# Vacuum Metallization of Paper and Outgassing Materials

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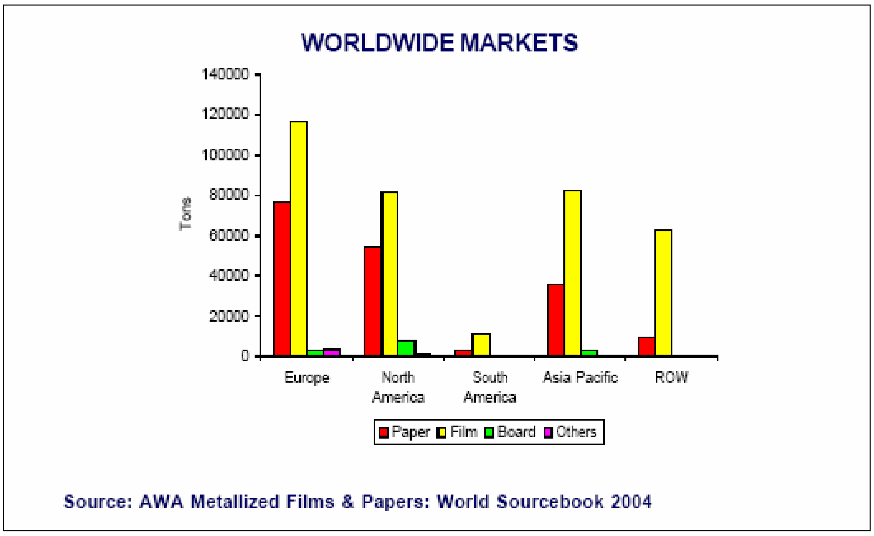
***Abstract***

Materials like paper, some kind of textiles and of plastic films contain a relatively high level of moisture or solvent which tend to be released in the vacuum chamber and to influence the metallization process. This paper will review the traditional methods to handle large gas and vapor loads in a vacuum chamber, which include separation in vacuum zones at different pressure ("Zoning"),and various combinations of vacuum pumps and cryogenics . The modern metallizers are characterized by high speed capability and larger material rolls, in addition, the metallizing applications are extending to raw materials with higher moisture content, all conjuring to the demand of more efficient pumping system. The presentation will illustrate and discuss the latest solutions proposed in the industry, by using a model to evaluate the pumping efficiency in relation to the type of pumps, the pressure regime and the energy consumption . Although this work primarily addresses the paper processing, it is also pertinent to the more ubiquitous film metallizing industry , which may be facing vacuum issues, caused by abnormal vapor release phenomena.

- **Introduction**:

a) Metallized Paper & Film :The market Outlook

The following diagram shows the estimated usage of the main metallized materials




b) Metallized Paper :Main Applications

The metallized paper is used mostly in the following industries :

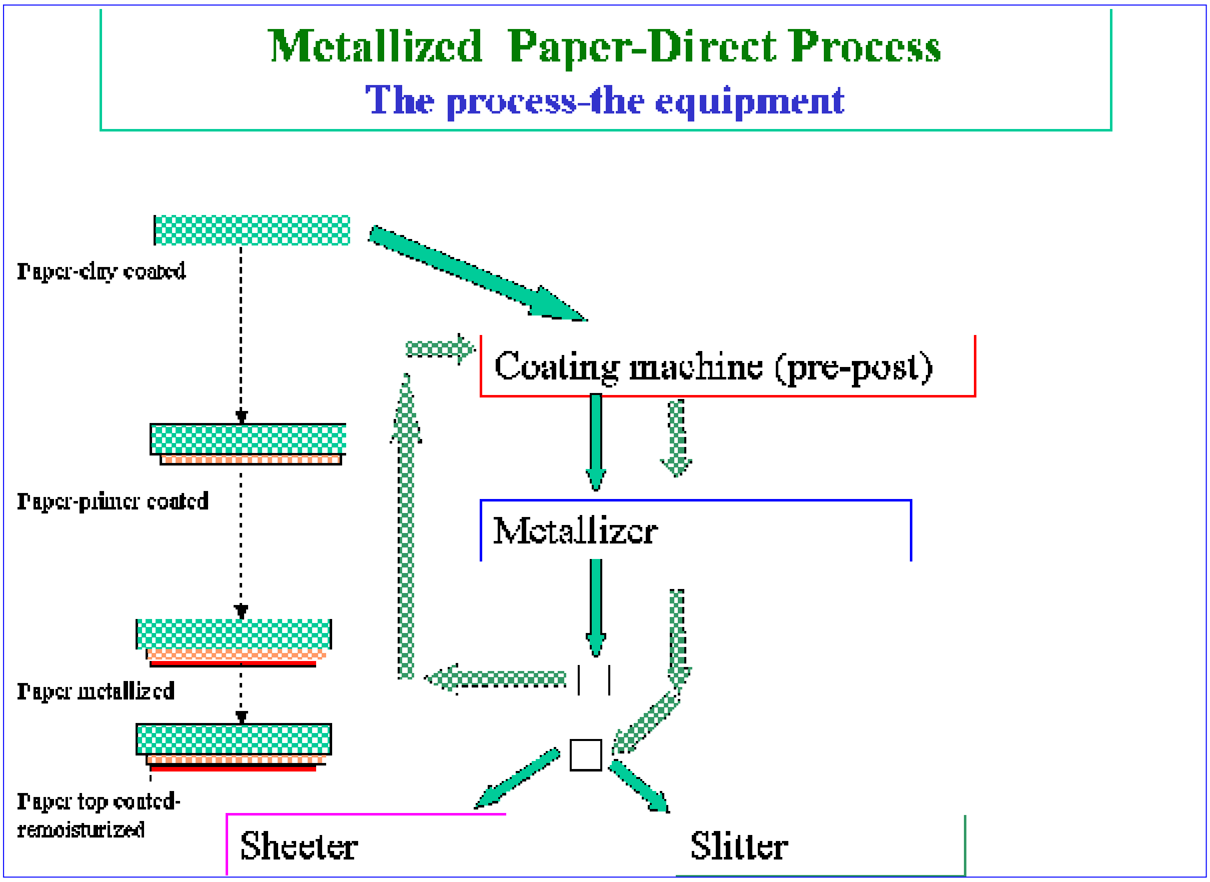
- Label for beverages, mainly for bier (grammage about 70 $g/m^2$)
- Tobacco : Inner liners for cigarette packs (paper 50-55 $g/m^2$); outer pack (board 180-230 $g/m^2$)
- General packaging, gift wrap and decoration (various weight: 80-180 $g/m^2$)

The base paper properties depend on the application; to cite the most typical, among others not less important : wet strength and alkali resistant for labels (mainly dictated by the selected bottle washing process); resistant to de-coloration and odor-free for tobacco; with various optical properties for packaging.

The impact of base paper on metallization process, will be described, rather than function of final product, as characterized by paper properties like grammage and moisture content

c) Metallized Paper : the manufacturing Process

The following block diagram shows the main steps of metallized paper production and the equipment required for the job . Finishing treatment (printing, embossing and others that depend on the specific application) are not shown but are also key parts of the production process.




- **Paper Properties and metallization process**.

The paper properties which are relevant to metallizing are basically two :

a) Thickness, grammage and mechanical properties
b) Moisture content and gas released

Another consideration is the Production output & Efficiency

- ❖ The impact of paper basis weight and mechanical properties on metallization process and equipment are usually not very critical : paper is a strong and rigid substrate, heat tolerant and not prone to wrinkles. However, the tensile strenght and yields are affected by the moisture content: each type of base paper has its own equilibrium moisture: excess water leads to reduced strength and a dry paper is brittle and tends to curl. Since metallization, with the addition of the upstream coating, causes a paper moisture loss, web break is a possible result and precautions should be taken to minimize the occurrence and the consequences. Moreover, slip properties and moisture or gas release associated with vacuum conditions can lead to roll telescoping when in motion or even in stand still .

  The mechanical features of a typical metallizer for paper are characterized by :

- Ability to run at moderate to high web tension, depending on the specific material thickness and properties.
- Nipping system to prevent telescoping and minimize material loss in case of web break.
- Straight or low curvature spreaders to minimize web transversal stress for possible paper brittleness.

- ❖ The water vapour release and the possible excess residual solvent from the pre-coating characterize the paper metallization process: the metallizers for paper must be suitable to withstand a significant gas load . The moisture content of metallizable grade paper can vary in a relative broad range: from 2.5 to 5%. The amount of water release in vacuum depends on the absolute content and on the type of paper ( porosity etc.) and is , to some extent, controlled, by the clay coating (in the paper mill) and the lacquer coating prior to metallizing. If the paper preparation is correct, the moisture loss in vacuum is far below 0,5%: this apparently small amount, represents, however, a large vapour volume at the low pressure typical of the metallizing process. Obviously, for a given weight of vapour transferred into the chamber, the volume is, roughly, inversely proportional to the pressure. The vacuum "zoning", i.e. the division of the vacuum chamber into two or more zones at different pressure, is a fundamental principle of metallizers for paper and is discussed in the following paragraph.

  A brief analysis of the mechanism by which vapours diffuse from the materials to the vacuum chamber is of interest to understand how vacuum design effect the performance of a paper metallization process. Although it varies according to the paper properties, the moisture release in vacuum appears to be time-dependent and described by the following formula, which is reported, in vacuum technology science, as representing the outgassing rate from any solid surface.

  $Q = Qo/(t/to)^r$ where Q is the rate of gas release, t the time elapsed from the surface exposure, the exponent "r" depends on the surface material. Qo is the outgassing rate, at a certain time, and is supposed to be determined by experiment . This formula can be represented by a straight line of slope "r" on a double-logarithmic diagram. In the case of industrial metallization, this mechanism explains the observation that the gas load, for a given material, increases with the process speed: that occurs for any material, including plastic films, but it becomes particularly severe for paper, given the nature of the surface and the moisture content. How critical the speed is and what is its limit could be correlated to the material through the value of "r".

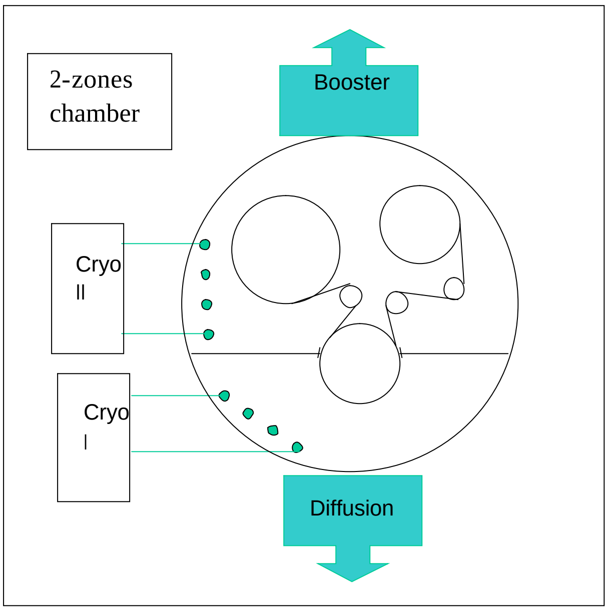
- ❖ Output & Efficiency

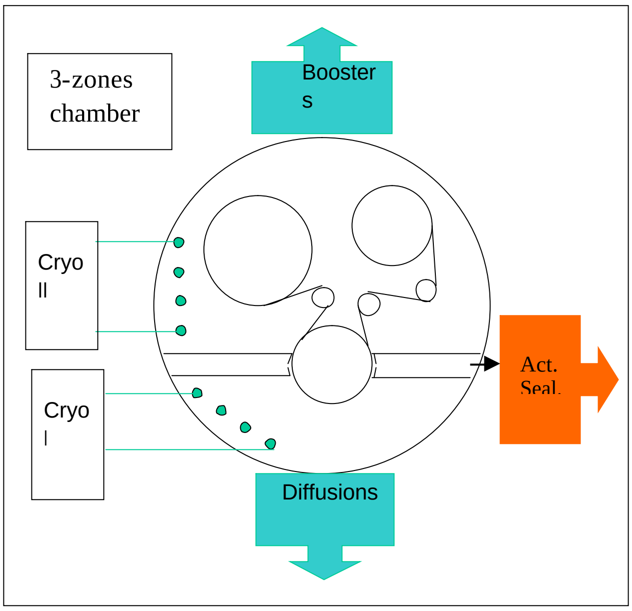
  The metallized paper in use is characterized by relatively high thickness, between 50 and 100 microns with the light card board reaching 200-250 microns. This obviously leads to the trend of metallizing large diameter rolls, in order to maximize the material length and optimizing the production cycle efficiency (processing vs. preparation time). While direct metallization for card board is a marginal production- (transfer process seems more suitable for this material) equipment for paper rolls of 1.2-1.3 m diameter are more and more common in this industry, representing the most balanced size for a high output.

- **Vacuum Systems for metallized paper or outgassing films**

The vacuum equipment to handle large vapour emission is designed following two main principles : 1-vacuum "zoning" ; 2- combination of cryogenic and mechanical pumping.

1. Vacuum Zoning As introduced in the previous paragraph, the principle of confinement of the gas released within a limited volume, "isolated" from the process zone, has been pursued since the beginning of the industrial metallization with the introduction, after the single chamber, the two and multi-chambers metallizers. The largest amount of moisture release occurs in the winding section, due to the constant presence of the roll of paper , the relative long time of paper exposure and the development of the gas and vapours entrapped in the coils at the unwinding point. The equilibrium between the outgassing rate and the vapours, removed by mechanical pumps and immobilized by condensation on the cryocoils, determines the pressure in the chamber. The higher is the pressure, the more likely is the gas transfer to the process chamber with the consequent contamination and loss of the required high vacuum. The isolation of the evaporation chamber is, therefore, a key requirement of these processes and various technical solutions have been developed, mostly using low "conductance" seals to separate the vacuum zones. In the following figure, the conceptual design of two classical solutions is shown: in the two-zones chamber, a partition with low conductance sealing keeps the pressure difference between the winding and evaporation area. In the three zones system, the partition is realized by a small chamber with low conductance sealing and with a separate gas extraction system: it represents, then, an "active sealing" and the gas removal can be done by pumps or by condensation on a cryocoil.

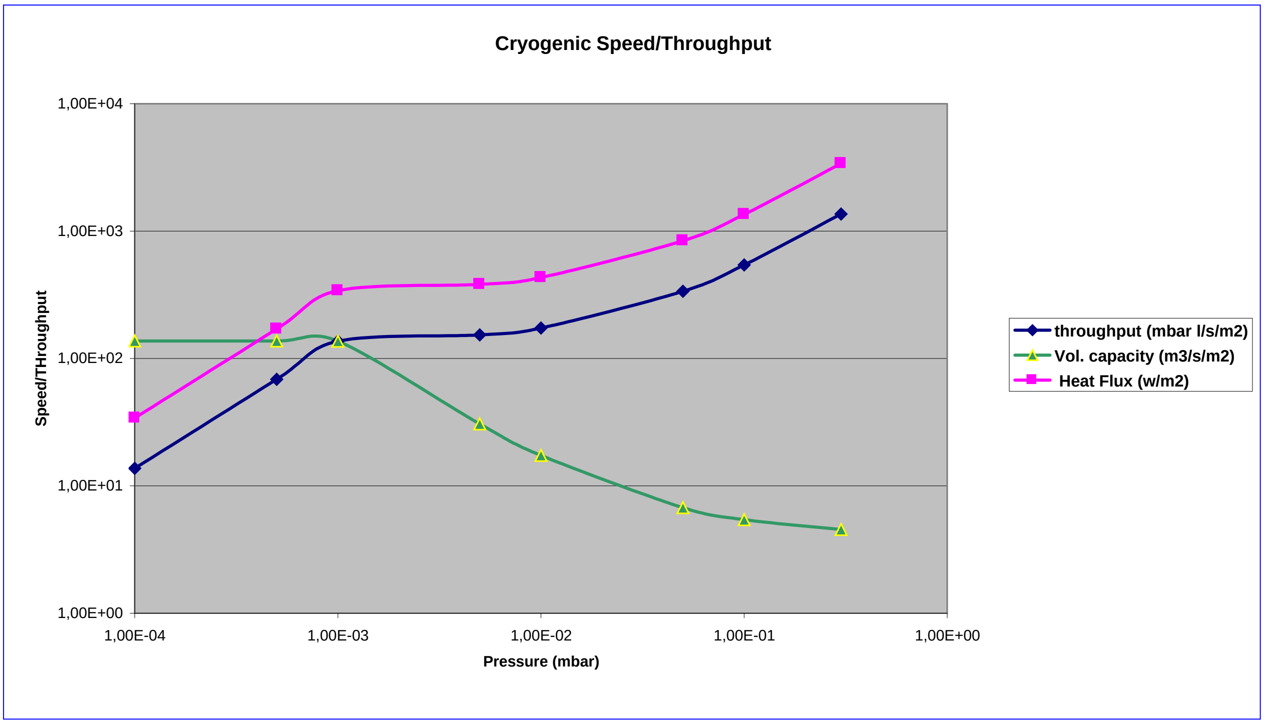


2. Cryogenics & Mechanical pumping.

The combination of mechanical pumps and cryogenics system has been in use already for many years: when severe outgassing occurs, the moisture condensation on the cold surface plays a fundamental role in keeping vacuum conditions. The pressure prevailing in the chamber has, however, an impact on the performance of the pumping system and will be considered in the following paragraph.

2.1. Cryogenics and pressure : Low temperature coils are very efficient vacuum "pumps" especially in the high vacuum region: a coil of 1 square meter cooled by liquid nitrogen or closed cryogenic unit has a capacity (at pressure below 10-3 mbar or 0.1 Pa) of more than 130,000 lt/s of water vapour, equivalent to the capacity of two big diffusion pumps. At such low pressure, typically existing in the coating chamber of a metallizer, the "throughput", or the weight of the condensing moisture is low (it is calculated as the product of volumetric flow by pressure): it is about 60 mbar/l/s per 1 square meter coil, corresponding to 50 mg/s of water . At different pressure the curves of capacity and throughput are shown in the following diagram. The curve of heat flux indicates the cooling capacity required for a unit surface of coil.




The diagram is helpful to summarize the functioning of cryosystem in the different chamber zones during paper metallization :

- In the evaporation area, the cryocoil have the maximum vapor extracting capacity, with relatively small amount of condensed water and limited energy flux. Ice build-up on coils is not a limiting factor. The coil temperature is critical, being the cryo-pumps driving force dominated by the difference between the water vapour pressure and the equilibrium pressure at the coil surface temperature : popular cryosystems in the industry operates at about –120°C; with liquid Nitrogen, the lower temperature (-170 °C) achievable has a minor effect on the pumping efficiency.

- In the winding section, with higher pressure, the capturing rate is higher even though the volumetric capacity drops. This leads to a relatively large amount of condensed and frozen water and a correspondingly high heat flux . The coil temperature can be higher than in high vacuum section (typically, -80 /-90° C). The presence of a larger concentration of inert gas in the chamber atmosphere causes the coil capturing efficiency to decrease, due to the lower rate of diffusion of the vapour towards the cold surface. All these phenomena leads to key facts for the cryogenic design :

- Cryogenics pumping can remove large amount of moisture released from the paper at the high pressure level (typically > 5x10-2 mbar) prevailing in the winding chamber as a balance between the outgassing and the pumps removal rate.
- Large coils surface area are required to support the high material and condensing heat flux.
- The cryogenerators available on the market are often limited in cooling capacity power and the use of liquid nitrogen is, in most of the case, the solution of choice. The cost of this consumable medium is to be considered in the metallized paper manufacturing cost and the system design should be optimized to increase the energy efficiency and minimize the nitrogen consumption.

2.2 Vacuum solutions and energy efficiency.
The metallization of outgassing materials is very demanding in terms of energy to extract moisture vapours from the chamber, whether they are condensed on the coils or are compressed to atmospheric pressure; if we compare the two modes, from cryogenics and mechanical booster pumps in the winding chamber, we can summarize the key facts as follows :
a) For a certain outgassing rate, depending on the material properties and on the web speed, less volumes have to be extracted at higher pressure in the winding chamber. The compression power would also decrease with an increasing pressure. Should the vapour be removed by condensation, the required power would be roughly independent on the pressure. Starting from 10-2 mbar, using pumps to remove the vapours from the chamber, is more energy efficient than using cryogenic coils.
b) Letting the pressure increase in the winding chamber, can be pursued with advantage up to the point that it interferes with the process, due to the leak of gas from the winding to the evaporation zone. The sealing between the zones is, therefore, instrumental to maintain a large pressure gap and to achieve an energy efficient process. Solutions such as the above mentioned “active sealing” represent a significant development for the future of paper metallization, in view of the demand of more outgassing substrate.
c) the ideal solution for paper metallization is a machine with the tighest possible isolation of the process zone ; it would allow “high” pressure in the winding chamber . The most energy and cost efficient solution would be booster mechanical compression if compared with the cryo-condensation.

- **Summary and Conclusions** : The properties of the basis paper and the pre-coating play a key role in determining the quality of metallized paper: vacuum metallizers have developed to process a broader range of raw materials quality with higher efficiency and output. The challenge of removing larger moisture amount can be met not only with the obvious use of bigger capacity pumping system but also with an equipment design which maximize the efficiency of the vacuum process . Among the various traditional solutions, It was proposed a developed version of the “vacuum zoning” design, denominated “active sealing”, which can lead to a more efficient combination of Cryogenics and mechanical pumping.