Impact of Split-Zone Technology on Oxidation Cycle Time and Cost of Carbon Fiber Production

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Introduction

The oxidation process in a carbon fiber line consumes the most energy, holds the largest factory footprint and is the greatest capital investment in the carbon fiber line. Improvements in the oxidation process can result in substantial savings for the carbon fiber production process.

The Despatch Split-Zone Oxidation Oven brings critical innovation to the oxidation process by creating two distinct temperature set points within a single zone. By tightly controlling temperature distribution, up to a 10 degree difference between upper and lower passes is possible. The result is faster oxidation (a proven 35% reduction in cycle time) in a fewer number of zones (from five to two), all of which provides significant reductions in the cost per pound of carbon fiber.

Typical Oxidation Process and Results

The oxidation process involves running precursor through a series of step changes in temperature. Each step is performed by a separate zone of the oxidation oven set (typically from four to eight separate zones). Each oven zone requires a large factory footprint and considerable cost (both initial investment and continuing operating costs). The oxidation process is the most expensive and longest step within the carbon fiber process flow.

Improvements in the oxidation process can produce substantial savings in carbon fiber production—as long as those improvements occur without sacrificing fiber oxidation quality and safety. The new Despatch Split-Zone Oxidation Oven uses innovative design to provide dramatic improvements in oxidation time and cost.

The Split-Zone Oxidation Process

The Despatch Split-Zone Oxidation Oven uses center-to-ends technology to produce uniform flow that contributes to increased carbon fiber production (Figure 1). A new supply nozzle design provides a more uniform flow and temperature distribution within the oven body (compared with current designs).

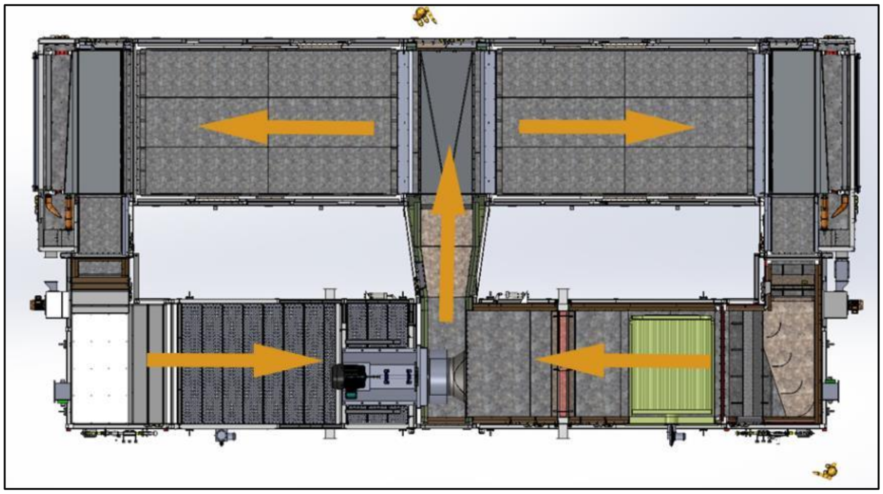

Figure 1. Center-to-Ends technology promotes uniform air flow

The Split-Zone Oxidation Oven is designed with two distinct temperature set points in a single oven zone. The bottom half of the zone runs at one temperature and the top half of the zone runs at a higher temperature (Figure 2). The unique parallel air flow pattern of the Split-Zone Oxidation Oven contributes to maintaining the temperature differential for the entire heated length of the oven.

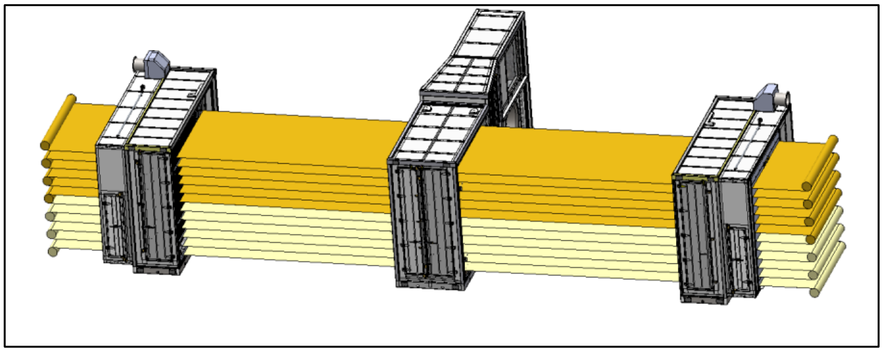

Figure 2. Two separate temperature set points within zone

Differential temperatures of up to 10°C are possible (Figure 3). The combination of airflow and temperature control within the Split-Zone Oxidation Oven allows uniform oxidized density and potential reductions in cycle time.

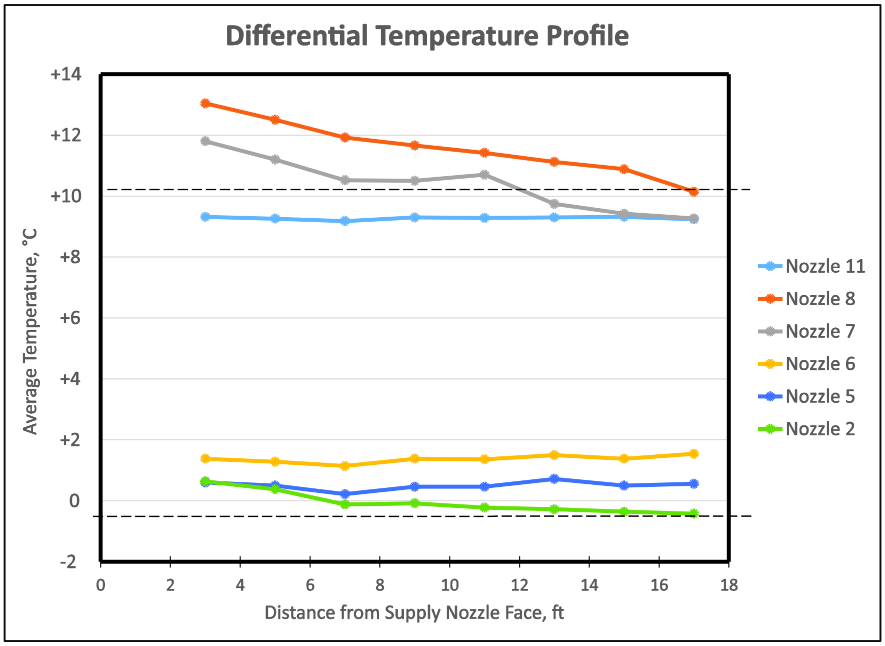

Figure 3. Temperature profile across heated length of the tow

Testing the Split-Zone Oxidation Oven Process

Several customer-driven tests were conducted on a single 3m wide Split-Zone Oxidation Oven zone. The tests covered two different implementation strategies for the Split-Zone technology, a conservative strategy to utilize the temperature differential within an existing line layout framework and an innovative strategy to maximize the potential of the Split-Zone technology.

The test zone was installed in-line with a creel, entrance and exit roll stands, and winder to facilitate the oxidation of precursor. Up to 24 tows were run through the zone at one time. The creel, roll stands, and winder could be moved to allow the precursor to run across the full 3m width. Two fiberglass cloths were strung through the zone in the span with no precursor to simulate a full oven for airflow and temperature stability. The tests ran a premium grade precursor through the zone and varied temperatures and dwell times using the Split-Zone methodology to reach target densities.

Under the conservative implementation strategy, tests were performed to evaluate how much faster the fiber could be run through the oxidation ovens for a roughly equivalent heated length, keeping an even number of zones. A design of experiments approach was utilized to determine optimum temperatures and speeds. An increase in baseline oxidation was found with the Split-Zone oxidation oven due to fewer passes requiring less reheat of the fiber. The result of the analysis on Split-Zone performance showed an increase of 20% over new baseline could be achieved. Taking into account both effects, an increase in throughput of 29% is obtained utilizing the new Split-Zone Oxidation Oven. The results of the test are summarized below (Table 1).

Table 1. Customer Precursor Testing: Single Pass, 50K Tow

Oxidation Time Improvement (Equivalent Target Density)				
Condition	**# of Zones**	**Heated Length**	**Line Speed**	**Improvement (%)**
Baseline	8 (2.1m)	1219.2 m	10 m/min	---
Split-Zone Baseline	6 (3m)	945 m	8.4 m/min	7.7
Split-Zone Optimized	6 (3m)	945 m	10 m/min	19.8

Different evaluation tests were run to try and maximize the Split-Zone technology to minimize overall oven zones were also performed. The first of these tests evaluated the impact of the temperature differential within the first oven zone only. Precursor was run once through the zone at a specific line speed and single temperature set point to provide the dwell time necessary to produce the target baseline density. Once the target density was verified, temperature differentials were introduced between the upper and lower set points within the zone and line speed adjusted to provide the same target density as the baseline, single temperature case. Two separate Split-Zone differential cases were tested with the results summarized below (Table).

Table 2. Customer Precursor Testing: Single Pass, 24K Tow

Oxidation Time Improvement (Equivalent Target Density)		
Condition	**Dwell Time (min)**	**Improvement (%)**
Single Temperature	23	---
Split-Zone Differential 1	20.6	10.43
Split-Zone Differential 2	17.4	24.35

The second test used the Split-Zone Oxidation Oven methodology proven during Test 1 to run precursor multiple times through the single zone to bring the fiber to a target density commensurate with a fully-oxidized state. Fiber was collected at the winder, transferred back to the creel and re-run through the oven. This process was repeated as needed to simulate the number of zones targeted in the experiment. Several combinations of temperature differentials and line speeds were tested and compared to the production process baseline below (Table).

Table 3. Customer Precursor Testing: Multiple pass, 24K Tow

Oxidation Time Improvement (Equivalent Target Density)		
# of Zones	**Dwell Time (min)**	**Improvement (%)**
5 (Baseline)	67.3	---
3 (Simulated)	52.8	21.55
2 (Simulated)	51.0	24.22
2 (Simulated)	44.0	34.62

Results from Split-Zone Oxidation

The Split-Zone Oxidation Oven provided significant improvements in oxidation time compared to traditional single temperature zones for different sizes and types of precursor: from 29% to 35% for fully oxidized fiber depending on implementation strategy. Preliminary tests indicate more improvement could possible (up to a 50% improvement), but complete oxidation testing was not completed at this time.

The improvements to oxidation time made possible by the Split-Zone Oxidation Oven can be used to significantly reduce the cost of fabricating carbon fiber. Line speeds can be increased to increase the output of the line, reducing the per pound cost. In addition, the Split-Zone methodology allows stepping through the precursor oxidation temperature steps in fewer individual zones. The resulting smaller number of zones allows for a significant reduction in capital outlays and on-going operating costs for carbon fiber lines. These tests demonstrate a reduction in required zones from the current five to two is possible while still providing fully oxidized fiber.

The cost impact of this reduction in oxidation time is considerable:

- Increased output production from carbon fiber line
- Reduced initial capital cost of the oxidation ovens (fewer ovens to purchase)
- Reduced ongoing operating costs of the oxidation process within the line from fewer zones
- Reduced footprint required on the factory floor allowing for smaller facility

These savings result in a significant decrease in the cost per pound of finished carbon fiber.