

Improvements in Cast Shop Processing Using Pyrotek's HD-2000 and PHD-50 Rotary Injector System

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Abstract

The ever-increasing demand for high quality aluminum creates the continuous need for improvements in the melt treatment process. Pyrotek's HD-2000 and PHD-50 are designed to replace conventional furnace treatments, such as steel flux wands, graphite flux tubes, and porous plugs. In addition, the HD-2000 and PHD-50 can also be used for injecting solid fluxes, injecting solid refining agents, and circulating metal in furnaces. This paper examines four companies that ran trials with the HD-2000 or the PHD-50 with different process performance goals. It also discusses their conventional method of operation, how the HD-2000 or PHD-50 was incorporated into their process, and the results.

Introduction

Pyrotek's HD-2000 provides fully automated metal processing for melting and holding furnaces. It is a fixed-position system best suited for repeatable operation in a large furnace. It features an integrated spinning rotor which has the ability to degas, inject solid fluxes, inject solid refining agents, and circulate metal. The HD-2000 is designed to be floor mounted next to the furnace or mounted on the side of the furnace. In the standby position, the mixing shaft and rotor are completely removed from the furnace (Figure 1). For operation, the mixing shaft and rotor pivot into position (Figure 2), and the rotor is completely submerged in the molten aluminum (Figures 3 and 4). This design maximizes the mixing action, provides efficient gas distribution for metal cleaning, and minimizes or eliminates emissions.

Pyrotek's PHD-50 provides portable metal processing for melting and holding furnaces (Figure 5). It is a compact unit more suited for multiple and smaller furnaces. It also features an integrated spinning rotor which has the ability to degas, inject solid fluxes, inject solid refining agents, and circulate metal. The mobile design allows the system to be moved between multiple furnaces and moved in and out of tight spaces. Like the HD-2000, the mixing shaft and rotor are completely removed from the furnace in the standby position. For operation, the mixing shaft and rotor pivot into position, and the rotor is completely submerged in the molten aluminum. As before, this design maximizes the mixing action, provides efficient gas distribution for metal cleaning, and minimizes or eliminates emissions.

Both the HD-2000 and the PHD-50 are considered "in-furnace" batch process degassers. They can use graphite shafts up to 72 in. (1830 mm) long and rotors up to 14 in. (355 mm) in diameter. Shaft length and rotor size are determined by furnace geometry.

This paper will document the benefits of the HD-2000 and PHD-50 compared to conventional furnace treatments from a series of cast shop trials at four different companies. The actual equipment performance tests were conducted during the normal production cycle at each company. Process improvements observed at these trials include better alkali metal removal, reduced chlorine consumption, better metal mixing, reduced emissions, and operational cost reduction.

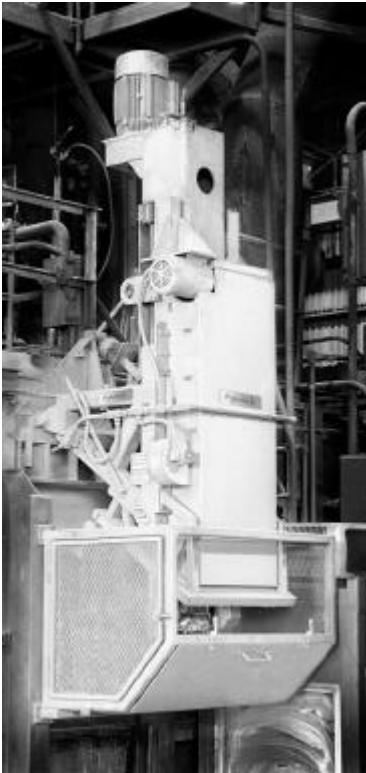


Figure 1: HD-2000 at rest position.



Figure 3: Position of injector assembly in empty furnace.



Figure 4: Injector assembly during treatment cycle.

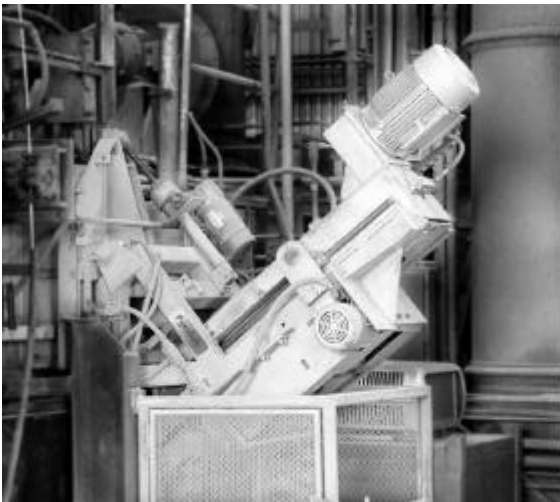


Figure 2: HD-2000 in treatment position.



Figure 5: PHD-50 during treatment cycle.

Fundamentals

To understand the results of the customer trials, it is important to review the current theories and practices on general gas fluxing and methods to improve fluxing.

The HD-2000 and the PHD-50 can be used to remove hydrogen, alkali metals, and inclusions from the liquid metal. Dissolved hydrogen diffuses into the treatment gas bubbles due to its high vapor pressure.¹ Mass transfer (diffusion) of hydrogen out of the molten aluminum and into rising gas bubbles is the rate-determining step at normal hydrogen levels; at very low hydrogen levels the rate becomes equilibrium controlled.^{2,3} Like dissolved hydrogen, the dissolved alkali metals can diffuse into the treatment gas bubble. The use of a reactive gas mixture enhances the elimination of alkali metals by the chemical reaction between the alkali metals and the reactive gas. Reactive gas mixtures also promote better inclusion removal. The treatment gases usually are either an inert gas (e.g., argon or nitrogen) or a mixture of an inert gas and a reactive gas (e.g., argon or nitrogen plus chlorine). Small, well dispersed bubbles increase available gas surface area and increase bubble-dwell time in the melt. Small bubbles in combination with vigorous mixing are necessary for good hydrogen removal,⁴ alkali metal removal, and inclusion removal.

To improve fluxing, gases should be injected in such a way that they invoke good mixing of the melt and produce small, well-dispersed bubbles. Longer residence times of the bubbles in the melt (i.e., a deeper bath, a deeper injection of the gas, and a smaller bubble) will promote the better removal efficiencies. Complete homogenization of the melt should be the goal. The reactive gas used should be minimized to only the amount necessary for reaction with the melt. Finally, there is a practical limit to the amount of hydrogen that can be removed efficiently from the melt, depending upon the alloy, gas flow rate, injection technique, burner firing practice, temperature, and humidity.

Critical to the application and performance of the HD-2000 and PHD-50 is the placement of the unit in the furnace. A number of water models representing various furnace designs and configurations were tested. A detailed analysis of the measured flow rates and resultant mixing motion was made. To promote efficient removal, the HD-2000 or PHD-50 should be located at the mid-section of rectangular furnaces. If this position is unavailable, then the system should be located at the quarter-point section of the furnace and angled at 50 degrees (pointed towards the far corner of the furnace) for best performance. Likewise for circular furnaces, the system should be angled 50 degrees from the radial axis. The shaft and rotor should be positioned at an entry angle of 30-40 degrees. The rotor should be positioned 4-5 in. (100-125 mm) from the furnace bottom. Finally, the rotor should be 12 to 14 in. (305 to 355 mm) in diameter.

Experimental Plan

Of the customer installations and trials conducted to date, four trials were selected for inclusion into this paper, two using the HD-2000 and two using the PHD-50. An additional PHD-50 trial, at the Reynolds Casting Research Center, is documented in another paper being presented at this conference.⁵ The included trials looked at each company's goals, current processes, furnace

configurations, and flux treatments. A set of comparison criteria was established. The current fluxing technique was then compared to the HD-2000 or PHD-50. Prior to the trial, the HD-2000 or the PHD-50 was installed and optimized for the particular furnace. Each test within the trial ran through a complete casting cycle. To ensure meaningful results, at least four repetitions under similar operating conditions were conducted. The metal and process were monitored from the initial charging of the metal to the casting of the treated metal. Hydrogen, inclusion, and alkali metal levels were measured before and after the metal treatment operations. The typical information collected during each test was:

1. Hydrogen, inclusion, and alkali metal levels
2. Charge makeup and composition
3. All metal additions and corrections
4. Complete chemical analysis of alloy
5. General layout of casting line from melter to casting station
6. Melting and holding furnace configuration (geometry)
7. Location of furnace bath thermocouple
8. Furnace temperature before and after treatment
9. Metal flow rate during transfers and casting
10. Amount and depth of metal in melter and holder (amount of heel before and after transfer)
11. HD-2000 or PHD-50 operating procedure, gas flow, rotation speed, and treatment cycle
12. Furnace thermal cycle, high, and low fire status
13. Process idle cycles and delays
14. Alloy, cast, drop, and ingot numbers
15. Trough and ingot head height
16. Furnace condition
17. Skimming practice
18. Amount and nature of dross generated
19. Ambient air temperature and relative humidity

Upon completion of the trial, the data was analyzed and compared to the initial criteria. The results for each company are described below.

Company A Results

The customer is a primary producer of large rolling ingot for the "re-roll" market. The source metal is 90% liquid metal transferred from the pot lines and 10% heavy internal scrap, such as crop ends. The customer produces 3000, 5000, and 6000 series aluminum alloys.

The goals for Company A during the HD-2000 trial, listed in order of priority, were reduce HCl emissions, reduce chlorine use, reduce alkali metal levels, reduce operating costs, improve alloy recovery, and generate less dross.

The typical process sequence for Company A was to fill the furnace, check the chemistry, add alloy, truck stir, preflux, check the chemistry again, skim, final flux, and pour. The complete cycle time was 4 to 8 hours with the preflux and final flux cycles lasting 1 to 4 hours each. The HD-2000 was installed to replace the preflux and final flux cycles, which used graphite flux tubes.

The tested furnace configuration for Company A consisted of a 160,000 lb. (73 MT) rectangular holder that was 16 ft. wide by

32 ft. long by 32 in. deep (5 m by 10 m by 0.8 m). The customer normally processed the furnace with 10 graphite flux tubes (5 tubes per furnace side) which were inserted at a 45 degree angle and submerged 12 in. (305 mm) into the melt. The tested processing parameters are given in Table 1.

Company A uses the preflux step to reduce the alkali metal content in the melt. During the first hour of fluxing, the efficiency of alkali metal removal increased with the HD-2000 when compared to using graphite flux tubes (see Table 2). In addition, Company A was able to reduce their total chlorine usage (scf per preflux cycle) by 98% using the HD-2000. The total chlorine injection rate for the HD-2000 was calculated at 0.04 lb. Cl₂/ton metal. By visual comparison, the HD-2000 appeared to generate less gross dross than graphite flux tubes being used in an adjacent, but similar, furnace. Finally, an improvement in alloy addition recoveries for copper and iron was observed when using the HD-2000 versus fork truck stirring.

Upon completion of the initial testing, Company A reported the following:

“The primary reason for testing the HD-2000 was to determine if the system would allow the company to meet the secondary MACT standard for HCl emissions of 0.40 lb. HCl/ton metal. Preliminary results indicate compliance to the standard, because the pounds of chlorine used is less than the secondary MACT standard for HCl emissions. Therefore, the HCl emissions are expected to be within the standard.”

A sample cost comparison, based on the trial data, is given in Table 3.

Table 1: Processing Parameters for Company A

Holding Furnace	Graphite Flux Tubes	HD-2000
Treatment	Nitrogen with 12% Chlorine	Nitrogen with 3% Chlorine
Nitrogen Flow Rate	1,000 scfh (26.3 Nm ³ /h)	430 scfh (11.3 Nm ³ /h)
Chlorine Flow Rate	140 scfh (3.7 Nm ³ /h)	13 scfh (0.34 Nm ³ /h)
Process Time	60-240 minutes	40-60 minutes
Rotor Speed	NA	350 rpm

Table 2: Typical Sodium and Lithium Removal Results

Holding Furnace	Graphite Flux Tubes	HD-2000
Sodium Level		
Before Treatment	4.0 ppm	7.2 ppm
After 1 hour of Treatment	2.0 ppm	1.9 ppm
Lithium Level		
Before Treatment	1.5 ppm	5.5 ppm
After 1 hour of Treatment	0.5 ppm	1.7 ppm

Table 3: Annual Operating Cost Comparison for Company A's 160,000 lb. Holder

Gas and Consumables Costs	Graphite Flux Tubes		HD-2000		
	Treatment Conditions		Treatment Conditions		
Nitrogen (\$/100scf)	0.55	Number of Tubes	10	Number of Units	1
Chlorine (\$/100scf)	3.60	Treatment Time (minutes)	240	Treatment Time (minutes)	60
Graphite Flux Tube (\$)	60	Total Gas Flow Rates		Total Gas Flow Rates	
Shaft and Rotor (\$)	1,500	Nitrogen (scfh)	1000	Nitrogen (scfh)	430
		Chlorine (scfh)	140	Chlorine (scfh)	13
Treatment Frequency/Life		Annual Costs		Annual Costs	
Treatments per day	2	Nitrogen (\$)	15,400	Nitrogen (\$)	1,656
Operating Days per year	350	Chlorine (\$)	14,112	Chlorine (\$)	328
Graphite Flux Tube Life (days)	3	Graphite Flux Tubes (\$)	70,000	Shafts and Rotors (\$)	17,500
Shaft and Rotor Life (days)	30	Total Annual Costs	\$99,512	Total Annual Costs	\$19,484
Environmental Impact				Annual Saving Summary	
Chlorine Usage w/Tubes (tons)	35.9			Gases (\$)	27,528
Chlorine Usage w/HD-2000 (tons)	0.8			Consumables (\$)	52,500
Chlorine Reduction (tons)	35.1			Total Annual Savings	\$80,028

Company B Results

The customer is a primary producer of billet for the external extrusion market. The primary source of metal is 90% hot metal transferred from the pot lines with 10% heavy metal scrap, such as sawn heads and butts. The customer produces 5000 and 6000 series aluminum alloys.

The goals for Company B during the HD-2000 trial, listed in order of priority, were reduce stack emissions, reduce chlorine use, reduce operating costs, improve hydrogen removal, and generate less dross.

The typical process sequence for Company B was to fill the furnace, check the chemistry, add alloy, truck stir, flux, skim, check the chemistry, settle, and pour. The complete cycle time was 2-3 hours, with the flux cycle lasting 1 hour and the settling period lasting 30 minutes. The HD-2000 replaced the flux cycle, which used graphite flux tubes.

The tested furnace configuration for Company B consisted of a 110,000 lb. (50 MT) circular holder that was 20 ft. diameter by 32 in. deep hearth (6.1 m diameter by 0.8 m deep). The customer normally processed the furnace with 10 graphite flux tubes inserted through the roof of the furnace. The tested processing parameters are given in Table 4.

The primary reason that this company purchased an HD-2000 was for the elimination of stack emissions as measured by the company’s state-trained “Opacity Monitors”. When processing with the HD-2000, no opacity was detected. Total chlorine usage (scf per flux cycle) was reduced 97% using the HD-2000. The total chlorine injection rate for the HD-2000 was calculated at 0.02 lb. Cl₂/ton metal. Hydrogen removal improved when using the HD-2000 (see Figure 6). Preliminary visual dross measurements indicated that the HD-2000 generates 1/6 of the amount as current practices. A “mass balance” gross weight test is planned which will compare the graphite flux tubes to the HD-2000. A sample cost comparison, based on the initial trial data, is given in Table 5. The cost savings is skewed by the use of argon in the HD-2000. If nitrogen had been used, there would be an additional \$12,950 of gas savings per year. Company B plans

to conduct further operational cost savings studies and molten metal cleanliness testing in the near future.

Table 4: Processing Parameters for Company B

Holding Furnace	Graphite Flux Tubes	HD-2000
Treatment	Nitrogen with 9% Chlorine	Argon with 1% Chlorine
Nitrogen/Argon Flow Rate	1,450 scfh (38.1 Nm ³ /h)	600 scfh (15.8 Nm ³ /h)
Chlorine Flow Rate	145 scfh (3.8 Nm ³ /h)	6.0 scfh (0.16 Nm ³ /h)
Process Time	60 minutes	40 minutes
Rotor Speed	NA	370 rpm

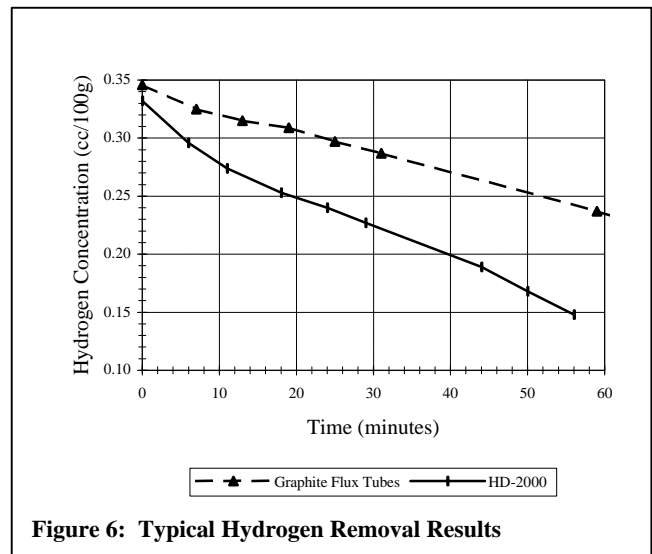


Figure 6: Typical Hydrogen Removal Results

Table 5: Annual Operating Cost Comparison for Company B’s 110,000 lb. Holder

Gas and Consumables Costs	Graphite Flux Tubes		HD-2000		
	Treatment Conditions		Treatment Conditions		
Nitrogen (\$/100scf)	0.55	Number of Tubes	10	1	
Argon (\$/100scf)	2.40	Treatment Time (minutes)	60	40	
Chlorine (\$/100scf)	3.60	Total Gas Flow Rates			
Flux Tube (\$)	88	Nitrogen (scfh)	1450	Argon (scfh) 600	
Shaft and Rotor (\$)	1,500	Chlorine (scfh)	145	Chlorine (scfh) 6	
Treatment Frequency/Life		Annual Costs		Annual Costs	
Treatments per day	5	Nitrogen (\$)	13,956	Argon (\$)	16,800
Operating Days per year	350	Chlorine (\$)	9,135	Chlorine (\$)	252
Graphite Flux Tube Life (days)	10	Graphite Flux Tubes (\$)	30,800	Shafts and Rotors (\$)	17,500
Shaft and Rotor Life (days)	30	Total Annual Costs	\$53,891	Total Annual Costs	\$34,552
Environmental Impact		Annual Saving Summary			
Chlorine Usage w/Tubes (tons)	23.2	Gases (\$)	6,039		
Chlorine Usage w/HD-2000 (tons)	0.6	Consumables (\$)	13,300		
Chlorine Reduction (tons)	22.6	Total Annual Savings	\$19,339		

Company C Results

The customer is a producer of rolling ingot for internal sheet and plate product. The primary source of metal is 30% hot metal transferred, 30% internal mill scrap, 30% purchased scrap, and 10% prime sow. All aluminum alloys are produced except the 4000 series.

The goals for Company C during the PHD-50 trial, listed in order of priority, were reduce chlorine use, reduce operating costs, improve inclusion removal, and generate less dross.

The typical process sequence for Company C (a melter/holder combination) was to melt, check the chemistry, add alloy, stir, check the chemistry, transfer to the holder, flux, skim, check the chemistry, and pour. This trial was conducted using the PHD-50 on both the melter and holder. The PHD-50 replaced the “stir” cycle in the melter, injecting a solid refining agent while mixing the melt. In the holder, the PHD-50 replaced the flux cycle which used steel flux wands.

The tested furnace configurations for Company C consisted of a 120,000 lb. (54 MT) round melter that was 20 ft. diameter (6.1 m diameter) and a 100,000 lb. (45 MT) rectangular holder that was 10 ft. by 32 ft. by 24 in. deep (3 m by 10 m by 0.6 m deep). The customer normally did not process the melter, but it did add a 10 lb. bag of solid refining agent to the charge materials. The holder was processed using three steel flux wands inserted at a 45 degree angle through the wall. The tested processing parameters are given in Table 6.

Company C measured a performance and yield improvement by injecting the solid refining agent into the melter with the PHD-50 versus a mechanical addition and stir. The amount of reactant was reduced from 10 to 5 lb. per melter charge. In the holding furnace, total chlorine usage was reduced 50% using the PHD-50 while maintaining the same sodium and lithium reduction. The total chlorine injection rate for the PHD-50 was calculated at 0.21 lb. Cl₂/ton metal. Initial results suggest a 15% improvement in N₂O inclusion removal (20-300 μm particles), as measured by LiMCA, when using the PHD-50 instead of steel flux wands. However, additional testing is needed to validate the inclusion results.

Table 6a: Processing Parameters for Company C – Melting Furnace

Melting Furnace	Mechanical Addition & Stir	PHD-50
Treatment	10 lb. bag of solid refining agent added with charge	Nitrogen with a 5 lb. bag of solid refining agent injected during the first 3 minutes
Nitrogen Flow Rate	NA	300 scfh (7.9 Nm ³ /h)
Chlorine Flow Rate	NA	0 scfh (0 Nm ³ /h)
Process Time	NA	15 minutes
Rotor Speed	NA	350 rpm

Table 6b: Processing Parameters for Company C – Holding Furnace

Holding Furnace	Steel Flux Wands	PHD-50
Treatment	Nitrogen with 42% Chlorine	Nitrogen with 26% Chlorine
Nitrogen Flow Rate	420 scfh (11.0 Nm ³ /h)	420 scfh (11.0 Nm ³ /h)
Chlorine Flow Rate	300 scfh (7.9 Nm ³ /h)	150 scfh (3.9 Nm ³ /h)
Process Time	20 minutes	20 minutes
Rotor Speed	NA	350 rpm

Company D Results

The customer is a producer of billet products. The primary source of metal is 40% internal mill scrap, 20% purchased scrap, and 40% prime sow and alloys. 2000, 5000, 6000, and 7000 aluminum alloys are produced.

The goals for Company D during the PHD-50 trial were to eliminate the use of chlorine in the holding furnace by using solid flux injection and to reduce hydrogen in the molten aluminum. The chlorine was used primarily to produce a “dry” dross. In both cases, nitrogen was used as the process/carrier gas.

The typical process sequence for Company D was to fill furnace, flux, skim, check the chemistry, and pour. The PHD-50 replaced steel flux wands during the flux cycle.

The furnaces used during the PHD-50 trial at Company D were 70,000 lb. rectangular holders that were 11 ft. by 21 ft. by 36 in. deep (3.4 m by 6.4 m by 0.9 m deep). The customer's standard practice was to inject a nitrogen/chlorine gas mixture through two steel flux wands. During the PHD-50 tests, a solid flux, with nitrogen as the carrier gas, was injected instead of a nitrogen/chlorine gas mixture. The PHD-50 was positioned at the mid-point of the long side of the furnace with the nozzle about 8 in. below the metal surface, angled down at approximately 30 degrees. The tested processing parameters are given in Table 7.

Company D used visual analysis to record quality of dross and an AISCAN unit to measure hydrogen levels. Six tests were run with the PHD-50. In all six tests, the dross was visually inspected and judged to be equal or better in quality, with respect to metal content (“dryness”), than dross generated during standard operating processes. Hydrogen readings were taken on the metal exiting the holder prior to the PHD-50 testing and on five of the six PHD-50 tests. With standard fluxing, the hydrogen levels ranged from 0.35 to 0.45 cc/100g with an average of 0.40 cc/100g. With the PHD-50, they ranged from 0.18 to 0.35 cc/100g with an average of 0.25 cc/100g. From this data, it appears that the PHD-50 obtained 38% lower hydrogen levels than standard fluxing.

Table 7: Processing Parameters for Company D

Melting Furnace	Steel Flux Wand	PHD-50
Treatment	Nitrogen with 19% Chlorine	Nitrogen with 15-28 lb. of solid flux injected during the first 3-4 minutes
Nitrogen Flow Rate	210 scfh (5.5 Nm ³ /h)	260-380 scfh (6.8-10.0 Nm ³ /h)
Chlorine Flow Rate	50 scfh (1.3 Nm ³ /h)	NA
Process Time	15-20 minutes	6-14 minutes
Rotor Speed	NA	260-500 rpm

Conclusion

The HD-2000 and PHD-50 furnace treatment systems offer improved performance when compared to conventional furnace treatments such as steel flux wands, graphite flux tubes, and porous plugs. The design characteristics of good mixing and fine gas bubble distribution enhance the removal efficiency of absorbed hydrogen, alkali metals, and inclusions found in molten aluminum melts. Additionally, the reduction in the amount of chlorine used to meet the desired results greatly reduces the impact of emission on the environment. In the four trials, the furnaces met the emission requirements of the secondary MACT standards by injecting chlorine at a lower rate than the allowable emissions. Reduction in melt loss was observed, but it was not quantified. The HD-2000 and PHD-50 can also inject solid fluxes and solid refining agents, as well as reactive gases, so that they will operate within the range of present and future environmental emission standards. Operating cost savings can be achieved by using the HD-2000 and PHD-50 in place of conventional furnace fluxing methods.

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