Energy and environmental issues of roll-to-roll vacuum deposition.

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ABSTRACT

At this time of high oil prices (at the time of writing $70 /barrel and predicted to exceed $90/barrel) and with the corresponding knock-on effect on the energy prices it is perhaps appropriate to look at some aspects of roll-to-roll vacuum deposition technology.

Anyone who has operated a vacuum metallizer or one of the more sophisticated sputter roll coaters will be aware that they spend an awful lot of money on electricity that ends up in heating water that is then poured down the drain.

Balanced against this waste of energy we can look at some of the overall benefits available as a result of the products produced by the technology. Examples of this might be aluminium metallised polymer films that are a direct replacement for aluminium foils, solar collectors that convert light into heat and photovoltaics that convert light into electricity.

Other industries are concerned enough about oil supplies that they are looking at alternative strategies. The latest change that we are now starting to see come to fruition is the move away from oil based polymer films. There are a new generation of films available made from plant sources that can be composted and are more easily biodegradable. These are being metallized and coated with transparent barrier coatings.

This paper will aim to cover a number of the energy/environmental issues that may play an increasing part in business decisions in the coming years. Also to highlight where process improvements might be possible.

INTRODUCTION

Until recently energy has been a topic that did not have to be thought about much. For most of us it was readily available and cheap. Similarly environmental issues could be largely ignored. With the great success of manufacturing and some abuses and/or lack of thought or regulation the quantity of waste and the profligate use of materials and energy has brought us to the point where it has become of interest to many groups. As a result of this the amount of regulation is increasing and an increasing amount of thought will have to be taken in how we use materials and energy as well as how we dispose of our waste materials.

As with all of these things we can all choose one of two paths, one is to be proactive and enthusiastically embrace the changes or the second is to be reactive and only respond to the changes once imposed. In this paper I aim to draw attention to some of the strategic questions that some manufacturers might like to thing about as well as some design and operational issues that might be tackled by machine manufacturers and users.

FILM PRODUCTION AND DOWNSTREAM PROCESSING.

There is a problem looming that has no easy answer. Most of us use polymer films. Over, at least, the last couple of decades the trend has been to build bigger, wider and faster film lines. Also many companies aim to become global suppliers either by manufacturing on a single site but shipping anywhere in the world or by having strategically sited manufacturing to reduce the shipping time and costs. The looming question is what will happen in the future. If the price of oil continues to rise how will this affect the polymer film raw material cost, the manufacturing processing cost and the shipping cost. The availability and price of oil is a key factor in this.

There is a temptation to chase after cheap manufacturing costs which some regard as cheap labour but which in future might also include cheap energy costs. Sources of cheap energy often have other less attractive issues associated with the energy production such as use of poor quality fossil fuel that pollutes the atmosphere, or nuclear energy that has a whole host of other implications.

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Added to this is the calculation of true total energy that is required to manufacture any given product. This becomes complicated because some wish to include the energy required in making the materials that went into the manufacturing plant to make the product and not just the direct energy costs of making the supply materials and the energy used in processing those materials into the final product. An outline of energy contributions is given in Figure 1.

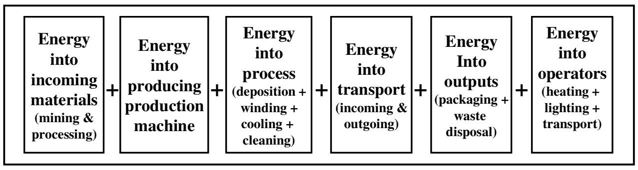

Figure 1. A variety of energy contributions that ought to be considered in determining the energy footprint of the deposition process.

What is clear is that most people underestimate the energy that is used in the manufacture of virtually everything. Industry possibly encourages this underestimation because nobody wants to be seen as either a polluter or an energy sink.

Aluminium is often used to highlight an energy costly material because of the electricity requirement of the refining process. Metallizing has long been regarded as a replacement for aluminium foil. Simplistically the thickness of the metallized aluminium is a small fraction of the aluminium foil and thus the energy saving has been related to the reduction in aluminium use. The reality is that often the final product is not just a metallized polymer film but also a more complex laminate structure. This requires that the comparison be made not between the metallized film and the foil but between the final laminate and the foil. When this is done the energy savings are much less. This is because of all the processing required to make and film the polymers as well as the increased number of manufacturing steps to wind, treat, metallize, coat and laminate the final structure.

There can still be savings but it can become less dramatic. Consider also that many laminates cannot be recycled easily and so disposal is to landfill (worst) or to incineration (better).

Tables 1 and 2 show some comparisons that were made between some different laminate structures (1). As can be seen replacing the aluminium foil does have a positive impact on reducing the energy consumption. The problem of disposal of laminates is now driving development of laminates that may be recycled rather than simply disposed of by incineration.

Table 1. A comparison of some different laminate structures with respect to energy use, including a laminated foil.

Energy	MJ/sq m	16	12	15	12	6
Equivalent	kWhr/sq m	4.4448	3.3336	4.167	3.3336	1.6668
	kg CO_2 /sq m	2.66688	2.00016	2.5002	2.00016	1.00008
Microns	PET	12	M12			
Microns	OPP			15	M20	20
Microns	Aluminium	7		7		
Microns	PE	50	50	50	50	
Microns	OPP					M20
M=metallized						

Table 2. A comparison between an aluminium foil and a PET tray for use in a 'chiller to oven' food application.

Tray 20cm x 30cm		Weight	Energy	Energy	CO_2 Emissions
chiller to oven use		gm	MJ	kWhr	Kg
Aluminium foil	90 microns + lid	22	4.09	1.136202	0.6817212
PET	200 microns + lid	17	3.57	0.991746	0.5950476
% reduction				**12.71**	

Another part of the energy balance, that is appropriate for some products, is the fact that the final product end use is for an energy generation or energy saving. At times it almost appears that because the product produces energy then it is more acceptable to squander energy during the manufacturing process. The other balancing view is that a number of these multilayer coatings are difficult to deposit and so the process is optimised to deliver the required performance that is critical, whereas the energy footprint is only of secondary importance. It could be viewed that this is an admission that the process may not be well enough understood to allow for the optimisation of the process energy requirements without losing the product performance.

A recent polymer group to hit the headlines are the biopolymers that often have headlines attached stating they have been made without oil. In one sense this is true, the raw materials are not oil based. However to manufacture most of these polymers requires a huge amount of energy and many manufacturing sites will be drawing power from a grid that has oil, coal or gas fired power stations. In fact the rapid growth of these products is possibly not as rapid as some predicted. The reason for this is because, although the price of the oil-based polymers is going up, because of the increase in oil price, the biopolymer price is also increasing. This price increase is because of the increase in energy costs as a knock-on effect of the increase in oil costs to power stations.

Strategic decisions relating to energy costs

Currently there is the opinion that the transport costs are of minor consideration and so a few large strategic manufacturing sites, shipping film long distances, is seen as an acceptable strategy. There are signs that this is changing. Polymer film often used to be manufactured by one company shipped to a converting company where it was slit into narrower rolls and sold on to end users. This can include shipping film half way around the world by a combination of rail, road and sea. To an extent this template is being changed either by the converter also becoming the end user or even to the polymer film manufacturer also becoming the converter and, in the case of the metallizers, the end user too. This change is being driven by two factors. One is that by eliminating the transport costs the manufacturing cost is reduced whilst maintaining the same profit margin. Secondly the film manufacturers also see that they are adding value to the substrate film and so are able to increase their profitability at the expense of some of their customers.

As the cost of road and sea transport increases with increasing fuel costs the proportion of the total cost will increase and so the driving force to reduce costs will increase thus changing the cost models.

Also as labour costs are gradually equalised across the world that particular driving force will fade and so economies in transport will further gain importance. If you think that the labour costs are not equalising then look at the Far East and Eastern Europe. In both areas the lowest cost labour country of 10 years ago, 5 years ago and currently are different. Thus any manufacturer wanting the lowest labour costs would have had to be moving their manufacturing base every 5 years or so. In Eastern Europe many moved their manufacturing to Poland within the last 5 years but the strengthening economy (up by 30% in last 3 years) and increasing labour costs means that labour costs are already at least 5 times lower in countries such as Bulgaria, Romania & Albania (2). As these countries change to qualify to join the European Union the economies are also likely to strengthen and the labour rates rise to match those in the rest of Europe.

There has been a different model proposed that, so far, has not found favour but which is likely to be reviewed in years to come. That is that instead of manufacturing plant becoming ever bigger to get economies of scale they will instead get smaller. These smaller manufacturing plants will be located in the centre of their sales area in order to minimise overall transport costs. If there is a large end-user this may include being sited next to their major customer. This can include a dedicated production machine sited on a customer's site. This model relies on long-term contracts and partnership manufacturing.

To work towards this goal it could be expected that many film manufacturers will continue to purchase downstream manufacturing companies to bring the expertise in house. This will also allow any new machine purchase to be sited adjacent to the film production.

The other trend over the last few years has been for rationalization of this mature industry. The driving force for this is to have fewer sources of substrate materials so that it is possible to force up prices and increase profitability. Price increasing is more easily achieved with fewer but very large manufacturing operations.
This proposed alternative view of smaller, more localized manufacturing makes industry rationalization much more difficult to achieve as it gives smaller manufacturers more opportunities to survive as the number of individual small manufacturing sites increases.

ENERGY USE IN METALLIZATION.

The broad view is that the energy used in resistance heated boat metallizers is split three ways, one third into the cooled end connectors, one third radiated away from the sources and one third used to evaporate the aluminium metal (3) of which much of this energy also ends up in the cooling liquid in the deposition drum.

Similarly in the sputter deposition systems the magnetron sputter cathodes are not particularly efficient and 75% of the applied power can disappear into the water as heat.

Energy recovery

It has always been viewed that energy is cheap and this has encouraged us all to be wasteful of it. Heat from the exhaust water from any vacuum deposition process as a source of heat energy is erratic and classed as low-grade heat. As it may be erratic in quantity and temperature it is easier to pour the hot water down the drain. In more than one case a recirculating water system has been installed, at great expense, including a cooling tower just for the one vacuum deposition machine. Despite the fact that one of the machines was sited in a region where snow could be present for 6 months of the year it was never considered as an option to use the heat from the machine to pre-heat the building heating or hot water system.

Contrast this with the solar collector industry, which takes sunlight and converts it to heat to pre-heat water (4,5), which is now established and growing quickly. This too can be considered to be an erratic source of heat as it depends on the local climate and number of sunshine hours as well as it only working during daylight hours. Therefore it too produces an erratic quantity and temperature of heated water. If anything a production metallizer has a more predictable output. The production cycle is known and so the period and quantity of heat can be predicted fairly accurately and apart from occasional unforeseen downtime would represent a regular source of available heat throughout both day and night. This ought to make this a more easily utilised source of pre-heating than the rooftop solar collectors.

Therefore it ought not to be beyond the intelligence of the metallizing industry to make better use of the exhaust hot water by recovering an amount of the heat and thus making an energy saving in the process.

Deposition efficiency improvement

It could be considered that the largest loss of energy in an aluminium metallizer is the collection efficiency of the aluminium. Often only 50% of he aluminium is collected on the web. A simple energy improvement would be to collect more aluminium on the web. One option for this would be to increase the deposition drum diameter. The down side of this is that the capital cost of the whole machine increases as well as the energy cost to pump a larger system and an increased energy cost in the increased quantity of material that goes into the larger system.

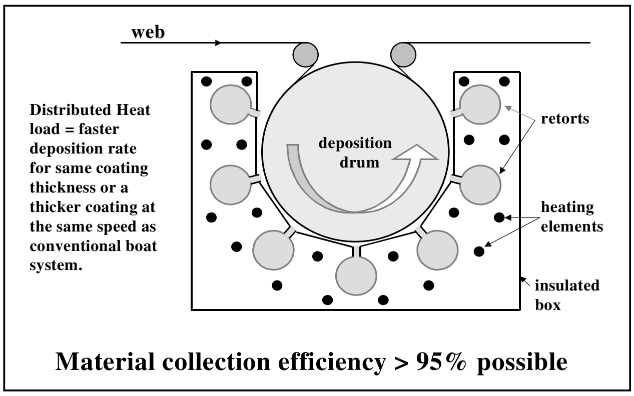

Figure 2. Schematic of distributed deposition source.

A second option is to use a high collection efficiency source as shown in the schematic in Figure 2. As many will know I have championed this type of source for some time. In my view the arguments only get stronger as the energy cost rise. The high collection source uses full width evaporation sources that are distributed around the deposition drum. As each source only has to contribute a proportion of the deposition they can be located closer to the drum and so the deposition losses are reduced. As there are several sources around the deposition drum the heat load is better spread and so the machine can also run faster than conventional machines.

A production machine was made for a different material and the collection efficiency was >95%. If this were carried through to the aluminium deposition the energy cost per unit area would be almost halved using this type of source (6).

Sidrabe have for years produced special resistance evaporation sources that could be fed from the ends that look capable of being used for distributed sources. (7). Also the in-line web coaters in Japan have used coated ceramic boats with lifetimes of over 100 hours (8). This would suggest that the use of distributed high material efficiency sources is entirely feasible. It only needs someone with the desire to make this happen to get a machine built.

Even if this approach were adopted it still only accounts for one third of where the input power goes. It is also worth reviewing the other two sources of energy loss, the water-cooled end connectors and radiation losses.

Energy reduction by design changes

The radiation loss would be reduced if it were possible to reflect some of the lost heat back onto the source. To some extent this already happens as everything within line-of-sight of the source heats up and radiates heat. This is not particularly efficient and too much heat is lost. It is entirely possible to design a high reflectivity shield to be placed behind the source to minimise the radiative heat loss and reduce the power required for the boat to reach the evaporation temperature.

The arguments against even trying this approach all relate to the fact that this particular area of the system is dirty. The aluminium can splash and with spits and backscattered material this whole area gets dirty quite quickly. The argument is that the difficulty in cleaning or the cost of regularly replacing a reflector would not justify the cost or the effort. This argument has never been proven with any real evidence. One possibility is that it has always been a convenient argument to justify not making the effort to test out the effectiveness and cost of such a reflector.

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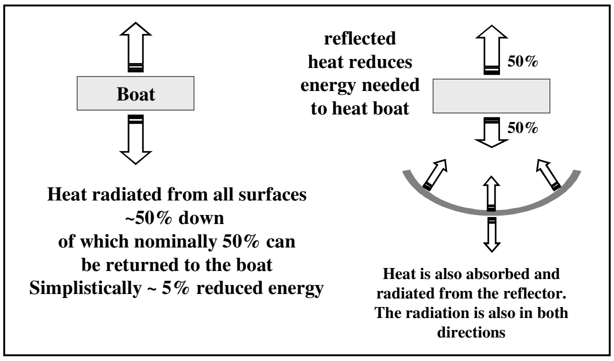

Figure 3. Heat reflector for reducing energy requirement for resistance heated evaporation boats.

Energy reduction by operational changes

Pumping is another item that has a significant high-energy consumption in aluminium metallizers. There has for some time been an economy option offered on new metallizers although few of the buyers opt for this control package. Included in this package are automatic controls to reduce the heating to the diffusion pumps during the time they are on standby between metallizing operations. Similarly when the system is at atmospheric pressure the roughing pumps, that may also be the diffusion pump backing pumps, do not need to be operating at full speed and can be operated at reduced power that will still sufficiently back the diffusion pumps that are only pumping a limited small closed volume. This optimisation of the power can make significant power savings. An example of this would be a reduction in power of the order of 60% during standby. This then begs the question, 'how can anyone elect to not chose the option?'. Again one has to suspect that some users still regard energy as being cheap enough that they can squander it.

COST OF WASTE.

The cost of disposing of manufacturing waste has been steadily increasing. In one paper, by the US Environmental Protection Agency, there were four main sources of waste identified with vacuum metallizers (9). These were scrap aluminium, nitrogen gas, scrap polypropylene and polyester film and finally scrap cardboard cores. Unfortunately this study also monitored solvent coatings too and all the recommended waste saving opportunities were for the solvent coating process and none for the metallizing process.

Earlier the comment was passed that development is progressing to produce packaging products that have structures that can still be recycled rather than scrapped. Part of the problem that some materials have is that many of the materials have to deliver a particular barrier performance. Lamination is used as a method of improving the performance of a more basic material that does not quite give the necessary performance. This is really a failing in the understanding and attention to detail in the process. A metal foil or glass sheet is regarded as having superb barrier characteristics. This includes thin foils or thin glass. The question that many have asked is why this same barrier performance is not available from vacuum depositing the same materials onto a polymer carrier. There are many references that describe the deposition of barrier coatings (10 – 16) and some include suggestions as to why the performance is not as good as it should be. If the quality of the substrate, or more particularly the quality of the surface and the cleanliness of the polymer substrate surface, can be improved there is no reason why the barrier performance should not be raised. This would enable simpler packaging products to be produced. This in turn ought to reduce the packaging costs as well as reducing the energy input into the final packaging materials. Added to this would be the improved opportunity to recycle the materials and thus reducing the environmental impact too.

CONCLUSION

Most vacuum coating processes have not yet been fully optimized with energy use and environmental issues in mind. This is good news because it means that there is plenty of scope for improvements. Hopefully some of the items mentioned above will show that there is still an opportunity to make everything from design changes to process changes including materials changes that can all reduce the energy footprint.

The more difficult decisions that the larger companies have to wrestle with are the strategic choices. By their nature these are long-term and high cost decisions that can affect the company performance. This will often cause the decisions to be delayed until there is sufficient consumer and government pressure to help the decision makers to push through decisions that might have shareholder & stock market opposition.

One could suggest that even though energy costs have, at the time of writing this, fallen back, the time is right to start to make the effort to review the design of all vacuum coaters with the goal of minimizing energy use and environmental impact. Including methods of recovering more of the waste heat that all of these methods produce. It is worth bearing in mind that the last rise in energy prices is viewed as small compared to the price that energy will cost in the near future. The last price spike was really a wake-up call that we all ignore at out peril.

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