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DEVELOPMENTS IN INERTING SYSTEMS FOR ELECTRON BEAM PROCESSORS

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Summary

Most electron beam curing applications require an inerting gas atmosphere in the curing region (i.e., reaction chamber). Both the effectiveness and efficiency of the inerting system are important, since effective inerting is a prerequisite to achieving the required product characteristics and efficient inerting minimizes the running costs of an e-beam curing production line. Recent developments regarding electron beam inerting systems are described that are directed towards both objectives. Special emphasis is placed on high speed flexible web applications where production speeds on the order of 400-500 meters per minute are becoming state-of-the-art.

1. Introduction

Many radiation curable coatings must be irradiated in an oxygen-free environment in order to avoid inhibition of the chemical reactions which produce the "cure". The common industrial method for excluding atmospheric oxygen is to replace the atmospheric air with nitrogen in the irradiation zone. This seemingly straightforward method becomes increasingly difficult to implement as production line speeds increase, new high performance coatings requiring higher degrees of oxygen exclusion are introduced and line widths increase.

There are two distinctly different problems. The first is technical: the oxygen concentration must be reduced below levels which inhibit curing. The second is economic: the cost expended for the nitrogen must not materially impact the profitability of the final product. Development of practical high performance inerting systems must therefore be concerned with both effectiveness and efficiency.

Our recent efforts are aimed at achieving effectiveness and efficiency for line speeds up to 500 m/min and web widths as wide as 3000 mm with coatings requiring inerting to levels below 50 ppm (parts per million) of oxygen. Until a few years ago, most lines operated below 300 m/min and did not require inerting better thin 100-200 ppm; this represented a performance range in which satisfactory inerting could be achieved with a consumption of nitrogen in the range of 6 - 10 standard cubic meters per 1000 square meters of processed web (.006 - .010 scm/m').

The current push to higher performances comes from applications as diverse as, for example, web offset printing and siliconizing of paper or film webs for controlled release products. Both of these applications are moving toward higher line speeds and the siliconizing application in particular requires inerting to 50 ppm or less. To be assured that our new BroadBeam® processors will meet the higher requirements for inerting performance and to improve the efficiency of current BroadBeam® systems, we have been developing and testing new and/or improved inerting components and systems. In addition, RPC has cooperative programs with production line equipment manufacturers and chemical suppliers that involve even more advanced inerting systems.

2. Nitrogen Manifold Developments

A high speed web carries with it a boundary layer of air which must be removed from the web and replaced with nitrogen. Devices normally described as linear manifolds, linear nozzles or nitrogen knives can be used to direct a continuous (across the web) high velocity flow of nitrogen onto the web to strip off the boundary layer. High velocity flow is created by using high pressure to force the nitrogen through the narrow linear gap or nozzle of the manifold. The mechanical design of the manifold must include a method for accurately maintaining the dimension of the gap for the full length of the manifold and also provide for the overall strength and rigidity of the manifold so that the flow impinging on the web will be uniform. Earlier systems used a series of drilled holes in a tube to overcome the mechanical problem of maintaining a uniform gap across the full width of the web. Unfortunately, it is not possible with such a system to achieve the high nitrogen velocities necessary to strip the boundary layer from the web at the line speeds required for economical production in today's highly cost competitive manufacturing environment.

in practical applications the space between the exit nozzle of the manifold and the moving web may be as small as 1.6 mm and the manifold gap smaller than 0.1 mm. The manifold shown in Figure 1 incorporates a proprietary method for maintaining a uniform gap as small as 0.025 mm. This method employs fixed shims in a configuration which does not significantly impede the flow uniformity across the length of the nozzle. Manifolds of this design are being used in production applications with webs more than 2000 mm wide.

The manifold shown in Figure 1 has a 750 mm x 0.11 mm gap and is presently installed in the pilot line at our Hayward, California plant.

The flow velocity measured along the length of the manifolds is typically uniform to ± 15% of the average velocity.

RPC's partners in a high performance 1250 mm e-beam pilot line, Pagendarm GmbH and Th. Goldschmidt AG (see Section 3 below) have made significant contributions to the evolving design of the linear manifold system. A useful modification was recently made to the manifolds installed in the pilot fine. The fixed shims were replaced with a spring loaded system which allows the gap dimension to be adjusted without opening the manifold and changing shims. This improvement also enabled enlargement of the plenum within the manifold to decrease the pressure drop across the length of the manifold, a factor which becomes increasingly important as the manifold length is increased.

3. Inerting Performance at High Web Speeds

The performance of an inerting system is difficult to quantify because there is not a convenient direct method for measuring the oxygen concentration at the surface of the web. Oxygen analyzers are useful in obtaining a reading of the average oxygen concentration at locations inside the reaction chamber (Le. curing region) but the reading thus obtained cannot be relied upon to indicate conditions within the boundary layer, nor can it be used quantitatively to compare the inerting effectiveness of one machine to another. in practical situations the system is considered effective if the coating is property cured by the incident electron beam at the expected dose level.

In most cases the final product performance characteristics are the ultimate determinant of inerting effectiveness. Some coatings are less reactive to oxygen than others and an inerting system which is effective for a particular coating may be ineffective in another case. Contrasting the inerting requirements for silicone release coatings to those for web offset inks provides a good illustration of this point. Many of the inks will cure with an indicated oxygen concentration of 150-200 ppm, but the silicone coatings require indicated levels of less than 50 ppm.

The measure of success which we've been using in our inerting development program is the ability to cure silicone release coatings, which we roughly equate to achieving an indicated oxygen concentration of less than 50 ppm. However, the real test is whether the coating is cured.

We have made a series of tests at the European Demonstration Facility (EDF) which is a cooperative undertaking between RPC Industries, Pagendarm GmbH, and Th. Goldschmidt AG (Figure 2). The EDF is capable of coating and curing silicone release coatings on 1250 mm wide webs at line speeds up to 450 m/min. The maximum dose rate is 1000 megarad-meters per minute. The web is in contact with the surface of a water cooled drum as it passes through the electron beam.

There are two nitrogen manifolds, spaced about 700 mm apart. Their angular orientation relative to the web and the space between the manifold and the web can be adjusted. Figure 3 is a photograph of the infeed section with the cover in the open, or web threading, position. The first nitrogen manifold can be seen directly above the roller. Figure 4 shows a simplified drawing of the infeed section and curing region of the processor.

In addition to the manifolds in the infeed section, a low velocity nitrogen "blanket" is introduced in the e-beam curing region. This manifold is located below the electron beam window as shown in Figure 4. The BroadBeam® processor window is water cooled; nitrogen is not blown across the foil for cooling purposes. Considerable care has been taken to seal the infeed region against the inflow of air. The main reaction chamber (containing the chill roll) has likewise been well sealed except at the exit slot.

The gas inside the reaction chamber can be sampled at three positions across the web. Six sensing ports are located in the clamp which holds the electron beam window foil in place; one pair is on the web centerline and the other pairs are 559 mm. to either side of the centerline. (The ports of each pair are on opposite sides of the clamp, spaced 375 mm apart and symmetrically located about the long axis of the electron beam foil). Gas samples can be drawn from any pair or any combination of pairs of ports and the oxygen concentration read by a Delta F® analyzer.

Tests were first run to determine the optimum manifold angles and to roughly determine the nitrogen flow to the two linear manifolds and the low velocity nitrogen source which would bring the oxygen to less than 100 ppm, while running a 1000 mm, wide web of 50 μm thick polypropylene film.

It was determined that the manifolds were most effective when the nitrogen flow was directed into the boundary layer at an angle of approximately 6* from the normal to the web. This angle was particularly critical for the second manifold. Changes in angle (+ or -) as small as a few degrees made large differences in the oxygen concentration. Both manifolds were finally set at 6*, with a 0.4 mm. flow gap and spacing of approximately 1.6 mm. between the nozzle exit and the web. Since the web is on, or near, a roll surf-ace while under the nitrogen manifolds it is possible to accurately maintain the 1.6 mm. clearance.

It was also found that the inerting effectiveness and stability were surprisingly sensitive to the flow from the second manifold. Very slight changes from the optimum flow, decreases or increases, made large changes in the indicated oxygen concentration.

With the manifold flow set as shown in Table 1, a series of runs was made with different flow settings for the reaction chamber manifold. For these runs Th. Goldschmidt RC 726 silicone release coating was applied to the 1000 mm web with coating weights of 1 gm/m' and irradiated to dose levels of 25 kGy at 180 kV accelerating voltage. Proper curing of the coating provided the ultimate test of inerting effectiveness.

Similar tests have been run on the 610 mm RPC pilot line. In Hayward, however, we are limited by the coating equipment to speeds below about 250 m/min, although the web itself can be run at speeds up to 400 m/min. The spacing between the two manifolds in the RPC pilot line is 510 mm. Seating of the infeed section is not as complete as at the EDF, but the reaction chamber is reasonably well sealed.

TABLE I. Nitrogen flow settings for web speeds of 400 and 450 m/min.

1000 m^2	Web Consumption Speed (m/min) (scm/1000 m^2)	Manifold 1 (scmh)	Manifold 2 (scmh)	Chamber Manifold (scmh)	per
	400	51	25	89	5.5
	450	51	25	128	6.1

We find that the two manifolds work well at an angle of 10' from the normal to the web, and as at the EDF, oxygen concentration is very sensitive to the flow from the second manifold. in one test the gap of the first manifold was set at 0.10 mm and the second at 0.025 mm. We ran 610 mm wide 25 pm polyester film at 305 m/min (without coating) and maintained the indicated oxygen concentration below 70 ppm.

As Table II shows, the consumption of nitrogen was minimized when there was flow from the second manifold. When the second manifold was turned off, it required greater flow to both the first manifold and the chamber manifold in order to maintain the inerted conditions.

At 400 m/min the indicated oxygen concentration remains below 35 ppm with total flow of 142 scmh apportioned 24 scmh, 14.4 scmh and 104 scmh between the two infeed manifolds and the chamber manifold. This corresponds to 9.8 scm. of nitrogen per 1000 m' of product, a higher value than observed at the EDF. We attribute the higher value mainly to the less complete seating of the infeed section.

TABLE II. Flow conditions illustrating sensitivity of nitrogen inerting to flow conditions at second manifold. RPC 610 mm pilot line at web speed of 305 m/min.

Nitrogen Flow

1000 m^2	Web Consumption Speed (m/min) (scm/1000 m^2)	Manifold 1 (scmh)	Manifold 2 (scmh)	Chamber Manifold (scmh)	per
	10.0	14.4	66.8	91.1	8.2
	11.9	0	109.4	121.5	11.0
	24.0	0	118.3	142.2	12.8
	41.3	0	110.9	152.2	13.7

4. Cost of Nitrogen

As the Table I data show, it can be expected that curing at a web speed of 400 m/min can be achieved with nitrogen consumption of 5.5 scm/1000 m' or less. It is instructive to compare the cost of the nitrogen to the cost of the silicone release coating and the substrate.

In Germany, the Th. Goldschmidt AG coating costs between DM 32/kg and DM 45/kg, depending on the formulation and quantity. Nitrogen can be obtained in quantity for about DM 0.30/scm. Substrate prices range from DM 0.11/m^2 for 15 pm BOPP to DM 0.40/M^2 for 36 µm PET. With a coating weight of 1 gm/m^2, using DM 32/kg for the coating and DM 0.11/m^2 for the substrate, the costs of the nitrogen, coating and substrate are as shown in Table III.

The nitrogen cost is only 1.1% of the total cost, and 5.2% of the coating cost. Nonetheless, because the production rate is so high, the total cost of nitrogen for a year can be quite impressive. With three shift operation, 6 days a week, 50 weeks/year, a plant operating a 2000 mm. line at 400 m/min would incur a nitrogen cost of DM 570,240 per year.

TABLE III. Relative cost of nitrogen, silicone coating and substrate. Substrate material, 15 µm BOPP; coating weight, 1 gm/m^2; web speed, 400 m/min.

	Cost per 1000 m^2 (DM/1000 m^2)	Percentage (% of total)
Substrate	110.00	76.6
Coating	32.00	22.3
Nitrogen	1.65	1.1
Total	143.65	100.0

Summary and Conclusions

The experimental results presented in this paper are part of an ongoing program at RPC Industries aimed at improving both the effectiveness and efficiency of inerting systems for production e-beam processors. Significant contributions have been made by Pagendarm GmbH and Th. Goldschmidt AG.

Utilizing a new linear manifold system to produce a uniform and repeatable high speed flow of nitrogen, it has been possible to "inert" a 1250 mm wide BroadBeate processor and cure silicone release coatings at line speeds up to 450 m/min. The absolute measure of good inerting has been the product itself, although a qualitative indication of the effectiveness of the inerting system is that it is possible to achieve and maintain an indicated residual oxygen concentration level of less than 50 ppm, even at a line speed of 450 m/min.

These results with silicone release coatings have been achieved while simultaneously reducing the consumption of nitrogen by more than 35%, compared with earlier systems. For other curing applications, such as web offset printing, where the level of residual oxygen can be somewhat higher, even greater economics in nitrogen consumption can be realized.

It is shown that the nitrogen cost per square meter of product is only about 1% of the cost of the substrate and coating, based upon the current prices of Th. Goldschmidt e-bearn silicone release coatings and a typical film substrate, even when taking into consideration the higher cost of liquid nitrogen in Europe.

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Figure Captions

1. Nitrogen manifold with 750 mm x 0. 10 mm gap.

2. European Demonstration Facility for electron beam curing of silicone release coatings on a 1250 mm web at web speeds of 450 m/min. Pagendarm GmbH five roll smooth coater below the RPC BroadBeam processor.

3. Infeed section of BroadBeam processor with infeed cover open, showing nitrogen manifolds.

4. Simplified drawing of BroadBeam processor showing the nitrogen manifold configuration.

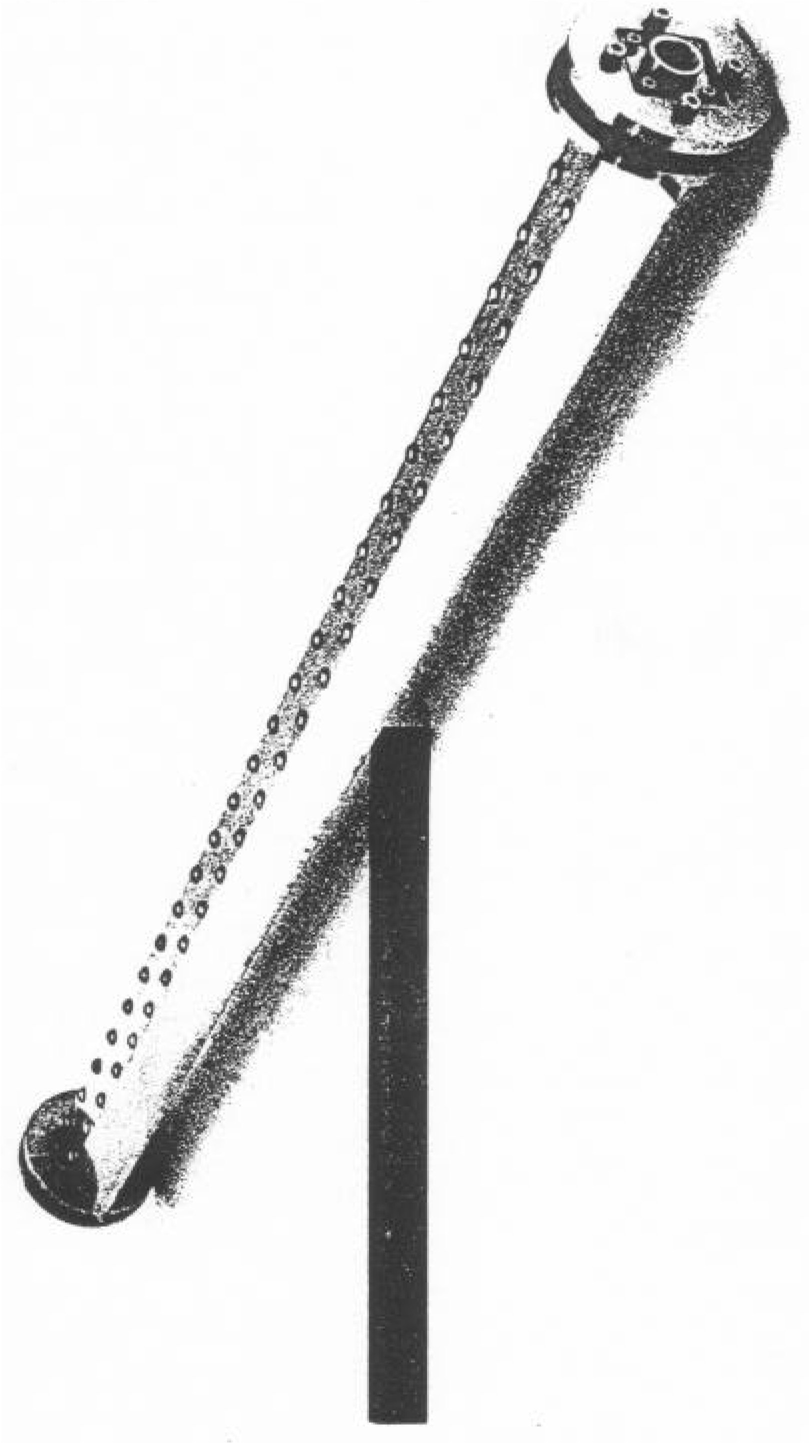

Figure 1. Nitrogen manifold with 750 mm × 0.10 mm gap.

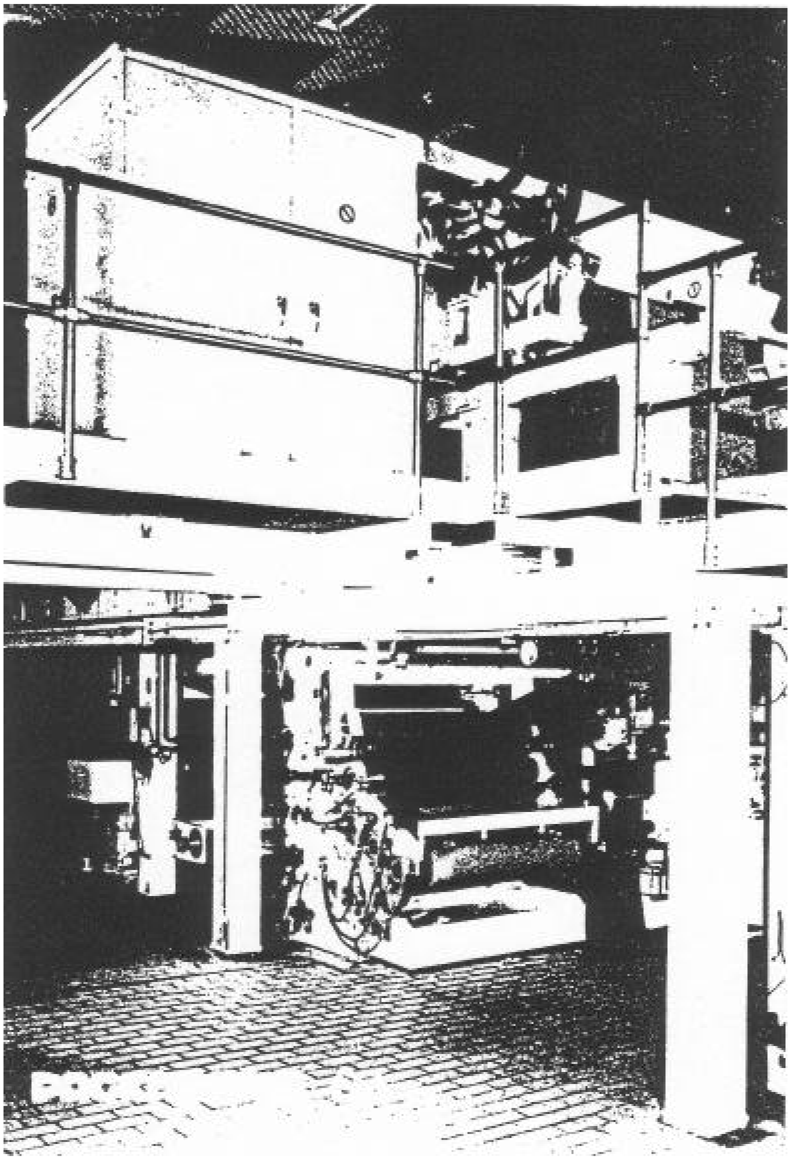

Figure 2. European Demonstration Facility for electron beam curing of silicone release coatings on a 1250 mm web at web speeds of 450 m/min. Pagendarm GmbH five roll smooth coater below the RPC BroadBeam® processor.

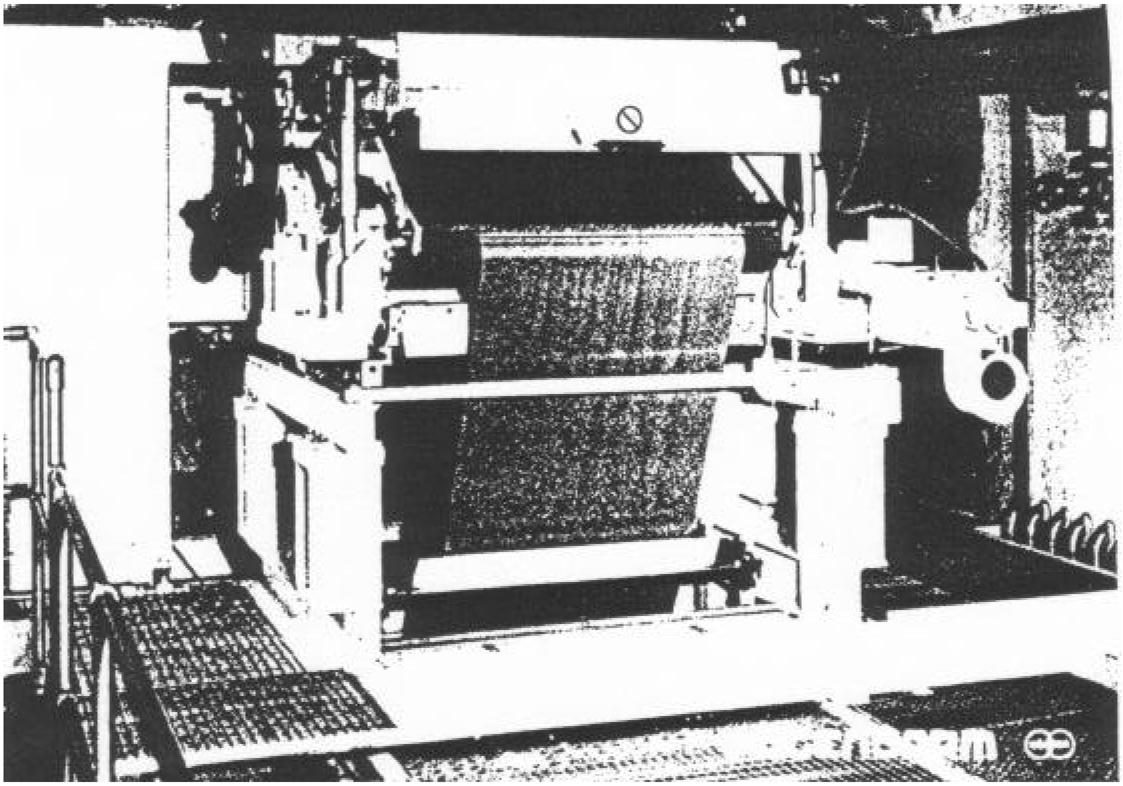

Figure 3. Infeed section of BroadBeam® processor with infeed cover open, showing nitrogen manifolds.

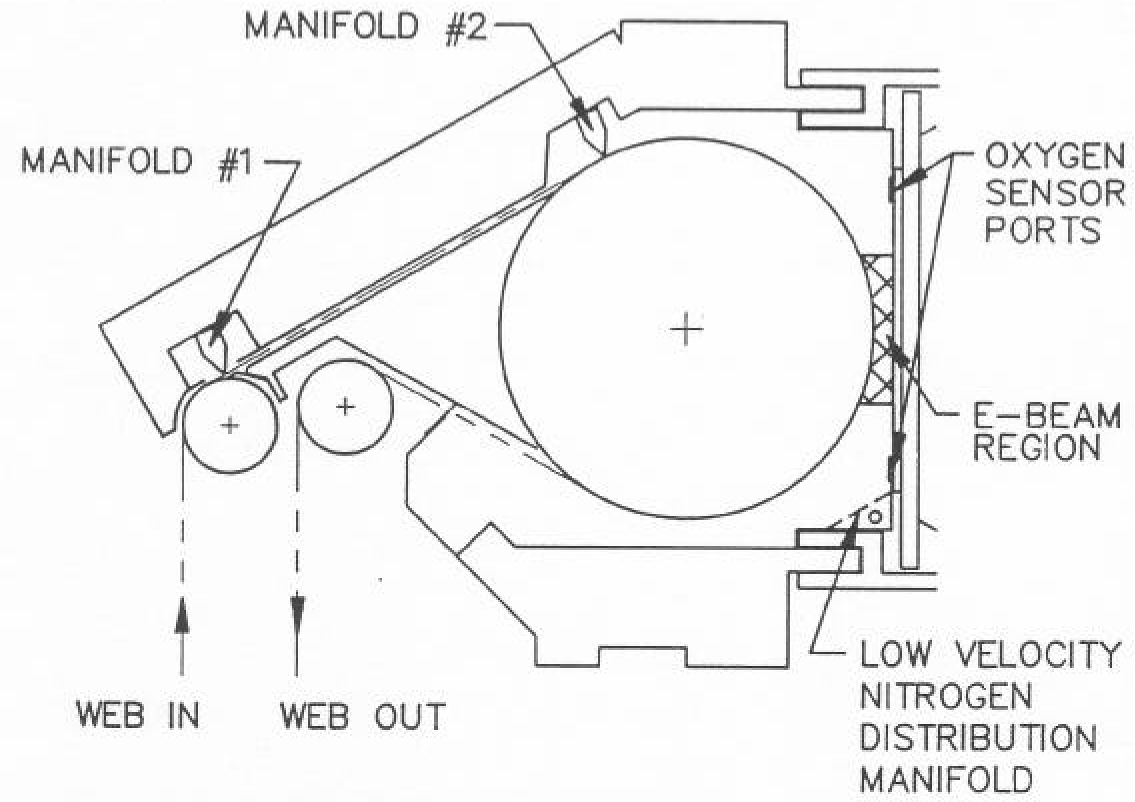

Figure 4. Simplified drawing of a BroadBeam® processor showing the nitrogen manifold configuration.