A Comparative Study of Oxygen Probe Accuracy between a Solid Zirconia Sensor and a Commercial Sensor

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Abstract

The performance and accuracy of the oxygen probe is crucial for heat treating operations. In this study, these properties were measured in two different probes, the Solid Zirconia sensor and a commercial sensor. Both probes were installed in the same conditions with different controllers on a carburizing furnace in a heat treat shop. Measurements were taken for a period of two months; each value was compared against the shim stock performed daily to the furnace to verify the actual carbon potential. At the end of the comparison trial, the obtained values from the probes, the corresponding shims stocks and any changes or modifications to their correction factors were statistically analyzed to provide the information required for this study. Results showed the Solid Zirconia sensor had higher accuracy and better performance against the commercial probe.

1.- Introduction

The oxygen probe is an in situ type device, meaning that it directly samples the atmosphere being measured. The electrical signal generated by an oxygen probe is directly proportional to the carbon potential of the atmosphere.

It is based on a theory on a hot ceramic electromechanical cell. The probe will respond to oxygen, hydrogen, carbon monoxide, water and carbon dioxide and thus can determine the oxidation potential of a gas.

The oxygen probe is a closed-end tube usually constructed of zirconia or yttria-stabilized material for temperatures up to 1600°C (2900°F). [1] A typical oxygen probe usually consists of the following in fig. 1.

When such a probe is subjected to elevated temperatures, the non porous sheath material acts as a solid electrolyte that permits the passage of oxygen ions when the inner and outer surfaces are subjected to atmospheres of different oxygen partial pressures. [2]

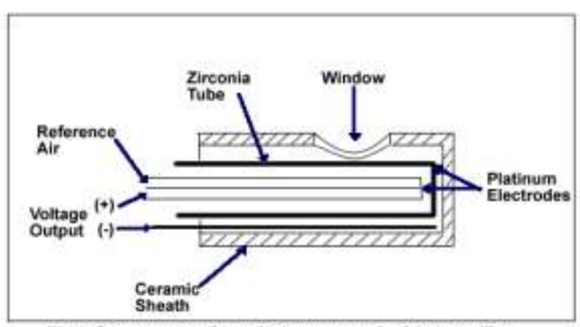


Fig 1. Components of a typical oxygen probe for controlling carburizing atmospheres.

The Solid Zirconia sensor is an oxygen probe whose innovative design permits a more accurate reading than the commercially used probes. The probe design is unique in that its Zirconia electrolyte tube is cast in one piece, without joints or seams. This single piece design contributes to accuracy by eliminating any short circuit oxygen diffusion paths and minimizing thermal expansion stress. All this extending the probe's useful life.

To protect the Zirconica electrolyte tube end from metal contamination from electrode contact, a special composition Zirconia pellet is added. Also, the outer electrode material (the part that is exposed to the furnace's atmosphere) is a special high temperature alloy. This alloy forms a conductive oxide surface, making it resistant to carburization.

Additionally, the outer electrode design allows the furnace gases to "flow through" which eliminates any stagnation points. This is important because stagnation points cause catalytic reactions that change the gas composition. All these properties are critical for long term accuracy in atmosphere control using oxygen probes.

The present study compared a commercial probe against the Solid Zirconia sensor in typical heat treating conditions to evaluate each probe's accuracy and performance.

2.- Experimental Procedure

For this study, the testing was carried out at DANA facilities in a randomly selected UBQ furnace, during normal production operations. Both the Solid Zirconia sensor and the commercial sensor were installed new just prior to beginning the test. The Commercial probe was used to control the furnace's carbon potential. Both sensors were installed in the roof of the furnace as shown in Figure 2 and Figure 3.

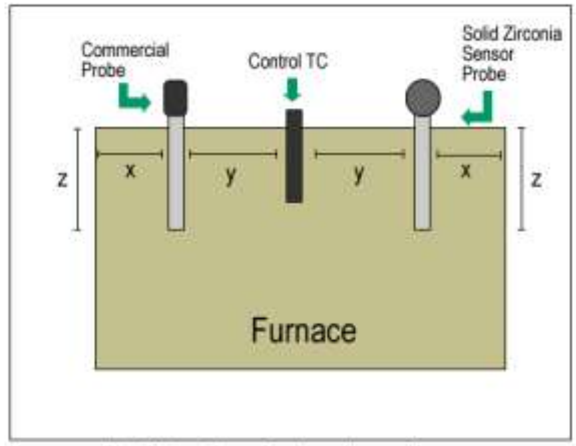


Fig. 2 Location of test probes on furnace

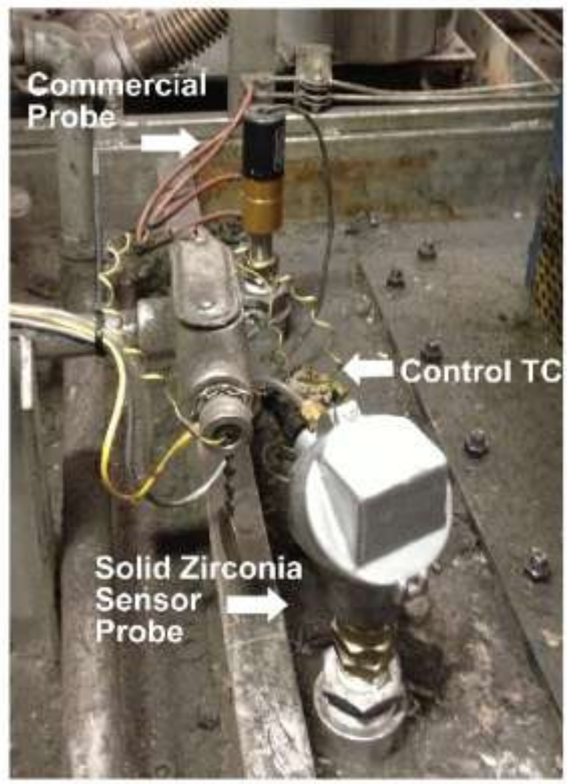


Fig. 3 Actual image of test probes on furnace

The output of the Solid Zirconia probe was monitored and data recorded via an independent Honeywell UDC 3200 controller. The true %C was determined by DANA personnel from weight gain measurements, shim stock procedure, which is DANA's standard practice.

The test was conducted from May 1st, 2013 to July 2nd, 2013, which was considered adequate for a valid conclusion.

During this time period 12 production cycles were run and all data logged. The carburizing temperature set point was 1750°F and 1.20%C, but because the Solid Zirconia Sensor was not controlling this process, it isn't necessarily expected that it would follow the set point.

3.- Results and Discussion

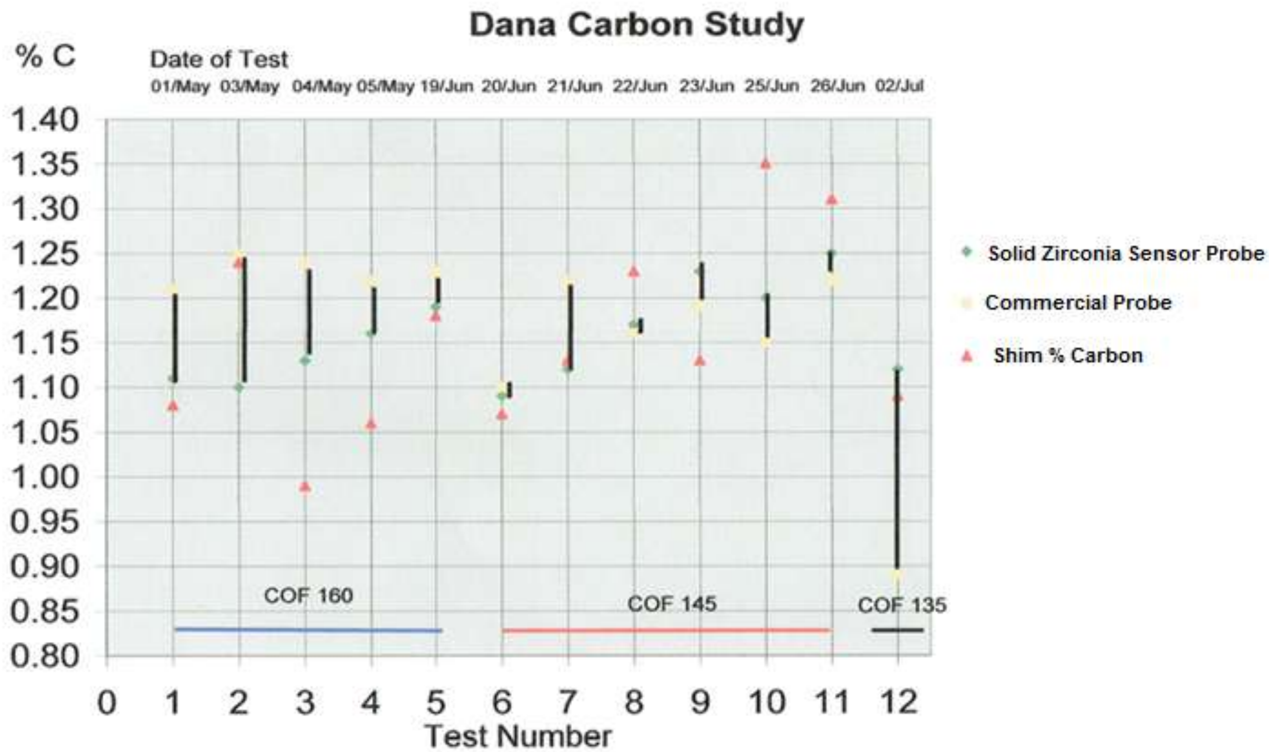
Twelve Sets of data were gathered through the SCADA as well as from the shim stock tests (Table 1). CO factor* was also added to the information logged. Carbon readings obtained from the Solid Zirconia Sensor proved to be closer to the real carbon values as verified by shim analysis. This sensor maintained readings close enough to shim analysis values that the COF for this sensor never required manipulation during the test.

A statistic analysis was conducted from the data retrieved during the comparison trial. The data from the Solid Zirconia Sensor was compared against the real values gathered from the shim stock test, obtaining the difference between them. The statistical analysis was performed for the commercial probe likewise (Graphs 1, 2, 3 & 4).

Day	Carbon Potential			Diference VS %C Real		COF	
	Real	Solid Zirconia Sensor	Commercial Probe	Solid Zirconia Sensor	Commercial Probe	Solid Zirconia Sensor	Commercial Probe
1	1.08	1.11	1.21	-0.03	-0.13	200	160
2	1.24	1.1	1.25	0.14	-0.01	200	160
3	0.99	1.13	1.24	-0.14	-0.25	200	160
4	1.06	1.16	1.22	-0.1	-0.16	200	160
5	1.18	1.19	1.23	-0.01	-0.05	200	145
6	1.07	1.09	1.1	-0.02	-0.03	200	145
7	1.12	1.12	1.22	0	-0.1	200	145
8	1.23	1.17	1.16	0.06	0.07	200	145
9	1.13	1.23	1.19	-0.1	-0.06	200	145
10	1.35	1.2	1.15	0.15	0.2	200	145
11	1.31	1.25	1.22	0.06	0.09	200	145
12	1.09	1.12	0.89	-0.03	0.2	200	135

Table 1. Probe Comparison Trial Data

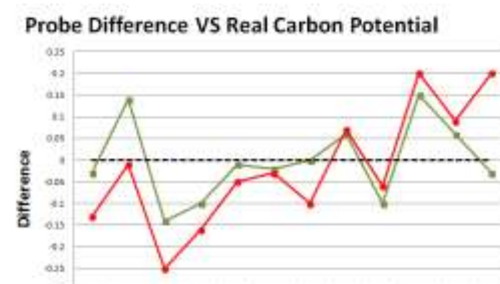
***CO Factor (COF):** An adjustment to the theoretical carbon potential calculation.



Graph 1. General data analysis.

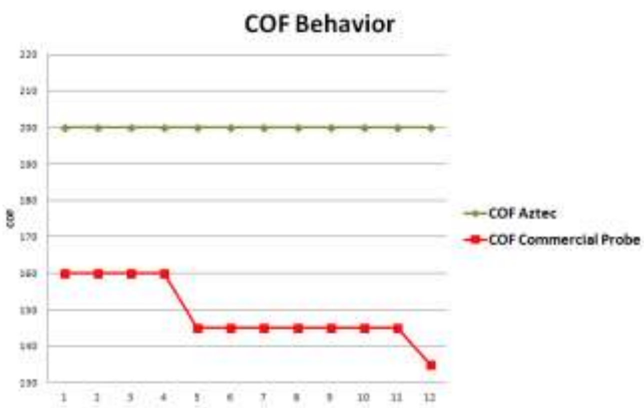
	1	2	3	4	5	6	7	8	9	10	11	12
NC Real	1.08	1.24	0.99	1.06	1.18	1.07	1.12	1.23	1.13	1.35	1.31	1.09
NC Aztec	1.11	1.1	1.13	1.16	1.19	1.09	1.12	1.17	1.23	1.2	1.25	1.12
NC Commercial Probe	1.21	1.25	1.24	1.22	1.23	1.1	1.22	1.16	1.19	1.15	1.22	0.89

Graph 2. Carbon Potential Readings Against Actual Reading According To Shim Stock



	1	2	3	4	5	6	7	8	9	10	11	12
Aztec VS Real	-0.03	0.14	-0.14	-0.1	-0.01	-0.02	0	0.06	-0.1	0.15	0.06	-0.03
Commercial VS Real	-0.13	-0.01	-0.25	-0.16	-0.05	-0.03	-0.1	0.07	-0.06	0.2	0.09	0.2
REAL	0	0	0	0	0	0	0	0	0	0	0	0

Graph 3. Comparison between probe's difference values.



Graph 4. Correction factor during trial.

4.- Conclusions

1. The Solid Zirconia Sensor measures %C in a carburizing atmosphere more accurately than the Commercial Probe.

2. The average deviation between true %C and the Commercial Probe %C was 0.11%C and the average deviation between true %C and the Solid Zirconia sensor was 0.07%C. This meaning that the readings from the Solid Zirconia Sensor are closest to the ones from the shim stock (real carbon potential).

3. The commercial probe required 3 different COF values during the test, meanwhile the Solid Zirconia sensor did not require any adjustment for this matter.

4. The Solid Zirconia Sensor's design shows a higher accuracy, without the need to constantly manipulate COF values. This zero maintenance accuracy uniquely eliminates human error and instills confidence in carbon potential readings in any carburizing furnace.

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References

[1] J.L. Dasset, H.E. Loyer, "Practical Heat Treating" Second Edition, ASM International (2006) pg 91-93

[2] "Metals Handbook: Heat Treating" Volume 4, ASM Handbook Committee, 9th Edition (2011) pg 365