VACUUM COATERS PRODUCTION AND ENERGY EFFICIENCY : NEW DESIGN AND INDUSTRY EXPERIENCE

By
Ivan Bevilacqua and Fabiano Rimediotti
Nordmeccanica- Vacuum Division - Piacenza Italy

INTRODUCTION

This paper represents the result of the end user and equipment manufacturer joined effort to set up an highly efficient vacuum coaters as requested by the high competitive metallized film market for flexible packaging.
The motivation behind this project is the interest of staying in a business which is continuing to grow at a moderate but consistent rate (approx. 4% as per AWA 2015 market survey).
Moreover, in recent years, there was a growing demand of metallized film in several geographical region which led the film manufacturing companies to invest in new equipment : in order to be competitive in this global business, the demand was for production efficiency, energy saving at controlled and consisten quality level, in order to minimize the production cost. The paper will discuss three aspects characterizing current demand for High Efficiency vacuum coaters :
Productivity and production efficiency
Energy saving strategies
Quality requirement with particular focus on achieving high barrier properties in metallized film.

PRODUCTION EFFICIENCY

Production efficiency of a roll-to-roll vacuum coater for aluminium deposition depends on the four main factors listed here :

- Actual metallization speed
- Uptime vs. Downtime,
- Machine utilization factor
- Wastes

To measure the relative effect of each single factor (speed, downtime, machine utilization and waste) on determining the productivity, it is useful a sensitivity analysys which measure the change of production output for any factor proportional change. Not suprisingly, the greater impact is from web width, counterbalanced by the detrimental effect of poor machine utilization due to unbalanced product mix .
Web speed and run length are significantly important but downtime reduction looks crucial as well.

A similar approach is done to evaluate the relative weight of the factors on the production cost. In this case, machine size has, somehow, a more limited effect due to the complexity and infrastructure cost of a very wide machine. The relative limited effect of waste film on the production cost is possibly true for film manufacturers, who have the opportunity to reprocess film scraps almost entirely, whereas for the film converters it becomes a real and net wasted material with relevant higher cost impact.

Metallization Speed

A representative value of industry state-of-the-art high metallization speed for Pet or BOPP is 1000 m/min at 2 OD with 5% deposition uniformity. Key points to consistently maintain this performance are : evaporation system, web tension control and film cooling efficiency

The evaporation system is the crucial part of any aluminium metallizer : high deposition rate and evaporation stability are instrumental to match-up with the high metallization speed. The ceramic evaporation boats needs to be powered and fed to deliver about 90% of the current maximum capacity standard. Design solutions for high evaporation boats are :

- Narrow spaced evaporators for a dense deposition cloud
- Stable aluminium feed
- Balance power distribution
- Integral cooling to withstand high intensity heat and long metallization run

The winding system of an high speed metallizer is designed to steadily support and guide the film during metallization : the main design features are :

- Low inertia rollers normally fabricated with high modulus material to guarantee rigidity and lightness
- Smooth surfaces roller to minimize the risk of film damage
- Tension control using latest generation of drive control system

Film cooling is a key requirement for high speed metallizers. For popular metallized materials such as Bopp, a very small temperature increase is allowed during the process. Chilled rollers are common solutions to remove the heat from the film with the heat exchange being enhanced by injection of a small quantity of gas to create a localized «high pressure" chamber between the film and the chilled roller

Downtime reduction

The main phases contributing to the machine downtime are :

- Vacuum generation
- Machine cleaning
- Roll loading and threading

Waste minimization

is another important item characterizing the latest generation, high efficiency metallizers : a maximum of 3% film waste through the whole production is a demanding but reacheable target.
Two examples of solution for waste reduction are a full production monitor and automatic control through supevision and data recording, aluminium thickness continuous measuring and control, cameras for defect monitoring.
Moreover, it is possible to move towards «zero off-spec» material during metallization start and stop (through «transient automatic control»).

Plasma Treatment

Many films are positively affected by plasma treatment. High speed metallizers require the use of higher power density plasma. The case study described in the last part of this presentation will demonstrate the benefit of a «treatment dose» in excess of 400 – 500 Joule/m2 corresponding to delivering power in excess of 5Kw per meter of width which has been so-far considered the maximum standard

ENERGY SAVING

Electrical Energy represents a major metallization cost items. It accounts for half of all consumable costs and 30% of the total metallization cost . A strategy to optimize the use of energy in metallization is one of the main current efforts to implement high efficiency metallizers

The nature of metallization process characterized by intensive heat requires an high capacity, somehow redundant cooling system.
Energy reduction strategies can be implemented by optimization of the power demand of selected phases of the production cycle without compromise for the system safety .

The Energy Saving solutions address two areas of intensive energy use , that is the pumping group and the refrigeration unit for the chilled drums cooling system.

- All major pumps are switched off for most of the downtime
- Diffusion pumps heating and temperature are controlled to minimize the power consumption
- The refrigeration unit can be designed with variable capacity compressors to tune the power demand to the minimum safe value.

They represent an estimated 10-15% of energy saving over an average production cycle

In addition to Energy saving , energy recovery system can be implemented by means of the use of heat pumps (this approach, which requires additional equipment and a more factory integrated strategy is not covered by this paper).

HIGH BARRIER METALLIZED FILM : a case Story

The last part of this paper describes an example of product quality improvement by describing results from a project aimed to develop high barrier metallized polypropylene . The test program, data collection and preliminary analysis has been done by a major european bopp manufacturer during the initial six-months running period of a new high efficiency metallizer.
Metallizing grade OPP is produced by many manufacturers in a great number of varieties. The barrier properties (Oxygen transmission and Water vapor transmission rate) published by the major manufacturers cover a broad range of material. We can roughly represent two categories of met-Bopp : a) commodity met-Bopp and b)ahigh bsrrier met-Bopp. Oxygen transmission rate ranges from 10 and 50 cc/m2/day for high barrier and from 70 to > 100 cc/m2/day

for commodity bopp. Water Vapor Transmission Rate from <0.1 to 0.3 gr/m2/day for high barrier and 0.4 to 0.8 gr/m2/day for commodity met- bopp

Four factors impact has been considered in the study :

- Base polymer film
- A special polymer skin to improve metal adhesion
- Plasma treatment
- Machine design and process parameters : by comparing the results of different generation machines

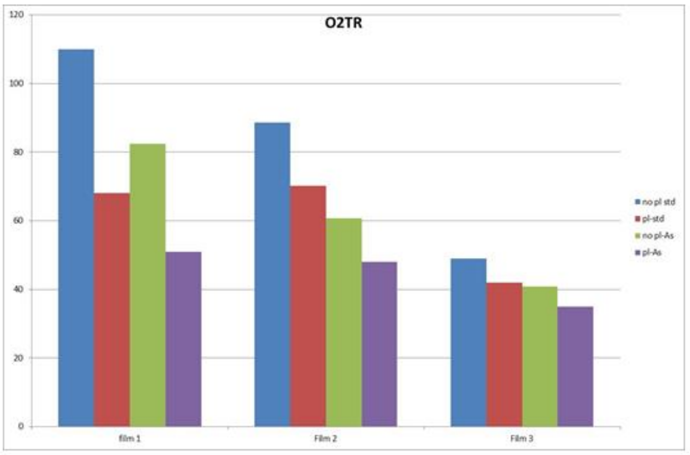
The graph shows the Oxygen transmission rates (O2TR) and Water Vapor transmission rate f(WVTR) for three different bopp materials:

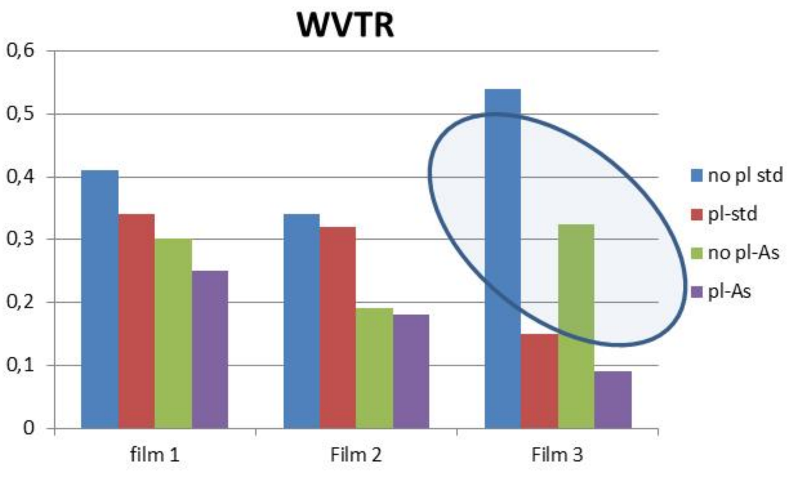
- Standard
- With plasma pre-treatment
- With the adhesion promoting skin and no plasma
- With adhesion promoting skin and plasma

All three films are «commodity grade»- 3-layers construction .. Film 1 and 2 differ only for thickness. Film 3 is a low temperature sealing bopp.

It is apparent that all factors contribute, to some extent, to barrier properties.
The data analysis shows the effect of film characteristics and plasma treatment on bopp barrier properties ; they can be summarized as follows :

- This project confirms the common wisdom that the film characteristics determine the barrier properties … but it shows a general positive effect of plasma treatment on O2TR & WVTR.
- The plasma contribution to barrier changes depending on film type.
- An adhesion promoting layer in film blend has a visible effect on improving barriers, too.
- Film 3 (representing a popular Bopp product) showed a dramatic effect of plasma treatment on moisture barrier.

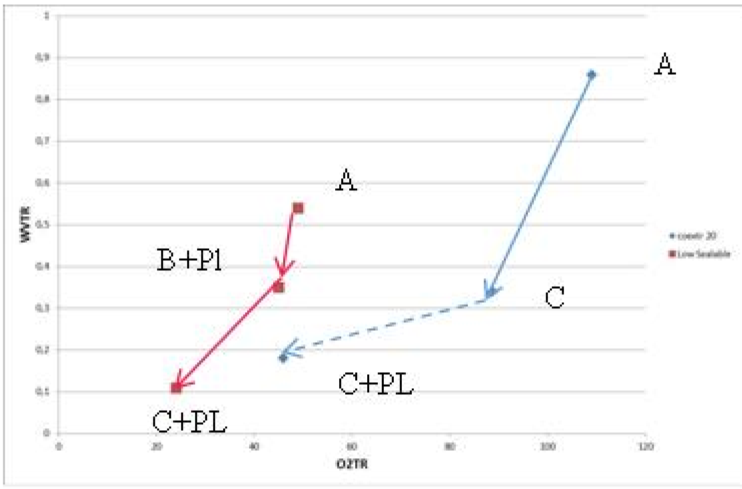




The machine design impact on bopp barrier properties has been studied by comparing barrier results from running same films on three different machines representing nearly 20 years of machine construction technology. Significant technical evolution are relevant to the following areas :

a) The evaporation system :
b) The winding system and tension control
c) Film cooling
d) Plasma treatment

The graph shows the barrier properties evolution (for machines A, B and C) of two very popular bopp film grades, that is a «standard» 20 micron and a low temperature sealable film.



	A	B+ Pl	C	C+ Pl	
Plasma	0	+	0	++	B<5 Kw/m C>5 Kw/m
Film Temp increase	0	+	++	++	A : 5-7 °C B : 4 – 5 °C C : 0 – 3 °C
Metal surface integrity	0	0	+	+	
Metal uniformity	0	+	++	++	

The table represents the relative value of the machine items which are likely to have an impact on the barrier properties inprovement:
Plasma treater was not installed on machine A, it was of «standard" design on machine B with less than 5 Kw per meter of width power supply and of up-graded design on machine C
The Film temperature control was improved from A to C machine by adding a post chiller and increasing the cooling surface
Metal surface integrity: absence of film surface defects possibly induced by poor winding and tension control.
Metal uniformity (and possibly vapour densification) depends on the aluminium evaporation design

A qualitative analysis of the equipment design and process impact on barrier properties can be summarized as fo llows :

- ✓ The Progress of Machine Design and Components leads, in overall, to higher product quality
- ✓ Plasma treatment represents a key tool for achieving high barrier : the study on Bopp shows :
  - Diversified but noticeable effect (on OTR or WVTR depending on material).
  - The latest generation plasma (higher power density, uniform spatial power distribution and faster arc protection) shows consistent advantages over first generation one.
- ✓ Although a comprehensive data analysis about the weighed effect of the other factors (Film cooling, surface integrity and deposition uniformity) is still in progress, it is possible to extrapolate realistic results also considering the commonly accepted mechanism of oxygen and water transmission through polymers.

Surface defects minimization are the most likely cause of Oxygen barrier improvement (which is a defect driven phenomenon).
Better film cooling and evaporation system are possibly the main responsible for the higher water vapor barrier (which is more linked to metal layer formation)

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