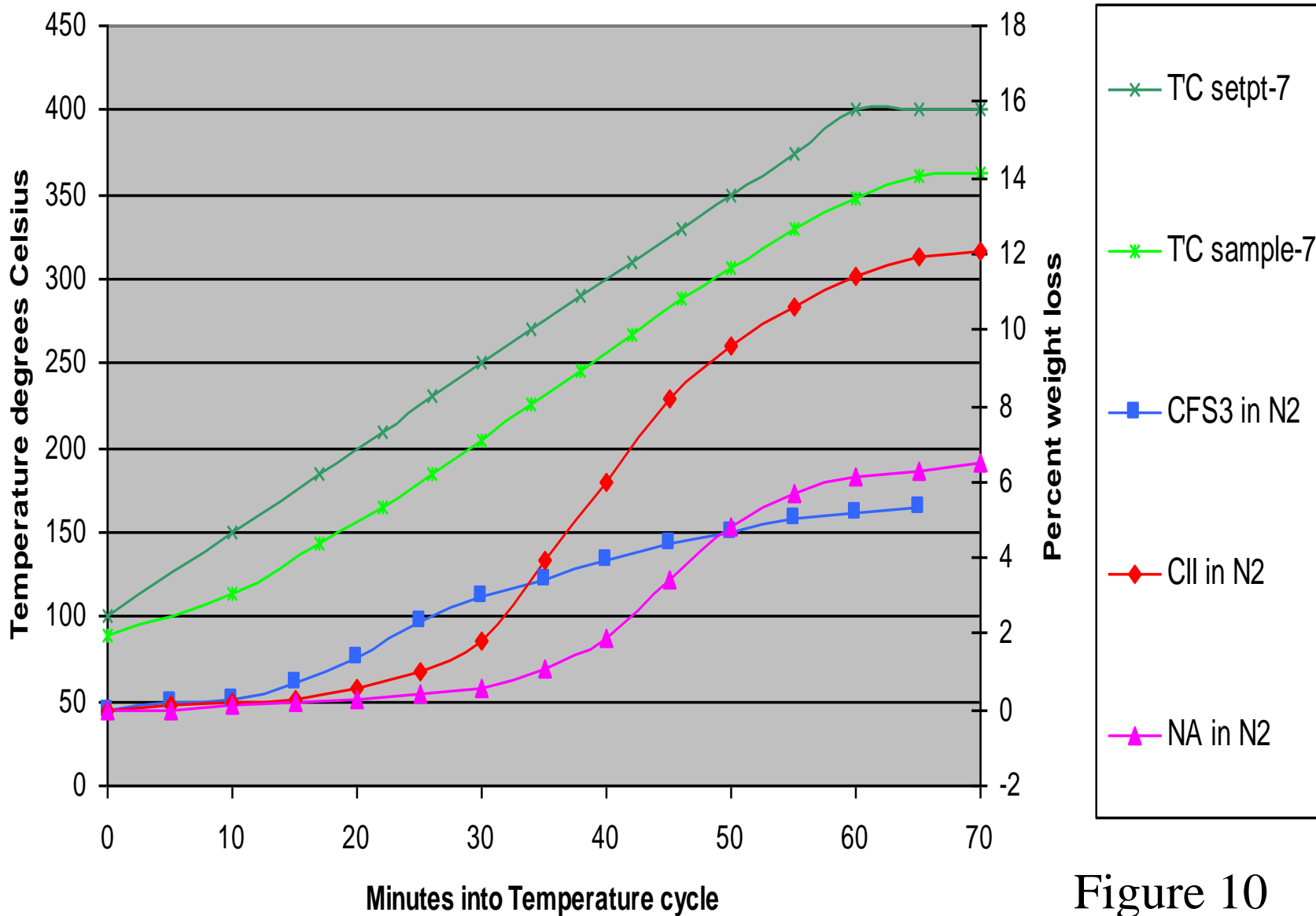


Figure 10

# TGA weight loss: Air vs Nitrogen

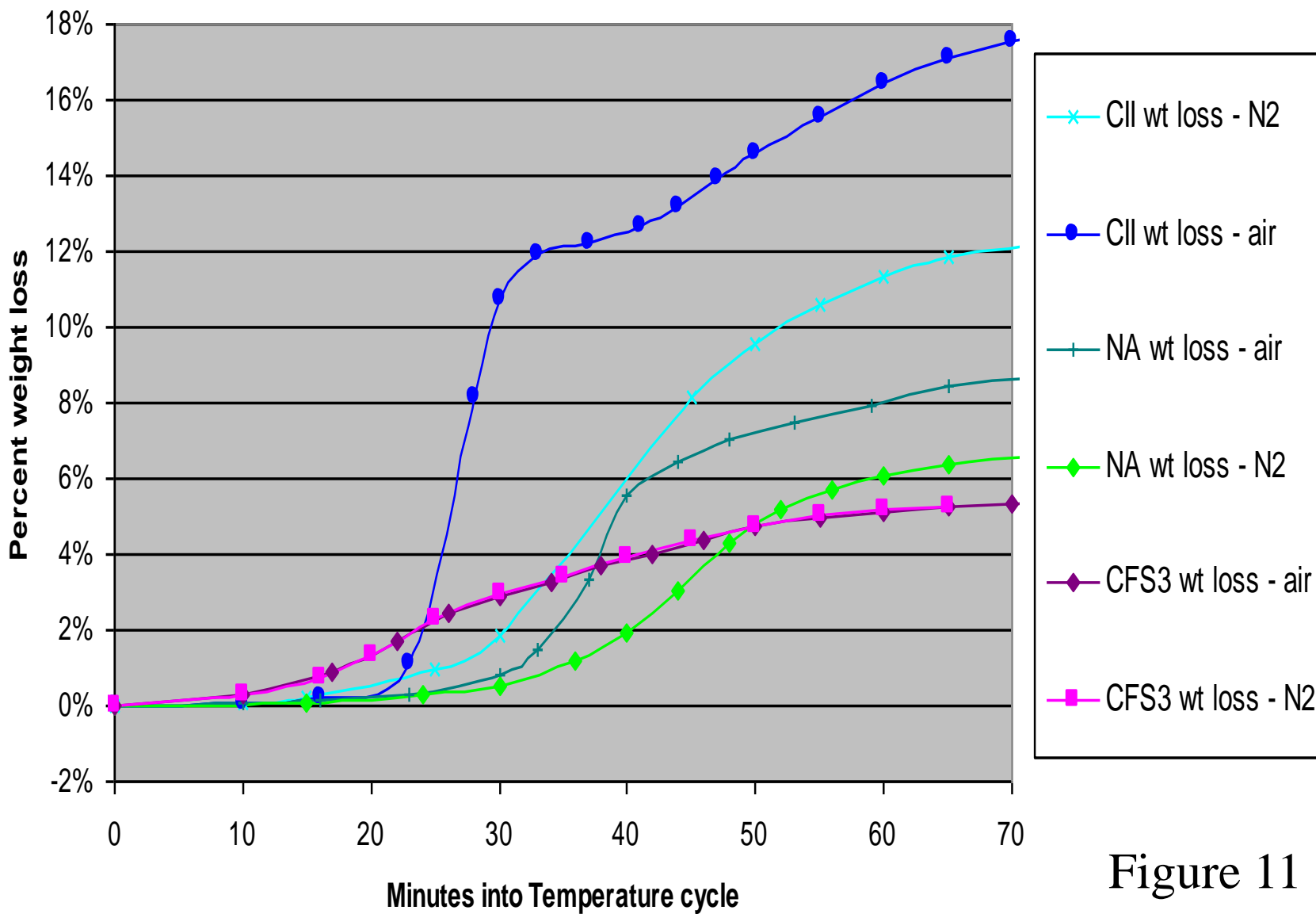


Figure 11

# TGA Nitrogen baselines and incremental air effect

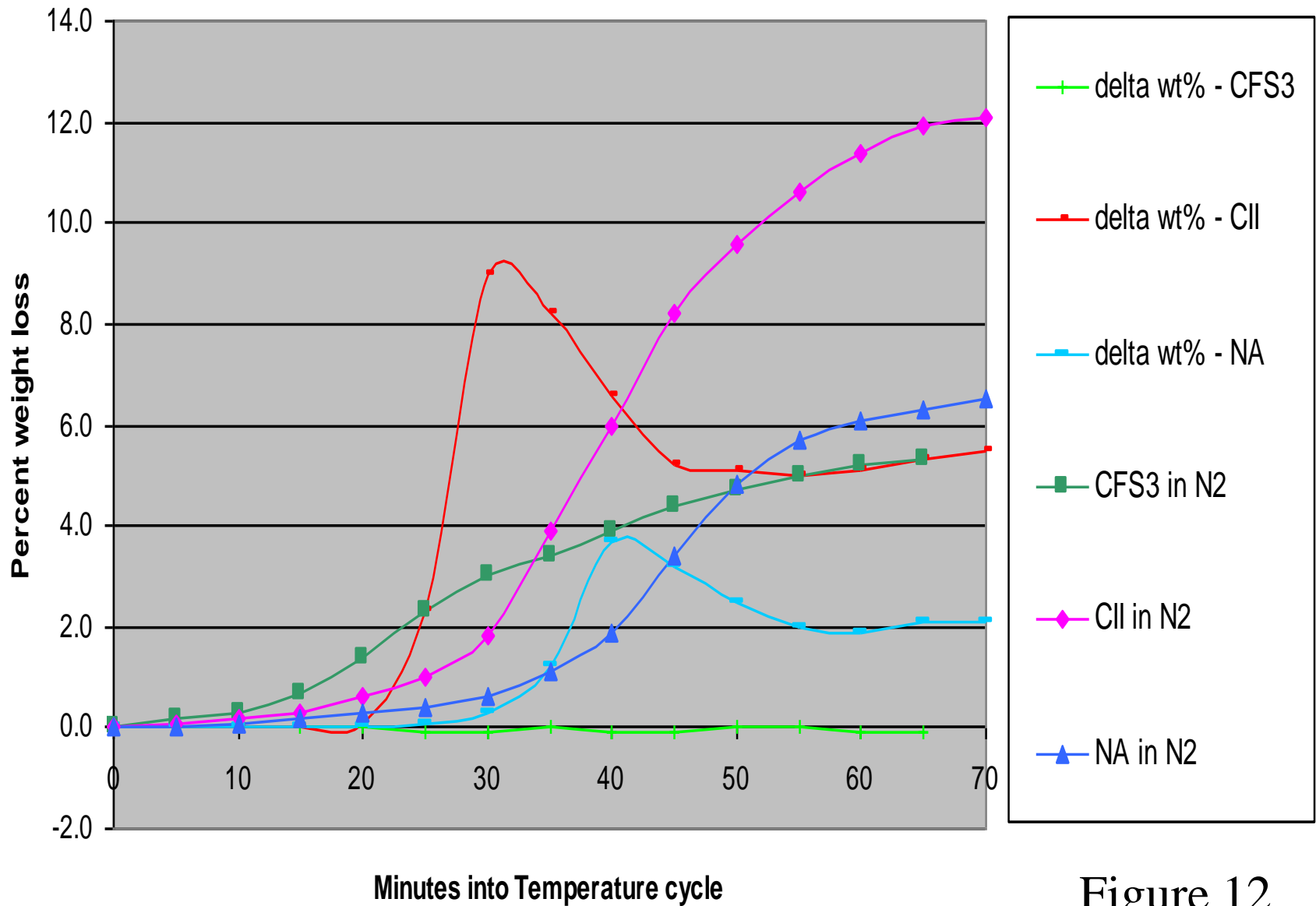


Figure 12

## CII and NA sample ramp Exotherms

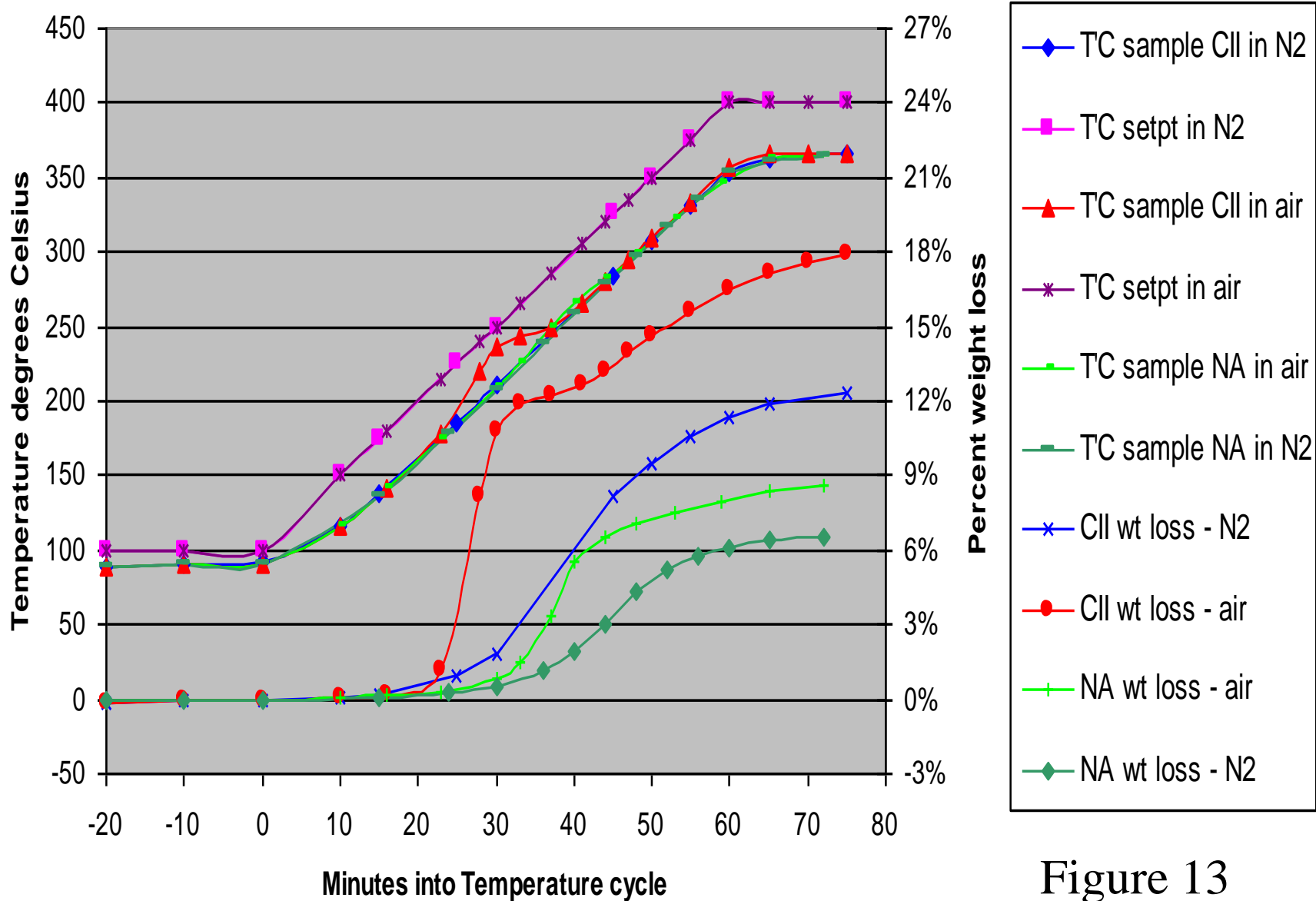
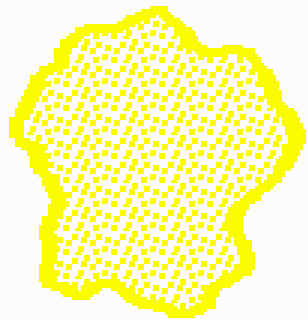


Figure 13

# Thermodynamics of Adsorption

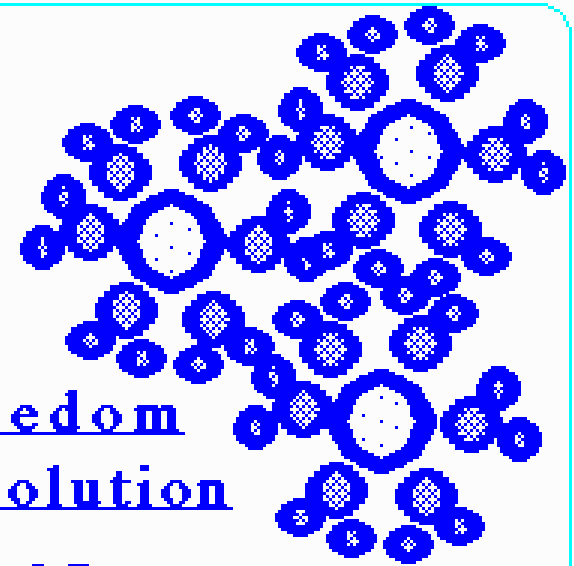
Adsorption  
in the particle



Tug of War



Freedom  
of Solution



or

Freedom  
of the gas phase

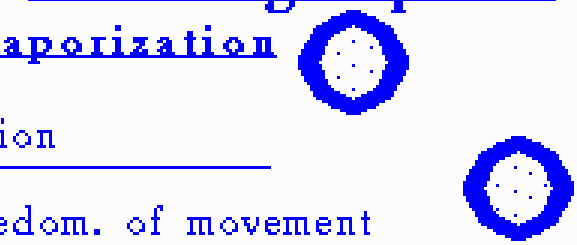


Figure 14

Adsorption

Solution/Vaporization

Highly desirable position

Ordinary position

but very little freedom.

but lots of freedom. of movement

High potential energy (depends on site)

Relatively low potential energy

Little entropy (like condensed phase)

High entropy (depends on pressure/conc.)

Finer the pore-the greater the energy

Lower the pressure/conc.-higher the entropy

# Criterion for Adsorption from Solution

For Spontaneous adsorption to occur at a specific site

$\epsilon$ , the potential energy of the adsorption site, must satisfy:

$$\epsilon_{\text{Ads.}} (\text{at site}) \geq RT \ln \{C_{\text{sat}}/C\}$$

Therefore, every adsorption site within the carbon structure with an adsorption potential equal to or greater than the above criterion will be occupied by a solute molecule., precipitated from solution.

Figure 15

# Adsorption Sites on Activated Carbon

## Distribution of Adsorption Forces for Butane

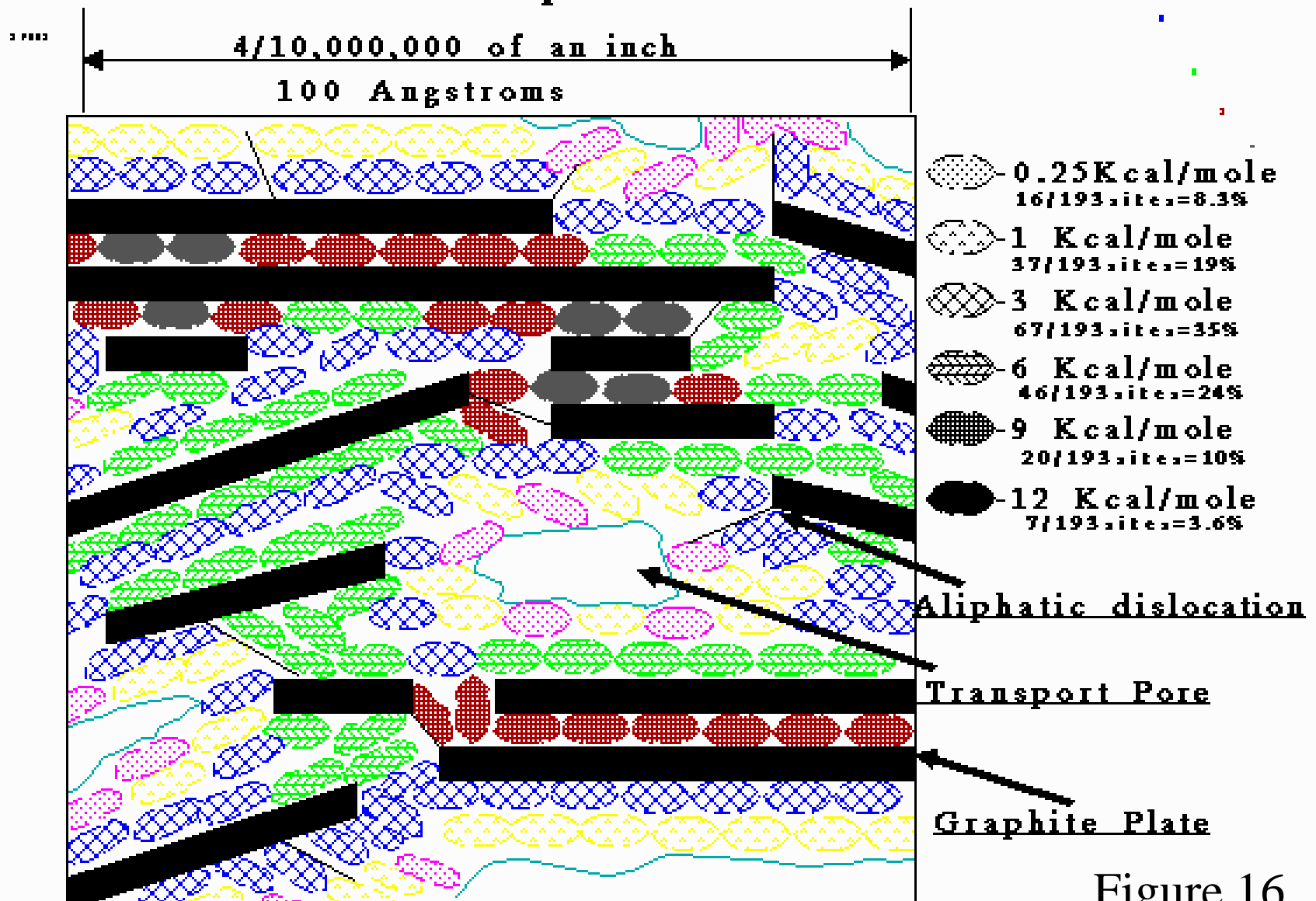


Figure 16

# Adsorption Potential vs Butane Pressure at Boiling Point -0.5C

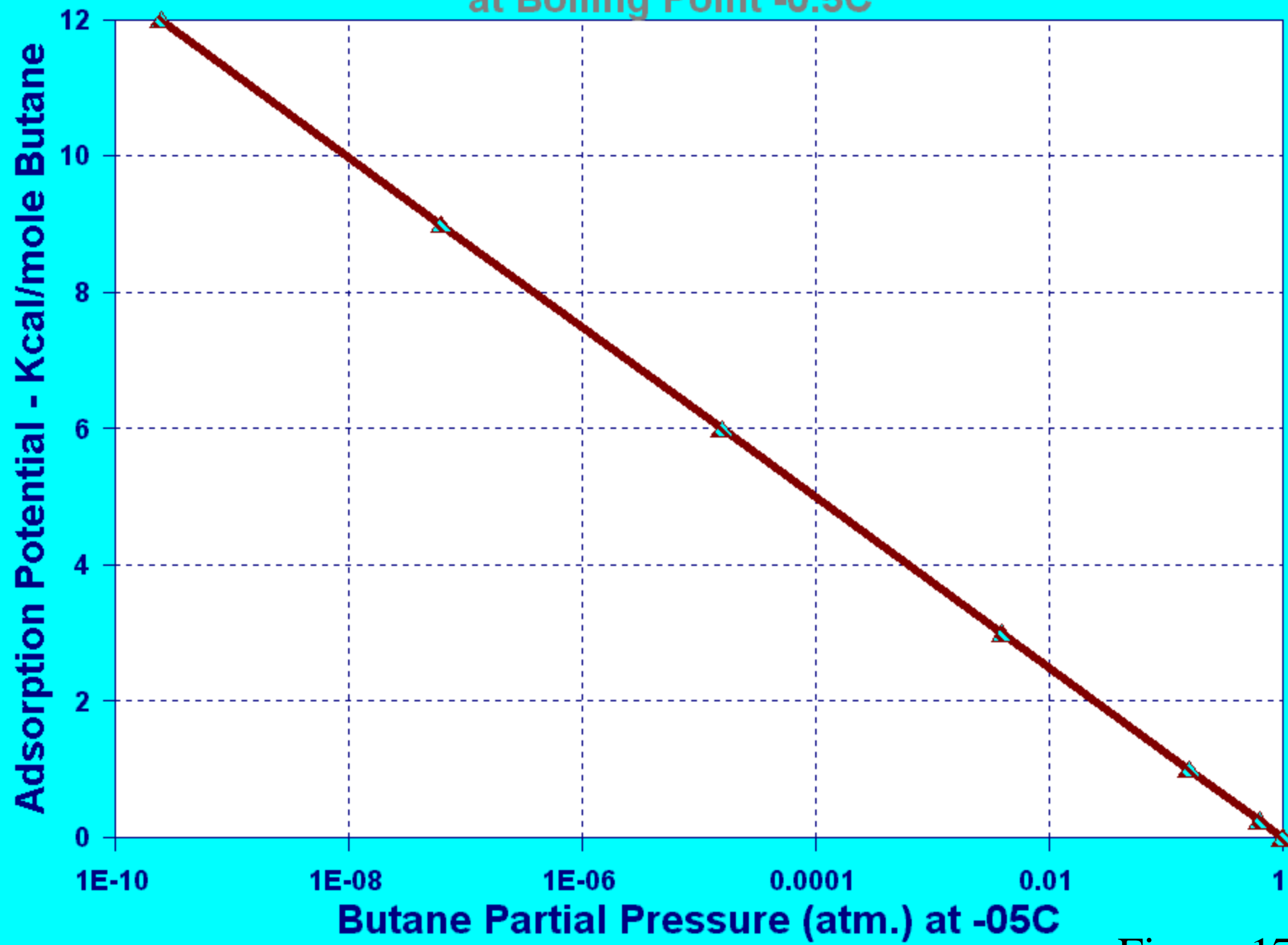


Figure 17



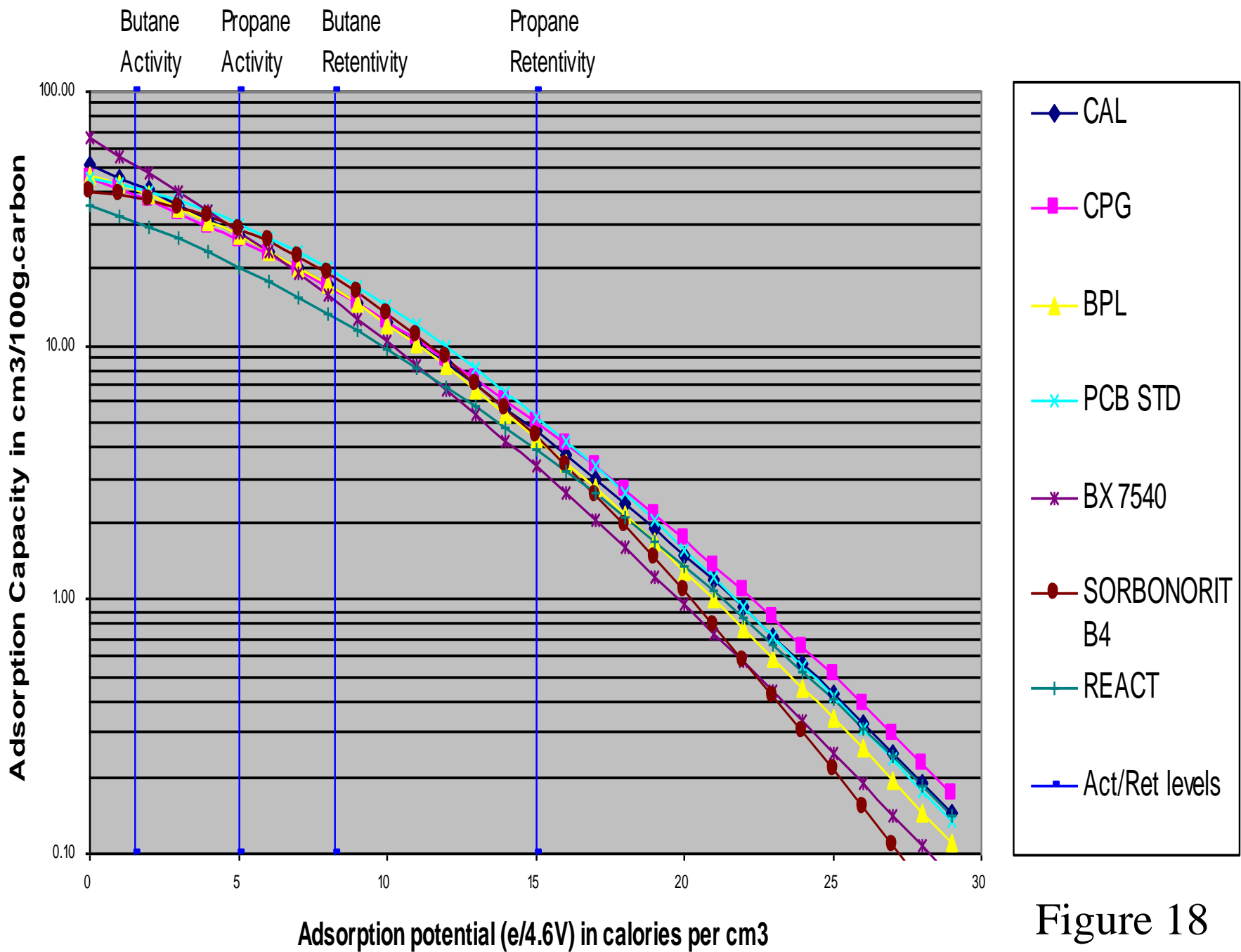


Figure 18

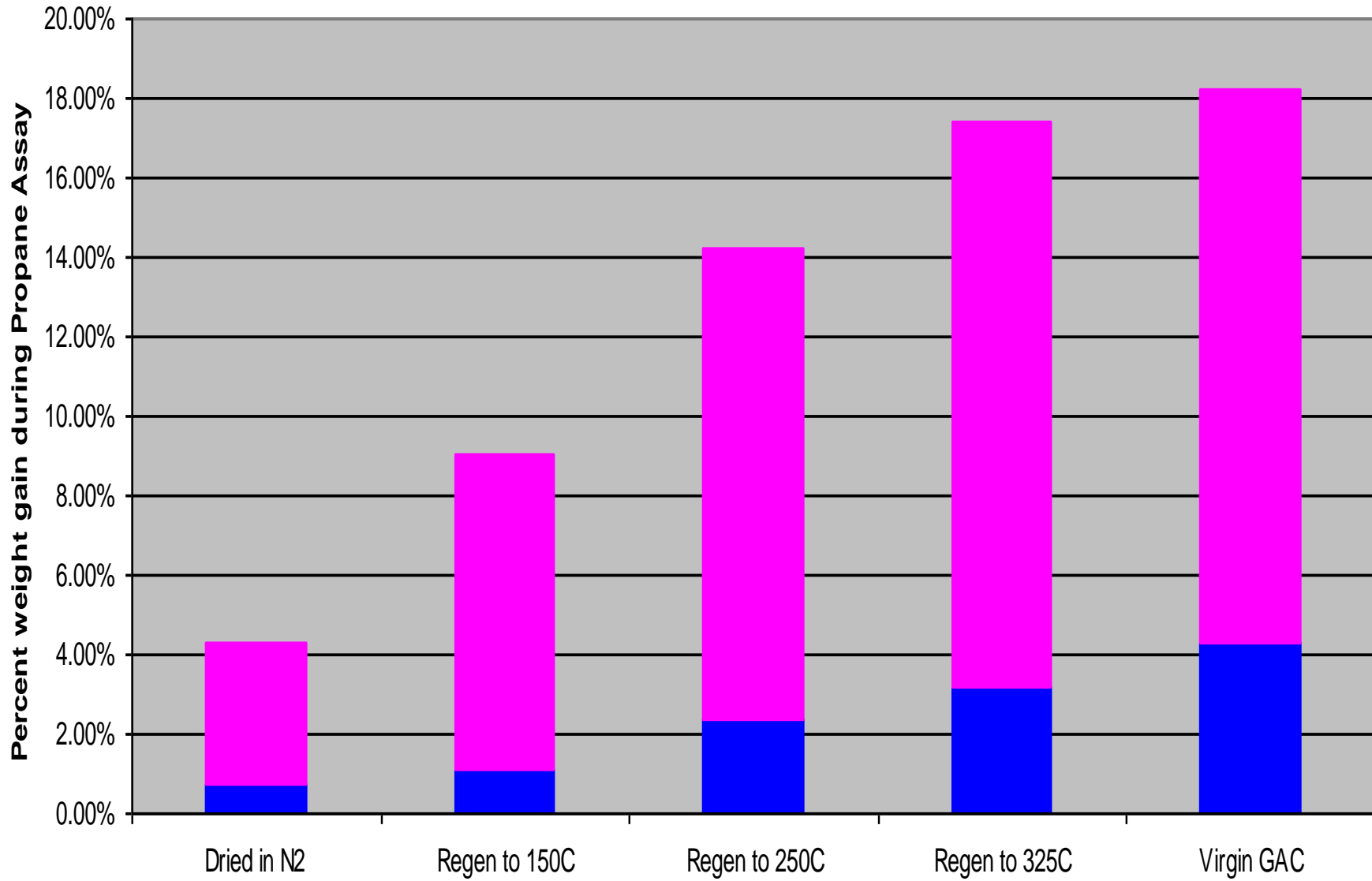
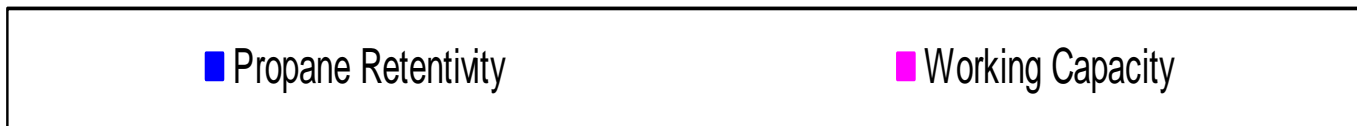


Figure 19



## Comparison of Regeneration Options

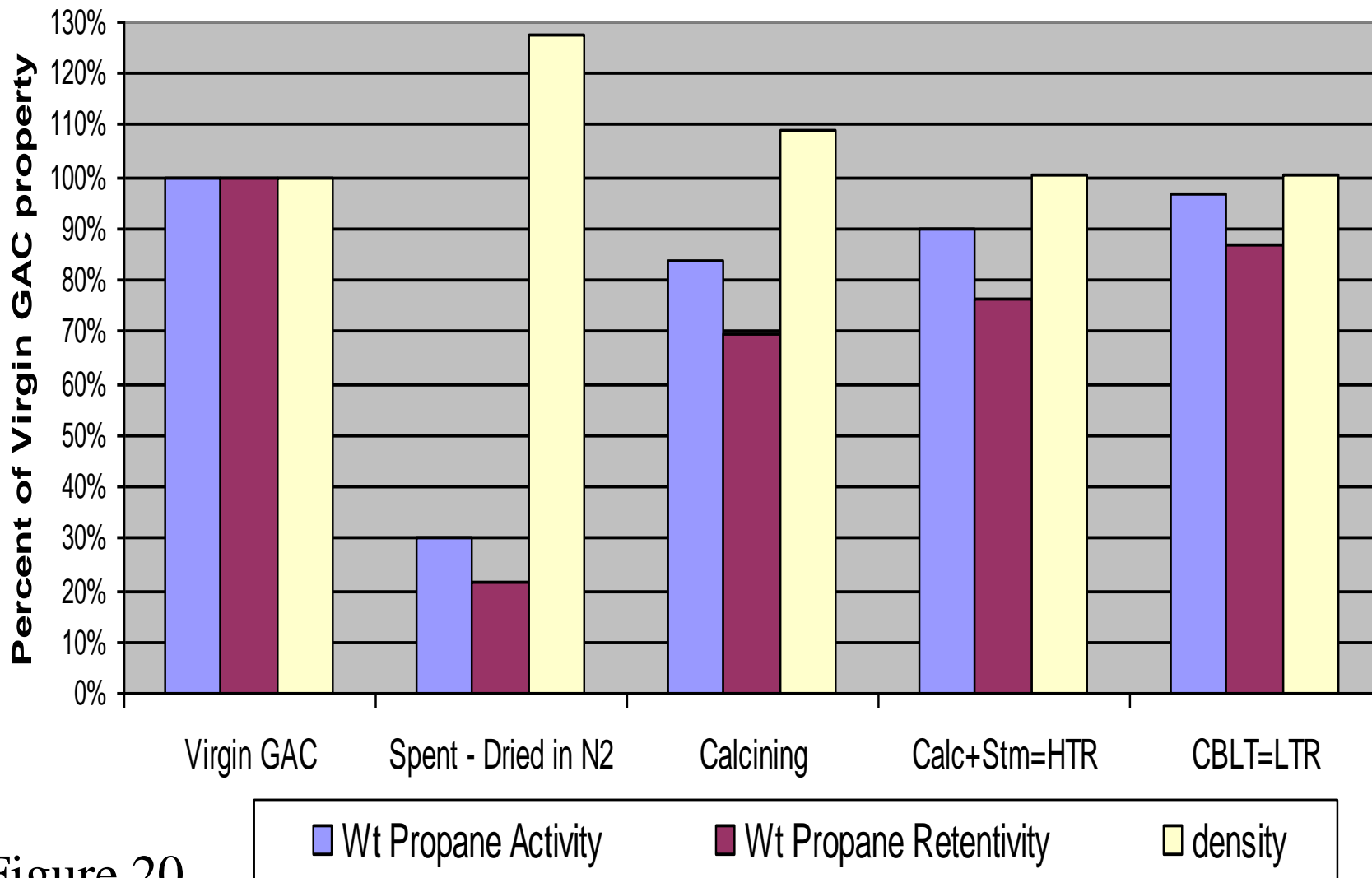
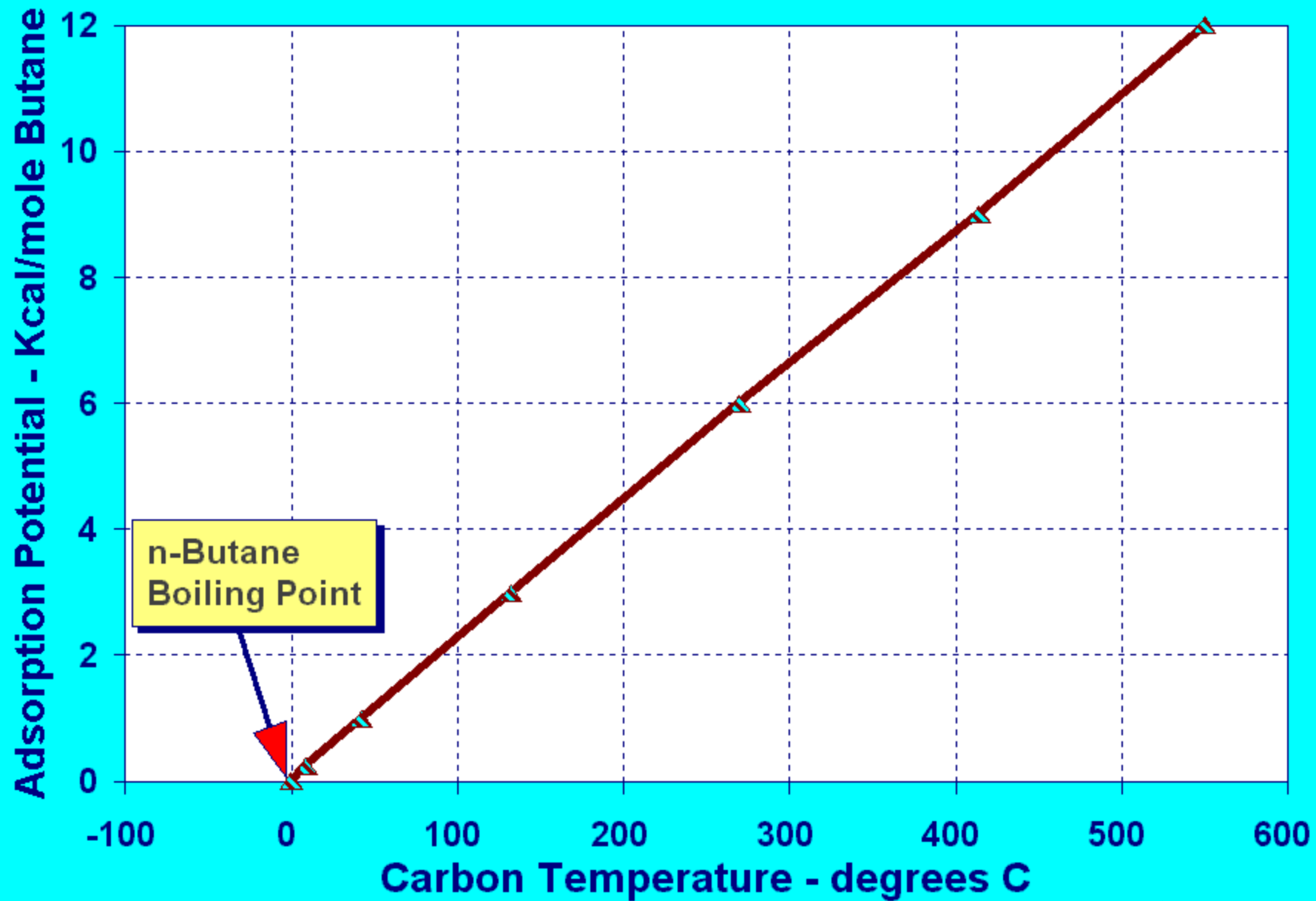


Figure 20

## Adsorption Potential vs Temperature For Butane at 1 atm. Partial Pressure



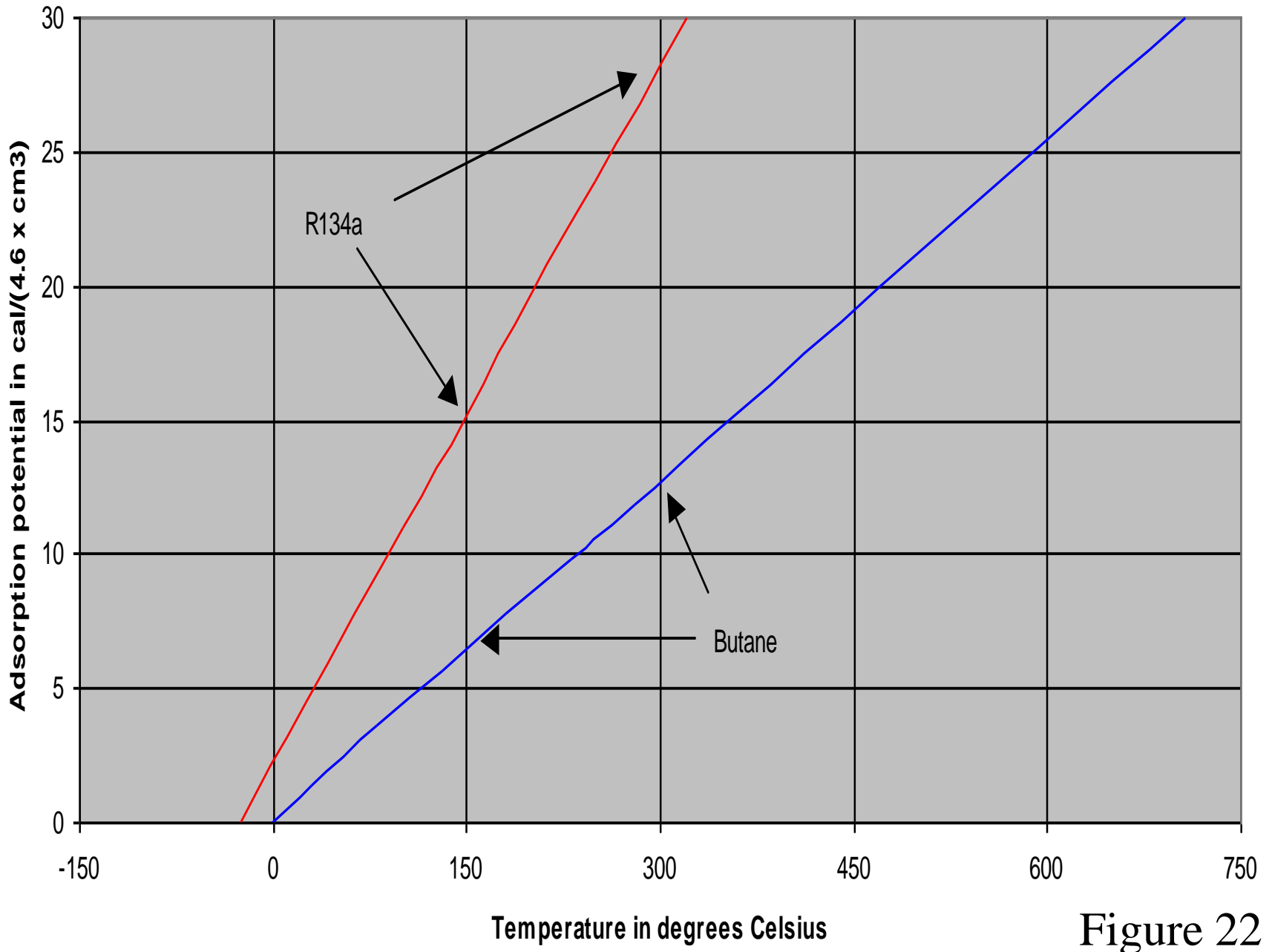


Figure 22

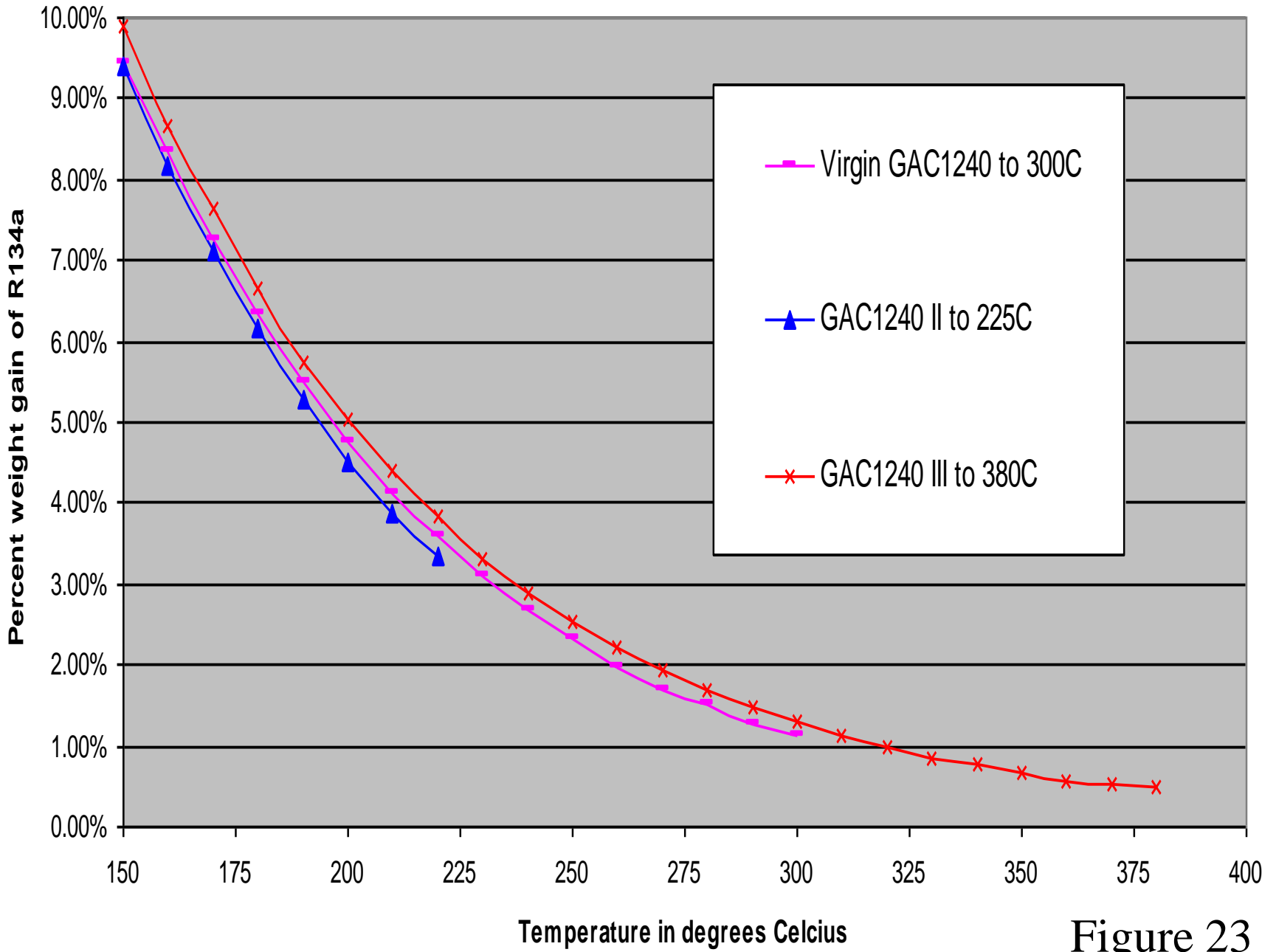


Figure 23

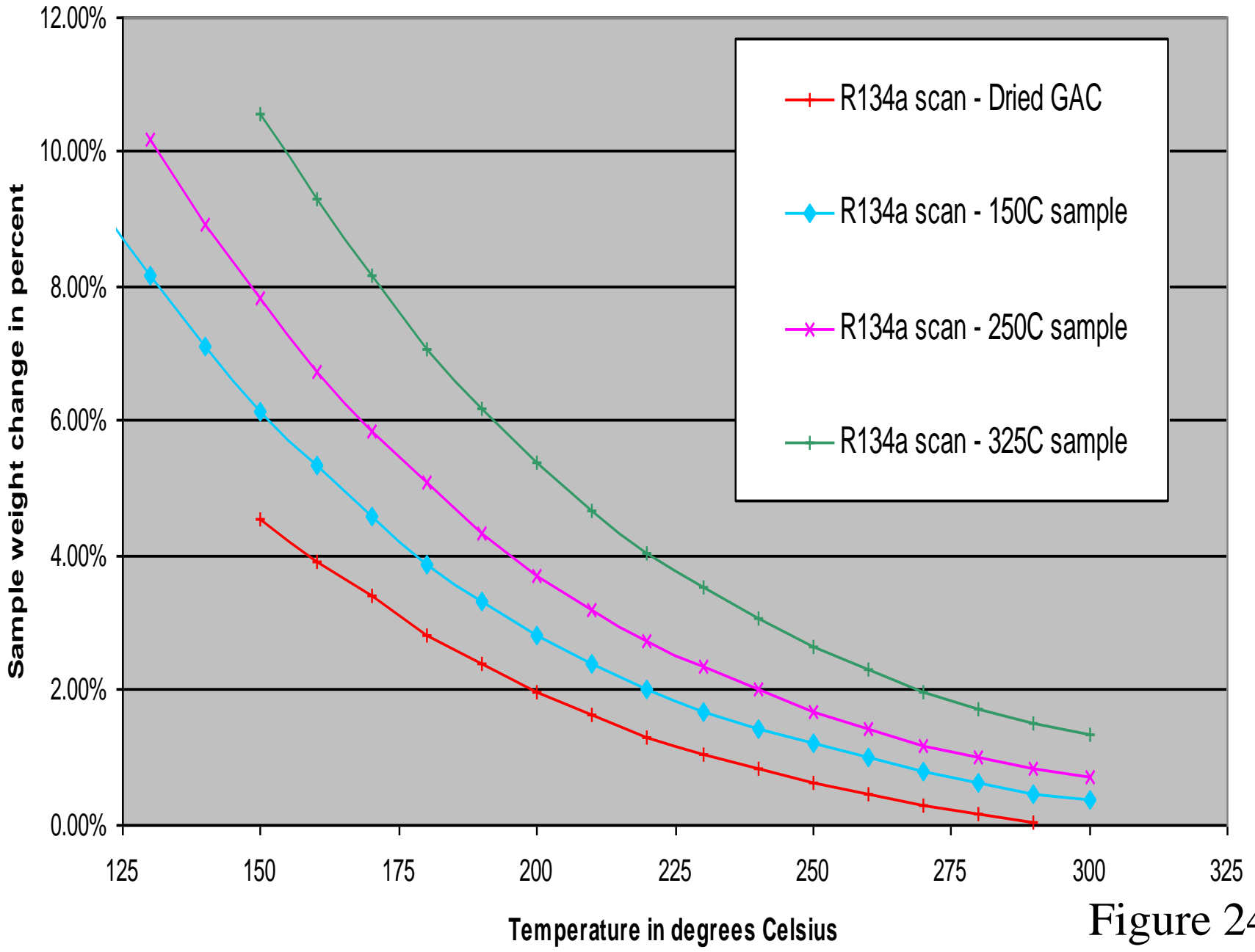


Figure 24

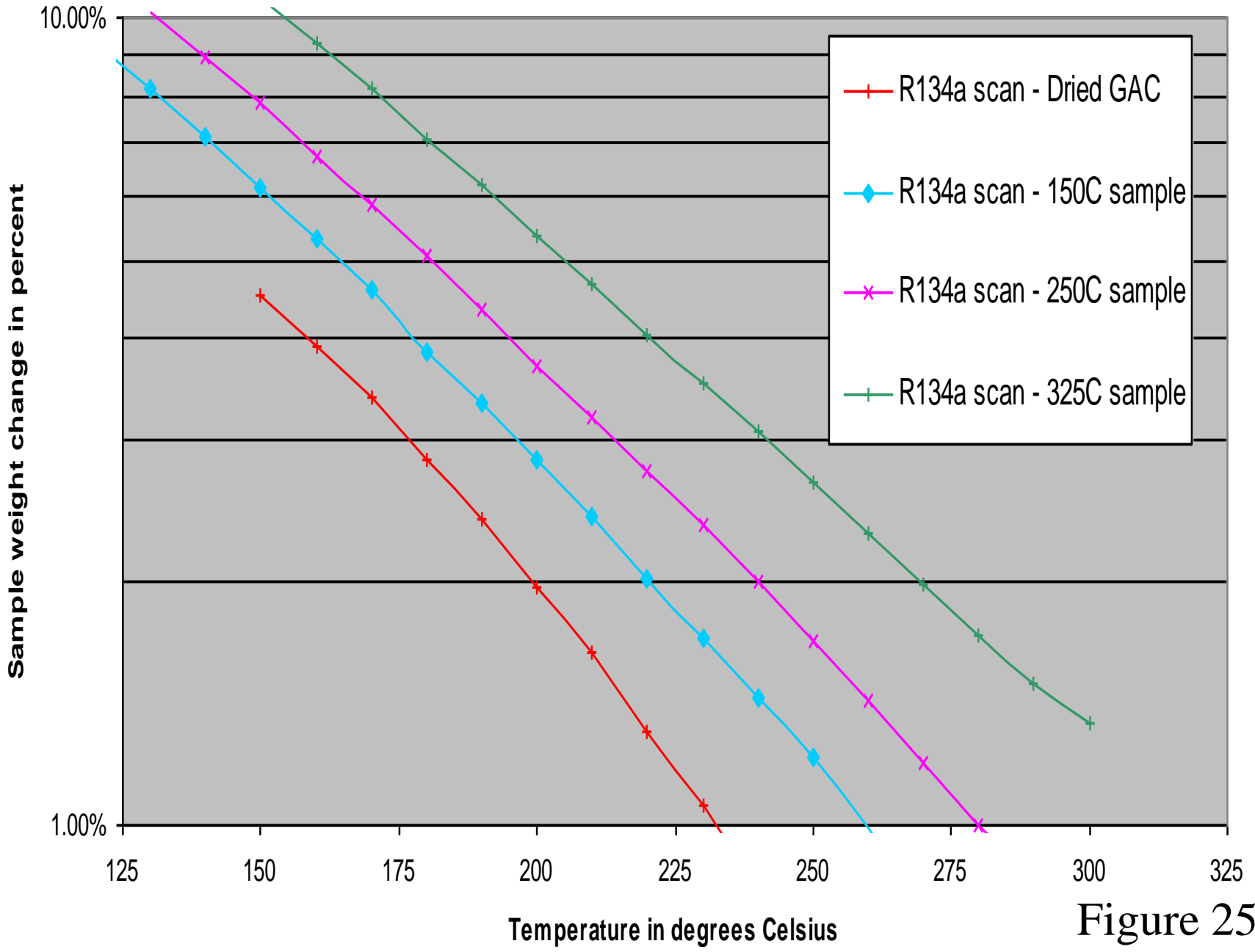


Figure 25



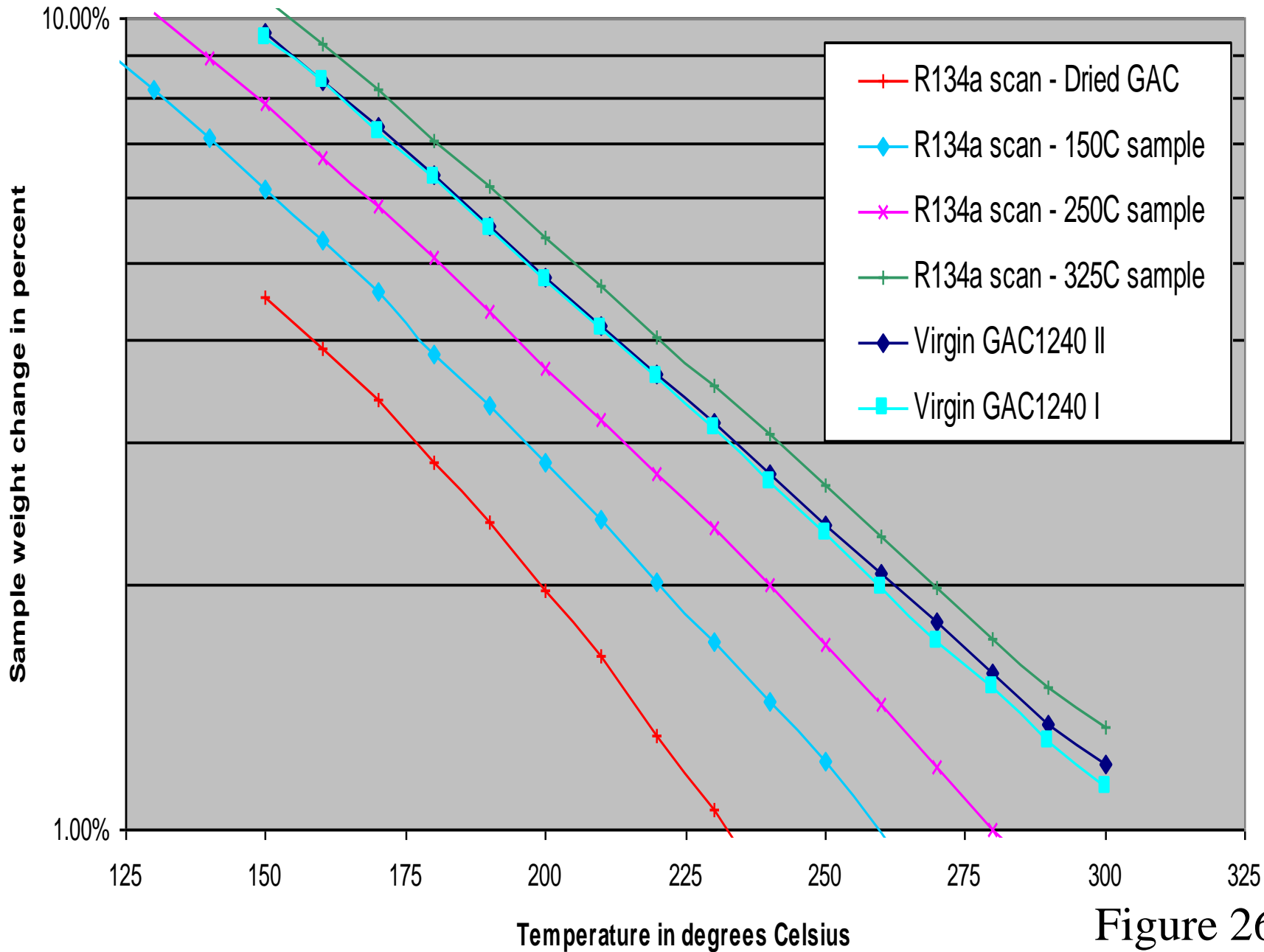


Figure 26

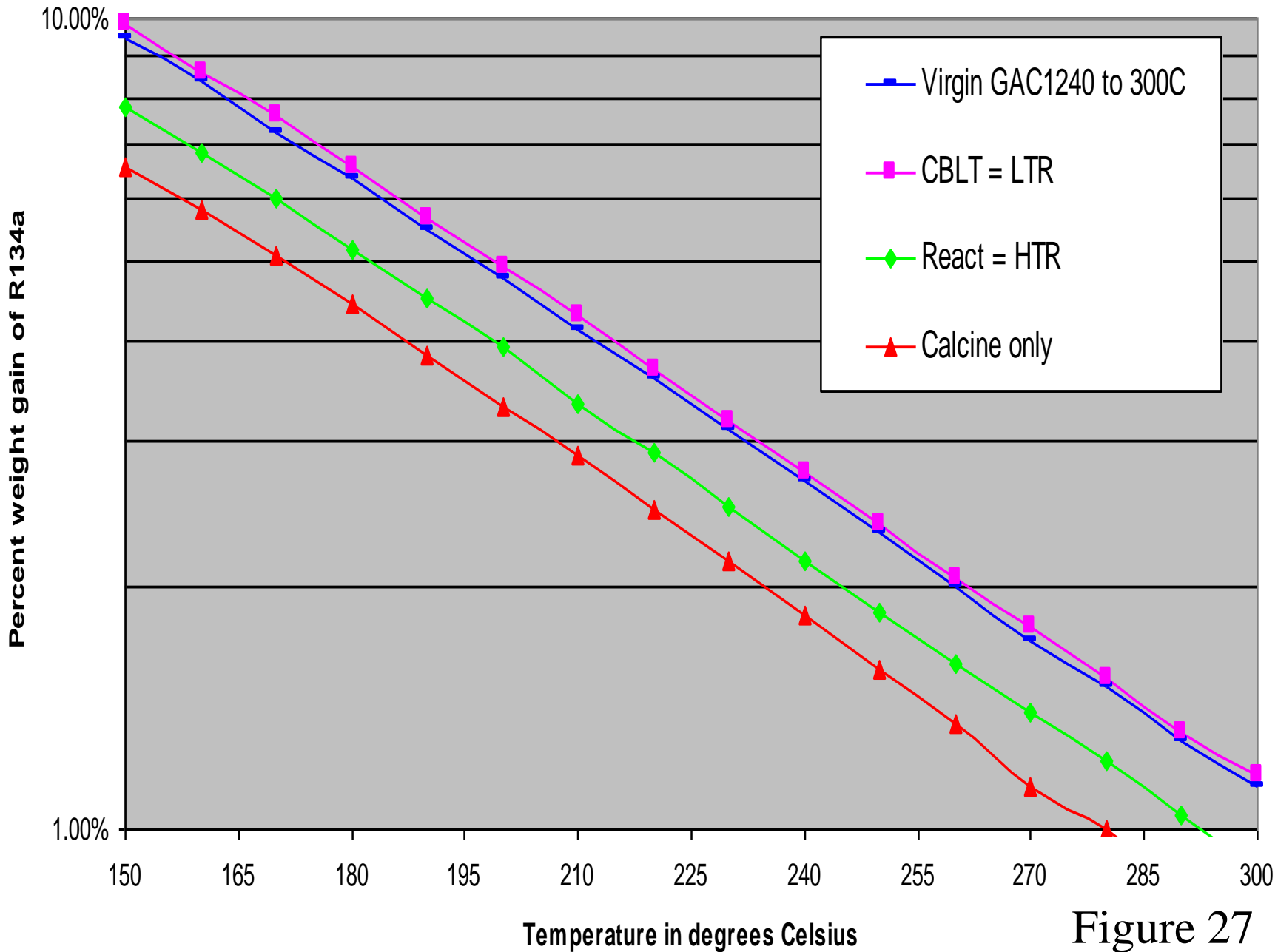


Figure 27

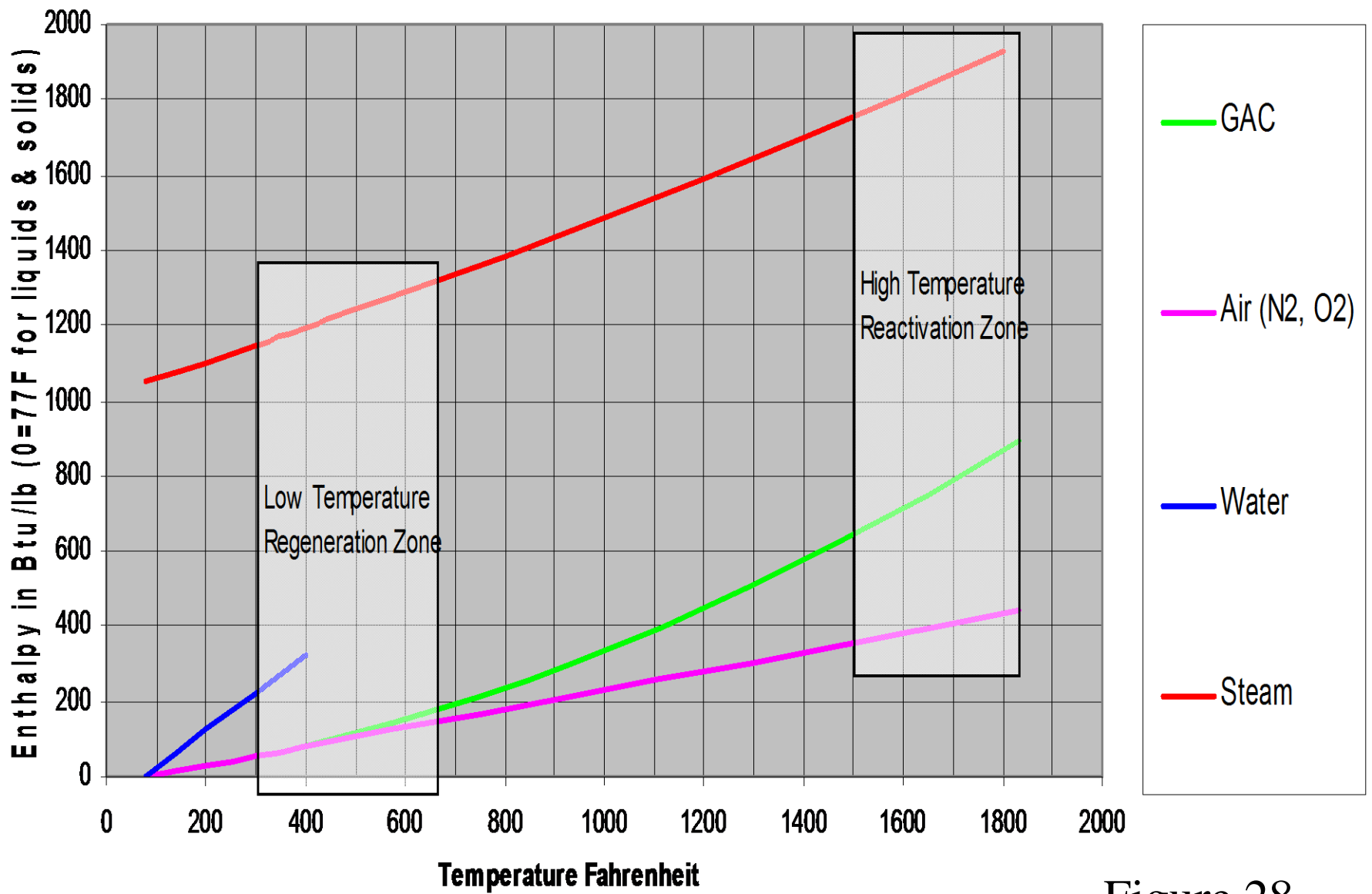


Figure 28

TABLE 2: Table of Reaction Stoichiometries and Heats of Combustion

Key:														
	oxygen	+ fuel				--->	products				dHcomb			
	O2(g)	C(s)	CO(g)	CH(l)*	CH2(l)**	C(s)	CO(g)	CO2(g)	H2O(g)	kcal	Btu	Btu	Btu	
mw	32	12	28	13	14	12	28	44	18	gmole	#mole	#fuel	#O2	
dHform	0.000	0.000	-26.416	1.953	-6.223	0.000	-26.416	-94.052	-57.798					
	0.5	1					1			-26.42	-47,549	-3,962	-2,972	
	0.5		1					1		-67.64	-121,745	-10,145	-7,609	
	1	1						1		-94.05	-169,294	-14,108	-5,290	
reaction	1.5				1			1	1	-145.63	-262,129	-18,723	-5,461	
	1				1		1		1	-77.99	-140,384	-10,027	-4,387	
stiochiometry	0.5				1	1			1	-51.58	-92,835	-6,631	-5,802	
	1.5			1				1	0.5	-124.90	-224,827	-17,294	-4,684	
	1			1			1		0.5	-57.27	-103,082	-7,929	-3,221	
	0.5			1		1			0.5	-30.85	-55,534	-4,272	-3,471	

dHform in units of Kcal/gmole

CH(l)\* based on 1/6th of the dHform of Benzene

CH2(l)\*\* based on 1/6th of the dHform of Cyclohexane

Note: 1 kW\*hr = 3412.1 Btu

1 watt = 14.34 cal per min

1 Btu = 252 calories

Figures 29, 30 & 31 deleted due to file size (jpg's)

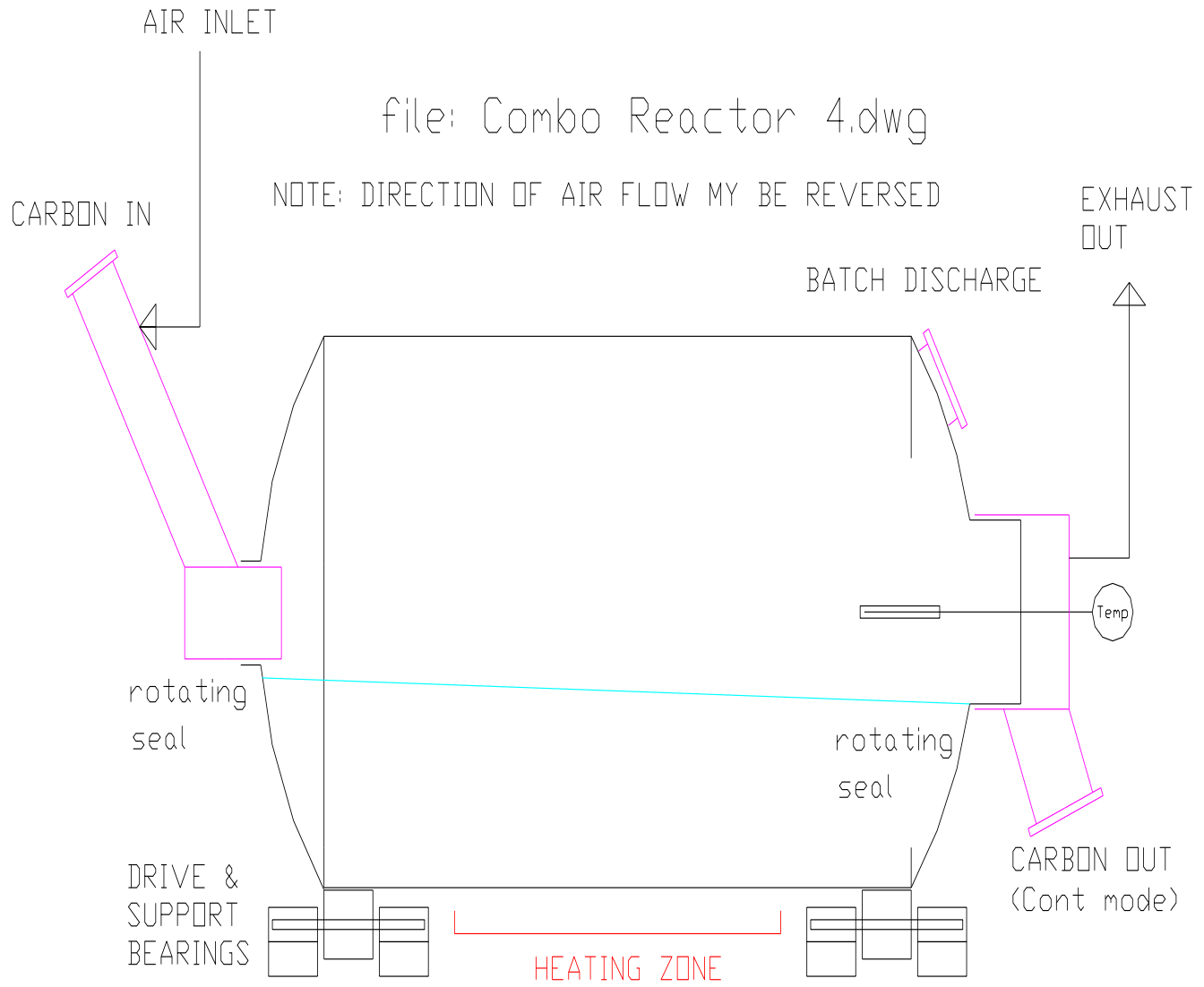


Figure 32

# CarbOxLT (LTR) vs Reactivation (HTR)

- Different Reaction Pathway & Conditions
  - HTR: Calcining adsorbates & Addn. Steam Activation
  - LTR: Surface Oxidation in air of Adsorbates
  - HTR: 850-1000 Celsius, LTR: 150-350 Celsius
  - HTR: Endothermic (add heat), LTR: Exothermic
  - HTR: raked bed <3” deep, LTR: stirred dense bed
- Different Economics of Operation
  - Capital: HTR: Refractory lined, LTR: CS/SS
  - Energy: HTR: 4,000+ Btu/#, LTR: <1,000 Btu/#
  - Losses/cycle: HTR: 3-5%, LTR: 1.5-3% (estimated)
  - Regeneration Efficiency: LTR > HTR

Figure 33

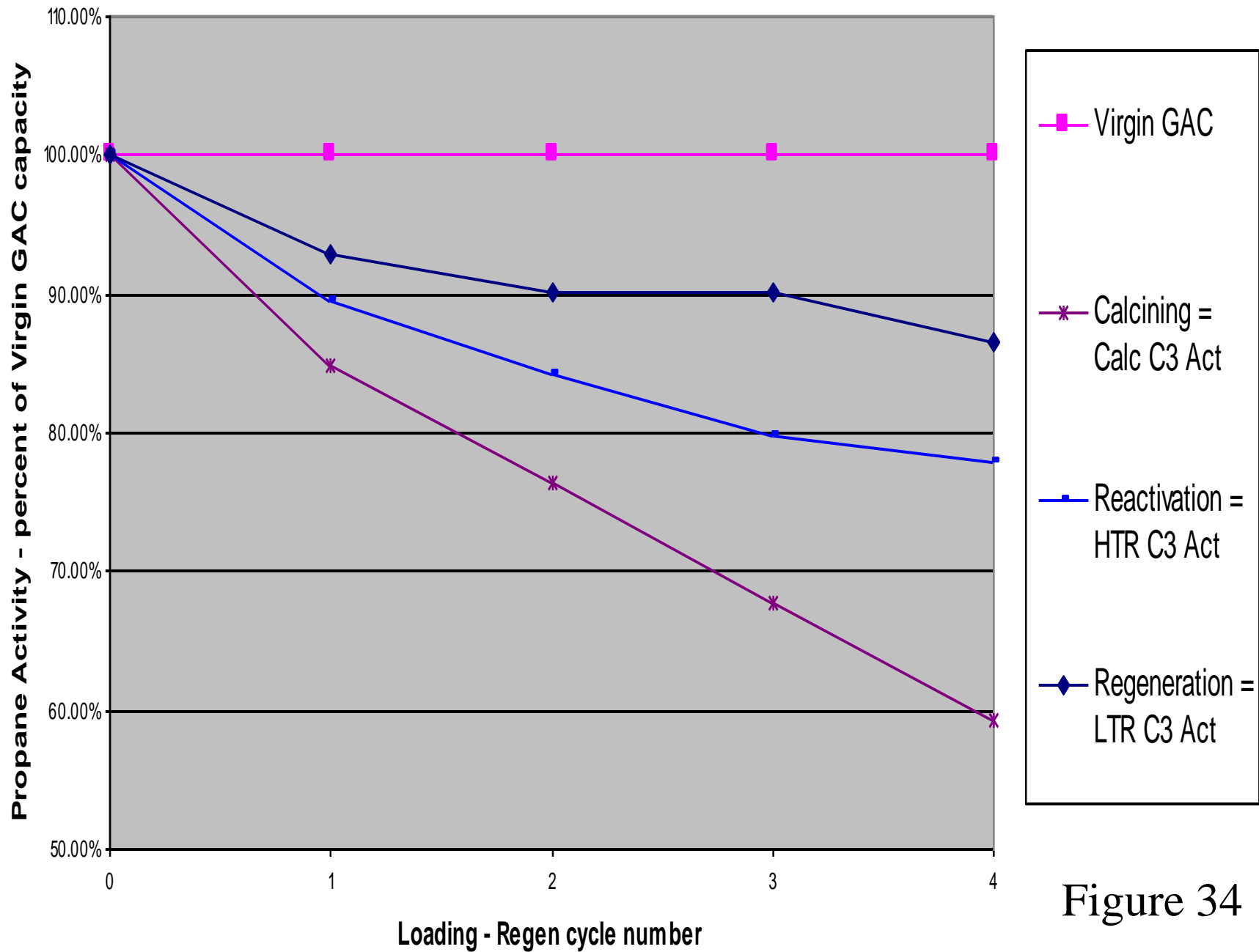


Figure 34



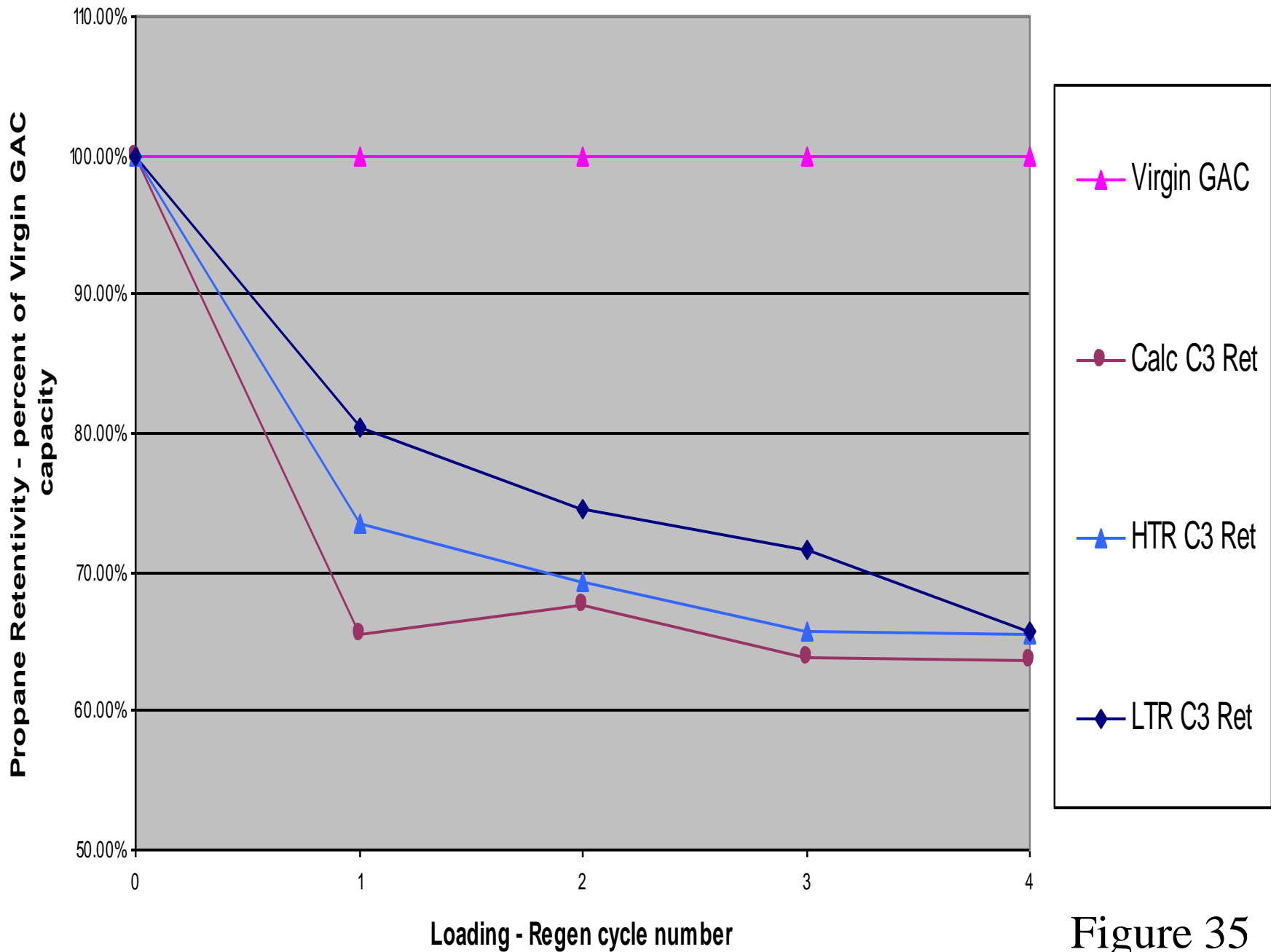


Figure 35