Startup and Evaluation
of the First SNIF SHEER™ System
at Kaiser Aluminum, Trentwood Works

by

Jane E. Buehler, Kaiser Aluminum, Spokane, WA
and
Robert A. Frank, Praxair, Tarrytown, NY

Presented at the
122nd TMS Annual Meeting
Denver, Colorado
February 24, 1993

Startup and Evaluation of the First SNIF SHEER™ System at Kaiser Aluminum, Trentwood Works

Jane E. Buehler, Kaiser Aluminum, Spokane, WA
Robert A. Frank, Praxair, Tarrytown, NY

The first, two-nozzle, SNIF SHEER™ system was installed and commissioned at Kaiser, Trentwood Works in December 1991. The new system is an improved version of the standard SNIF® "R" system. Following the system startup, an extensive evaluation and optimization was performed. A standard structural aluminum alloy (AA6061) was utilized. The performance of the refining system was measured as a function of the argon and chlorine flow rate. Hydrogen and inclusion removal were measured to determine the performance of the system. The conditions for optimal refining were determined. A comparison of the performance of the new and standard systems was made.

<u>Author Data:</u>

Jane E. Buehler
Kaiser Aluminum & Chemical Corp.
Trentwood Works, P.O. Box 15108
Spokane, WA 99215-5108
Phone: (509)-927-6226 FAX: (509)-927-6101

Robert A. Frank
Praxair, Inc.
777 Old Saw Mill River Road
Tarrytown, NY 10591-6714
Phone: (914)-789-2192 FAX: (914)-789-2506

I. Introduction

Originally constructed from 1942 to 1943, in Spokane, Washington, Kaiser Aluminum's Trentwood Works has been modernized to become one of the most advanced flat-rolled products mills in the world. The principal products include beverage can end, tab, and body stock; heat-treated sheet, coil and plate; and common alloy coil and flat sheet. Trentwood serves several principal aluminum markets, including distributors, aircraft/aerospace manufacturers, beverage can producers, and the computer and transportation industries.

The first SNIF SHEER™ (SHEER) system was installed at Trentwood Works in December 1991 so that Kaiser could evaluate the increased performance of the new design. Conversion of their existing SNIF® (standard) systems to SHEER systems would allow more high quality production with a minimal capital investment. This paper documents the performance of both standard SNIF and SNIF SHEER systems.

II. Brief Description of Casting Line and New SNIF SHEER System

The casthouse receives incoming metal from a variety of sources. The melter is charged with hot metal which can be prime from the reduction facility or remelted UBC and internal scrap. Cold metal sources include pig/sow, internal scrap, purchased scrap, and master alloys. The charge will vary according to the type of alloy that is being made. Once the charge is melted, and the alloy is within compositional limits, it is processed by skimming and fluxing. The metal is then transferred to the holder where it is further processed. Upon casting, the metal exits the holder and passes through a SNIF system and a ceramic foam filter before entering the casting table.

A SNIF system refines molten metal by injecting a process gas through a two-piece graphite spinning nozzle equipped with a stator which permits high-speed rotation without vortexing. The nozzle's spinning action creates a large amount of fine bubbles which are dispersed throughout the melt. These gas bubbles clean the aluminum by desorbing hydrogen dissolved in the aluminum and by helping to carry harmful nonwetted, nonmetallic particles (inclusions) up to the layer of dross floating on the metal surface. The SNIF R-140 system is the standard two nozzle (two chamber) version of this system. Figure 1 shows a cross-sectional view of the standard system.

The SNIF SHEER system incorporates changes to the chambers and nozzles which increase the efficiency of the system. A cross-sectional view of the SNIF SHEER R-140 is shown in Figure 2. A rib has been added to the bottom of each chamber. The rib helps to stabilize and equalize the metal flow pattern within the chamber. The nozzle modifications help to direct the two phase mixture (gas and metal) downward and distribute it evenly throughout the chamber. These changes promote a better distribution of the bubbles, a more stable fluid pattern, a flat bath surface during processing and idle, and less splashing which increase the system efficiency and make it easier to maintain.

III. Description of Experimental Plan

The performance of a standard SNIF system was measured under Kaiser's normal operating conditions. This data served as the baseline for comparison of the SNIF SHEER system's performance. The performance of the SHEER system was measured as a function of the argon and chlorine flow rate. Rotor speed was also varied slightly, but this was done more to optimize the bubble pattern, not to affect the system performance. Although metal flow rate and alloy type can have a large effect on system performance, they were held relatively constant throughout this study. The alloy used during the testing was AA6061. Table I lists the major variables and the experimental values that were used. Table II lists all the major experimental conditions. An attempt was made to keep all remaining process variables as constant as possible. For each experiment, the metal was melted and prepared in a similar manner. Any exceptions were noted.

The following data were gathered for each experiment: general observations of the SNIF system and casting line, hydrogen levels before and after the SNIF system, and inclusion levels before and after the SNIF system. During each experiment, as well as during idle, the surface of the bath in each chamber was observed. The bubble pattern, wave motion, amount of splashing, and amount of dross buildup were noted. Hydrogen levels were determined by the use of a Telegas I (by Praxair) and AlSCAN (by Kaiser) apparatus. The instruments were placed side by side and multiple measurements were made in each location. This setup allowed for comparison of the instruments and duplication of the data. Two LAIS apparatus were used to sample the metal stream for inclusions. Kaiser used a 500 g sample while Praxair used a 1000 g sample. Each sample was then cut in half, and each company rated two halves. Thus, four values, two per sample, were obtained for each location. The multiple samples allowed for comparison of rating scales and duplication of the measurements. To minimize the sampling time, hydrogen sampling was done on one side of the SNIF system while inclusion sampling was done on the opposite side. The order of sampling, inlet versus outlet, was varied from experiment to experiment to prevent any bias from sampling order.

IV. Results and Discussion

Observation of the SNIF systems at idle showed that the SNIF SHEER system provided a better distribution of the gas bubbles than the standard system. This led to a flatter bath surface, less splashing, less dross buildup, and less buildup on the roof. On standard systems, idle gas can sometimes exit the stator from only one side creating big bubbles and splash. With the SHEER nozzle, the idle gas is distributed evenly around all sides of the stator. The result is a ring of small bubbles just around stator. The bubbles produce very little splash and do not disturb the majority of the bath surface. This meant that the dross and roof buildup at idle, mainly due to idle gas splashing, are greatly reduced with the SHEER design. In fact, the dross and roof buildup appeared to be less with the SHEER nozzle than with standard nozzles which are rotated during idle.

During processing, the SHEER system produced gas bubbles that were evenly distributed throughout each chamber, even into the corners. There was no evidence of the occasionally large bubbles, and associated splash, which are a result of instabilities in the metal flow patterns on standard systems. The telltale rolling motion of the surface in standard systems did not exist in the SHEER system. This eliminated most of the exit trough wave motion found with standard systems. The bath surface during processing was nearly as flat as the surface at idle. The dross buildup and roof buildup during processing may also have been less, but this was hard to quantify. From a setup standpoint, the SHEER system is much easier to "tune" than a standard system. When the bubble pattern in the SHEER system becomes well distributed, the bath surface changes dramatically from a point slightly rougher than a standard system to a flat surface. The motor current also increases about one amp while the speed remains virtually constant. This makes it easy to monitor whether the system is running correctly by watching the combination of process gas flow, rotor speed, and motor current.

Table III provides the hydrogen results for each of the major experiments. Included in the table are two sets of values calculated from the hydrogen levels: the hydrogen removal and the reactor (system) constant. Hydrogen removal is the amount of hydrogen removed by the SNIF system, in percent, as defined by equation 1:

$$\%\ \text{Removal} = 100\,\frac{H_i - H_f}{H_i}$$

where:

H_i = Inlet Hydrogen Concentration (cc/100g)
H_f = Outlet Hydrogen Concentration (cc/100g)

The reactor constant is a number which describes how efficiently the SNIF system is operating. It is based on the standard chemical engineering equation for a well-mixed, steady state, staged reactor.[1] This model has previously been applied to in-line degassing systems.[2,3,4] The reactor constant is defined by equation 2:

$$k = \frac{v_{Al}}{n\,v_{Ar}}\left[\left(\frac{H_i}{H_f}\right)^{\frac{1}{s}} - 1\right]$$

where:

H_i = Inlet Hydrogen Concentration (cc/100g)
H_f = Outlet Hydrogen Concentration (cc/100g)

v_{Ar} = Argon Flow Rate per Nozzle (cfh)
v_{Al} = Aluminum Flow Rate (ton/hr)
n = number of nozzles per stage (-) = 1 for standard and SHEER R-140
s = number of stages (-) = 2 for standard and SHEER R-140
k = Reactor Constant (ton/cf)

The reactor constant takes into account the argon flow rate, the metal flow rate, and number of nozzles whereas hydrogen removal does not. Using the reactor constant, the performance of different systems or the same system operating under different conditions can be compared.

Three tests were done where only the outlet hydrogen levels were measured. Table IV summarizes the experimental conditions and outlet hydrogen readings for those experiments. These experiments show directly the effect of the argon flow rate on the outlet hydrogen concentration.

Figure 3 shows a graph of the side-by-side AlSCAN and Telegas readings. There is a difference in the measured hydrogen levels between the two instruments. The average difference was 0.05 cc/100g. Although the difference has an effect on the reported performance of the systems, a discussion of the correct hydrogen value is not in the scope of this paper. All calculations and comparisons will be given for both the AlSCAN and Telegas results.

Tables V and VI summarize the inclusion results of both sets of samples as rated by Praxair and Kaiser personnel, respectively. The inclusion removals, in percent, are included in the tables. Inclusion removal is calculated in the same manner as hydrogen removal. The inclusion removal ranged from 70-90% for both systems. Figure 4 compares Kaiser's and Praxair's inclusion rating systems. Figure 5 compares Kaiser's and Praxair's samples using both rating systems. There is little correlation in the inclusion data with respect to rating system or sampler.
From these graphs, it is apparent that the variability of the data is large. Therefore, no conclusions will be made on the inclusion removal performance of either SNIF system.

The results from similar operating conditions are averaged and summarized in Table VII. Data from tests with nozzles operating at 580 and 600 rpm were combined. The difference in system performance between these two speeds was not significant. The data in Table VII is compare the different operating conditions. These comparisons are shown in Table VIII. A standard student's t-test was used with a significance level of 95% to determine if the difference in performance was significant for the different operating conditions. From Table VIII, it is readily apparent that very few of the comparisons are significant. The lack of significance is an indication of the large variability in the data. To have a statistically significant comparison, more data points are required.

Regardless of the variability, comparisons of the different conditions can be made to get an understanding of how the systems behave. Figures 6-9 display the hydrogen removal and reactor constant as a function of argon flow rate for both the Telegas and AlSCAN data. Figures 10-12 display the outlet hydrogen levels (for a single experiment) as a function of argon flow rate for both the Telegas and AlSCAN data.

The hydrogen results were analyzed to determine:

1) the performance of the SHEER system versus argon flow rate,
2) the performance of the SHEER system versus the standard system,
3) the performance of the SHEER system using only one nozzle, and
4) the performance of the SHEER system with no chlorine through nozzle 2.

Examination of Figures 6 and 7 show that hydrogen removal peaks at 3.5 cfm. Figures 10, 11, and 12 show that the outlet hydrogen level also reaches a minimum at 3.5 cfm. Figures 8 and 9 show that the value of the reactor constant is steady until 3.5 cfm. At higher flow rates, the value declines. This corresponds to the breakdown of the good bubble dispersion and flat bath surface at the higher gas flows. To maintain, a good pattern, the rotor speed needs to be increased based on the argon flow rate. At an argon flow rate of 4.5 cfm, a nozzle speed greater than 640 rpm was required. The configuration of the existing equipment at Kaiser prevented the rotor speed from being maintained at levels higher than 600 rpm. If the higher speeds could have been maintained, then the reactor constant should have remained steady, and the hydrogen removal should have continued to increase. Since the reactor constant was steady at the lower flow rates, this is a good indication that this is the correct value for this system. The value can be used to calculated the theoretical system performance at different operating conditions.

Overall the hydrogen removal of the SHEER system was better than the removal by the standard system. Comparing the best performance of the SHEER system (at 3.5 cfm/nozzle) with that of the standard system (at 4.5 cfm/nozzle) showed an increase of 20% in hydrogen removal while the amount of argon used was decreased by 22%. The reactor constants, also, were higher with the SHEER system (0.15 versus 0.07 and 0.12 versus 0.05, for the Telegas and AlSCAN data, respectively). The larger reactor constants imply that the hydrogen removal capacity of the SHEER system is higher than the standard system.

Tests with only one SHEER nozzle running during the cast showed that the hydrogen removal performance was nearly the same as the performance of the standard system using both nozzles. The reactor constant was the same as the reactor constant using two nozzles. This further supports the validity of the model which uses equation 2 and the reactor constant to determine and predict the performance of the system.

There was no change in hydrogen removal when chlorine was eliminated from nozzle 2. Both the hydrogen removal and reactor constant were the same as those when chlorine was used in nozzle 2. This is not surprising since the amount of chlorine used in both SNIF systems was low (between 1 and 2% of the process gas).

Based on the model for hydrogen removal, as described by equation 2, a SNIF system should not have a point of optimal performance. The hydrogen removal should increase with argon flow as long as the bubble patterns are maintained and the surface turbulence is minimized. However, the system can be set at the minimum argon flow required to perform the necessary hydrogen and inclusion removal, possibly with a safety margin. At Kaiser, this meant setting the SHEER system at 3.5 cfm argon and 600 rpm with a minimum level (0.05 cfm) of chlorine through both nozzles.

V. Conclusion

Overall the new SNIF SHEER system performs better than the standard SNIF system. The SHEER system has a flatter bath and a better bubble distribution which minimized splashing and buildup at idling and during processing. The SHEER system is easier to maintain and setup. The hydrogen removal of the SHEER system is greater than the standard system. The SHEER system removed 20% more hydrogen with 22% less process gas. Because of the large variability in the inclusion measurements, differences in inclusion removal could not be detected. The optimum settings for a SNIF system depend on the removal requirements of a particular casting line. At Kaiser, the optimum setting for the SHEER system was 3.5 cfm of argon/nozzle at 600 rpm with 0.05 cfm of chlorine/nozzle.

VI. Acknowledgements

The authors wish to thank Kaiser Aluminum and Praxair, Inc. for their cooperation and support for this project. The authors would also like to thank Michael Klepacki for his help with the experimental measurements and Kelly Driscoll and Arthur Paulsen for their efforts in mounting, polishing, and rating the inclusion samples, as well as their technical input.

VII. References

1. Octave Levenspiel, Chemical Reaction Engineering (New York, NY: John Wiley & Sons, 1972), 97-149.

2. G.K. Sigworth and T.A. Engh, "Chemical and Kinetic Factors Related to Hydrogen Removal from Aluminum," Metallurgical Transactions B, 13B(3)(1982), 447-460.

3. R.N. Dokken, S.A. Engel, and P.J. Flisakowski, "Recent Advances in Molten Aluminum Refining Technology" (Paper presented at the Casting Technology Seminar, New Orleans, LA, 10-12 May 1989).

4. Christophe Leroy and Gerard Pignault, "The Use of Rotating-Impeller Gas Injection in Aluminum Processing," JOM, 43(9)(1991), 27-30.

Table I: Major Experimental Variables

Experimental Variable	Experimental Values
System	Standard SNIF or SNIF SHEER R-140
Argon Flow Rate	0.4, 2.5, 3.5, 4.0, or 4.5 cfm/nozzle (nozzles may be independent)
Chlorine Flow Rate	0.05 cfm in nozzle #1 0.05 or 0 cfm in nozzle #2
Rotor Speed (set as a function of the argon flow rate)	100, 430, 580, or 600 rpm/nozzle (nozzles may be independent)

Table II: Major Experimental Conditions

Test #	SNIF System (-)	Argon Flow (cfm)	Chlorine Flow (cfm)	Rotor Speed (rpm)	Metal Flow (ton/hr)
0	STD	4.5	0.05	430	24
1	STD	4.5	0.05	430	24
2	STD	4.5	0.05	430	24
3	SHEER	4.5	0.05	580	25
4	SHEER	4.5	0.05	580	25
5	SHEER	4.5	0.05	580	25
6	SHEER	4.5	0.05	580	25
10	SHEER	3.5	0.05	580	27
11	SHEER	4.5	0.05	580	26
12	SHEER	3.5	0.05	600	25
13	SHEER	3.5	0.05	600	24
13A	SHEER	4.0	0.05	600	24
14	SHEER	2.5	0.05	600	25
15	SHEER	2.5	0.05	580	25
16	SHEER	0.4 & 3.5	0 & 0.05	100 & 580	25
16A	SHEER	3.5	0.05	580	25
17	SHEER	3.5	0.05	580	29
18	SHEER	3.5	0.05 & 0	580	29
19	SHEER	3.5	0.05 & 0	580	29
20	SHEER	3.5 & 0.4	0.05 & 0	580 & 100	18
21	SHEER	0.4 & 3.5	0 & 0.05	100 & 580	27
21A	SHEER	3.5	0.05	580	27
22	SHEER	3.5 & 0.4	0.05 & 0	580 & 100	25
22A	SHEER	3.5	0.05	580	25

Note: If two values are listed, the first value applies to nozzle 1, the second applies to nozzle 2.

Table III: Hydrogen Results for Major Experiments

Test #	Telegas I				AISCAN			
	Inlet (cc/100g)	Outlet (cc/100g)	Removal (%)	Reactor Constant (ton/cf)	Inlet (cc/100g)	Outlet (cc/100g)	Removal (%)	Reactor Constant (ton/cf)
0	0.264	0.107	59.3	0.051	0.307	0.139	54.9	0.044
1	0.221	0.070	68.4	0.070	0.323	0.118	63.5	0.059
2	0.247	0.080	67.8	0.069	0.306	0.113	63.1	0.058
3	0.254	0.065	74.3	0.090	0.333	0.124	62.8	0.059
4	0.277	0.077	72.0	0.083	0.341	0.135	60.4	0.055
5	0.301	0.067	77.9	0.106	0.397	0.105	73.6	0.089
6	0.285	0.066	77.0	0.101	0.363	0.133	63.4	0.060
10	0.224	0.062	72.3	0.117	0.293	0.112	61.8	0.080
11	0.290	0.074	74.5	0.094	0.347	0.117	66.4	0.069
12	0.289	0.064	77.7	0.133	0.361	0.118	67.4	0.090
13	0.235	0.047	80.1	0.144	0.288	0.086	70.1	0.096
13A	0.235	0.047	79.8	0.124	0.288	0.088	69.4	0.082
14	0.257	0.066	74.4	0.163	0.304	0.093	69.4	0.135
15	0.256	0.062	75.9	0.162	0.322	0.113	65.1	0.108
16	0.352	0.118	66.4	0.183	0.450	0.149	66.9	0.186
16A	0.352	0.061	82.6	0.166	0.450	0.080	82.2	0.164
17	0.468	0.067	85.6	0.224	0.529	0.080	85.0	0.215
18	0.285	0.059	79.3	0.168	0.340	0.097	71.5	0.122
19	0.290	0.059	79.6	0.167	0.348	0.081	76.7	0.147
20	0.305	0.104	66.0	0.132	--	--	--	--
21	0.287	0.101	64.8	0.184	0.317	0.131	58.6	0.145
21A	0.287	0.059	79.4	0.154	0.317	0.087	72.5	0.116
22	0.265	0.105	60.2	0.145	0.262	0.126	51.8	0.106
22A	0.265	0.061	77.1	0.131	0.262	0.089	66.0	0.086

Table IV: Hydrogen Results for Outlet Only Experiments

Test #	SNIF System (-)	Argon Flow (cfm)	Chlorine Flow (cfm)	Rotor Speed (rpm)	Metal Flow (ton/hr)	Telegas I Outlet (cc/100g)	AlSCAN Outlet (cc/100g)
7A	SHEER	4.5	0.05	580	26	0.063	0.123
7B	SHEER	3.5	0.05	580	26	0.057	0.101
7C	SHEER	2.5	0.05	580	26	0.073	0.125
7D	SHEER	3.0	0.05	580	26	0.064	0.125
7E	SHEER	3.5	0.05	580	26	0.063	0.121
8A	SHEER	4.5	0.05	580	25	0.064	0.117
8B	SHEER	3.5	0.05	580	25	0.057	0.111
8C	SHEER	2.5	0.05	580	25	0.065	0.121
8D	SHEER	2.0	0.05	580	25	0.070	0.124
8E	SHEER	3.5	0.05	580	25	0.055	0.111
9A	SHEER	4.0	0.05	660	25	0.051	--
9B	SHEER	3.5	0.05	610	25	0.053	--
9C	SHEER	2.5	0.05	580	25	0.064	--
9D	SHEER	3.5	0.05	580	25	0.055	--
9E	SHEER	4.5	0.05	580	25	0.053	--

Table V: Inclusion Results - Praxair Rating of Samples

Test #	Praxair Samples			Kaiser Samples		
	Inlet (mm^2/kg)	Outlet (mm^2/kg)	Removal (%)	Inlet (mm^2/kg)	Outlet (mm^2/kg)	Removal (%)
0	--	--	--	--	--	--
1	0.0200	0.0186	6.7	0.0074	--	--
2	0.0331	0.0275	16.9	0.1747	0.0745	57.4
3	0.0164	0.0015	90.7	0.0361	0.0218	39.8
4	0.0962	0.0032	96.6	0.0289	0.0012	95.9
5	0.0806	0.0006	99.3	0.1474	0.2118	-43.6
6	0.0735	0.0092	87.5	0.0691	0.0204	70.4
10	1.0160	0.0439	95.7	1.8637	0.0189	99.0
11	--	--	--	--	--	--
12	0.0632	0.0052	91.8	0.1062	0.0239	77.5
13	0.1587	0.0491	69.1	0.1142	0.0212	81.4
13A	--	--	--	--	--	--
14	0.0566	0.0058	89.7	0.0726	0.0229	68.5
15	0.0106	0.0015	86.1	0.0239	0.0066	72.2
16	0.1494	0.0363	75.7	0.2432	0.0074	97.0
16A	--	--	--	--	--	--
17	0.2053	0.0192	90.6	0.2290	0.0441	80.7
18	0.1307	0.0168	87.1	0.2149	0.0092	95.7
19	0.2065	0.0319	84.6	0.0411	0.0374	9.1
20	0.3351	0.0768	77.1	0.0830	0.0116	86.0
21	0.9266	0.2909	68.6	0.3294	0.2807	14.8
21A	--	--	--	--	--	--
22	0.1859	0.0330	82.2	0.1236	0.0964	22.0
22A	--	--	--	--	--	--

Table VI: Inclusion Results - Kaiser Ratings of Samples

Test #	Praxair Samples			Kaiser Samples		
	Inlet (mm^2/kg)	Outlet (mm^2/kg)	Removal (%)	Inlet (mm^2/kg)	Outlet (mm^2/kg)	Removal (%)
0	--	--	--	--	--	--
1	0.1675	0.0413	75.4	0.1387	--	--
2	0.3300	0.1071	67.5	0.7928	0.1856	76.6
3	0.1431	0.0437	69.5	0.2876	0.1856	35.5
4	0.5239	0.0694	86.8	0.1473	0.0694	52.9
5	0.3813	0.0646	83.1	0.6991	0.7008	-0.2
6	0.5239	0.0407	92.2	0.3495	0.1387	60.3
10	2.5698	0.2622	89.8	4.1952	0.5753	86.3
11	--	--	--	--	--	--
12	0.2079	0.1101	47.0	0.4943	0.0991	80.0
13	0.6601	0.1355	79.5	0.6991	0.1387	80.2
13A	--	--	--	--	--	--
14	0.4158	0.0892	78.6	0.5891	0.0550	90.7
15	0.2051	0.0425	79.3	0.2774	0.0694	75.0
16	0.5239	0.3368	35.7	1.1097	0.2966	73.3
16A	--	--	--	--	--	--
17	0.2619	0.0781	70.2	0.5549	0.1061	80.9
18	0.4667	0.1188	74.5	0.6991	0.1967	71.9
19	0.4667	0.2143	54.1	0.5549	0.2673	51.8
20	0.7409	0.6991	5.6	0.4404	0.4676	-6.2
21	1.0478	2.3771	-126.9	1.1097	0.9989	10.0
21A	--	--	--	--	--	--
22	0.5392	0.4943	8.3	0.5606	0.3146	43.9
22A	--	--	--	--	--	--

Table VII: Summary of Similar Operating Conditions

Conditions	Statistic	Telegas I		AlSCAN		Inclusion Removal (%)			
						Praxair Ratings		Kaiser Ratings	
		Hydrogen Removal (%)	Reactor Constant (ton/cf)	Hydrogen Removal (%)	Reactor Constant (ton/cf)	Praxair Sample	Kaiser Sample	Praxair Sample	Kaiser Sample
(A) R-140 4.5 cfm Ar 430 rpm	Average	65.2	0.063	60.5	0.054	11.8	57.4	71.5	76.6
	Std Deviation	5.1	0.011	4.8	0.008	7.2	--	5.5	--
	# of Samples	3	3	3	3	2	1	2	1
(B) SHEER R-140 4.5 cfm Ar 580 rpm	Average	75.1	0.095	65.3	0.067	93.5	40.6	82.9	37.1
	Std Deviation	2.3	0.009	5.1	0.014	5.4	60.7	9.7	27.0
	# of Samples	5	5	5	5	4	4	4	4
(C) SHEER R-140 4.0 cfm Ar 600 rpm	Average	79.8	0.124	69.4	0.082	--	--	--	--
	Std Deviation	--	--	--	--	--	--	--	--
	# of Samples	1	1	1	1	--	--	--	--
(D) SHEER R-140 3.5 cfm Ar 580-600 rpm	Average	79.3	0.153	72.1	0.121	86.8	84.7	71.6	81.8
	Std Deviation	4.2	0.035	8.6	0.050	12.0	9.7	18.2	3.0
	# of Samples	7	7	7	7	4	4	4	4
(E) SHEER R-140 2.5 cfm Ar 580-600 rpm	Average	75.2	0.163	67.2	0.121	87.9	70.3	78.9	82.8
	Std Deviation	1.1	0.001	3.1	0.019	2.6	2.6	0.5	11.1
	# of Samples	2	2	2	2	2	2	2	2
(F) SHEER R-140 3.5 cfm Ar 580 rpm Nozzle 1 Only	Average	63.1	0.138	51.8	0.106	79.7	54.0	7.0	18.9
	Std Deviation	4.1	0.009	--	--	3.7	45.3	1.9	35.4
	# of Samples	2	2	1	1	2	2	2	2
(G) SHEER R-140 3.5 cfm Ar 580 rpm Nozzle 2 Only	Average	65.6	0.183	62.7	0.166	72.2	55.9	-45.6	41.6
	Std Deviation	1.1	0.001	5.9	0.029	5.0	58.1	115.0	44.7
	# of Samples	2	2	2	2	2	2	2	2
(H) SHEER R-140 3.5 cfm Ar 580 rpm no Cl_2 in Nozzle 2	Average	79.5	0.167	74.1	0.134	85.8	52.4	64.3	61.8
	Std Deviation	0.2	0.001	3.7	0.018	1.8	61.2	14.5	14.2
	# of Samples	2	2	2	2	2	2	2	2
(I) SHEER R-140 3.5 cfm Ar 580-600 rpm all Cl_2 levels	Average	79.3	0.156	72.6	0.124	86.5	73.9	69.2	75.2
	Std Deviation	3.7	0.031	7.6	0.045	9.4	32.9	16.0	12.3
	# of Samples	9	9	9	9	6	6	6	6

Table VIII: Summary of Comparison between Operating Conditions

Conditions	Statistic	Telegas I		AlSCAN		Inclusion Removal (%)			
						Praxair Ratings		Kaiser Ratings	
		Hydrogen Removal (%)	Reactor Constant (ton/cf)	Hydrogen Removal (%)	Reactor Constant (ton/cf)	Praxair Sample	Kaiser Sample	Praxair Sample	Kaiser Sample
(A) versus (B)	t-value	3.904	4.453	1.318	1.440	16.021	--	1.491	--
	Significant?	YES	YES	NO	NO	YES	--	NO	--
	% Change	15.3	49.4	8.0	23.8	691.3	-29.2	16.0	-51.5
(A) versus (B)	t-value	4.569	4.175	2.169	2.214	7.860	--	0.012	--
	Significant?	YES	YES	NO	NO	YES	--	NO	--
	% Change	21.6	140.8	19.3	124.9	634.5	47.5	0.2	6.8
(B) versus (D)	t-value	1.958	3.545	1.587	2.316	1.018	1.433	1.090	3.292
	Significant?	NO	YES	NO	YES	NO	NO	NO	YES
	% Change	5.5	61.1	10.5	81.6	-7.2	108.4	-13.6	120.4
(E) versus (D)	t-value	1.290	0.388	0.764	0.017	0.120	1.942	0.534	0.190
	Significant?	NO	NO	NO	NO	NO	NO	NO	NO
	% Change	5.4	-6.2	7.3	-0.5	-1.2	20.3	-9.3	-1.2
(F) versus (D)	t-value	4.780	0.544	--	--	0.780	1.464	4.716	4.065
	Significant?	YES	NO	--	--	NO	NO	YES	YES
	% Change	25.7	10.3	39.2	13.8	9.0	56.7	925.7	333.9
(G) versus (D)	t-value	4.314	1.174	1.424	1.166	1.580	1.099	2.270	2.060
	Significant?	YES	NO	NO	NO	NO	NO	NO	NO
	% Change	20.8	-16.7	15.0	-27.1	20.3	51.5	-257.1	96.5
(H) versus (D)	t-value	0.070	0.556	0.305	0.359	0.106	1.173	0.485	3.054
	Significant?	NO	NO	NO	NO	NO	NO	NO	YES
	% Change	-0.3	-8.7	-2.6	-10.1	1.1	61.5	11.4	32.3

Note: A significance level of 95% was used in the standard student's t-test.
The letters indicate the conditions listed on the previous table.

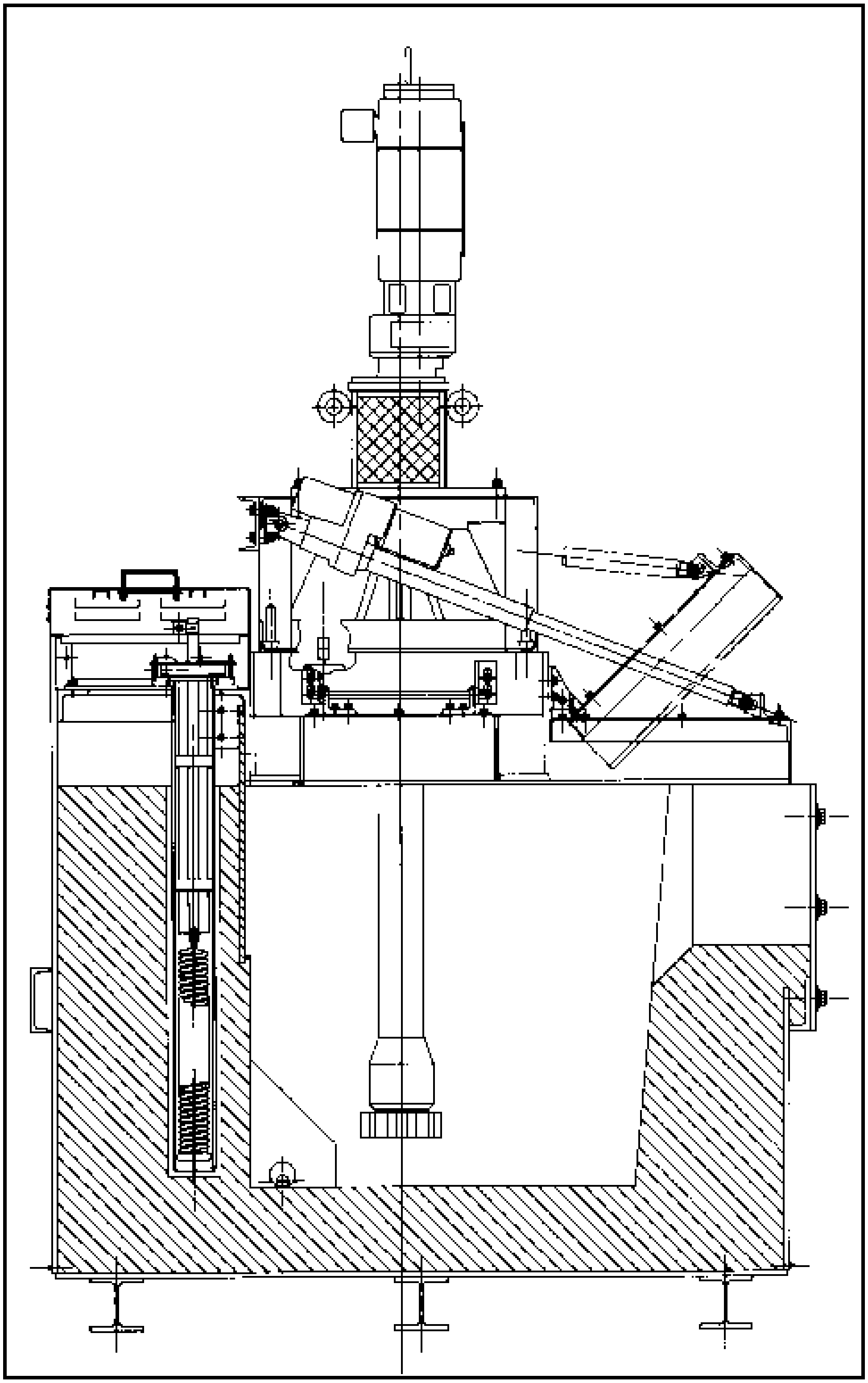

Figure 1: Cross-Section of a SNIF R-140 System

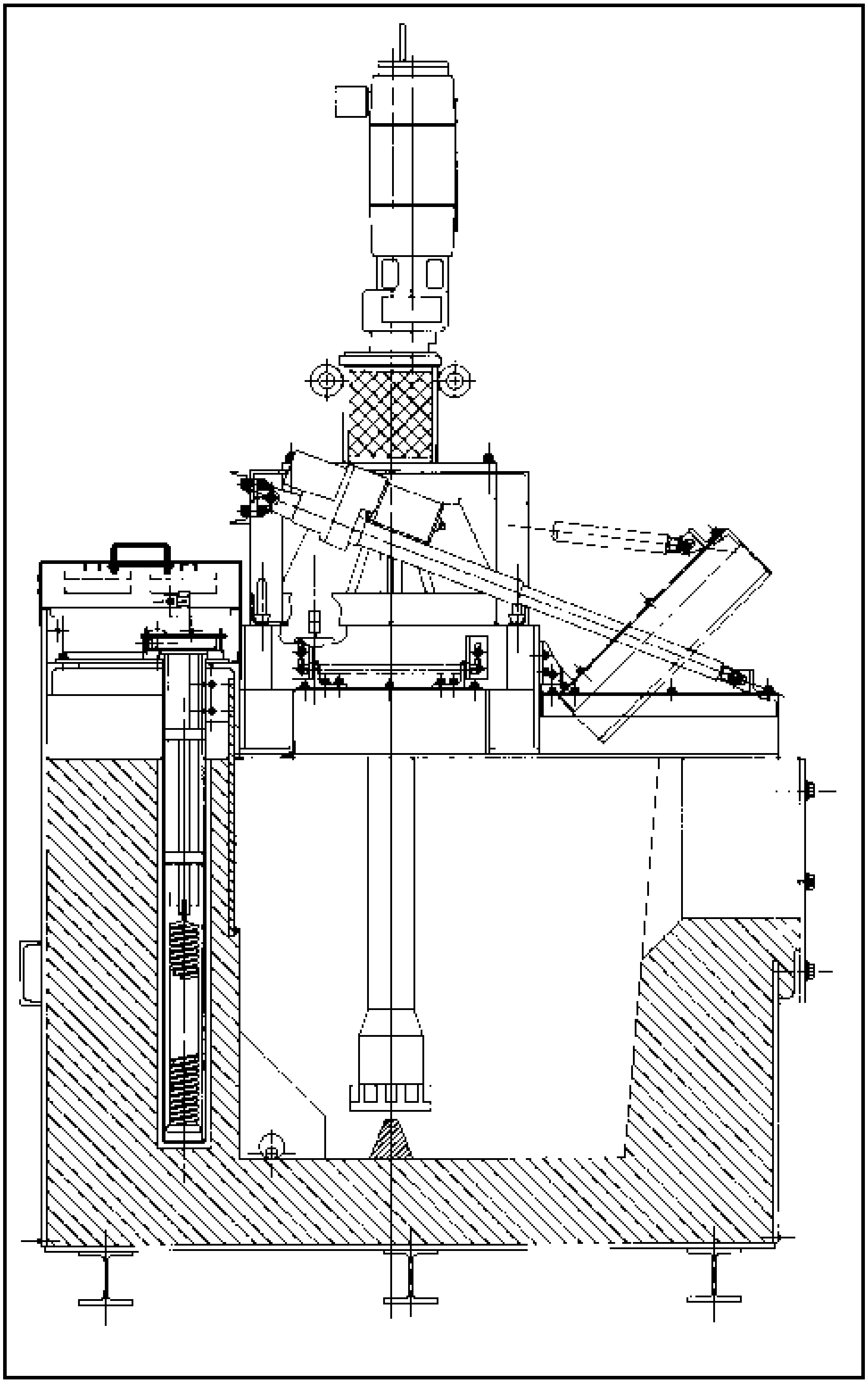

Figure 2: Cross-Section of a SNIF SHEER R-140 System

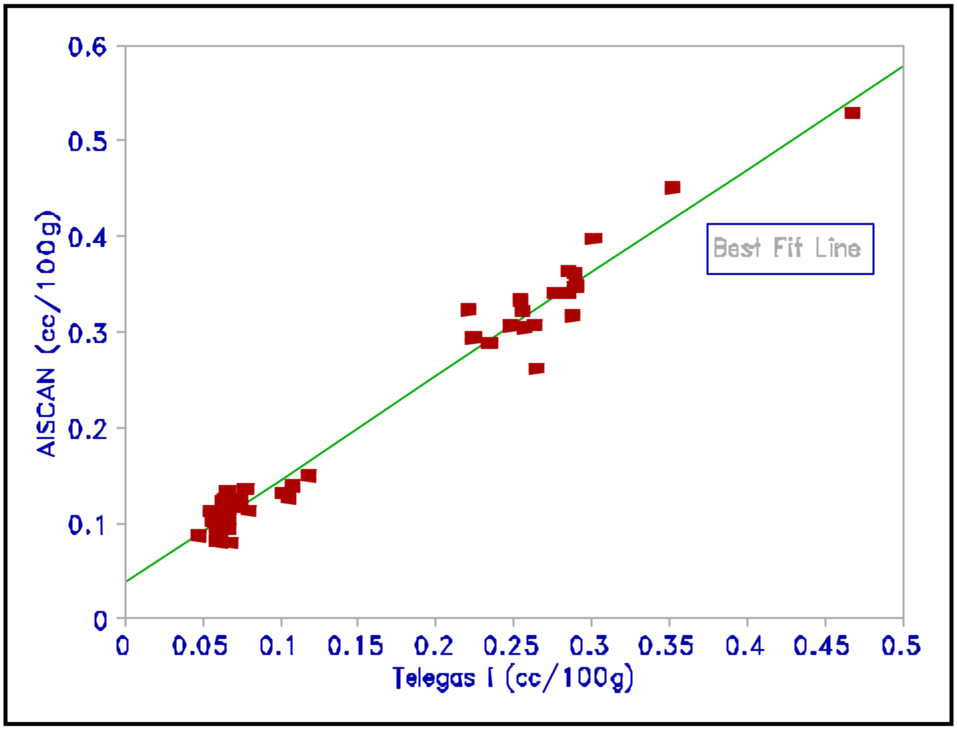

Figure 3: Comparison of AlSCAN and Telegas I Hydrogen Concentrations

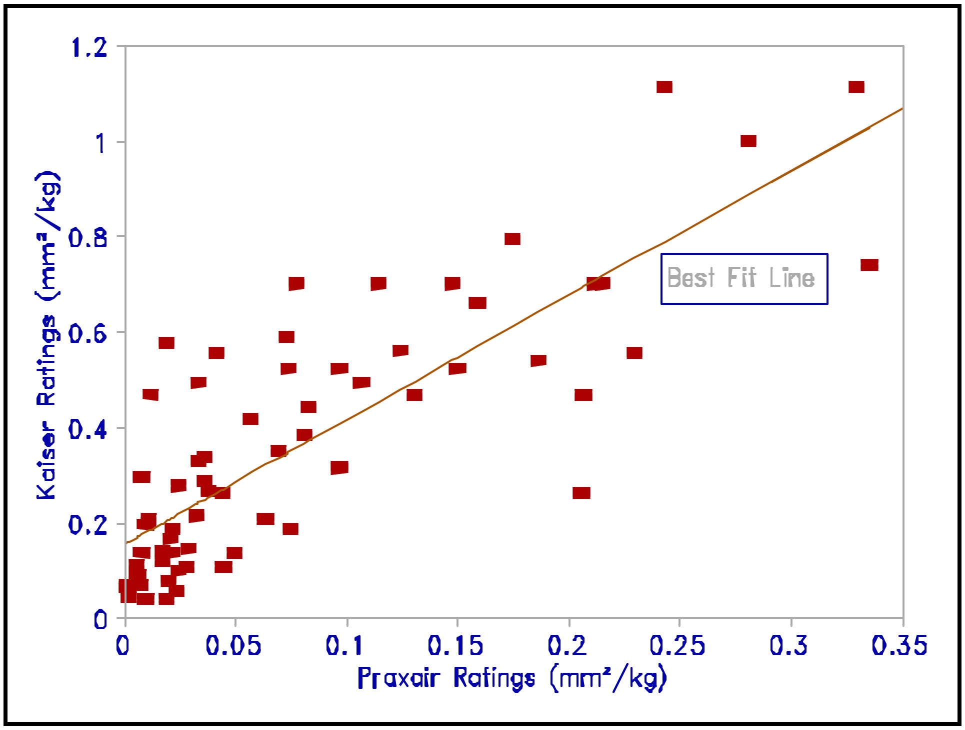

Figure 4: Comparison of Kaiser and Praxair Ratings for All Inclusion Samples

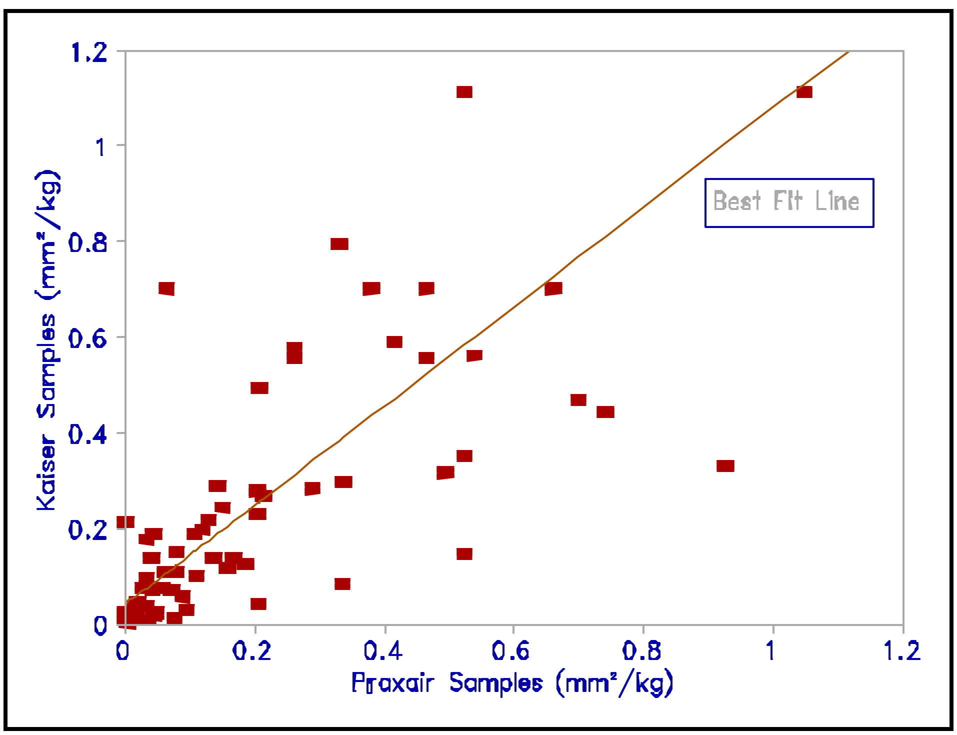

Figure 5: Comparison of Kaiser and Praxair Inclusion Samples for Both Rating Systems

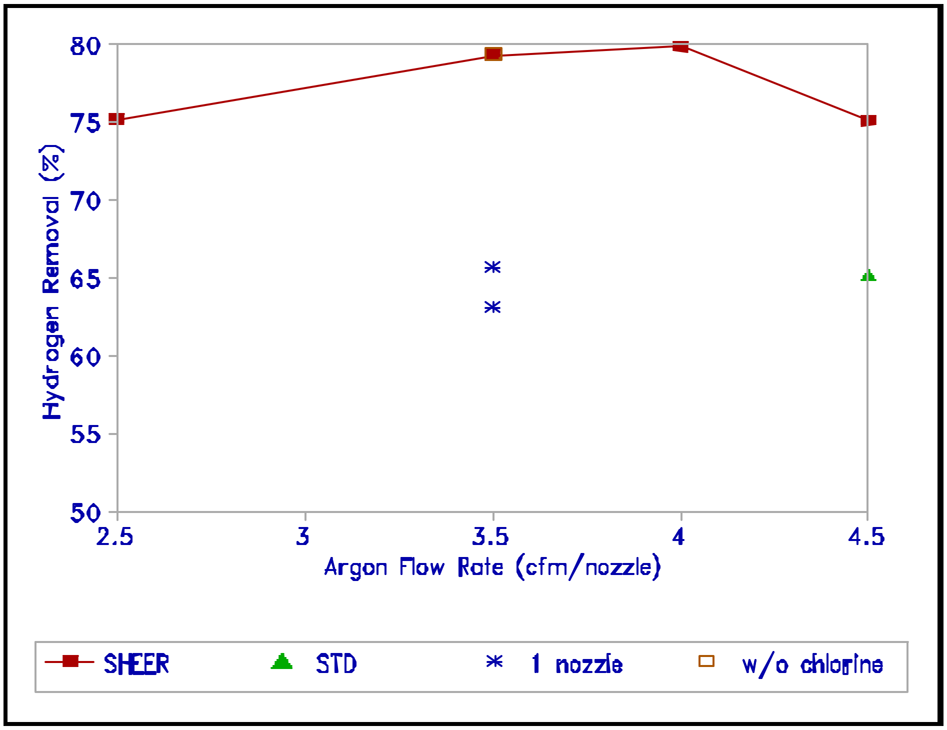

Figure 6: Comparison of Hydrogen Removals at Different Operating Conditions as Measured by Telegas I

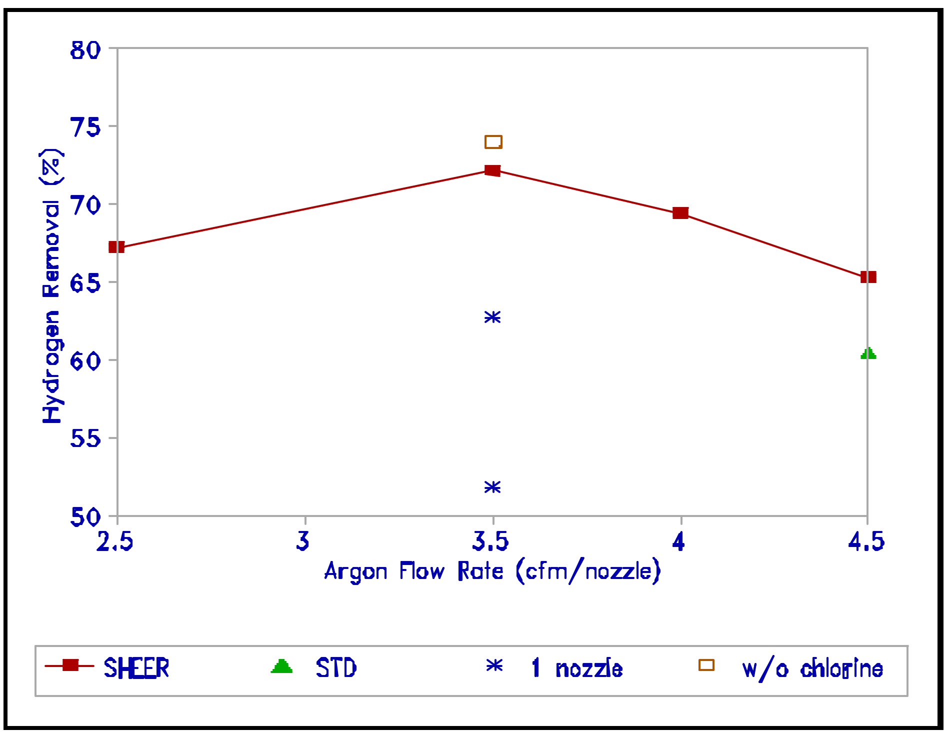

Figure 7: Comparison of Hydrogen Removals at Different Operating Conditions as Measured by AlSCAN

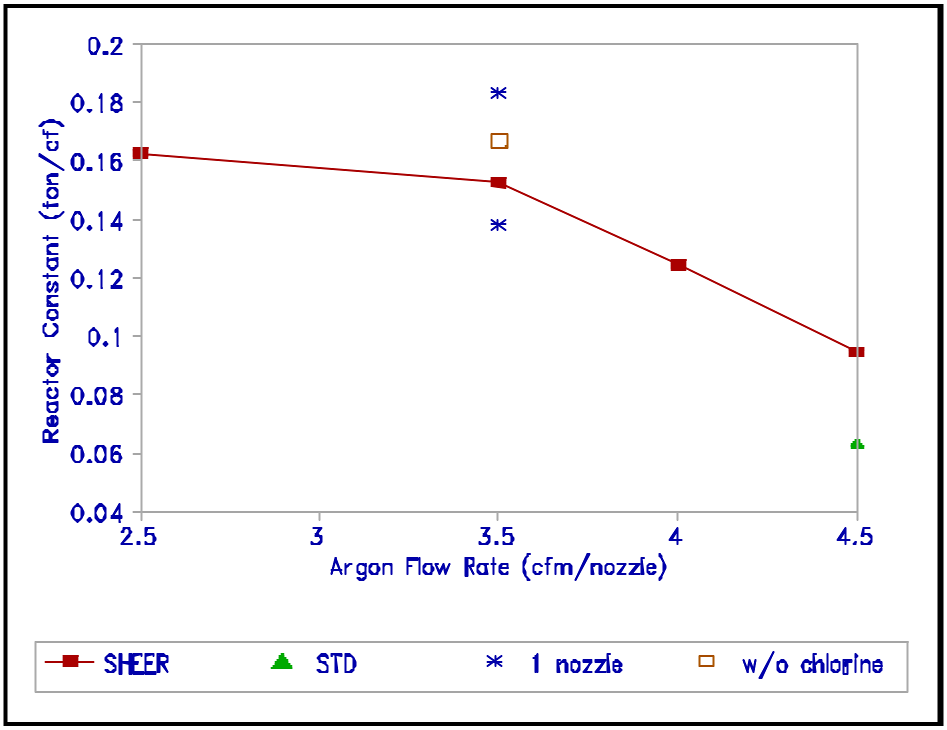

Figure 8: Comparison of Reactor Constants at Different Operating Conditions as Measured by Telegas I

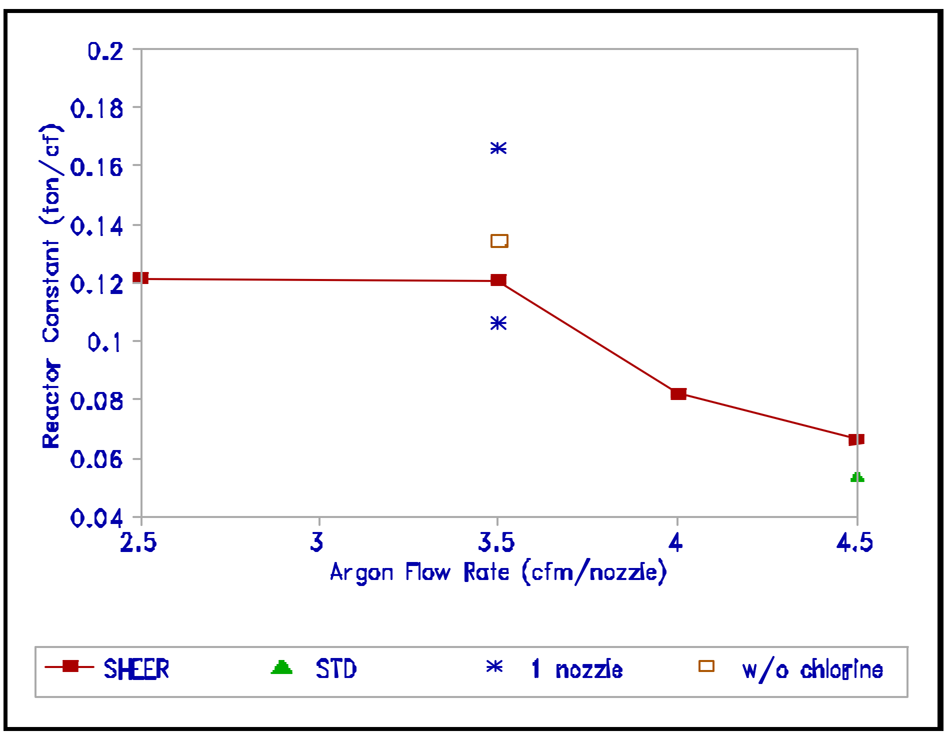

Figure 9: Comparison of Reactor Constants at Different Operating Conditions as Measured by AlSCAN

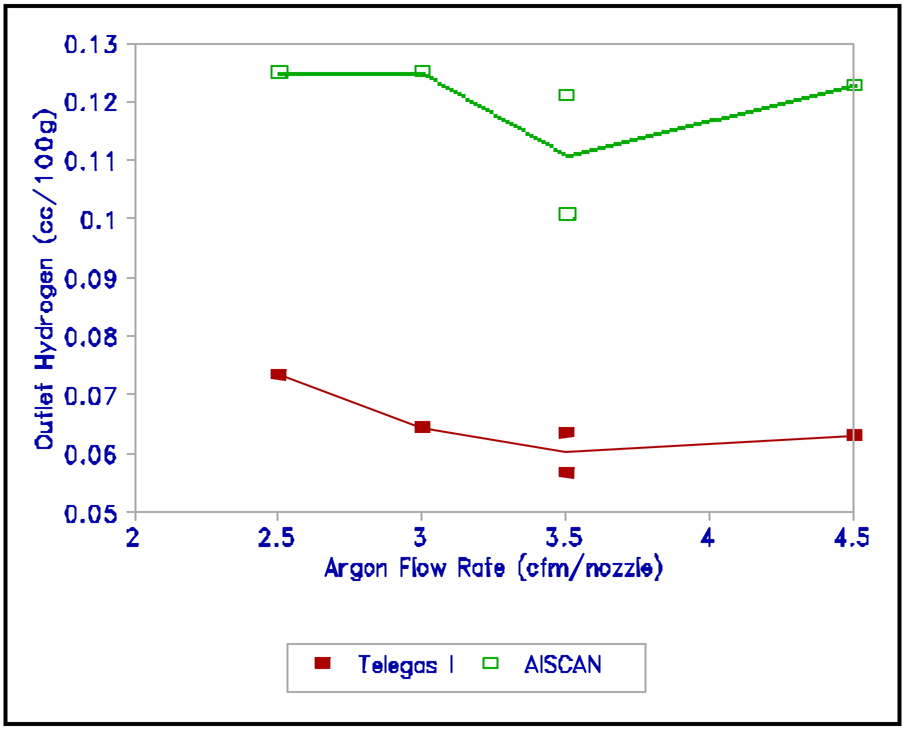

Figure 10: Comparison of Outlet Hydrogen Levels at Various Argon Flow Rates as Measured by Telegas I and AlSCAN - Test 7

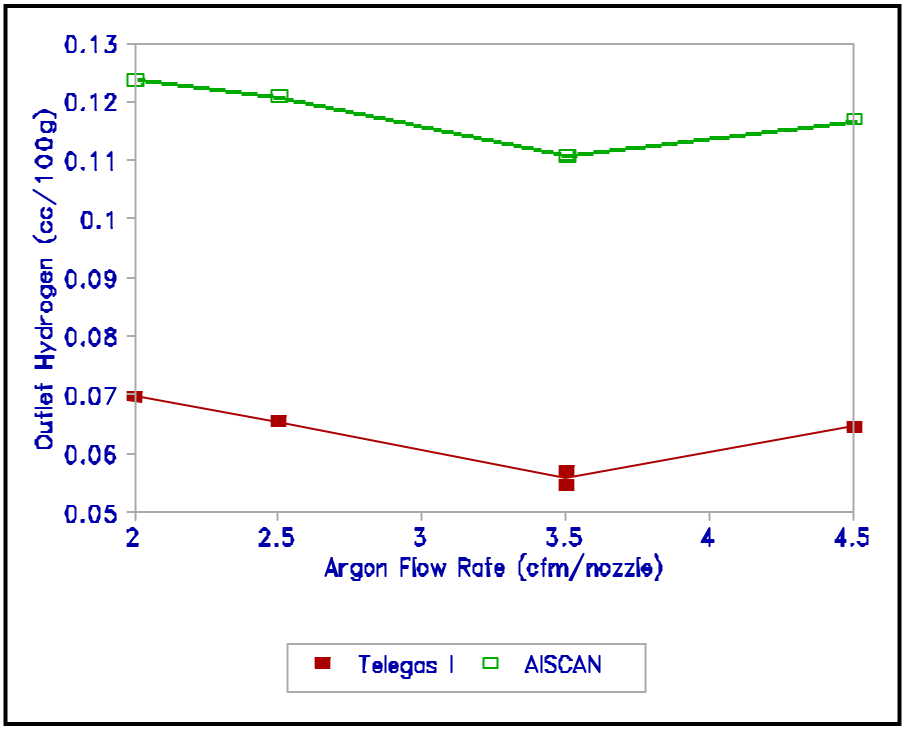

Figure 11: Comparison of Outlet Hydrogen Levels at Various Argon Flow Rates as Measured by Telegas I and AlSCAN - Test 8

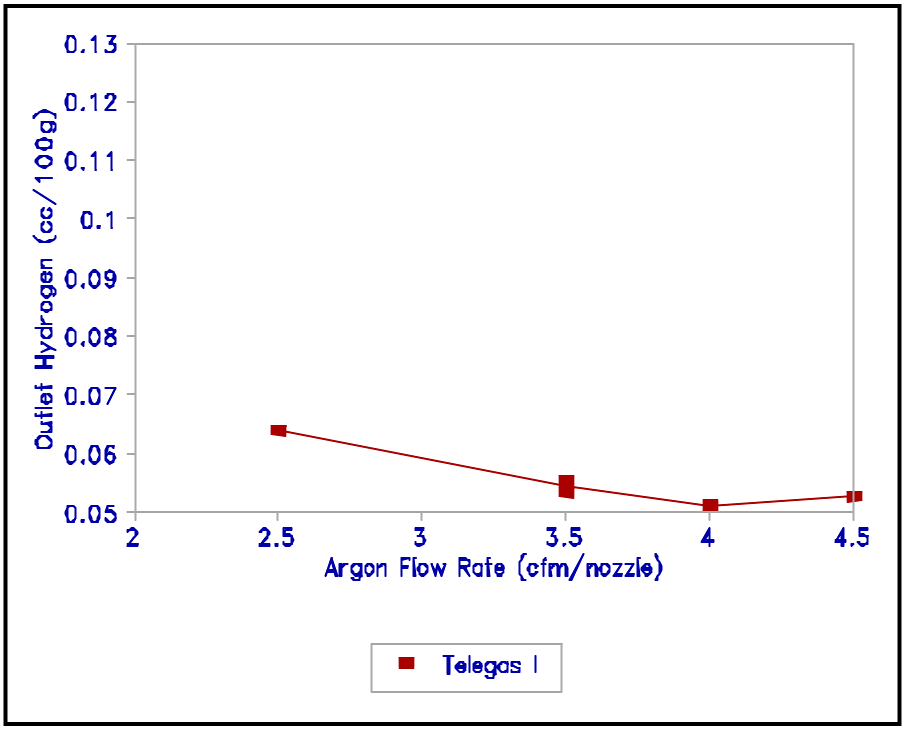

Figure 12: Comparison of Outlet Hydrogen Levels at Various Argon Flow Rates as Measured by Telegas I - Test 9