the Energy to Lead

Program to Evaluate the Implications of Gas Variability in California

Stakeholder and Project Advisory Committees Meeting

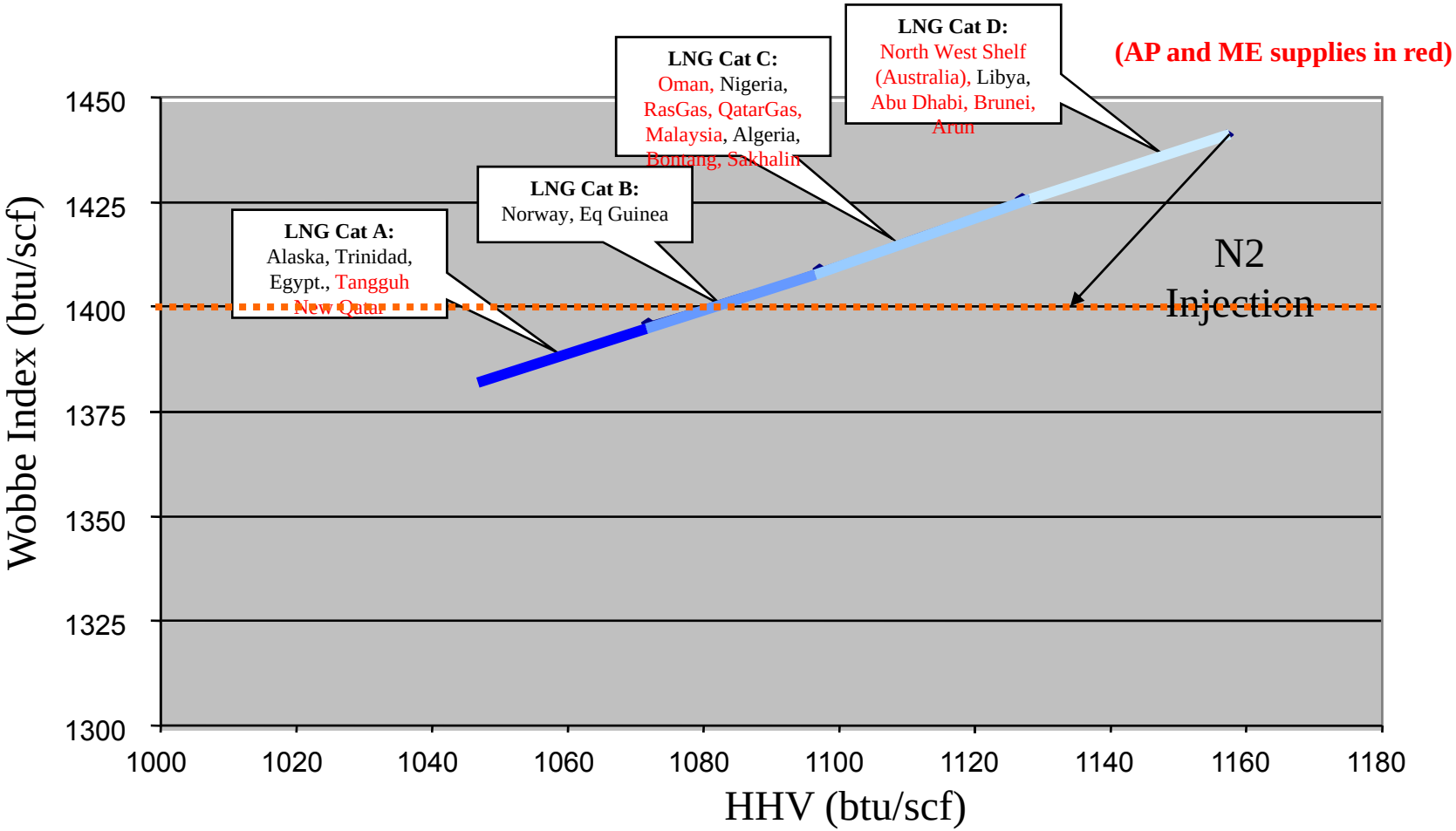
February 15, 2012

gti

Overall Program Objective

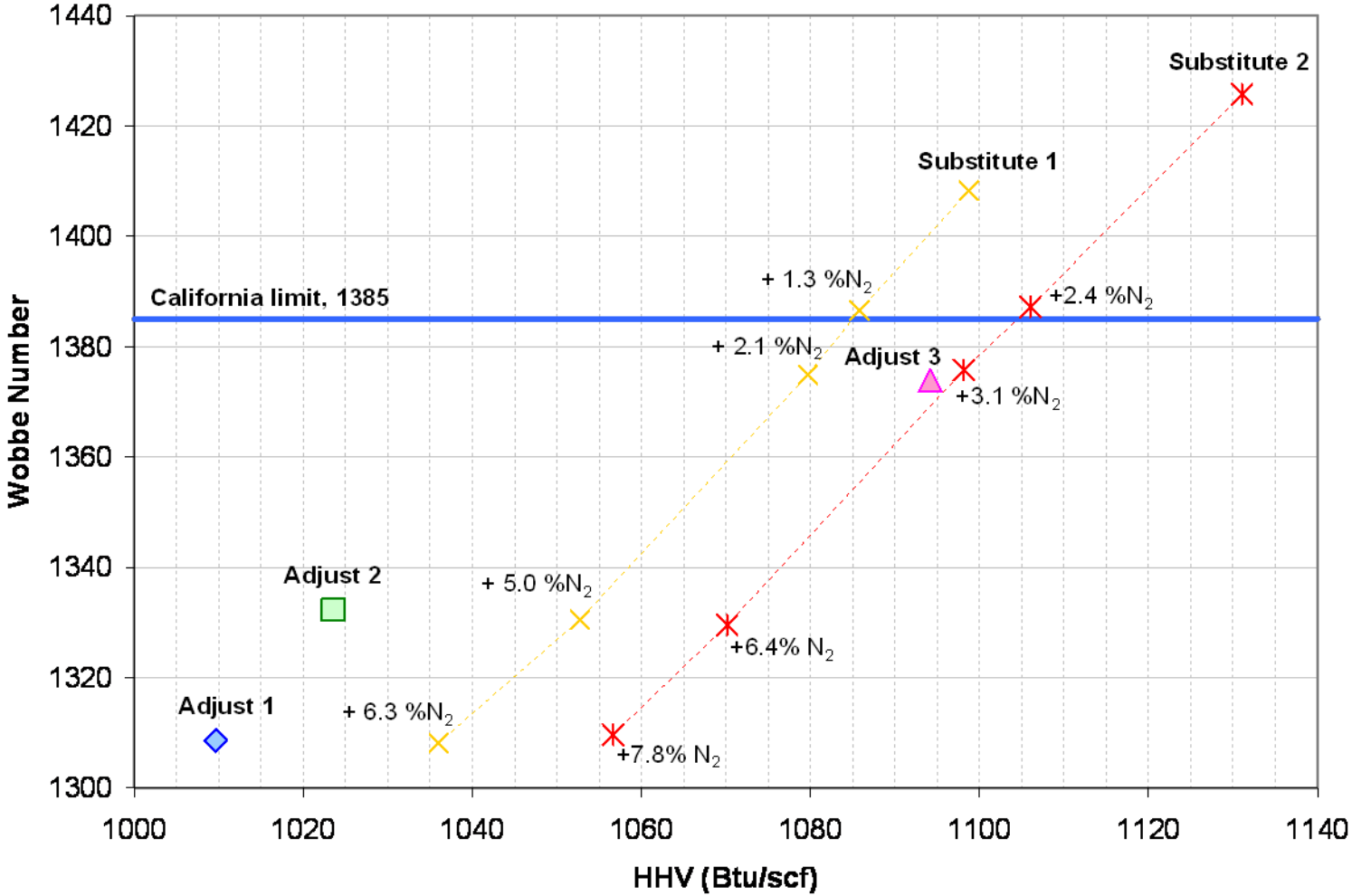
- To provide information to policymakers, regulators and industry such as on the potential safety, performance and air quality impacts of increased variability in the California natural gas supply, and specifically related to the use of LNG.
- Industrial combustion systems – GTI
- Field testing of industrial combustion systems – GTI
- Foodservice appliances - GTI
- Appliances, indoor and outdoor air quality, range hoods - LBNL

LNG Supplies



- **LNG expectational ranges only, might not be true reflection of guarantees from LNG export plant**
- **N2 tuning for example only**

Test Gases Selected for Industrial Burner and Commercial Food Service



Burners Selected for IX Testing

- All relevant types are covered
- Top sellers – by market presence

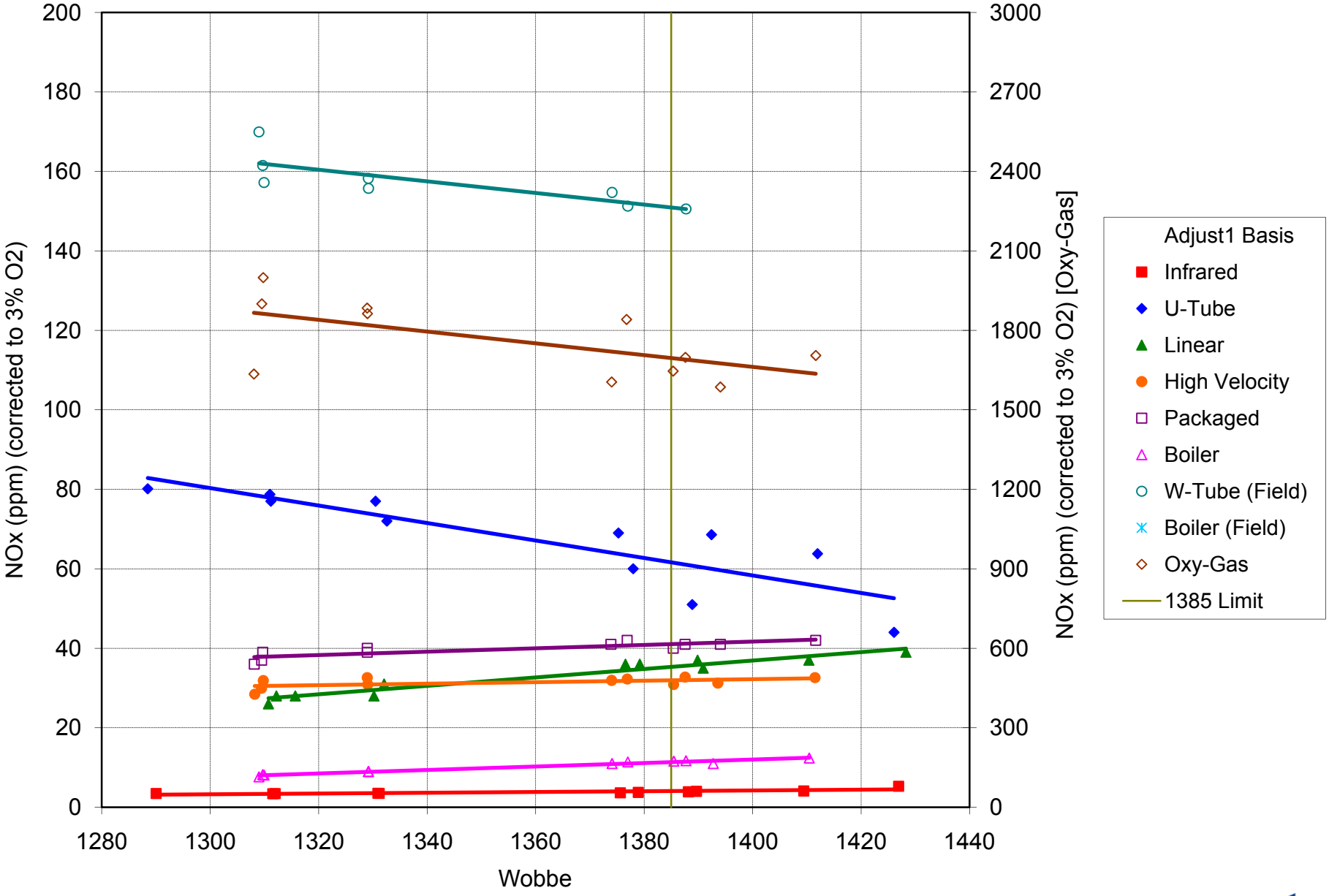
Manufacturer	Model Name	Comment	Control	Capacity, MMBtu/hr
Radiant Burners				
North American	Evenglow	Radiant Tube	Modulating +Pressure Balance	0.02—0.5
Maxon	Radmax	Radiant Panel	On/Off + Venturi mixer	0.025 per head
Boiler Burners				
Powerflame	NVC	Packaged System	Cam linkage + O_2 Trim	2-14.7
Cleaver-Brooks	SB-200-080-150	Packaged System		80HP
Linear/Grid/Duct Burners				
Flynn Burner	Pipe	Linear Burner (baking)	Modulating +Venturi mixer	0.04 per inch
Oxygen Enhanced Combustion				
Eclipse	PrimeFire 300	High Luminosity	On/Off + Pressure Balance	0.5 – 8.0
Nozzle Mixed Burners				
Eclipse Combustion	ThermJet	High Velocity	Modulating +Pressure Balance	0.15-20

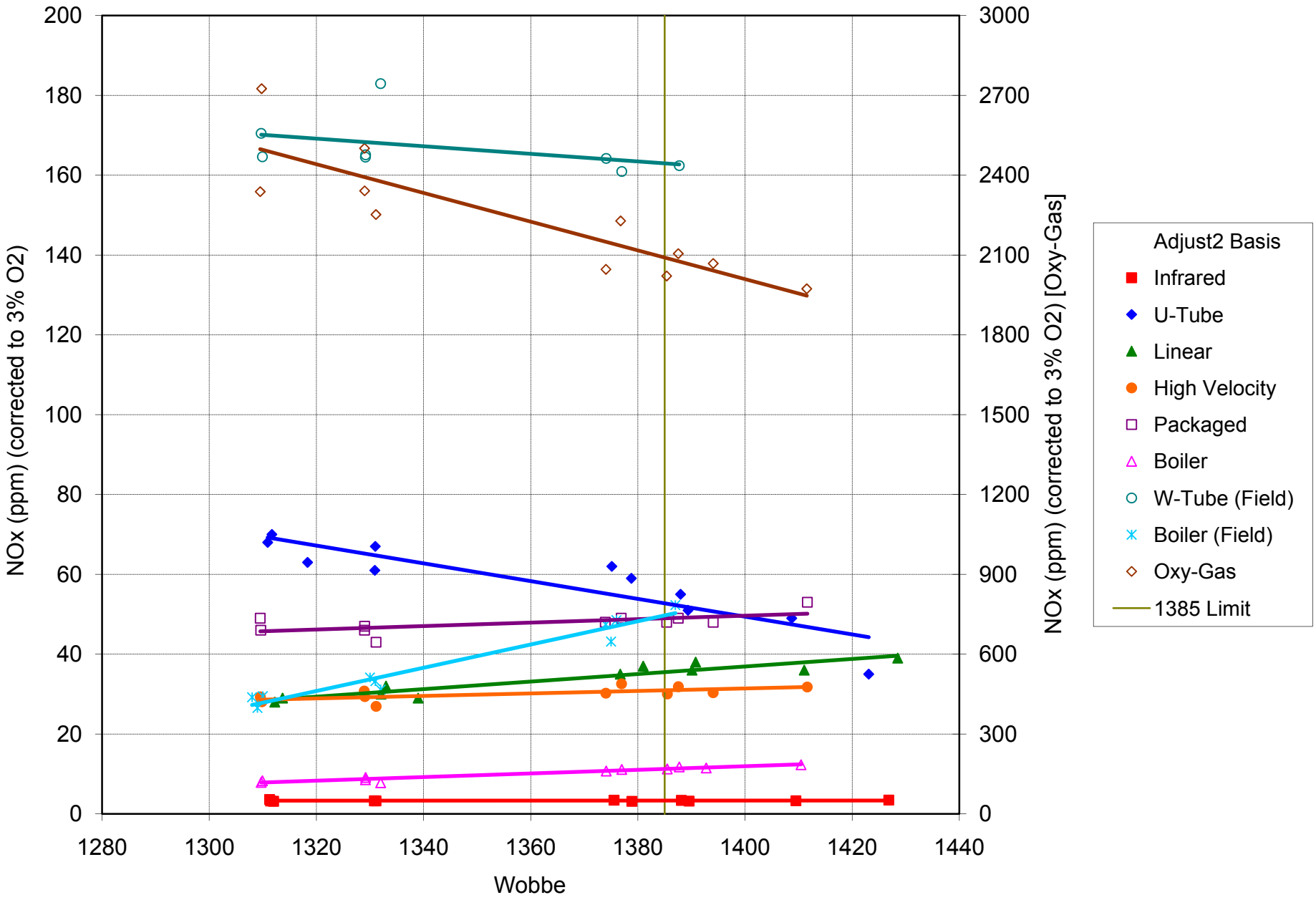
Radiant Tube Test at California Steel Industries (CSI)

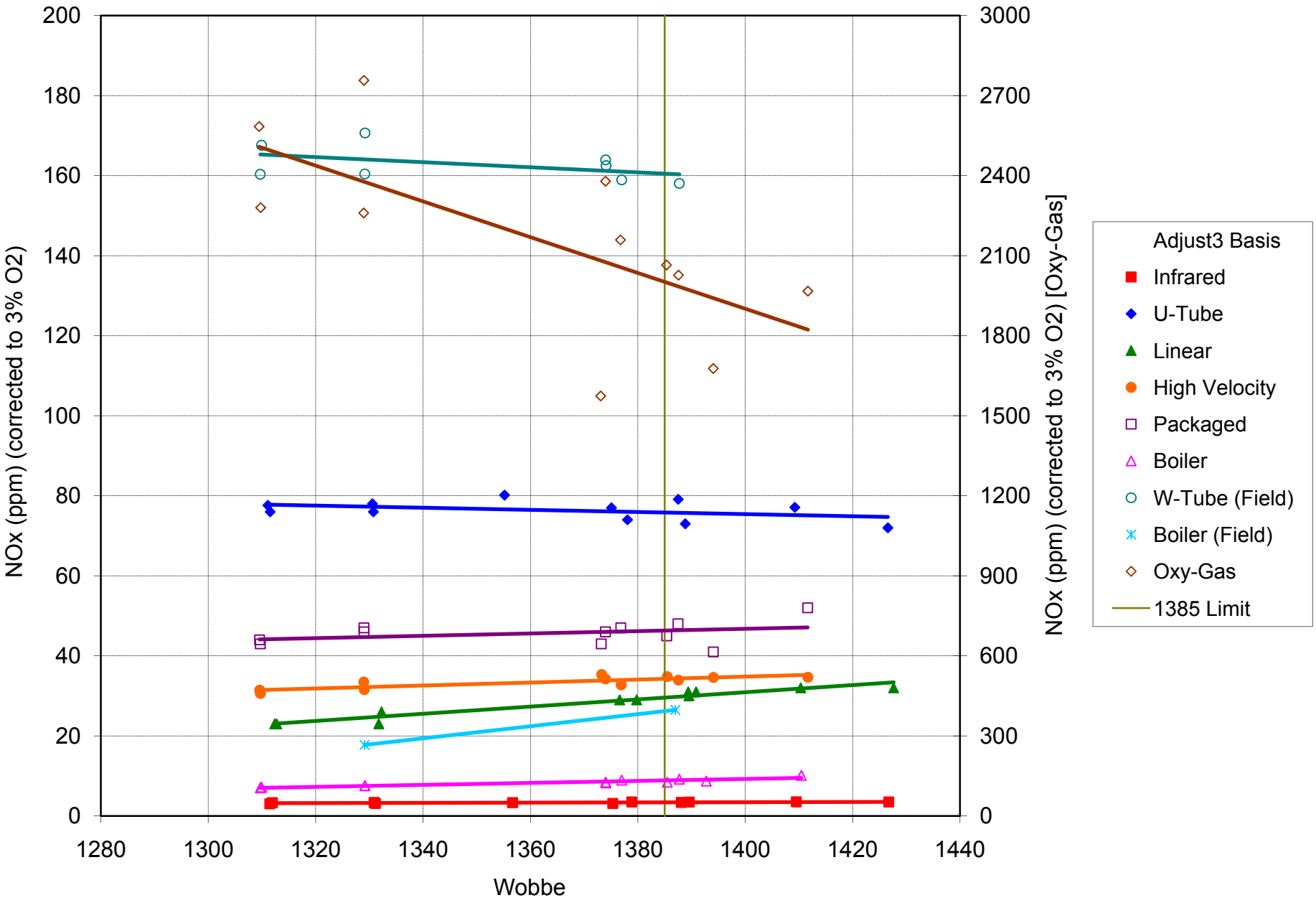
- #2 galvanizing line with 3 zones
  - Preheat using 24 direct, flat flame burners
  - Heating zone with 21 W radiant tubes using Bloom 2320 burners
    - Burner N5 used for tests
  - Recuperator and cooling zone
  - GC to monitor natural gas supply
  - Blending station allowed adding nitrogen and propane
  - Thermocouple put in exhaust duct
  - Dedicated O2, CO, NOx, hydrocarbon analyzers

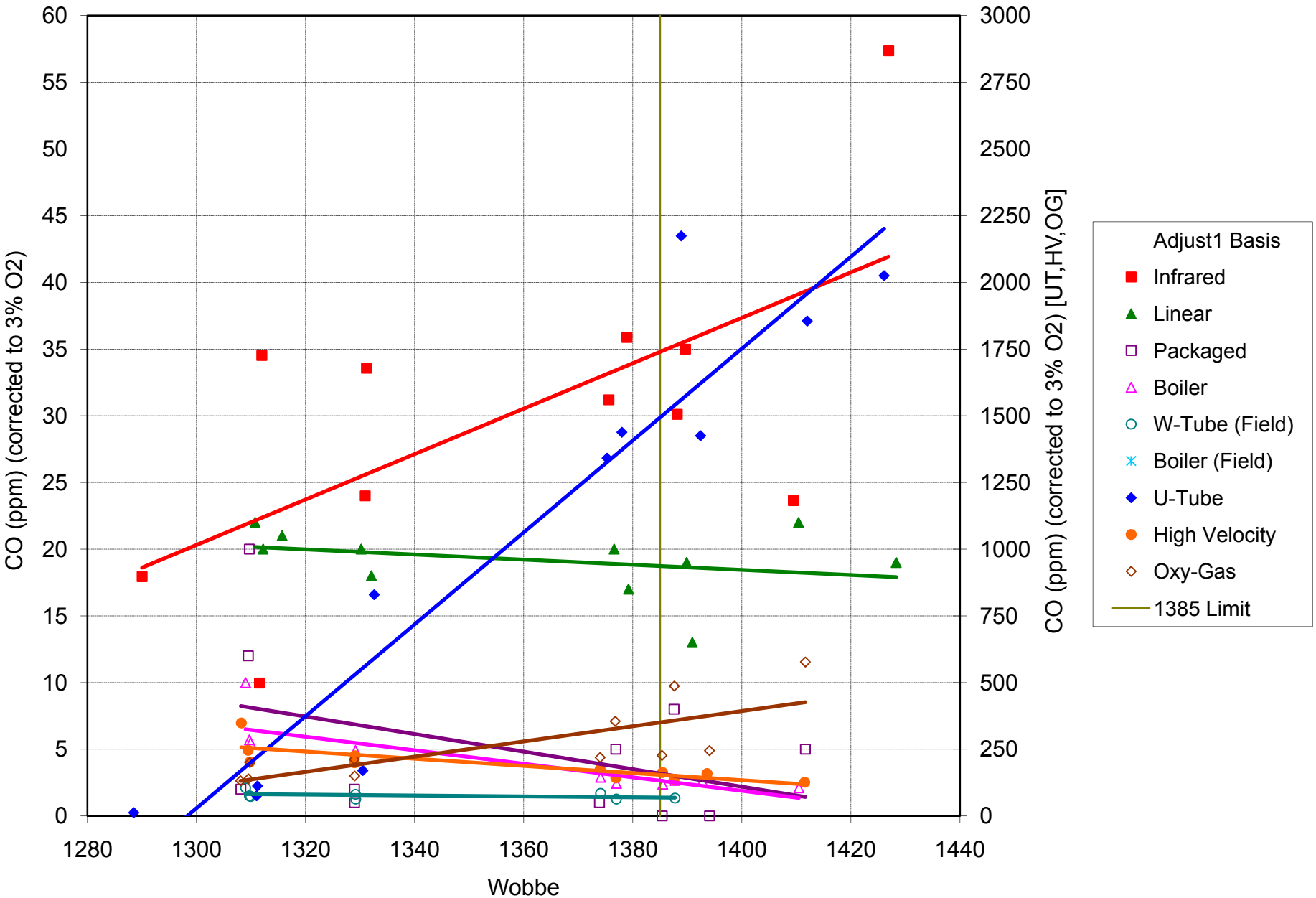
Parker Model 48L Low NOx (30 ppm) Industrial Packaged Steam Boiler

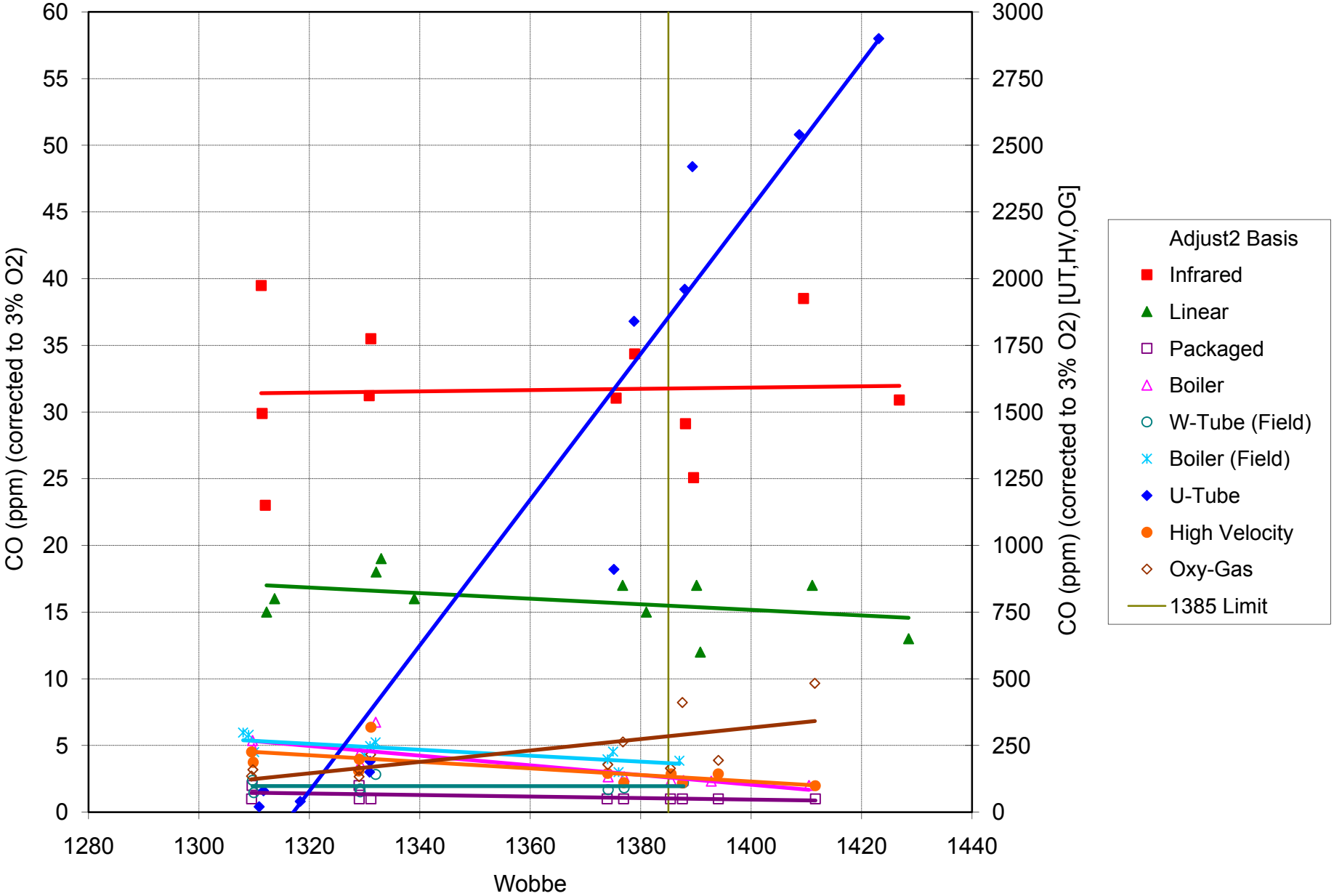
- 48-hp, 1,995,000 Btu/h, 100-psig
- Horizontal drum sectional water tube boiler
- Modulating control based on steam pressure
  - VFD on blower for air flow control
  - Ratio regulator for gas flow control
- Metal fiber burners
  - Premixed gas and air
  - Bottom mounted manifold

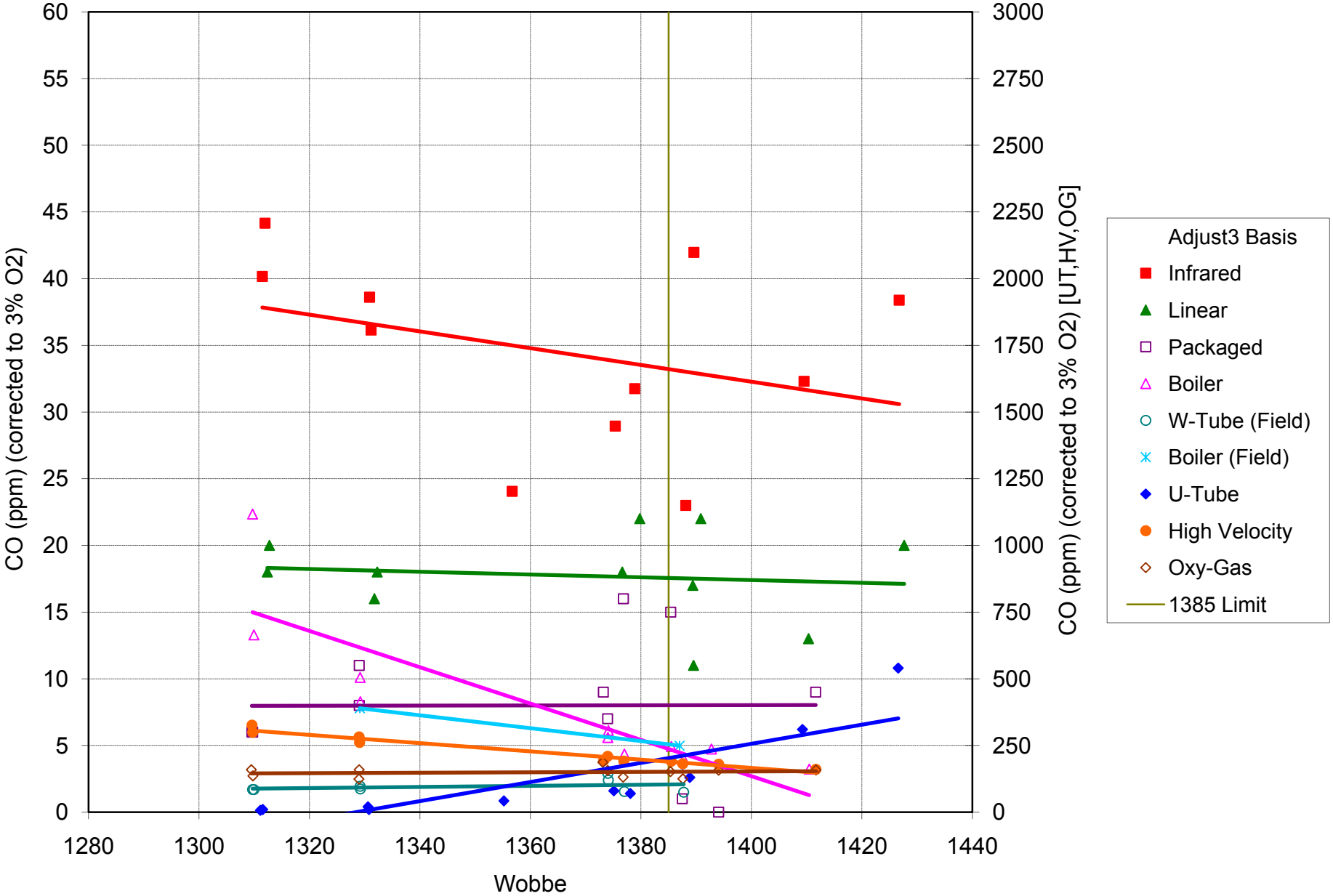

NOx (ppm) (corrected to 3% O2)
NOx (ppm) (corrected to 3% O2) [Oxy-Gas]
Wobbe
200
180
160
140
120
100
80
60
40
20
0
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust1 Basis
Infrared
U-Tube
Linear
High Velocity
Packaged
Boiler
W-Tube (Field)
Boiler (Field)
Oxy-Gas
1385 Limit

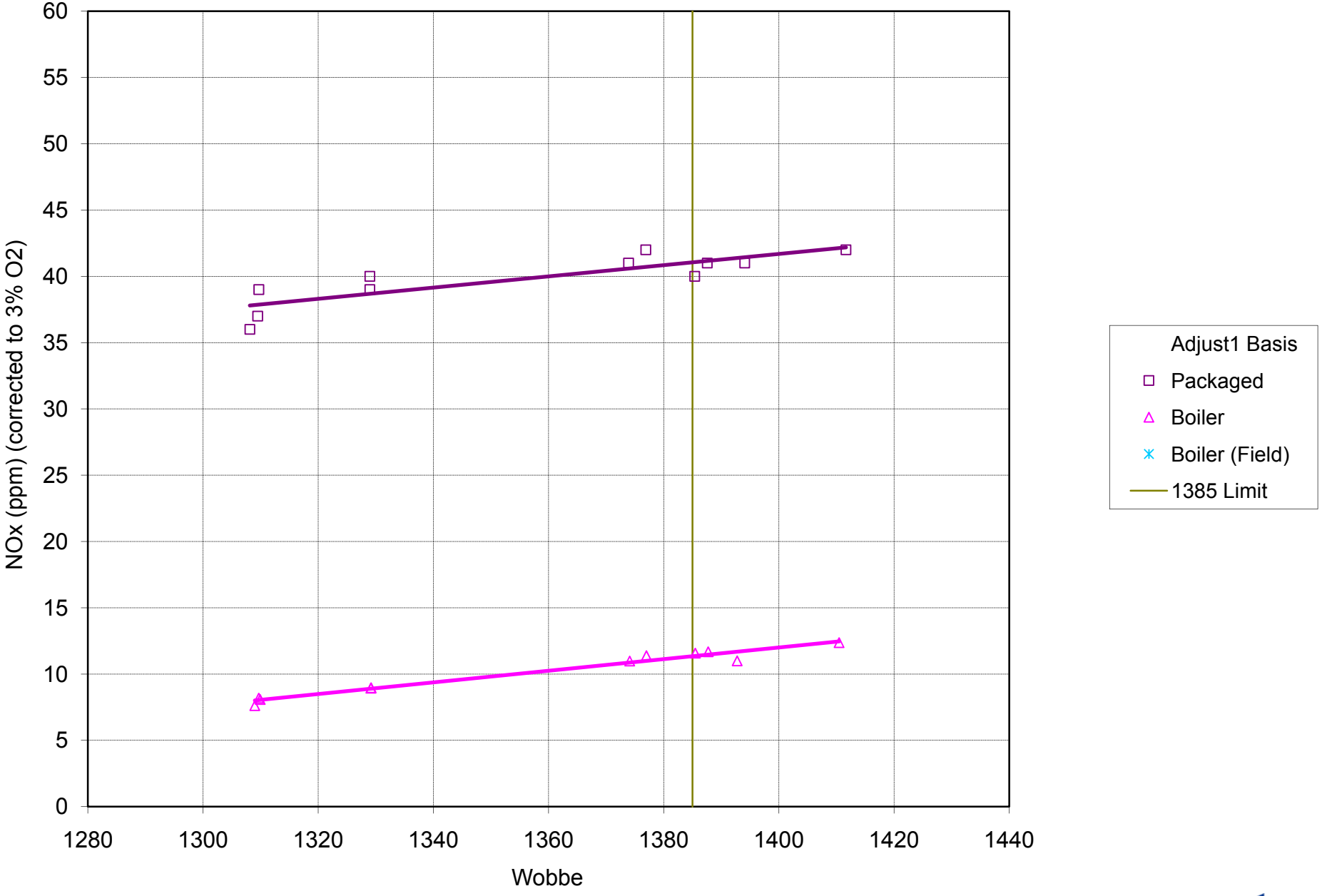

NOx (ppm) (corrected to 3% O2)
NOx (ppm) (corrected to 3% O2) [Oxy-Gas]
Wobbe
0
20
40
60
80
100
120
140
160
180
200
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust2 Basis
Infrared
U-Tube
Linear
High Velocity
Packaged
Boiler
W-Tube (Field)
Boiler (Field)
Oxy-Gas
1385 Limit

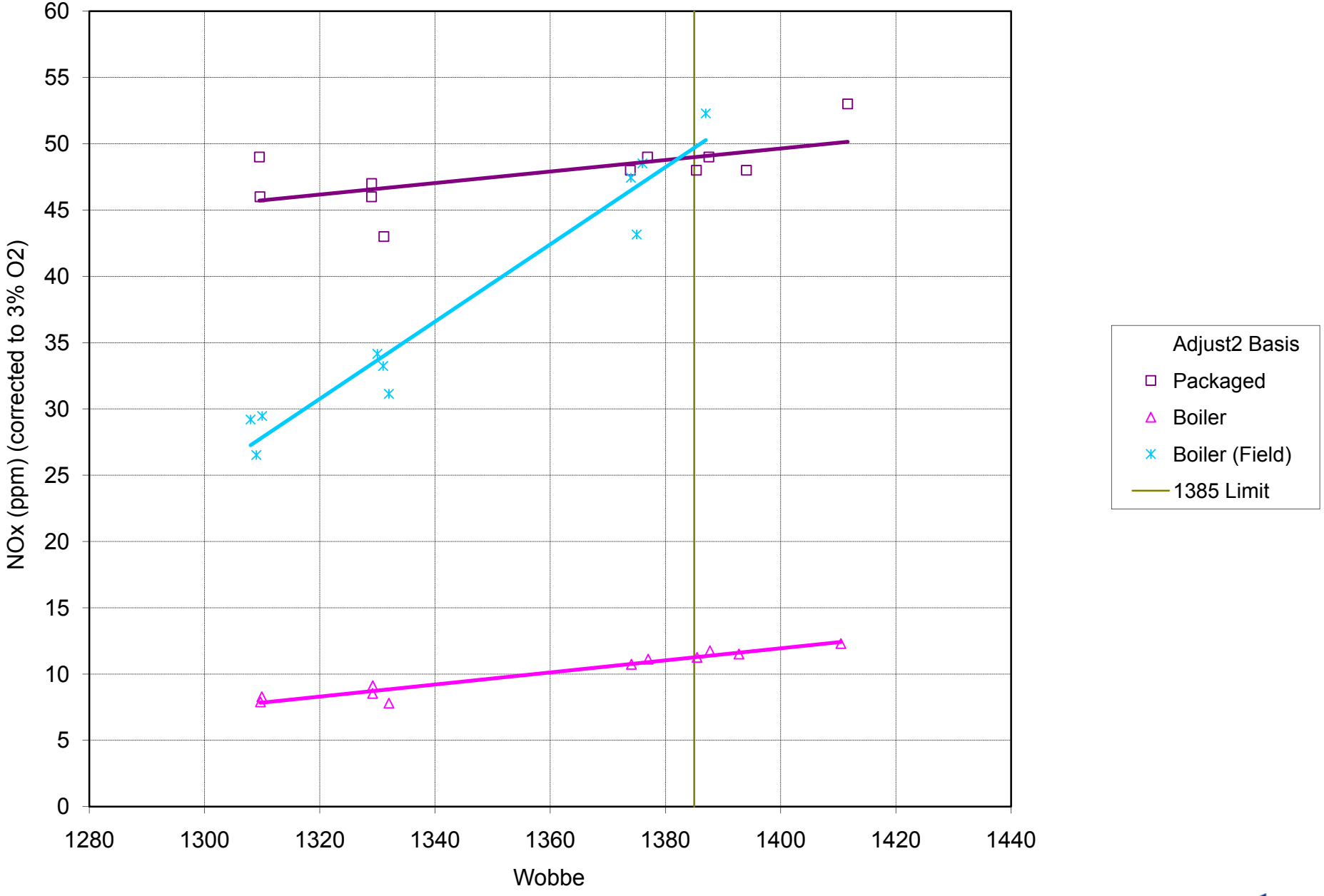

NOx (ppm) (corrected to 3% O2)
NOx (ppm) (corrected to 3% O2) [Oxy-Gas]
Wobbe
0
20
40
60
80
100
120
140
160
180
200
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust3 Basis
Infrared
U-Tube
Linear
High Velocity
Packaged
Boiler
W-Tube (Field)
Boiler (Field)
Oxy-Gas
1385 Limit

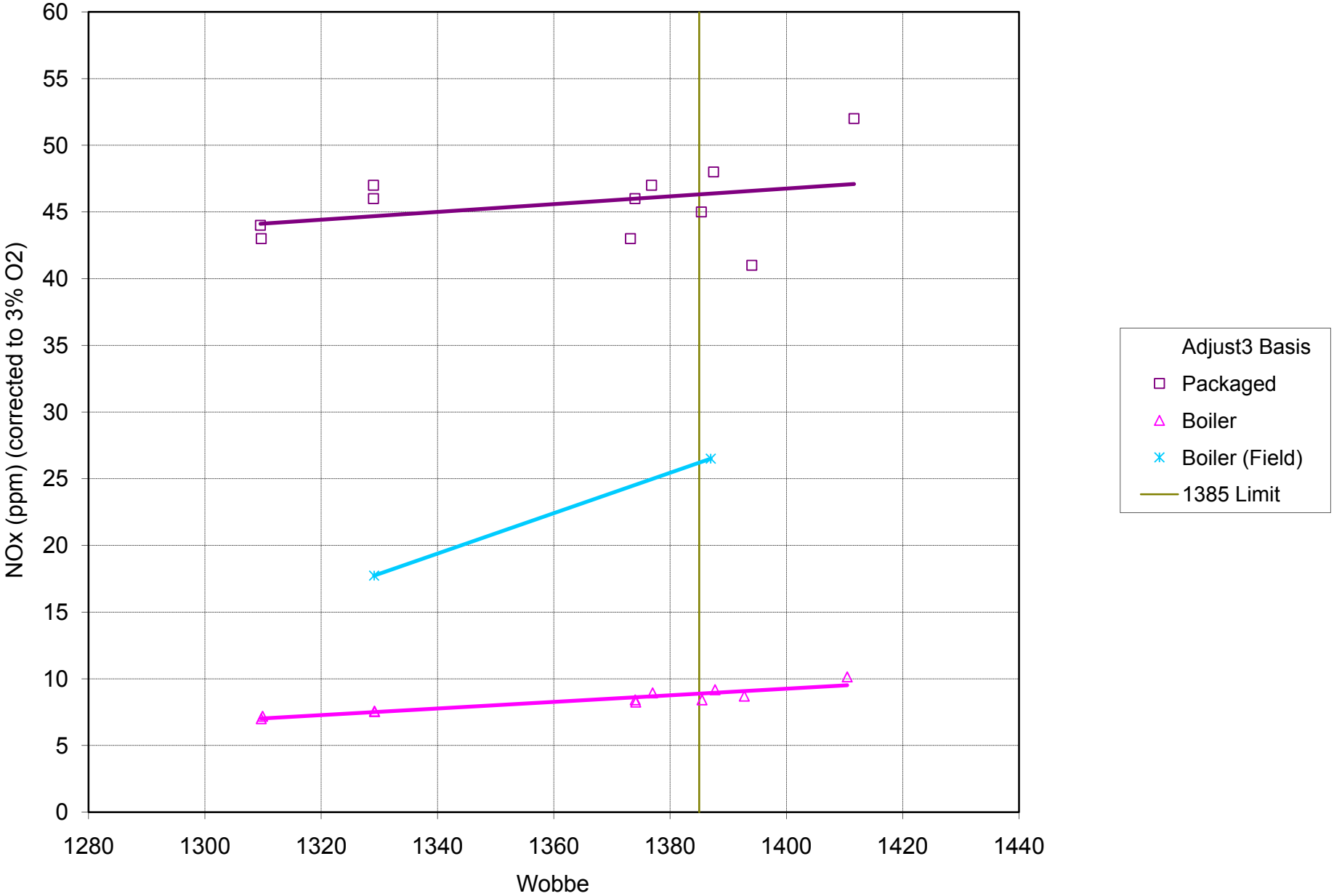

CO (ppm) (corrected to 3% O2)
CO (ppm) (corrected to 3% O2) [UT,HV,OG]
Wobbe
0
5
10
15
20
25
30
35
40
45
50
55
60
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust1 Basis
Infrared
Linear
Packaged
Boiler
W-Tube (Field)
Boiler (Field)
U-Tube
High Velocity
Oxy-Gas
1385 Limit

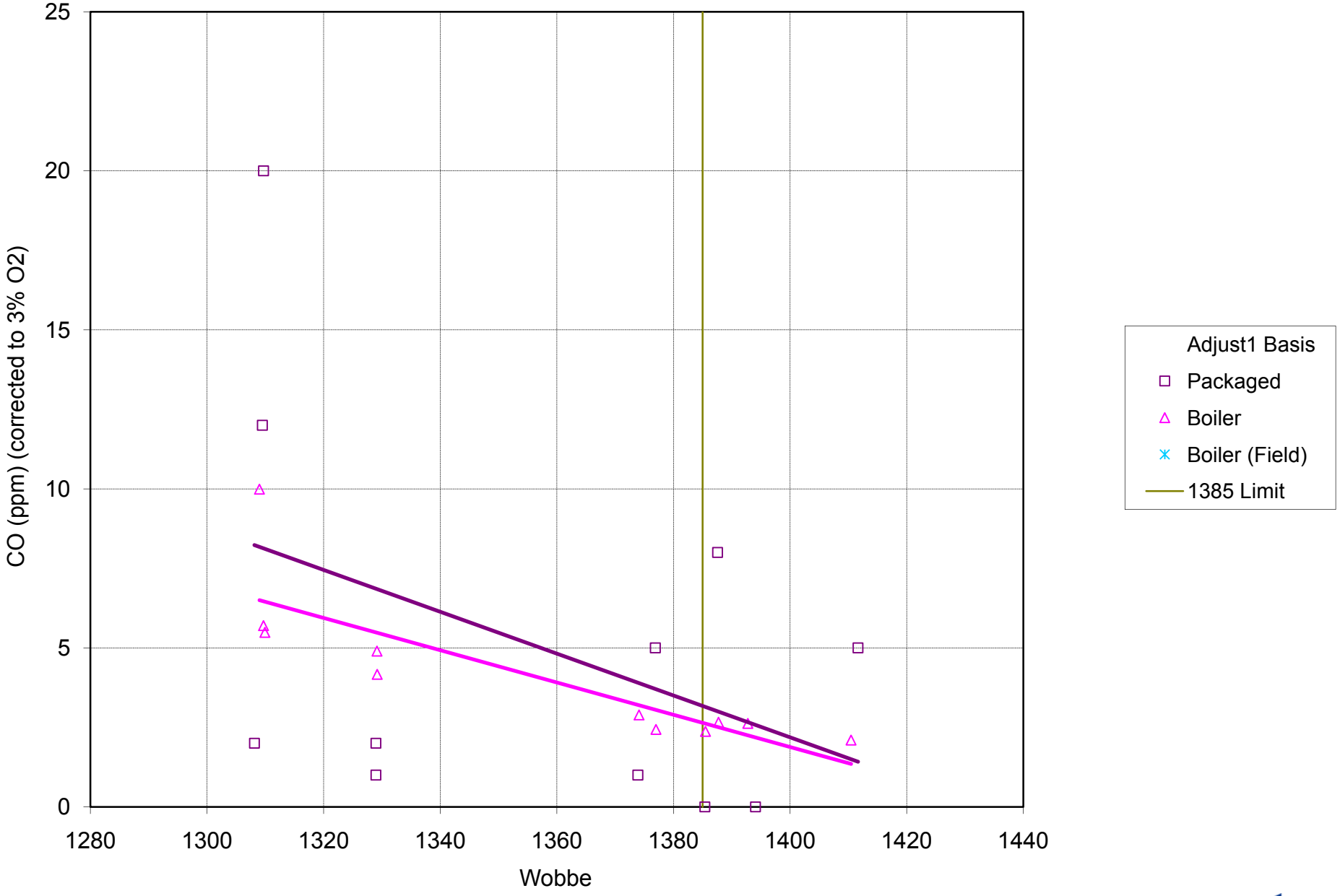

CO (ppm) (corrected to 3% O2)
CO (ppm) (corrected to 3% O2) [UT,HV,OG]
Wobbe
0
5
10
15
20
25
30
35
40
45
50
55
60
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust2 Basis
Infrared
Linear
Packaged
Boiler
W-Tube (Field)
Boiler (Field)
U-Tube
High Velocity
Oxy-Gas
1385 Limit

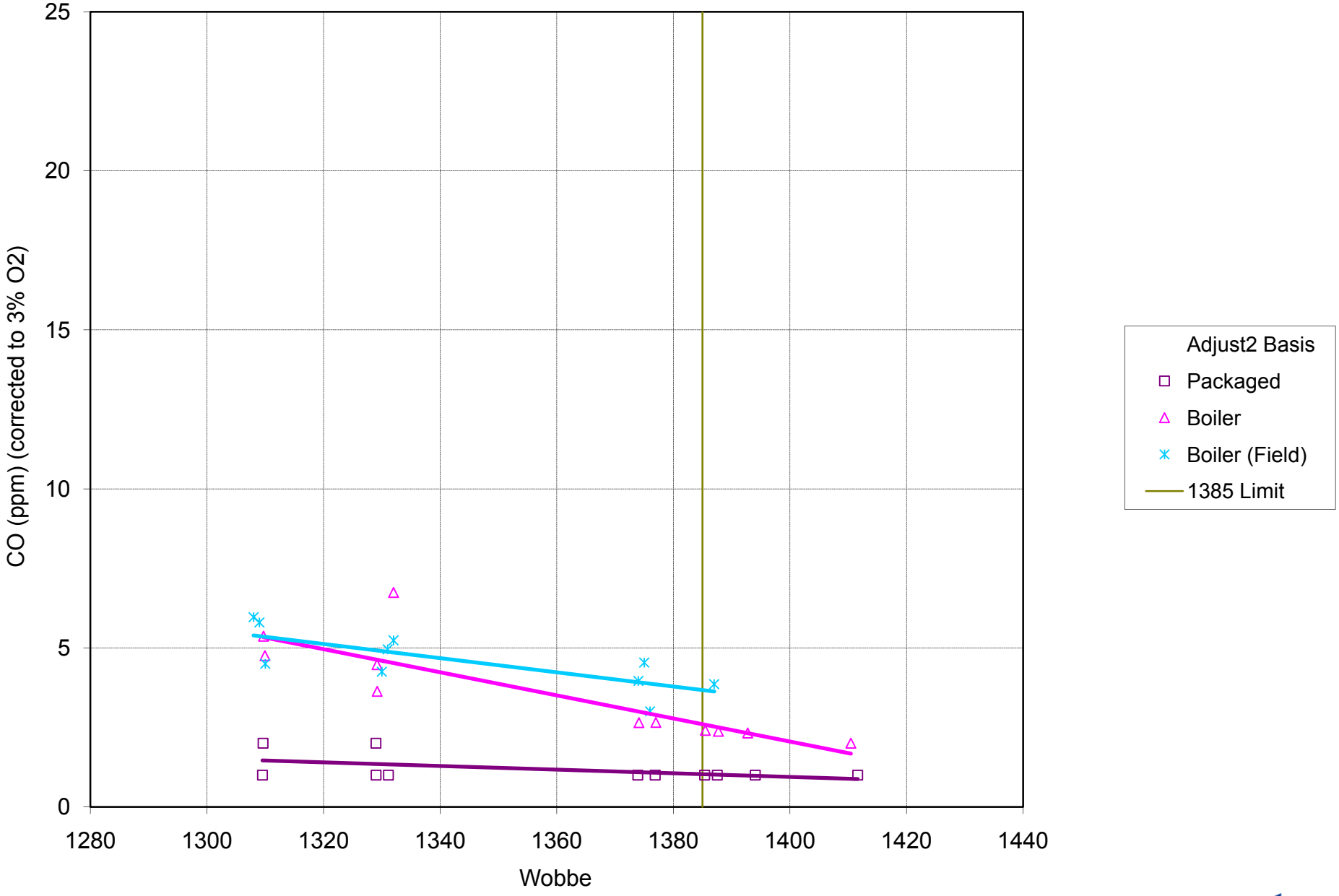

CO (ppm) (corrected to 3% O2)
CO (ppm) (corrected to 3% O2) [UT,HV,OG]
Wobbe
0
5
10
15
20
25
30
35
40
45
50
55
60
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust3 Basis
Infrared
Linear
Packaged
Boiler
W-Tube (Field)
Boiler (Field)
U-Tube
High Velocity
Oxy-Gas
1385 Limit

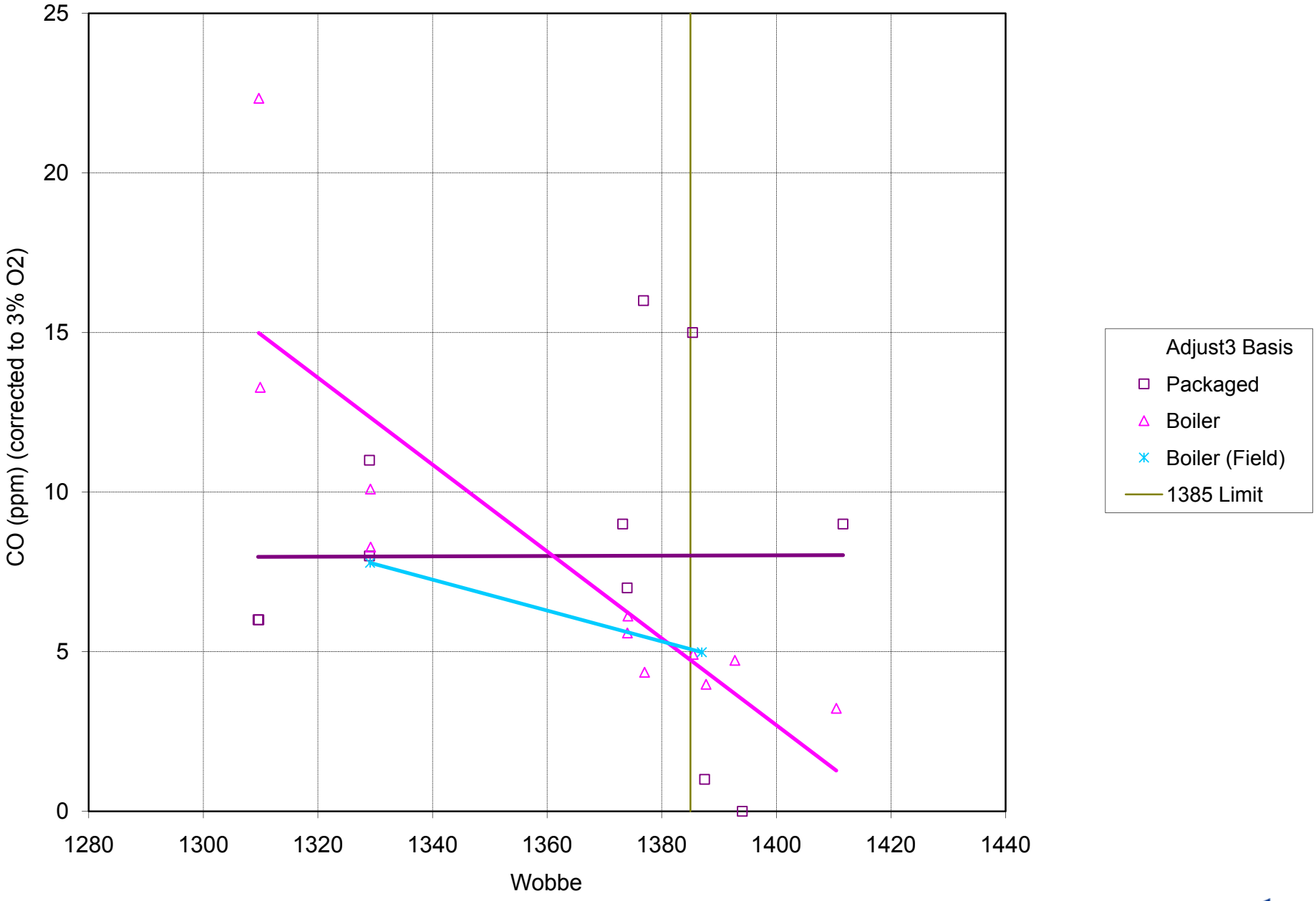

NOx (ppm) (corrected to 3% O2)
60
55
50
45
40
35
30
25
20
15
10
5
0
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust1 Basis
Packaged
Boiler
Boiler (Field)
1385 Limit

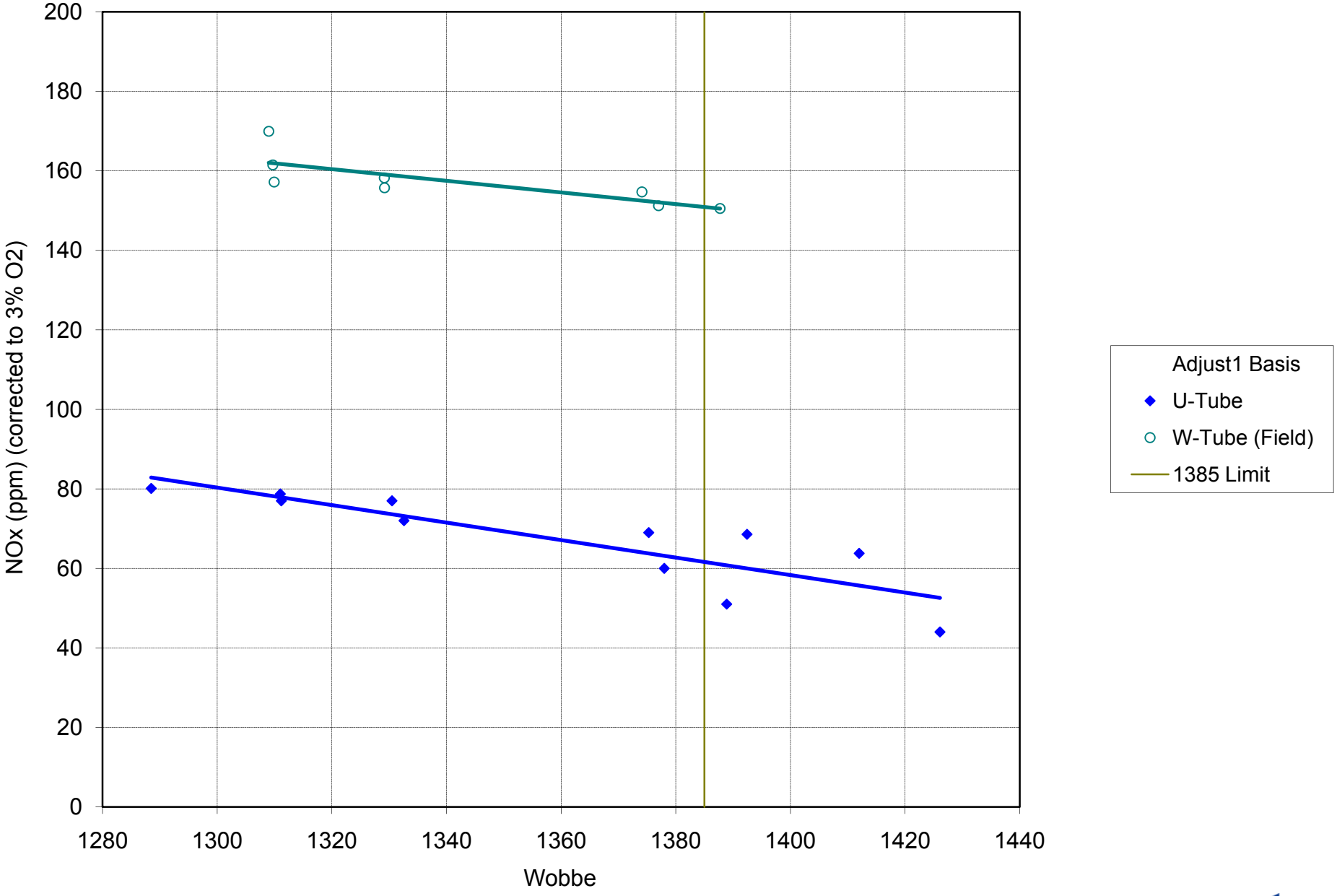

60
55
50
45
40
35
30
25
20
15
10
5
0
NOx (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust2 Basis
Packaged
Boiler
Boiler (Field)
1385 Limit

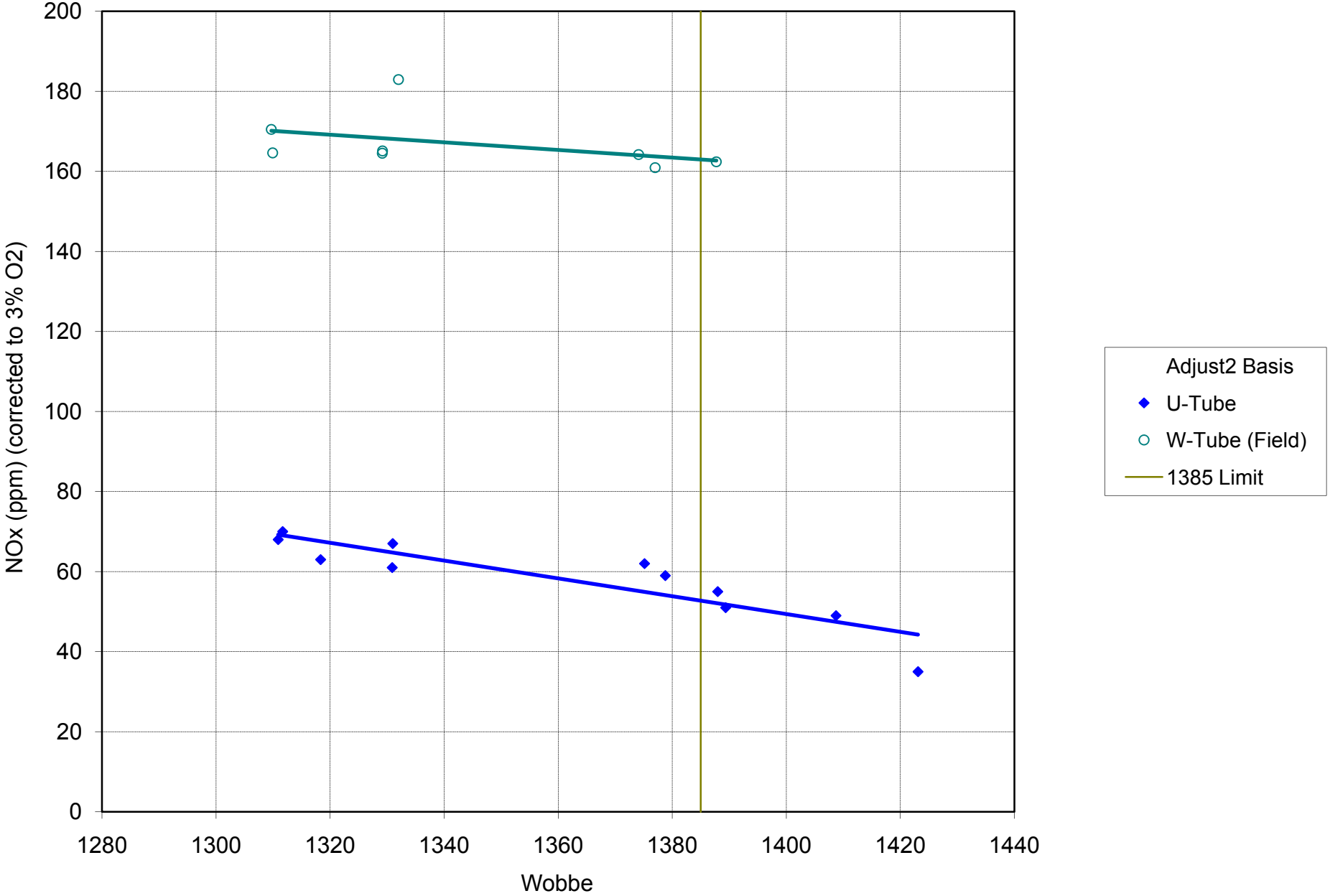

60
55
50
45
40
35
30
25
20
15
10
5
0
NOx (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust3 Basis
Packaged
Boiler
Boiler (Field)
1385 Limit

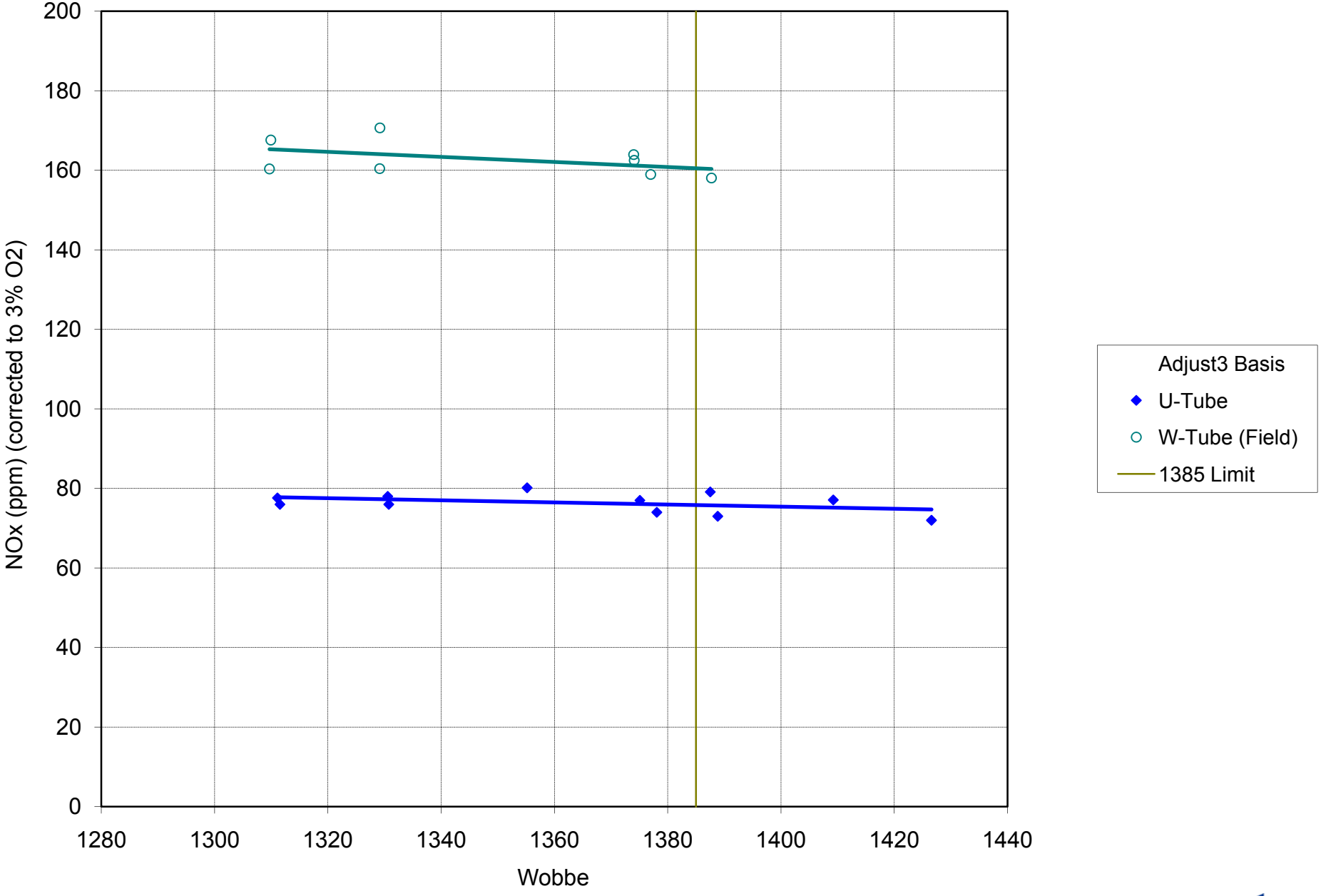

25
20
15
10
5
0
CO (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust1 Basis
Packaged
Boiler
Boiler (Field)
1385 Limit

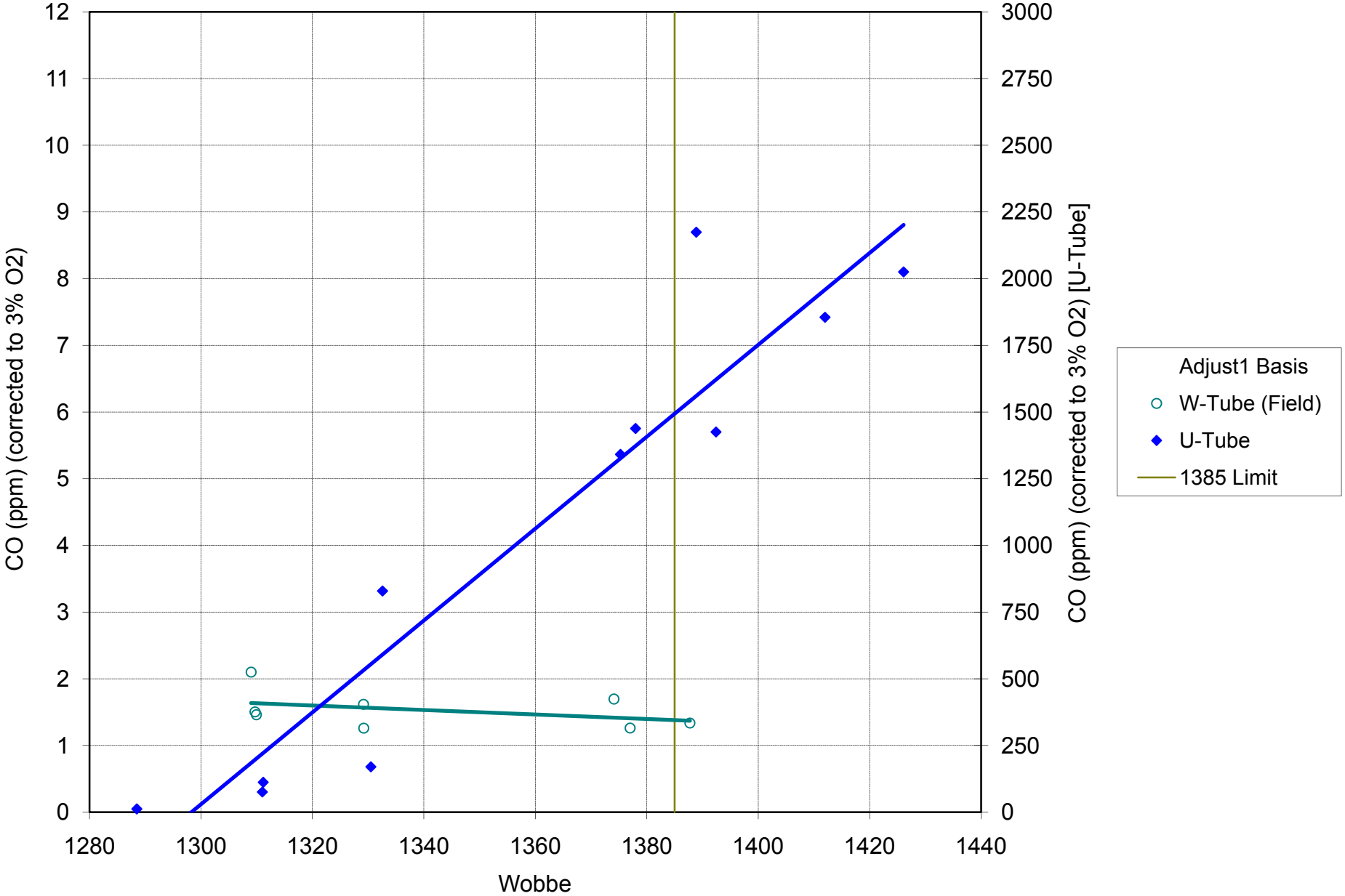

25
20
15
10
5
0
CO (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust2 Basis
Packaged
Boiler
Boiler (Field)
1385 Limit

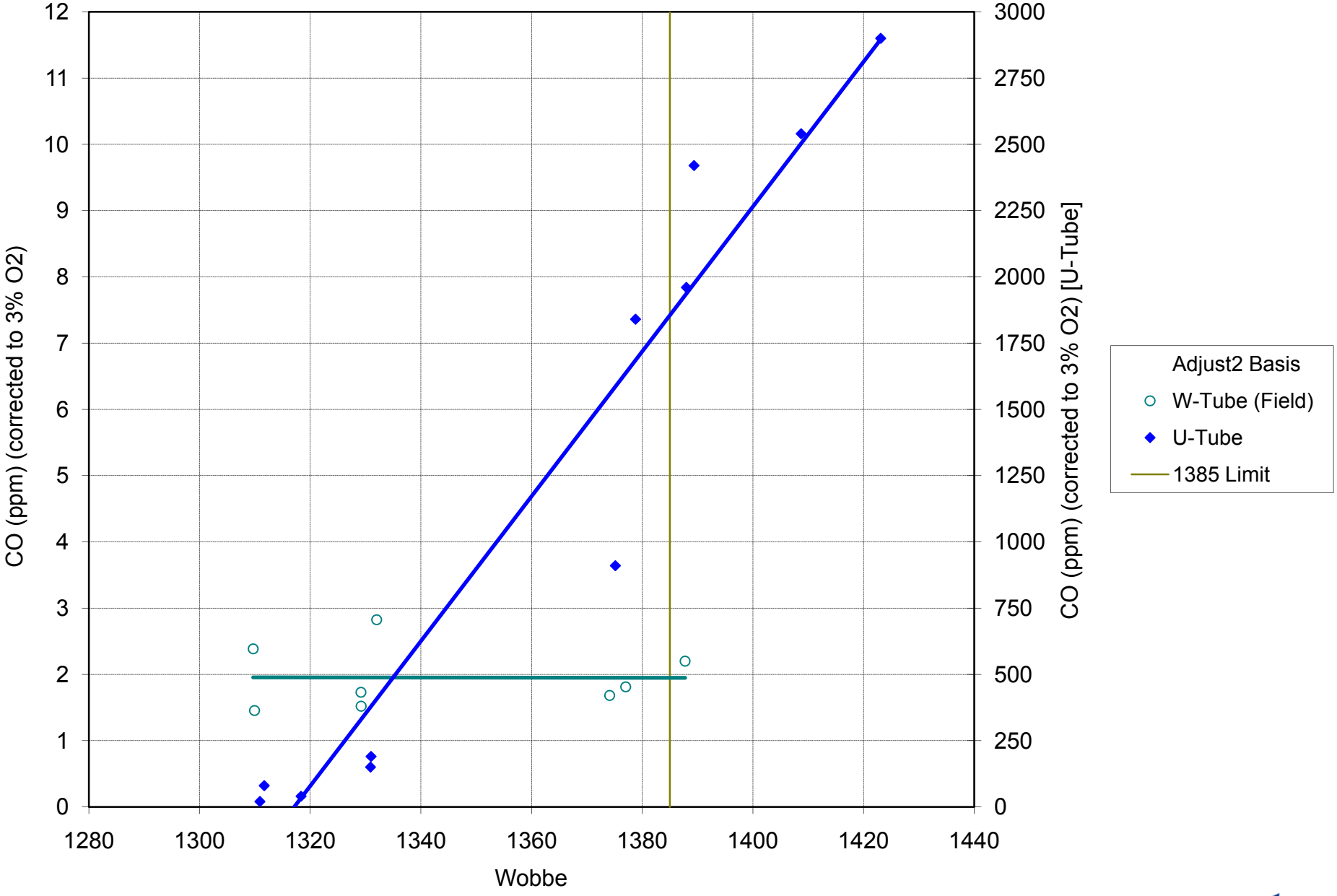

25
20
15
10
5
0
CO (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust3 Basis
Packaged
Boiler
Boiler (Field)
1385 Limit

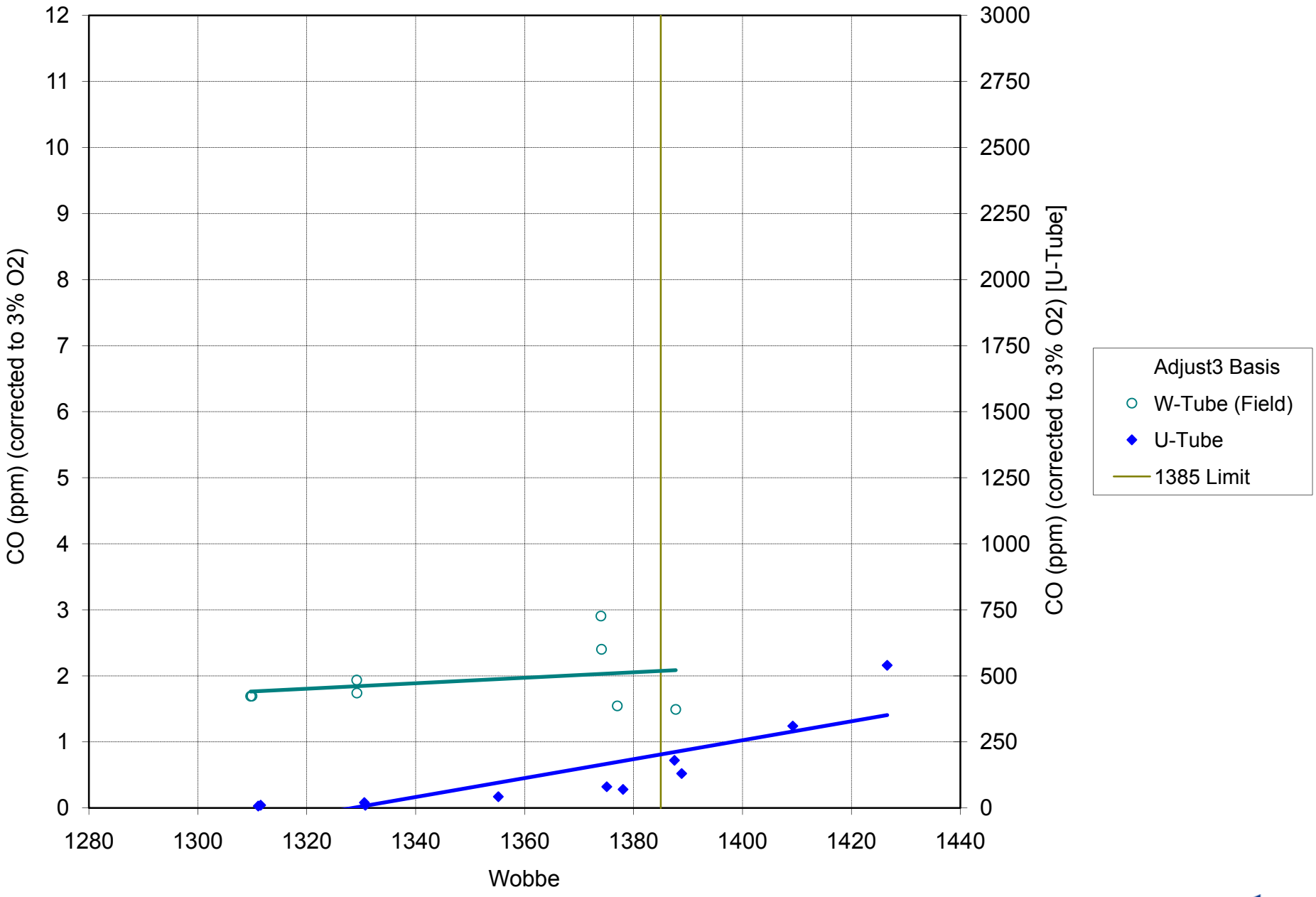

200
180
160
140
120
100
80
60
40
20
0
NOx (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust1 Basis
U-Tube
W-Tube (Field)
1385 Limit


200
180
160
140
120
100
80
60
40
20
0
NOx (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust2 Basis
U-Tube
W-Tube (Field)
1385 Limit


200
180
160
140
120
100
80
60
40
20
0
NOx (ppm) (corrected to 3% O2)
1280
1300
1320
1340
1360
1380
1400
1420
1440
Wobbe
Adjust3 Basis
U-Tube
W-Tube (Field)
1385 Limit


CO (ppm) (corrected to 3% O2)
CO (ppm) (corrected to 3% O2) [U-Tube]
Wobbe
0
1
2
3
4
5
6
7
8
9
10
11
12
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust1 Basis
W-Tube (Field)
U-Tube
1385 Limit


CO (ppm) (corrected to 3% O2)
CO (ppm) (corrected to 3% O2) [U-Tube]
Wobbe
0
1
2
3
4
5
6
7
8
9
10
11
12
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust2 Basis
W-Tube (Field)
U-Tube
1385 Limit


CO (ppm) (corrected to 3% O2)
CO (ppm) (corrected to 3% O2) [U-Tube]
Wobbe
0
1
2
3
4
5
6
7
8
9
10
11
12
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
1280
1300
1320
1340
1360
1380
1400
1420
1440
Adjust3 Basis
W-Tube (Field)
U-Tube
1385 Limit

Industrial Burners - Observations

- NOx and CO vary with gas composition for all burners
  - Variations are minor for many burners
  - CO can vary dramatically for certain burners
  - Classes of burners behave in similar patterns
  - Burners in the field are often not ideally tuned
- Emissions sensitivity can be predicted and depends on
  - burner tuning
  - excess air level
  - Burner geometry
- Optimal tuning for low emissions depends on
  - Consideration of both NOx and CO
  - Range of anticipated gas compositions
  - Time distribution of operation at difference gas compostions

Looking Ahead – Industrial Burners

- Optimal emission levels can be achieved for most burners by specifying tuning protocols
- Burners in field use are often not properly tuned or tuned often enough
- For classes of burners needing attention to minimize emissions
  - A multi-point measurement protocol can be standardized and implemented
  - Routine field tuning can be established and followed
  - Gas suppliers can maintain customer contacts to provide
    - real-time guidance on gas supplies
    - needed adjustments to burners and controllers

CA Foodservice Appliance Population

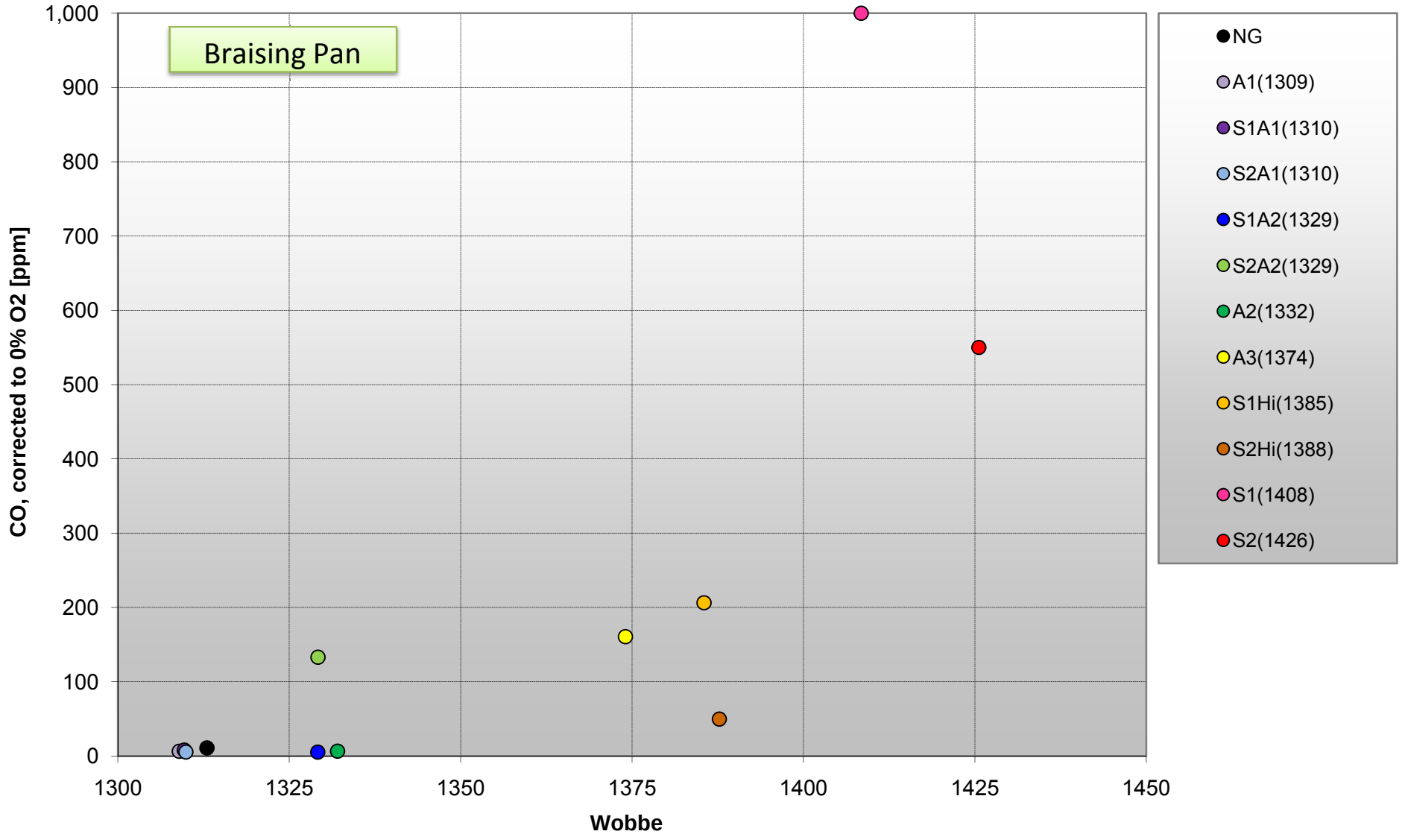
Appliance	California Population (units)	Baseline Efficiency, %	Annual Energy Use per Unit, therms	Total Annual Energy, million therms
Convection Oven	65,000	30	860	56
Deep Fat Fryers	110,000	30	1,390	153
Griddles – standard	41,000	30	810	33
Steamers - pressureless	29,000	15	2,190	63
Total				305

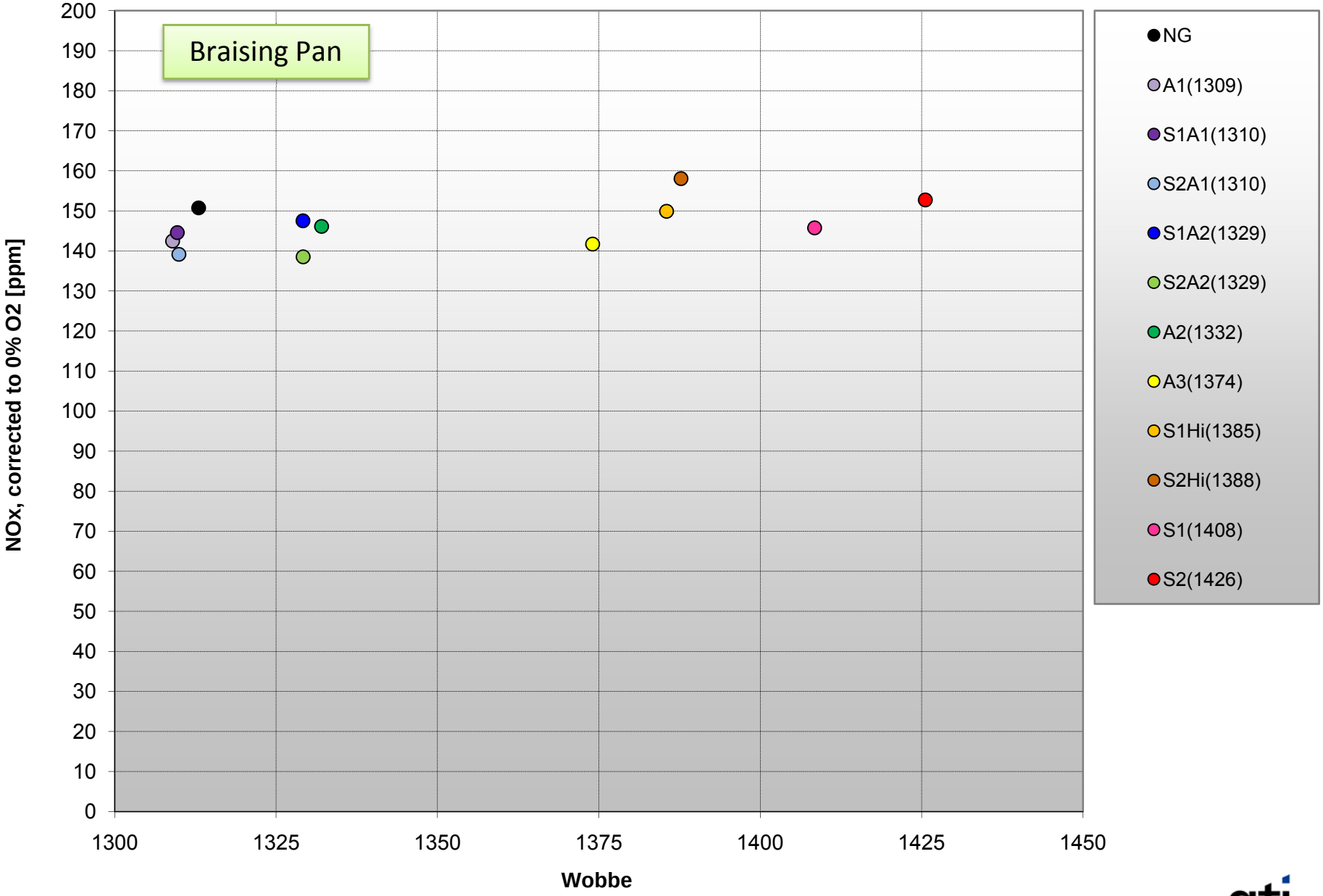
Foodservice Appliances Tested

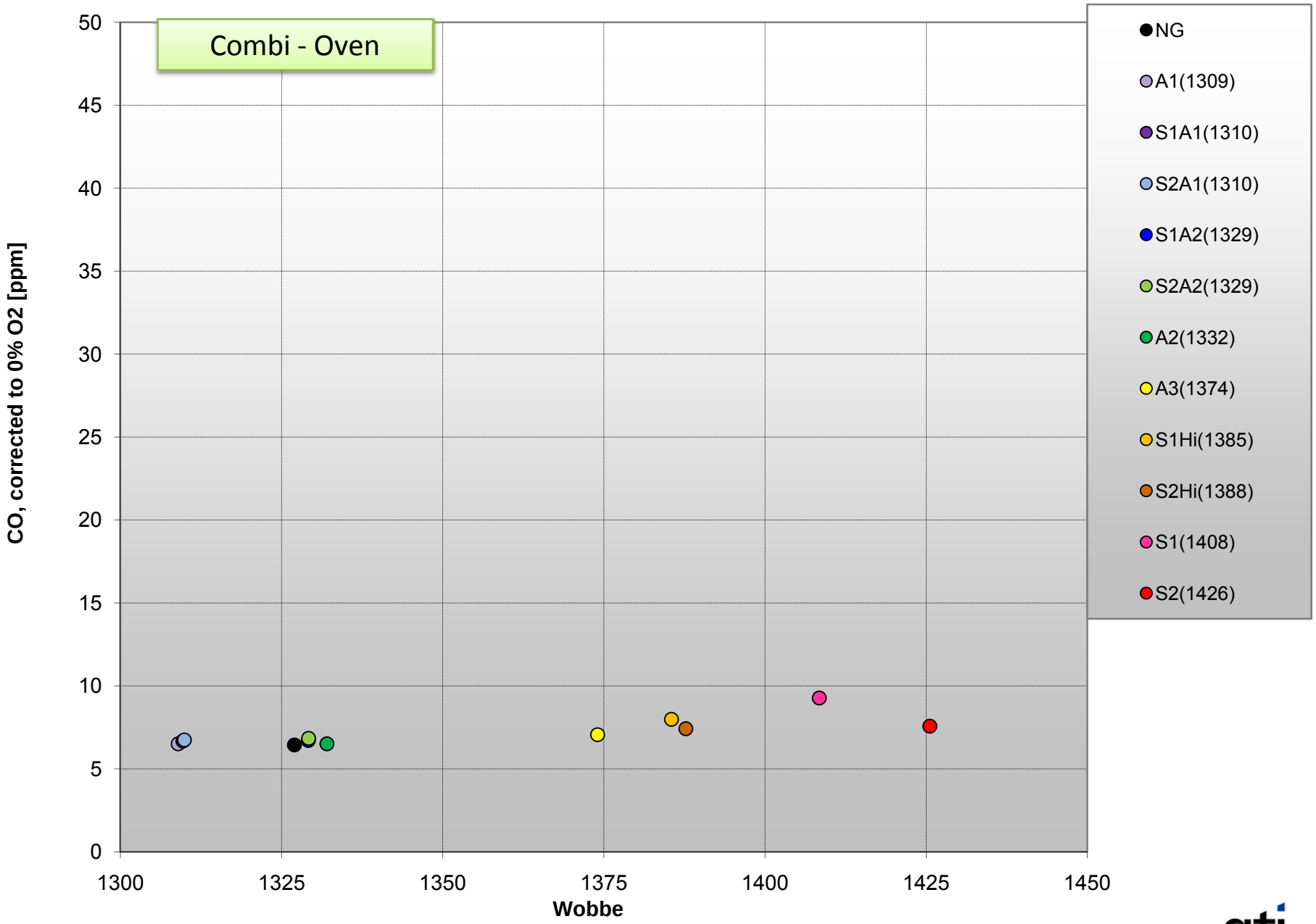
			Nameplate
Appliance	Manufacturer	Model	Btu/h
Fryer 1	Frymaster	FH155CSD	80,000
Griddle	Vulcan	36RRG-1	82,500
Convection Oven	Blodgett	DGF100	55,000
Steamer	Accutemp	Evolution	66,000
Braising Pan	Groen	BPM-40G	144,000
Combi Oven / Steam	Cleveland	Convotherm OGB-6.20	68,200
Combi Oven / Oven	Cleveland	ConvothermOGB-6.20	75,700
Range Top	Garland	G36-6R	33,000
Fryer 2	Pitco	SG14R	122,000
Oven	Garland	G36-6R	38,000

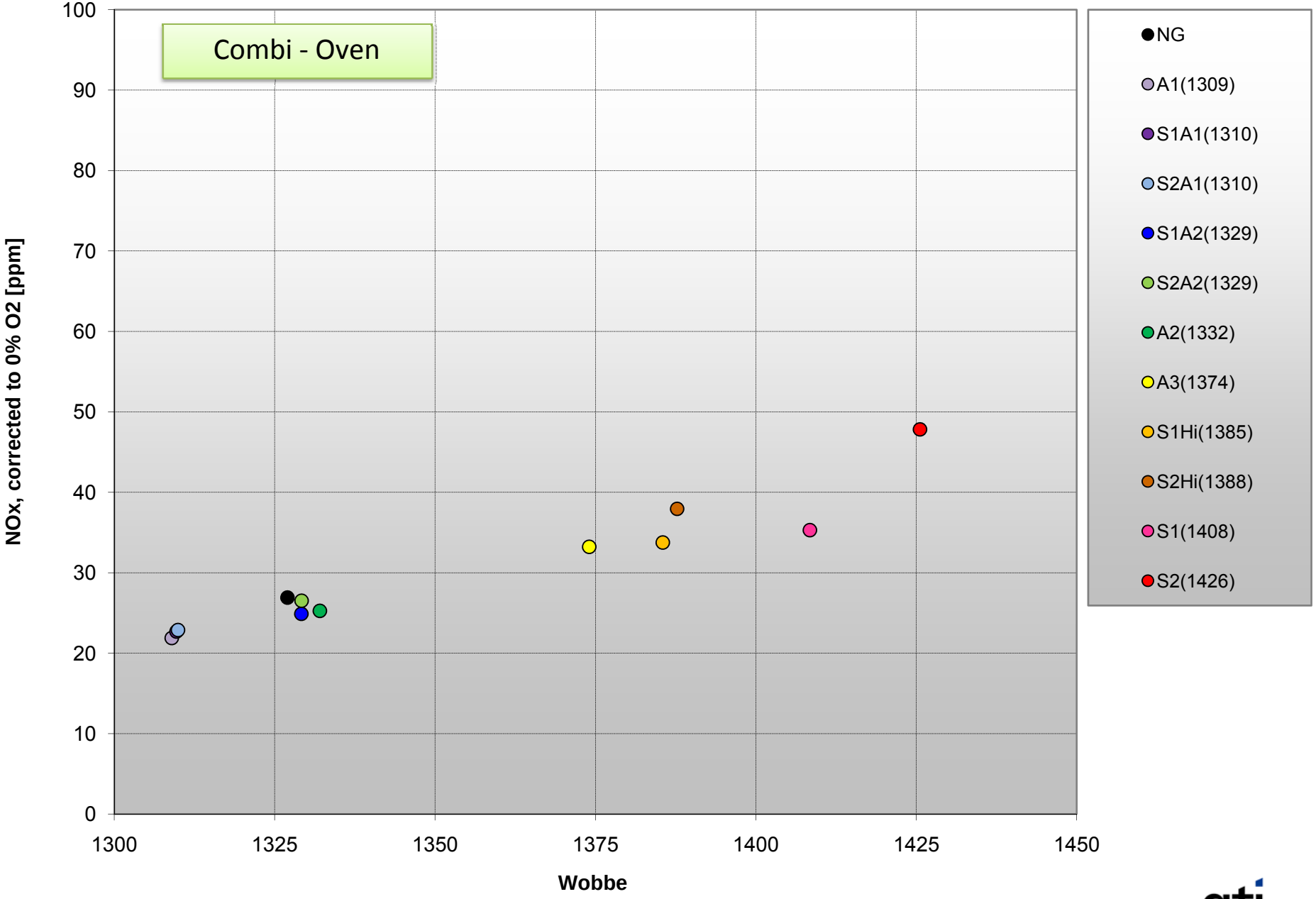
Data Collected for Each Appliance

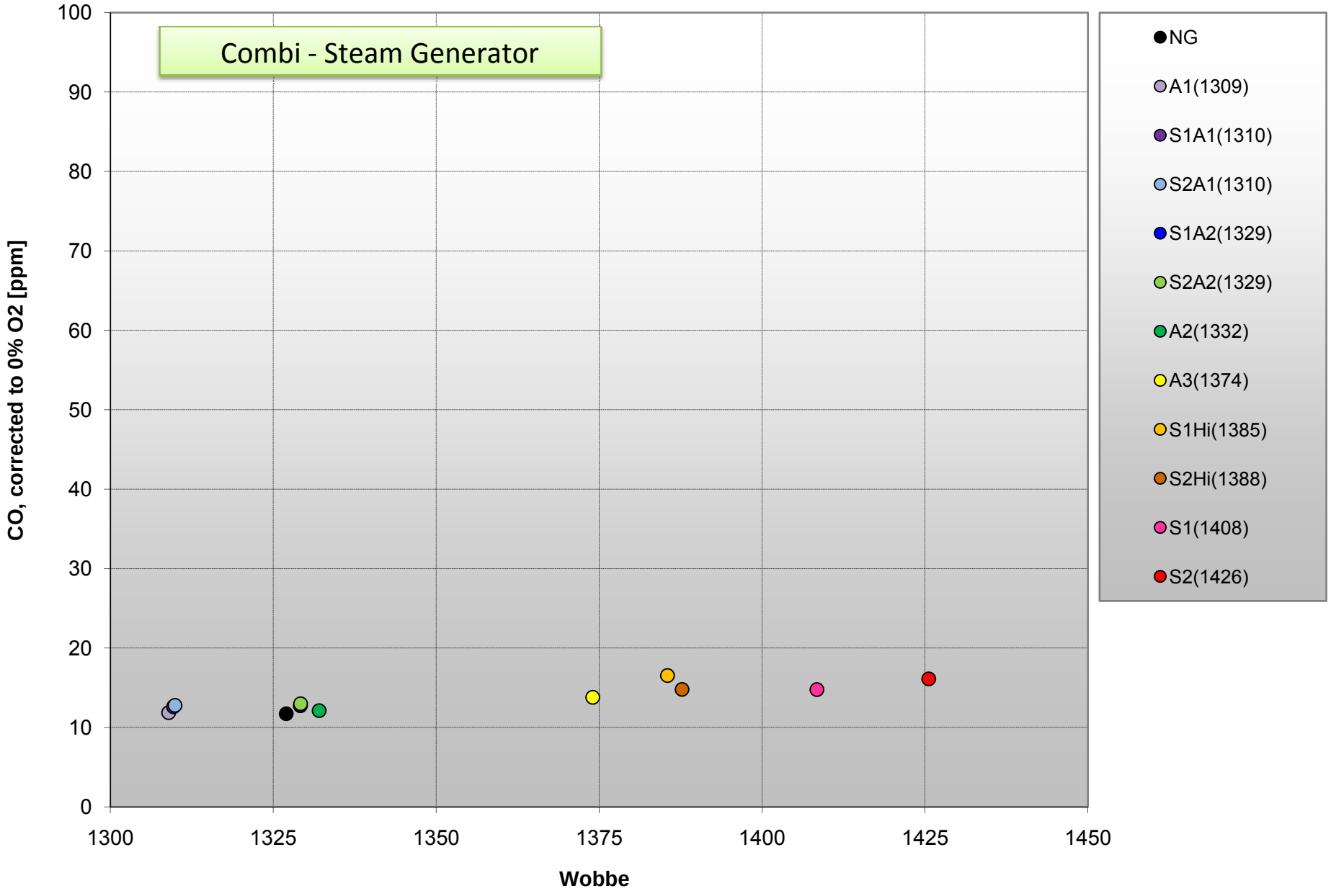
- GTI analyses during testing
  - Transient temperature profile
  - Transient emissions profile
  - Carbon monoxide (CO)
  - Oxide of nitrogen (NO_x)
  - Total unburned hydrocarbons
- GTI sampling, shipment, analysis by LBNL
  - Formaldehyde and related species

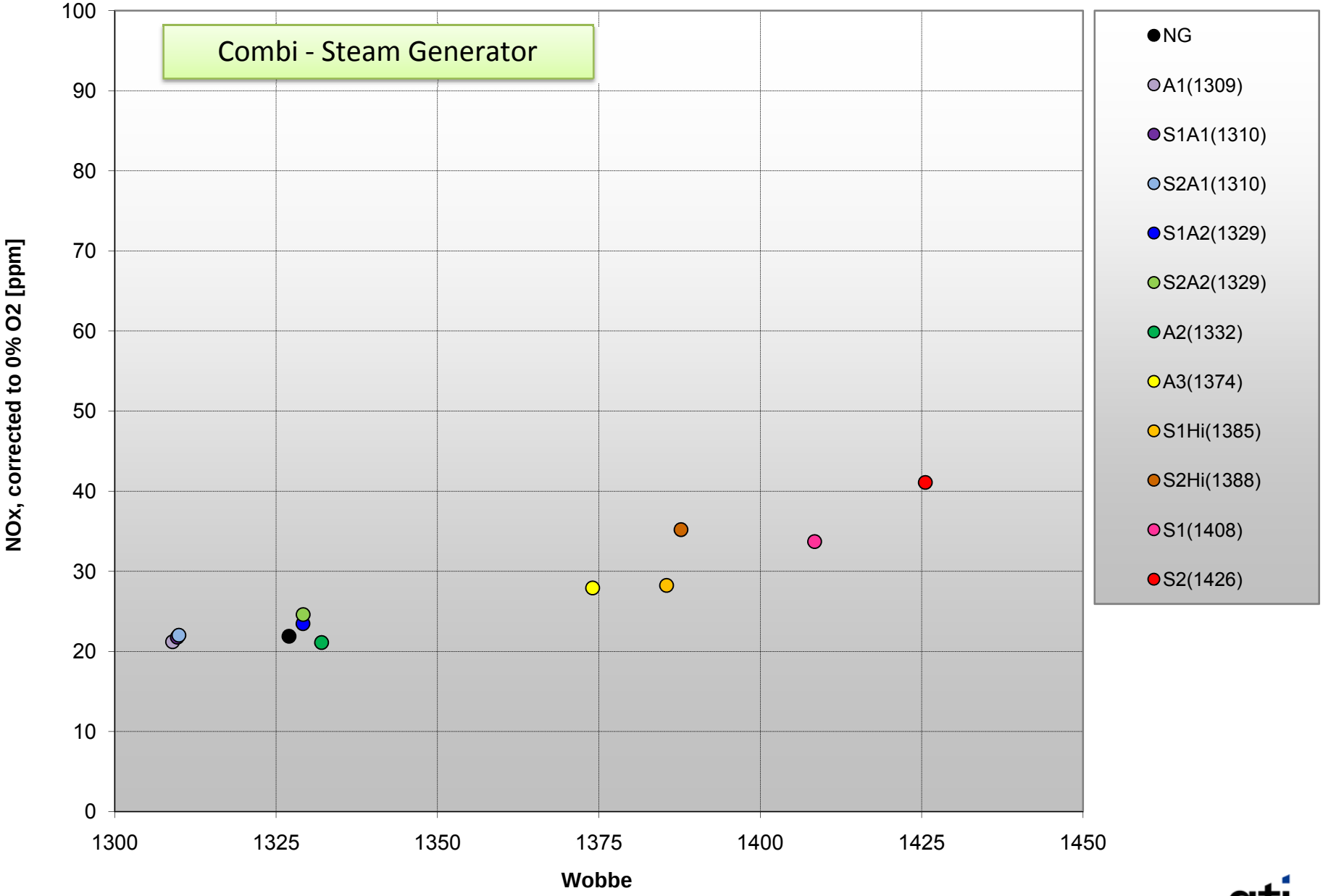

Braising Pan
CO, corrected to 0% O2 [ppm]
1,000
900
800
700
600
500
400
300
200
100
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

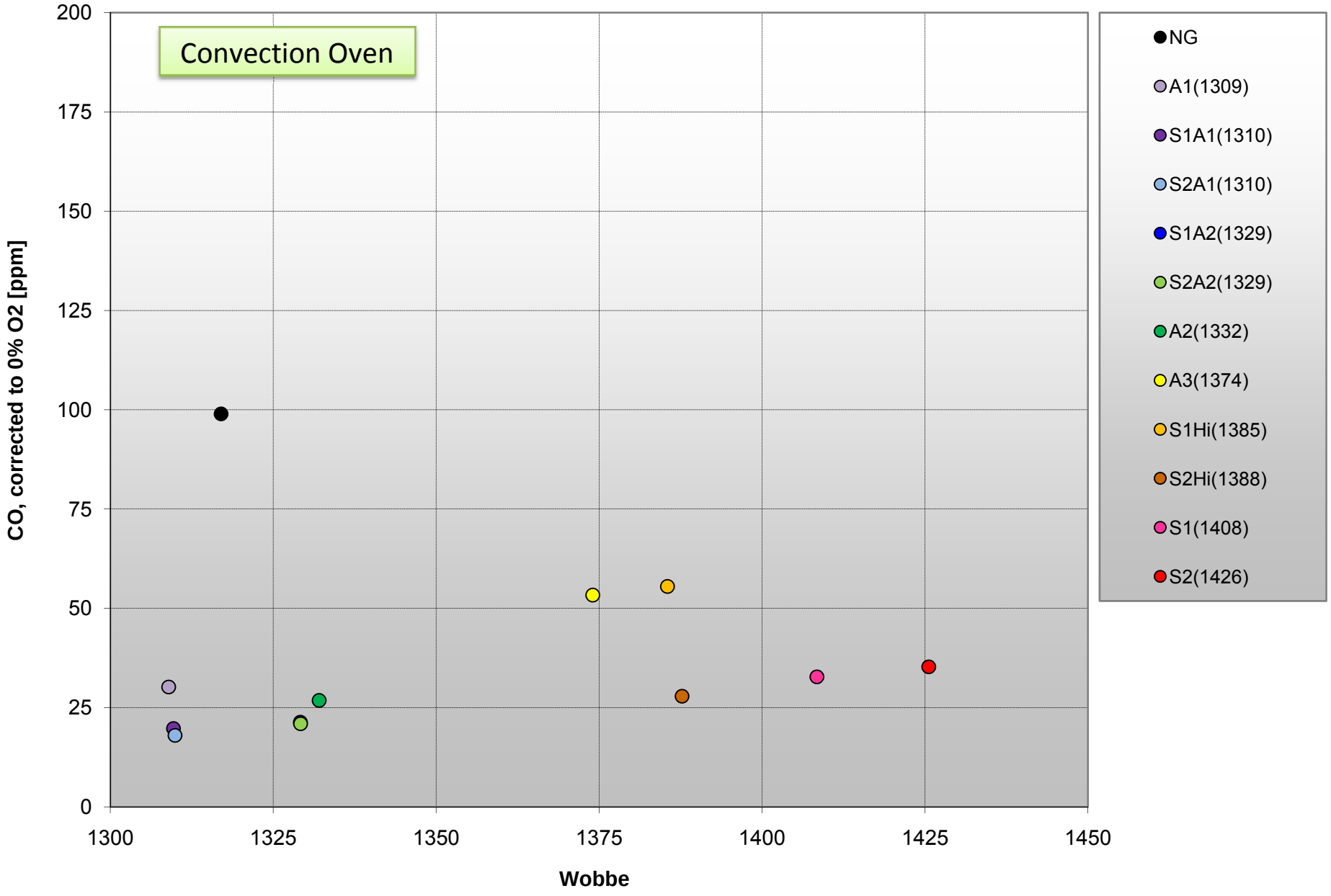

Braising Pan
NOx, corrected to 0% O2 [ppm]
Wobbe
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

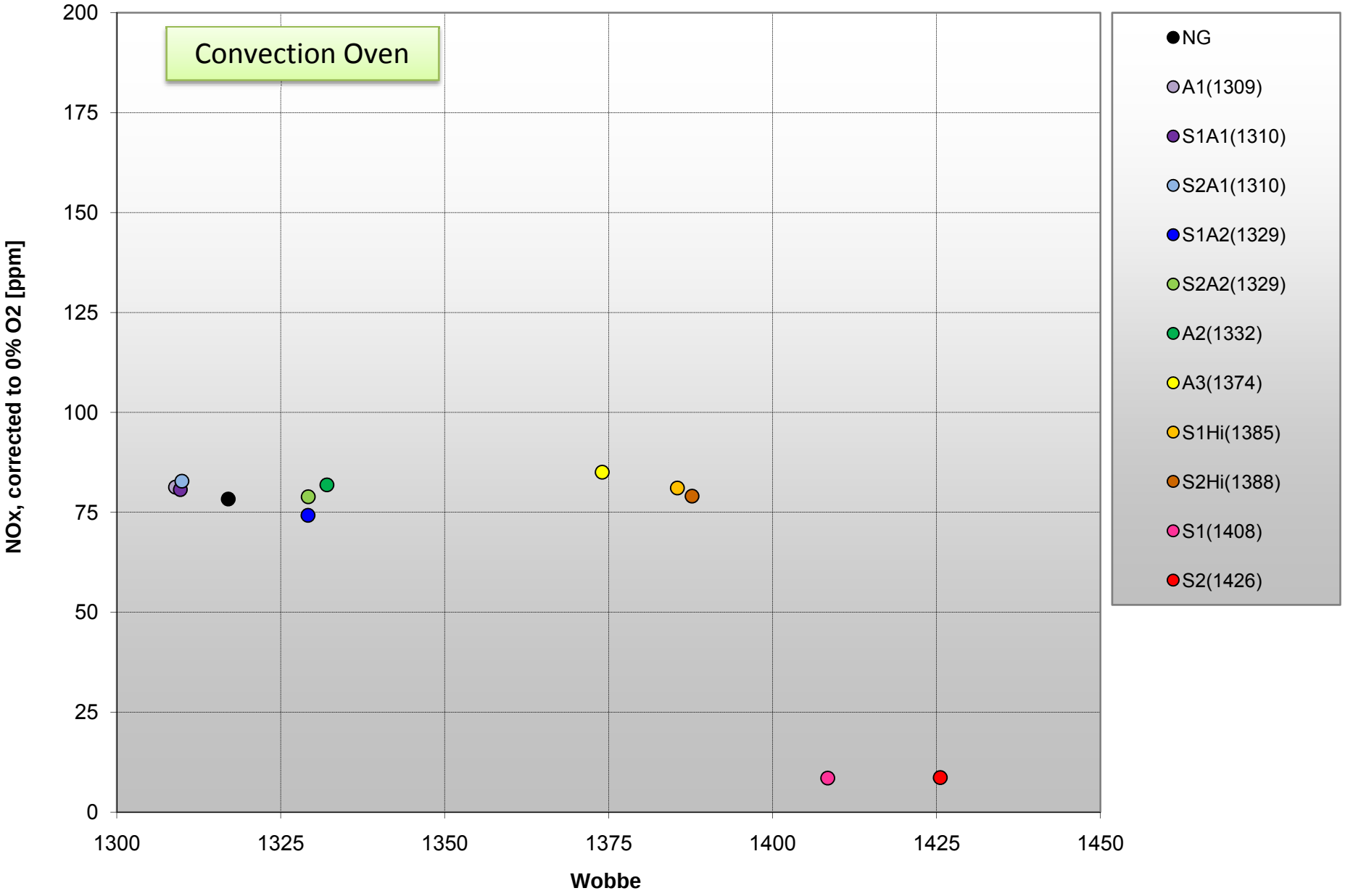

Combi - Oven
CO, corrected to 0% O2 [ppm]
50
45
40
35
30
25
20
15
10
5
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

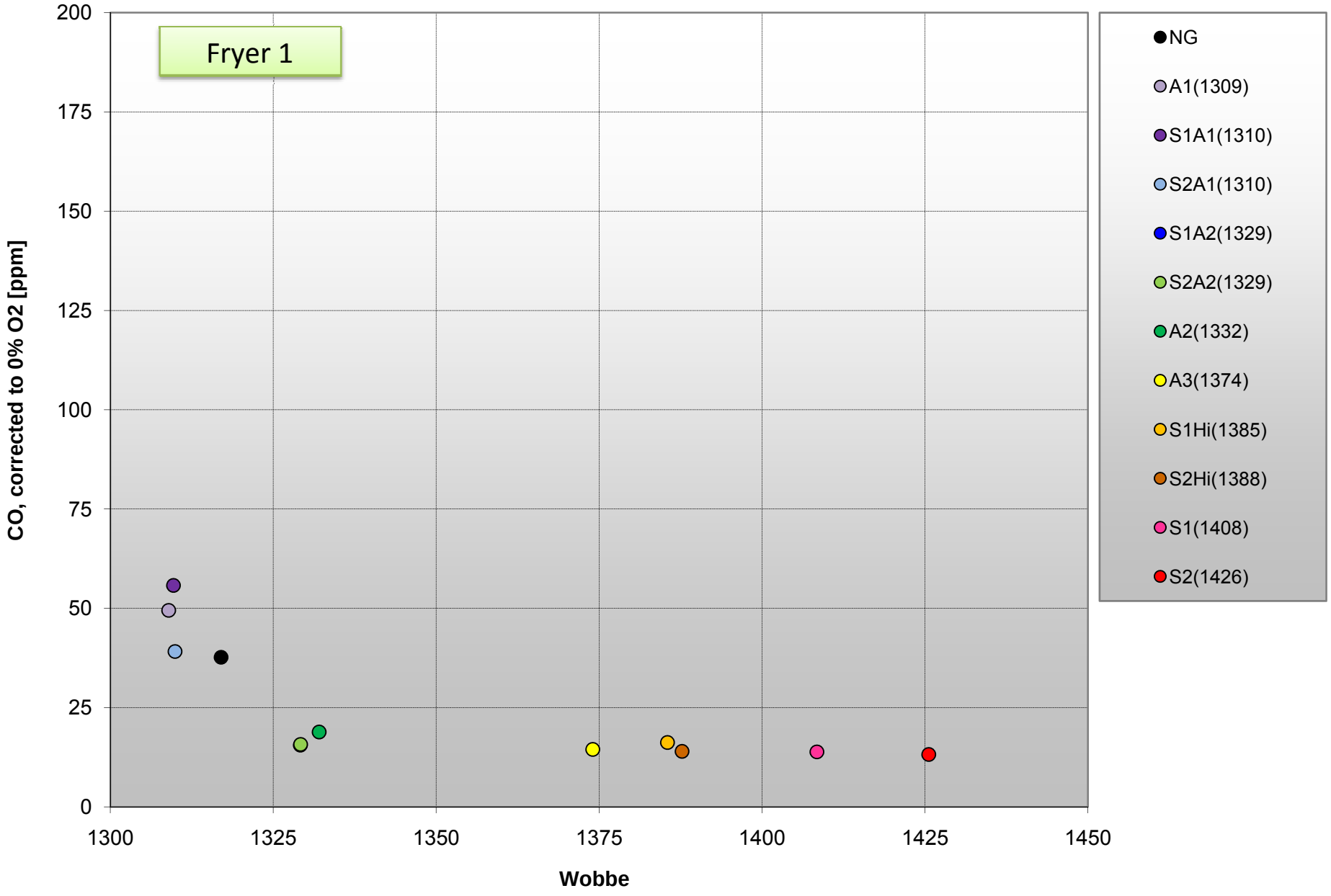

Combi - Oven
NOx, corrected to 0% O2 [ppm]
Wobbe
0
10
20
30
40
50
60
70
80
90
100
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

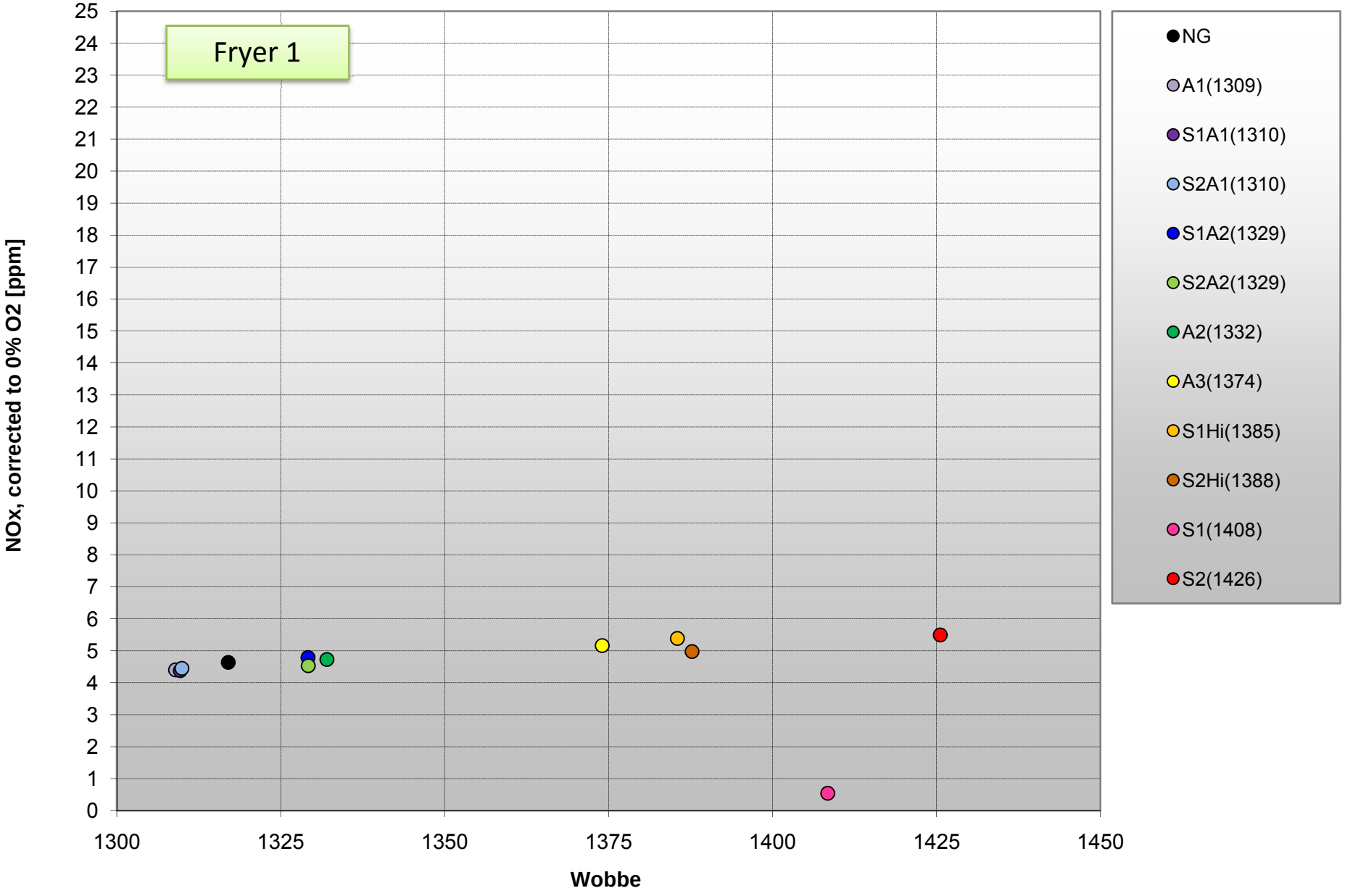

Combi - Steam Generator
CO, corrected to 0% O2 [ppm]
Wobbe
0
10
20
30
40
50
60
70
80
90
100
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

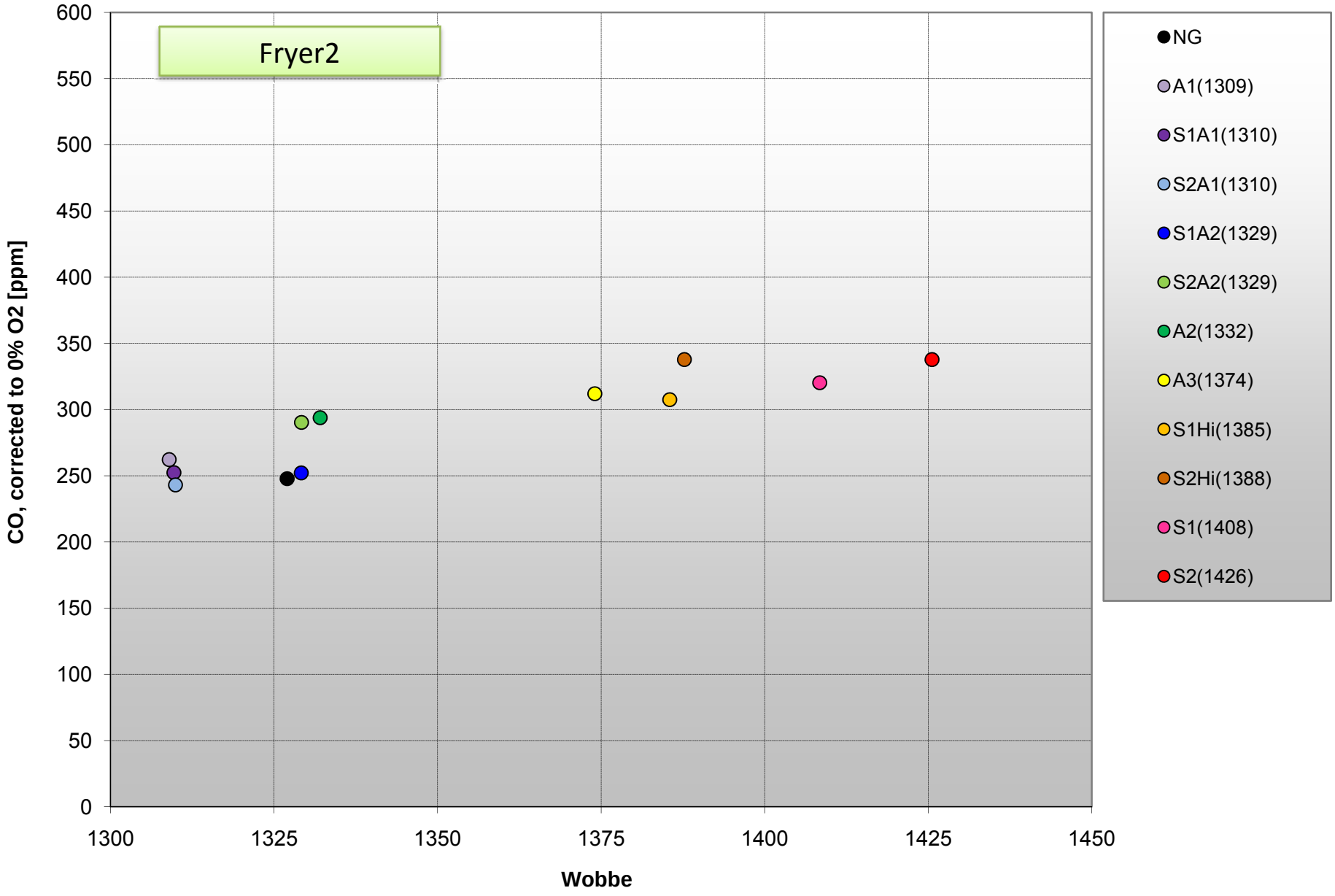

Combi - Steam Generator
NOx, corrected to 0% O2 [ppm]
Wobbe
0
10
20
30
40
50
60
70
80
90
100
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

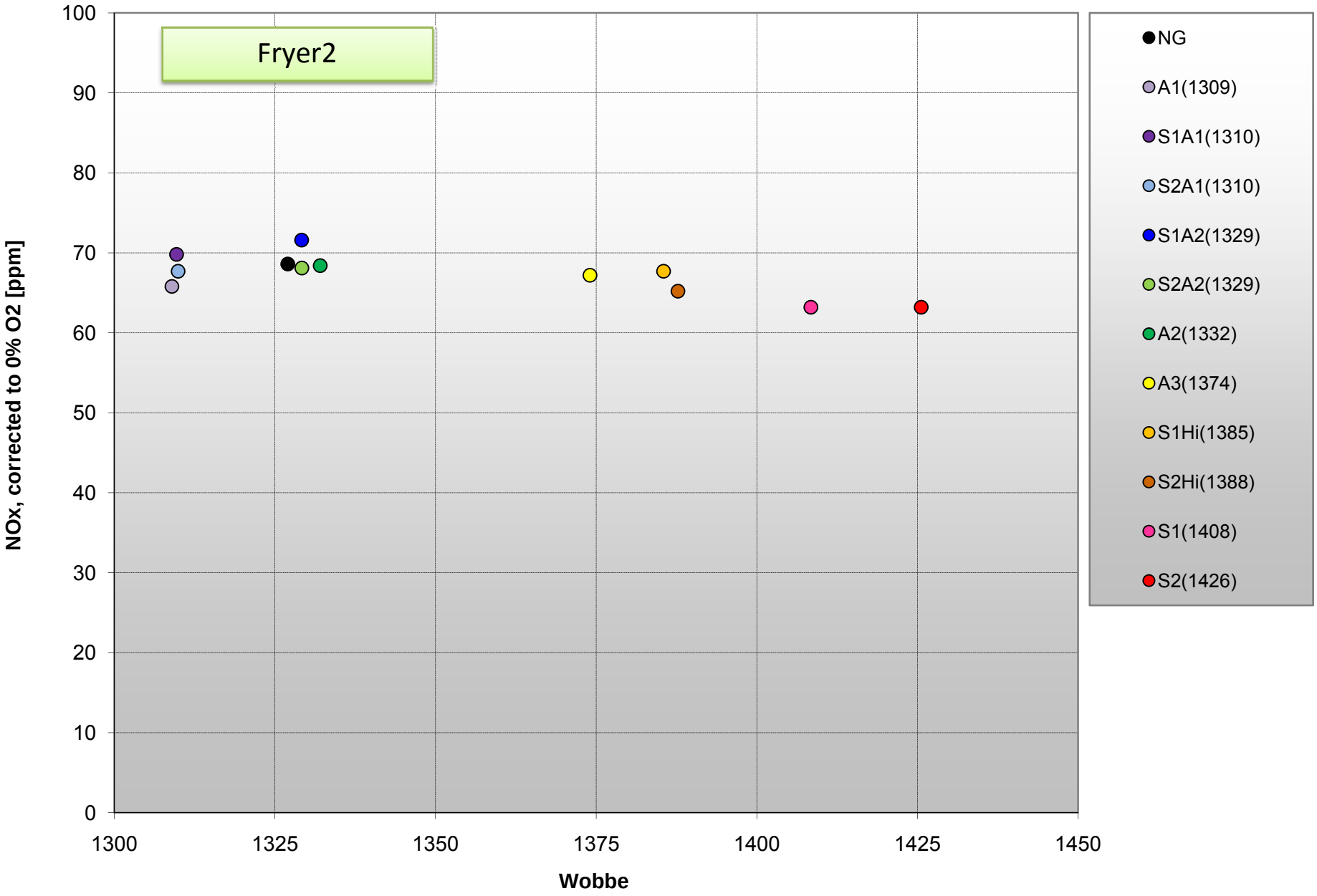

Convection Oven
CO, corrected to 0% O2 [ppm]
Wobbe
200
175
150
125
100
75
50
25
0
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

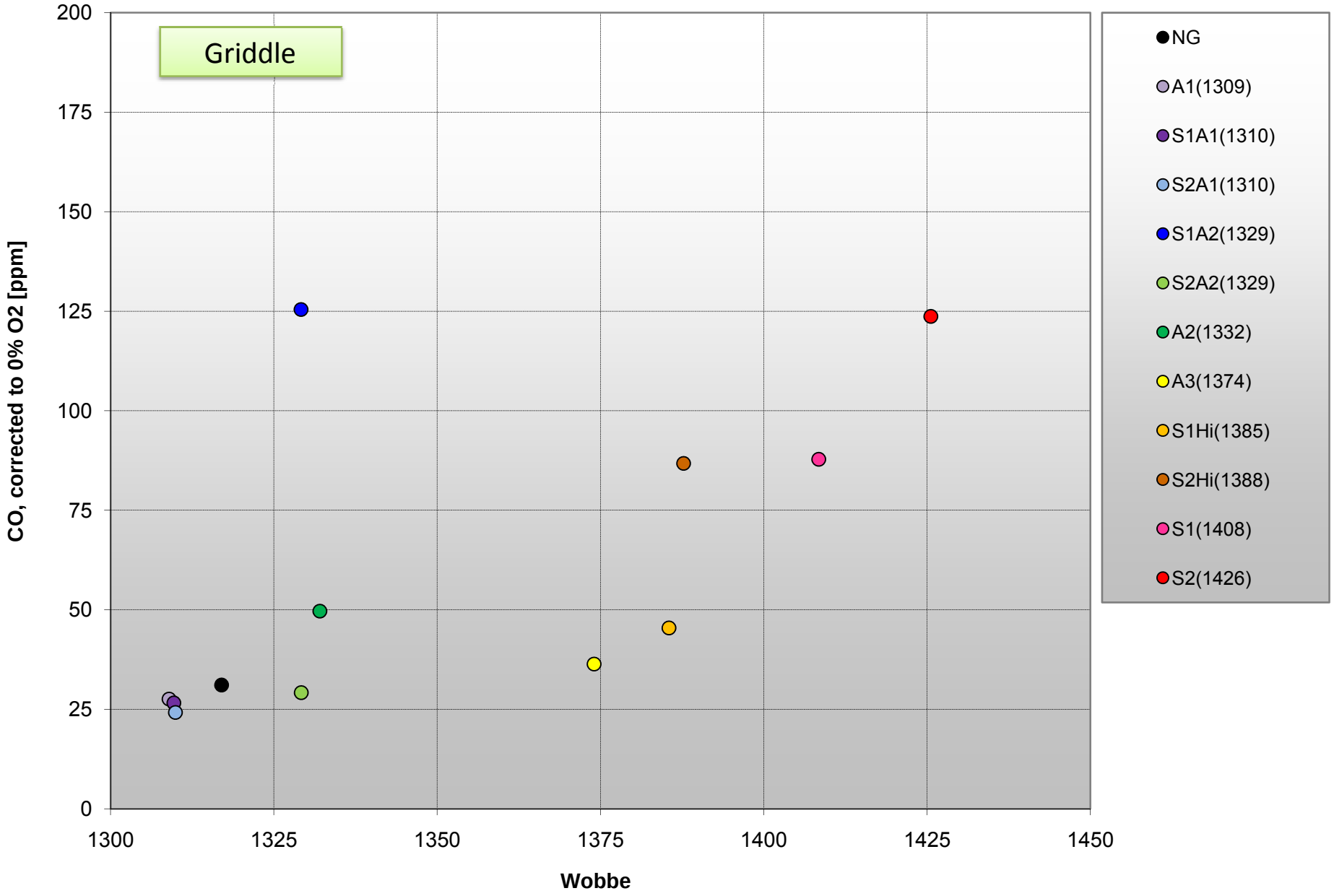

Convection Oven
NOx, corrected to 0% O2 [ppm]
200
175
150
125
100
75
50
25
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

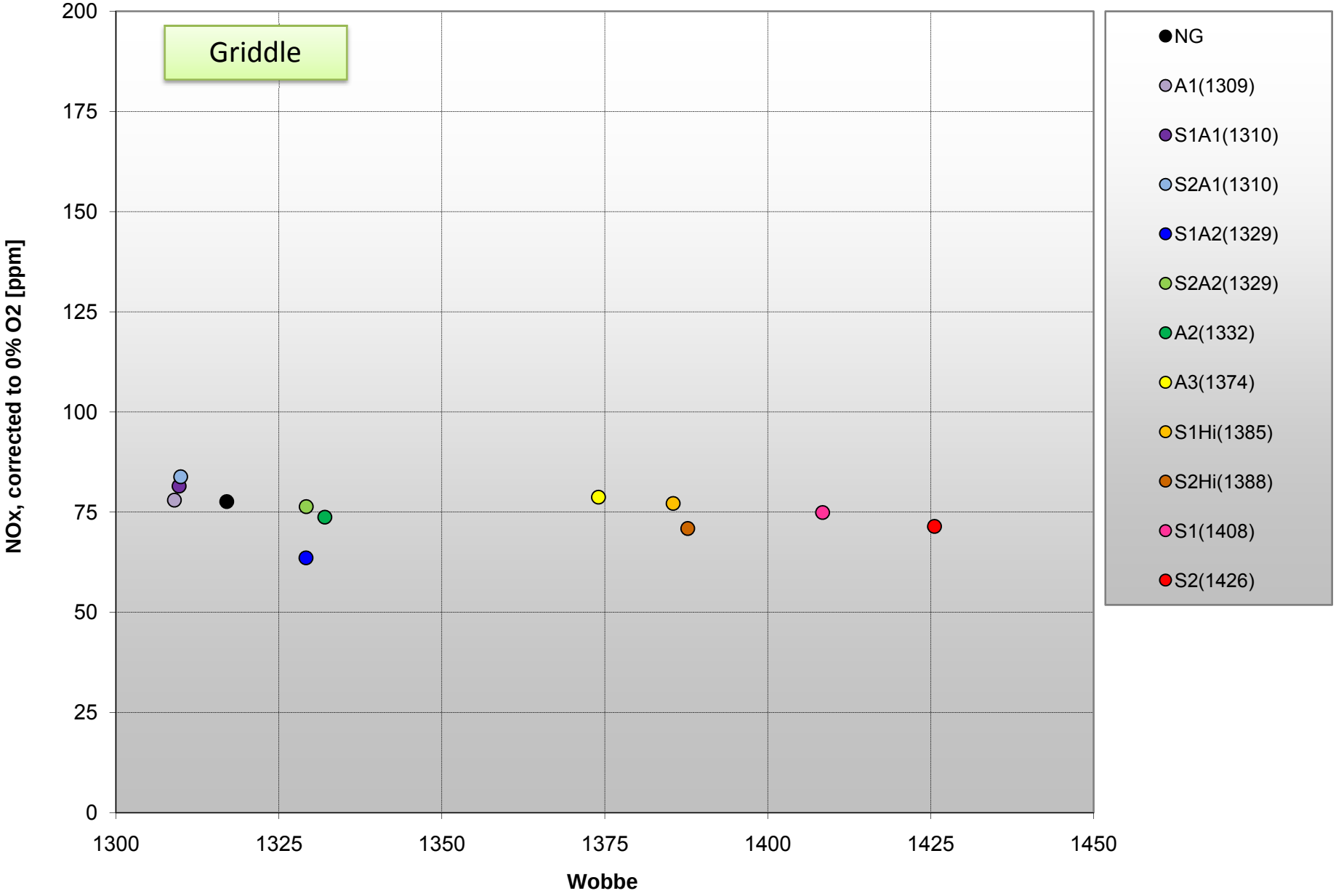

Fryer 1
CO, corrected to 0% O2 [ppm]
200
175
150
125
100
75
50
25
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

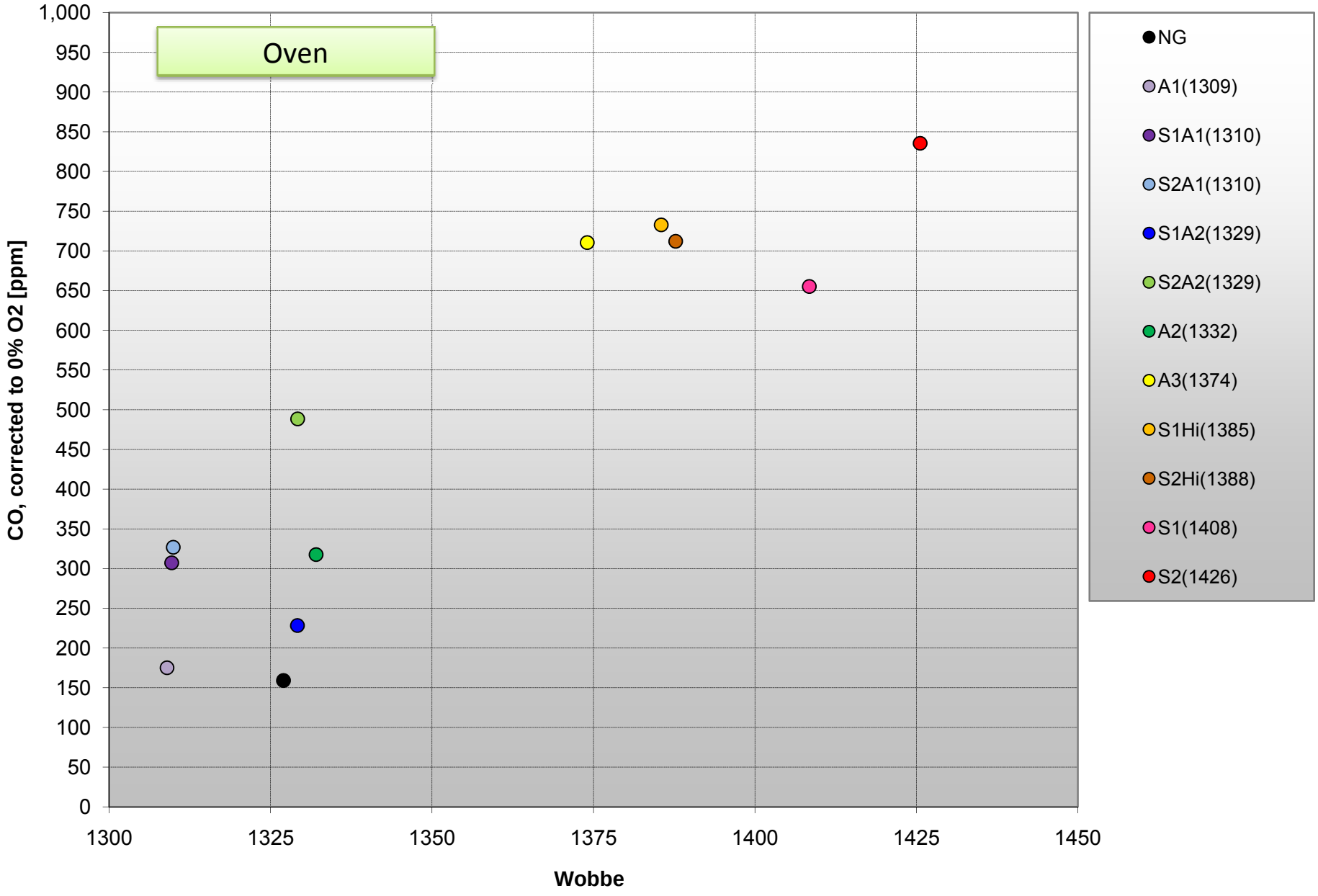

Fryer 1
NOx, corrected to 0% O2 [ppm]
Wobbe
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

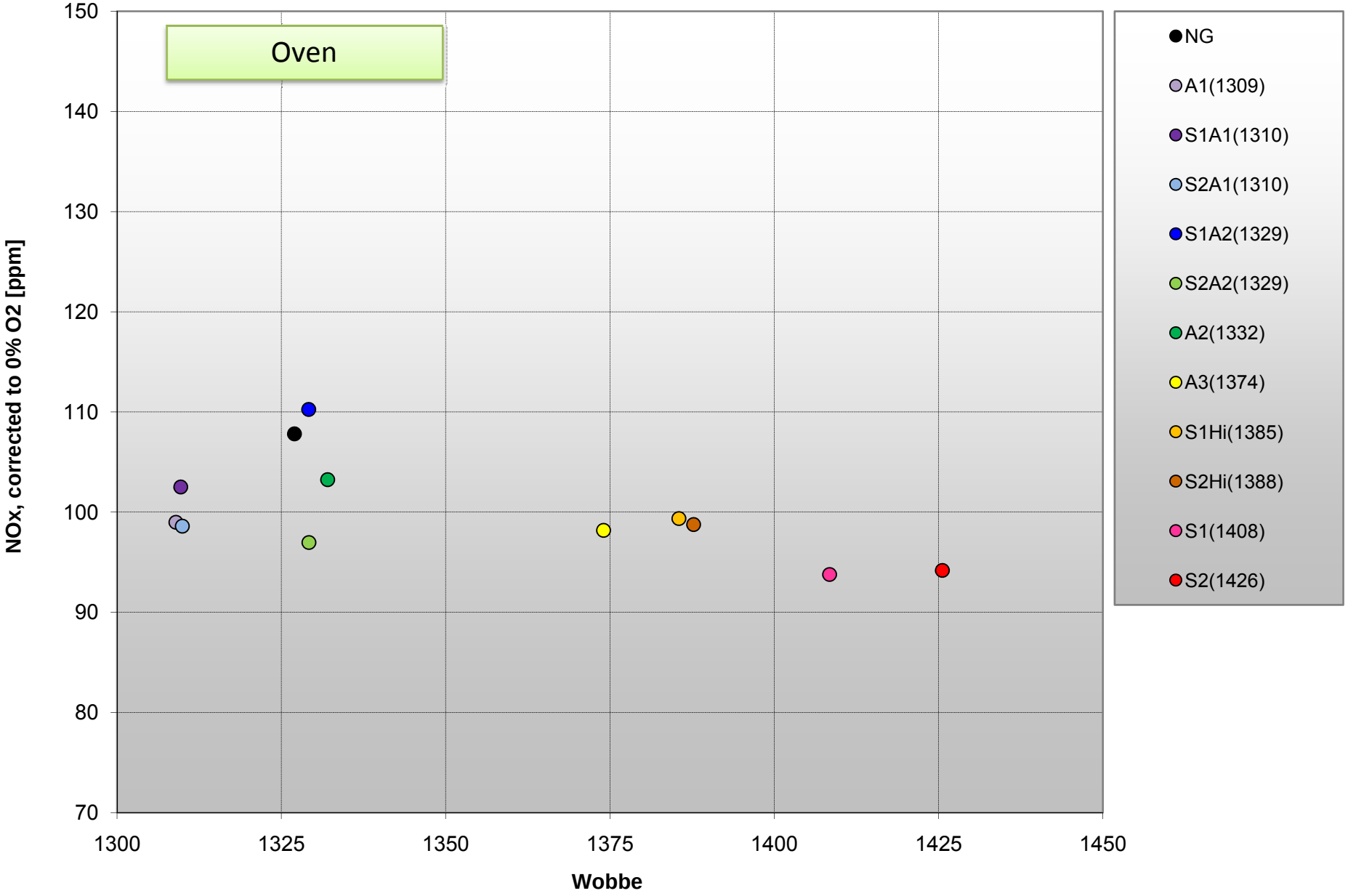

Fryer2
CO, corrected to 0% O2 [ppm]
Wobbe
600
550
500
450
400
350
300
250
200
150
100
50
0
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

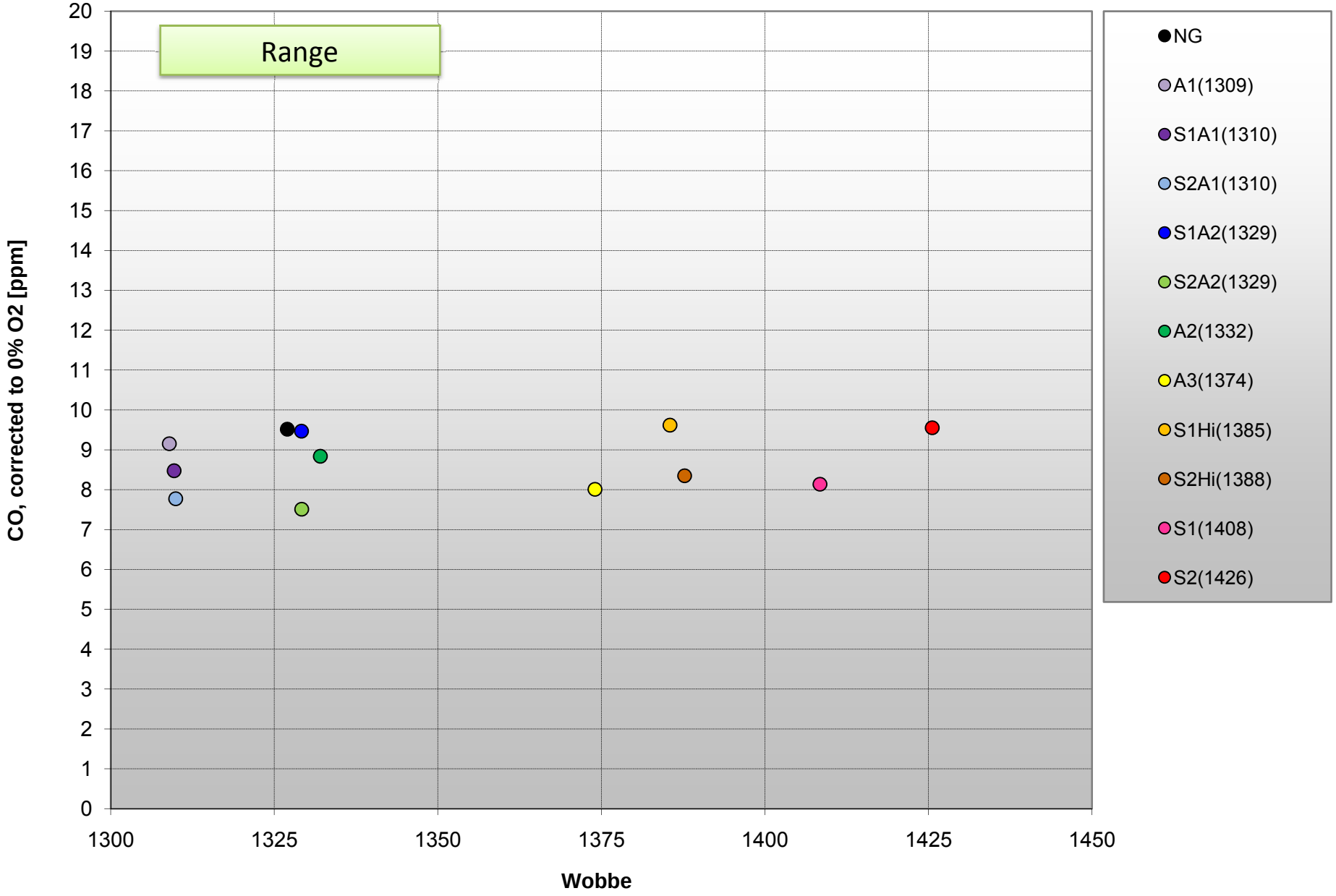

Fryer2
NOx, corrected to 0% O2 [ppm]
Wobbe
100
90
80
70
60
50
40
30
20
10
0
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

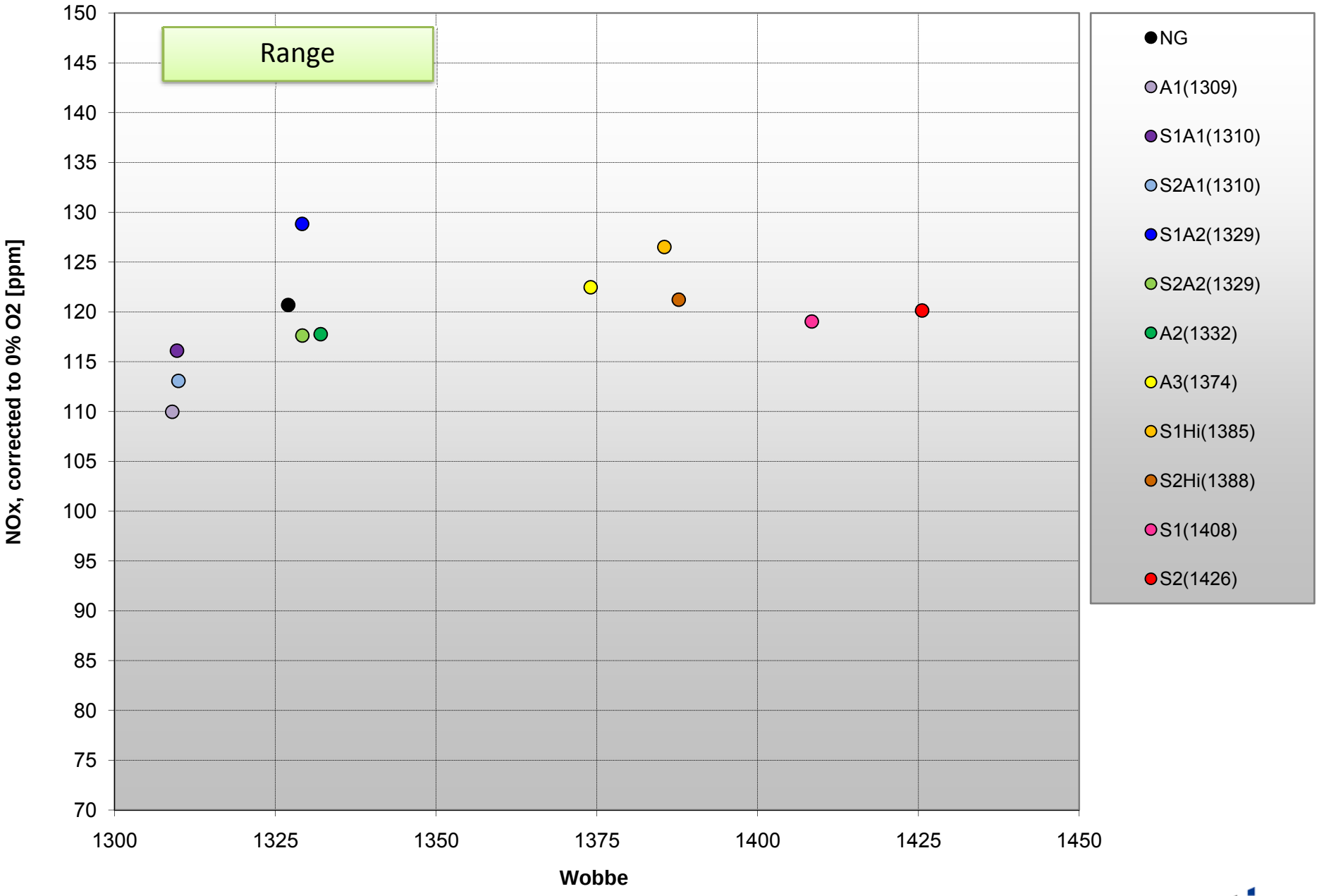

Griddle
CO, corrected to 0% O2 [ppm]
Wobbe
200
175
150
125
100
75
50
25
0
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

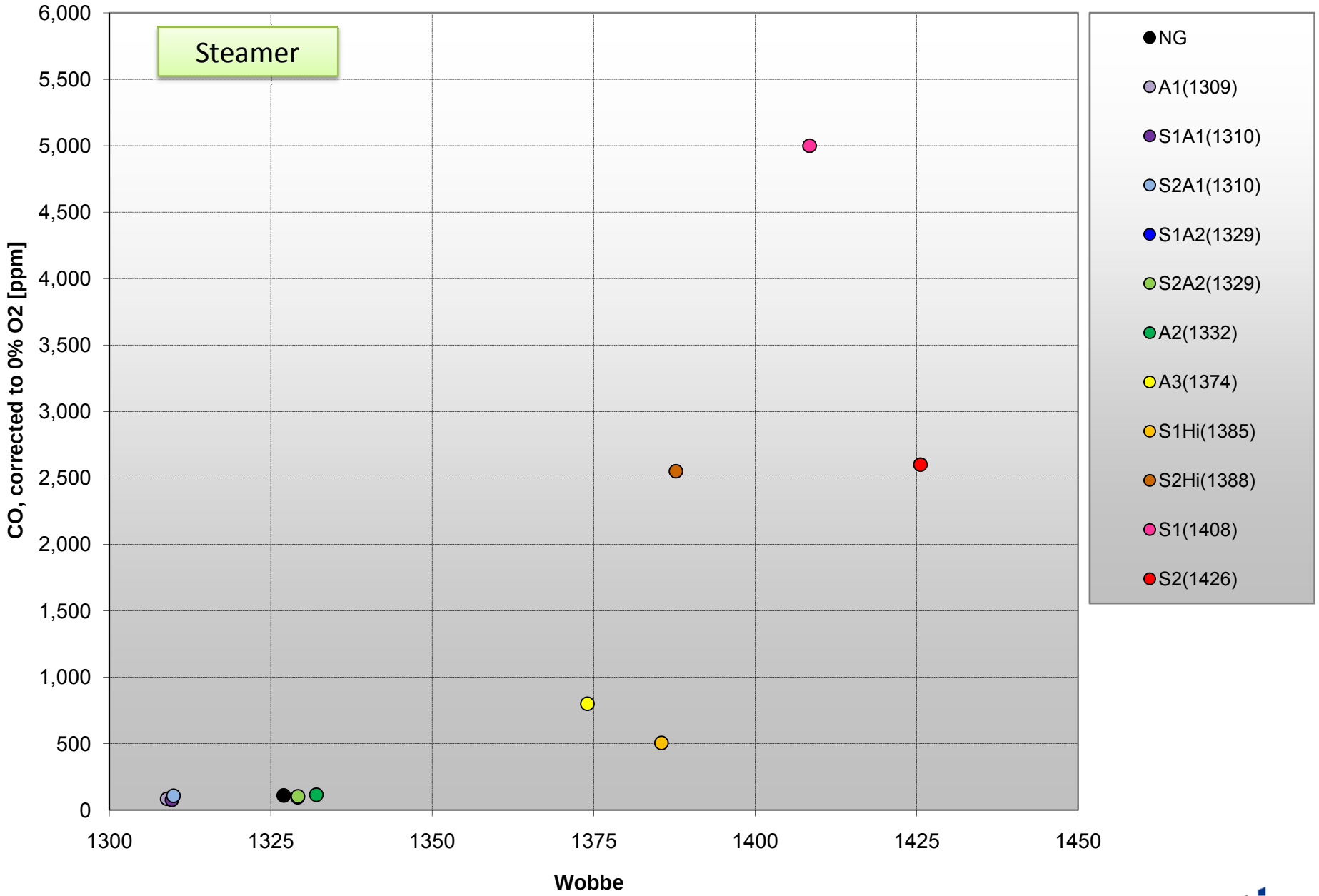

Griddle
NOx, corrected to 0% O2 [ppm]
200
175
150
125
100
75
50
25
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

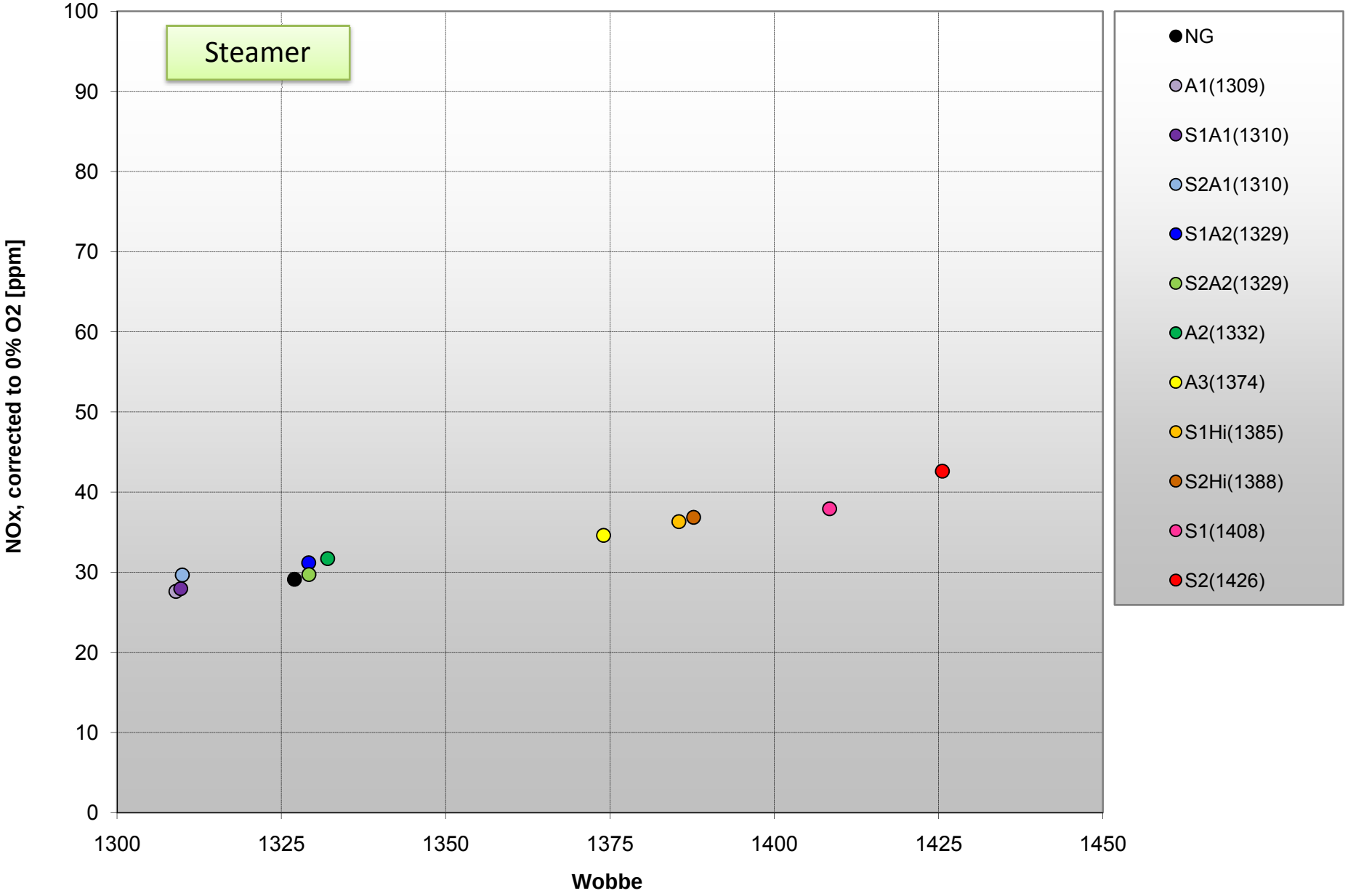

Oven
CO, corrected to 0% O2 [ppm]
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)


Oven
NOx, corrected to 0% O2 [ppm]
150
140
130
120
110
100
90
80
70
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

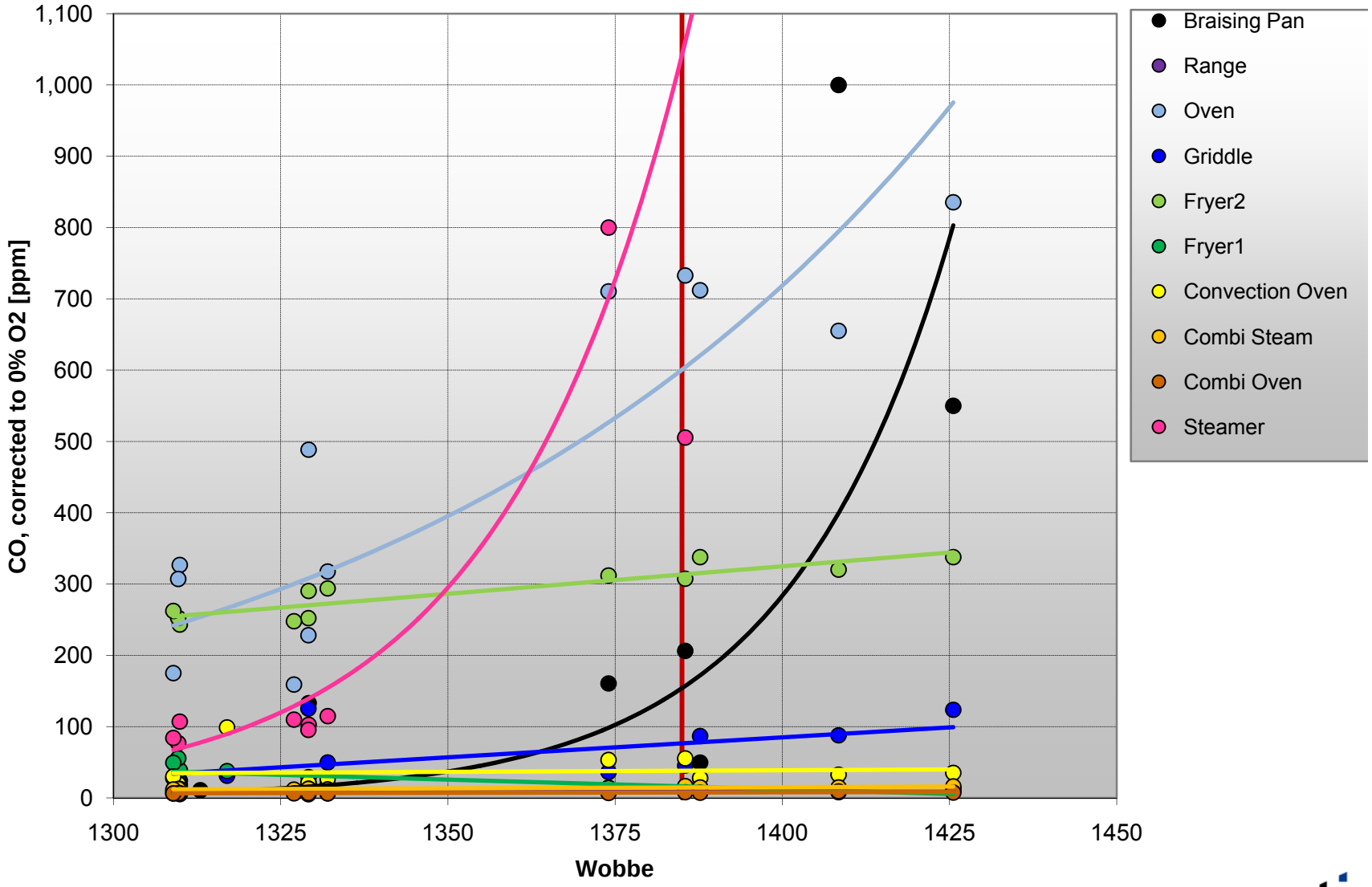

Range
CO, corrected to 0% O2 [ppm]
Wobbe
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)


Range
NOx, corrected to 0% O2 [ppm]
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

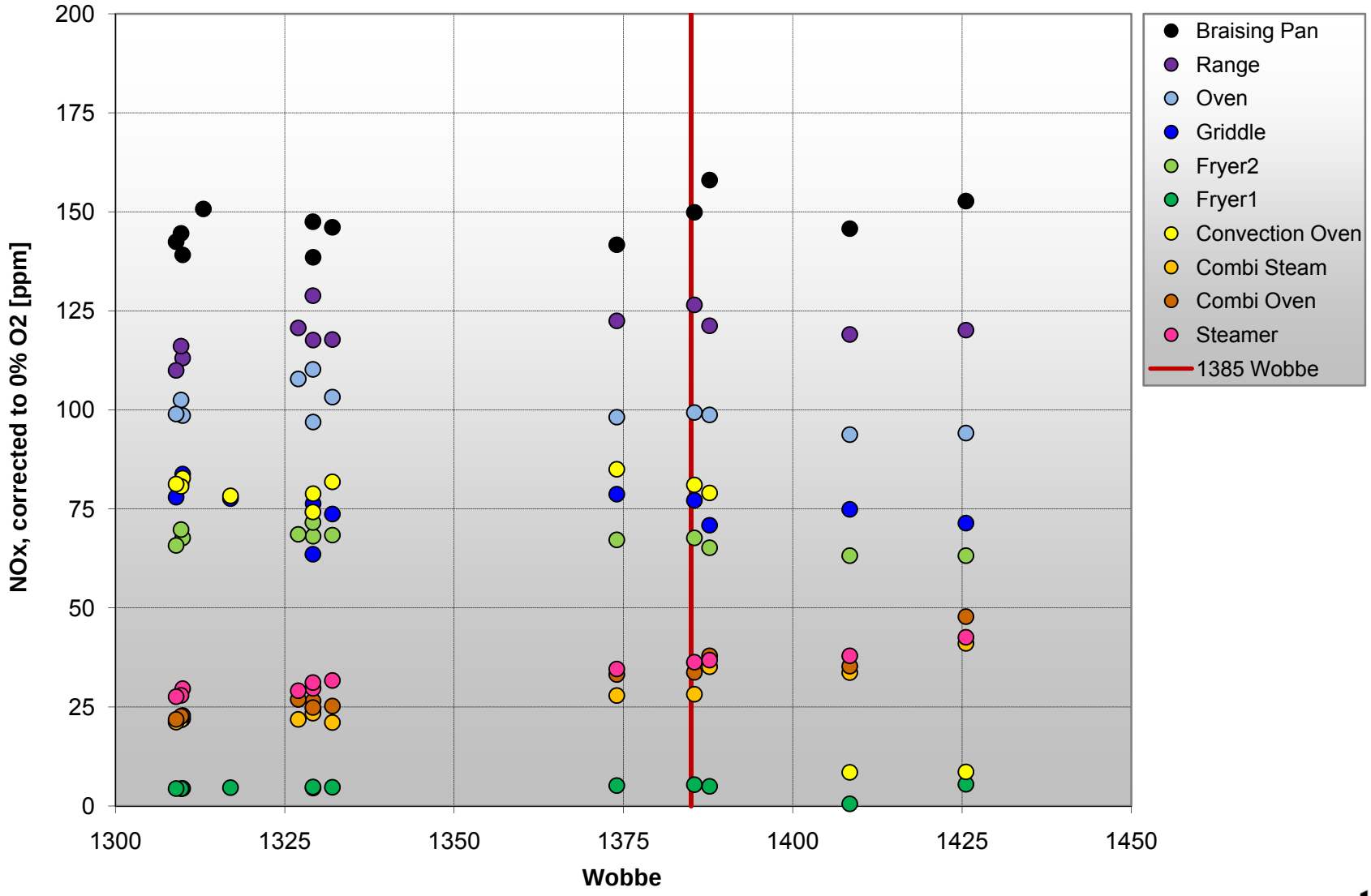

Steamer
CO, corrected to 0% O2 [ppm]
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1300
1325
1350
1375
1400
1425
1450
Wobbe
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)


Steamer
NOx, corrected to 0% O2 [ppm]
Wobbe
0
10
20
30
40
50
60
70
80
90
100
1300
1325
1350
1375
1400
1425
1450
NG
A1(1309)
S1A1(1310)
S2A1(1310)
S1A2(1329)
S2A2(1329)
A2(1332)
A3(1374)
S1Hi(1385)
S2Hi(1388)
S1(1408)
S2(1426)

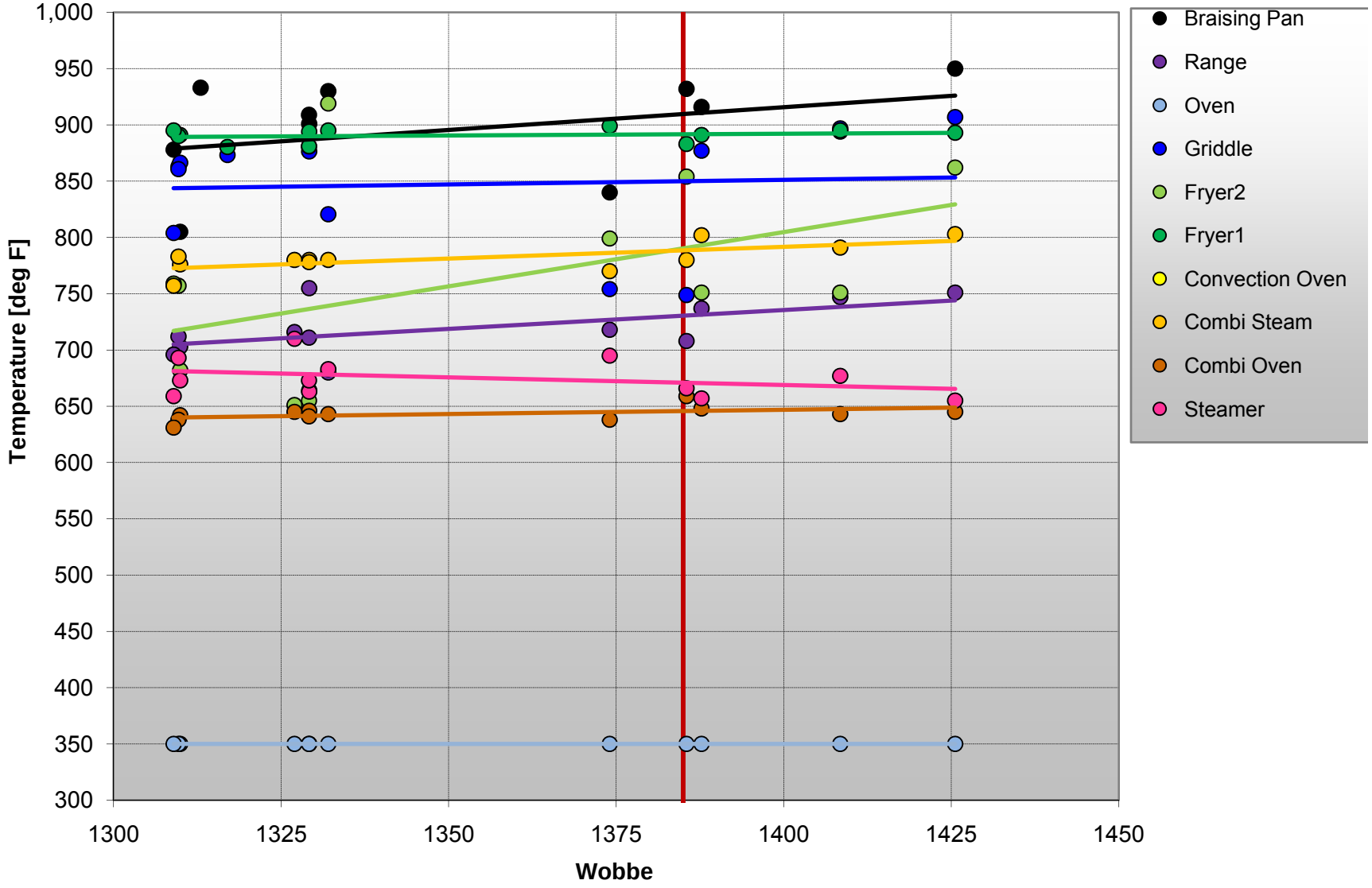
Food Service Equipment Summary - CO



Food Service Equipment Summary - NOx



Food Service Equipment – Flue Temperatures



Foodservice Equipment Behavior

- Higher Wobbe gas led to flame impingement for some appliances
  - Moderate CO increase for braising pan, griddle, fryer2
  - Large CO increase for braising pan
- Higher Wobbe gas led to insufficient O2 in one case
  - Large CO increase for tightly tuned steamer
- Moderate NOx increase for combi-oven, combi-steamer and steamer
  - Confined space led to higher flame temperatures
- Only the range top had higher flue temperature with higher W gas (up to 1385 W)

Looking Ahead – Foodservice Equipment

- Equipment cannot be readily tuned in the field by end users
- Appliances often run daily for years without adjustment
- No interchangeability field testing has been done
- Emissions of CO (and sometimes NOx) can increase with higher Wobbe gas
- Causes of emissions increases are identifiable so specific appliance types of interest can be addressed

Recommendations - Foodservice

- Develop larger interchangeability data base
- Laboratory testing of more types of equipment
- Field testing of appliances of most concern
- Development of protocols for set-up of equipment that will be operated over know Wobbe ranges
- Work with manufacturers to develop appliances with low emissions over wide Wobbe range
- Assist end users in maintaining appliances at optimal performance levels