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Title.

An investigation of mechanisms involved in the web-to-drum heat transfer coefficient when using gas injection between the web & drum.

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Extended Abstract

Background.

Many vacuum deposition processes are limited in the speed they can be run at because of the deposition heat load. In previous work it has been shown that the rate-limiting factor is the heat transfer coefficient between the back surface of the polymer web & the cooled deposition drum. This heat transfer coefficient is not only the rate-limiting factor but is also a variable & is also generally an unknown variable. The heat transfer coefficient depends upon the surface roughness of the deposition drum, the surface roughness of the back surface of the polymer web & the moisture content of the polymer. The surface roughness of the two surfaces controls the number of point contacts between the two surfaces & this determines the amount of heat transferred by direct conduction. The moisture content of the polymer determines the amount of gas trapped between the web & drum which enables further transfer of heat from the web to the drum. As the moisture content is different for different polymers the heat transfer coefficient will also be different for different polymers. Even with the same polymer the moisture content will also vary. The moisture content can be dependant upon the process conditions and also the humidity during manufacturing & also downstream processing & storage.

Hugh Clow developed & patented (ref. 10) a process for injecting gas between the web & drum as a method of improving the heat transfer between the web & deposition drum. This process has been used on some high-speed metallizers to improve the deposition speed.

Other deposition processes also have a problem of removing the heat but the deposition rate and hence the winding speed is much lower.

The perception has been that gas injection would not work for slow speeds & narrow webs. However nobody seemed to be prepared to define where the cut-off point on speed & width might be.

Thus this led to putting the question, where is the boundary of the combination of speed & width where injecting gas is a benefit?

This also led to other questions such as if the gas leaks out of the edge between the polymer & drum does the allow the edge to collapse on to the drum & seal the rest of the gas in or does the tension applied to the web squeeze the gas out from the centre of the web to the edge progressively & hence all the gas is lost within a finite time? The first scenario would suggest that the gas could still be a benefit at slow speed whereas the second scenario would suggest that it would not.

Process

The analysis looks at the dissipation of the heat load by radiation, conduction & convection between the web & drum. In particular looking at the benefits of using a gas injected between the web & drum and the possible limitations of using such a process at low speed or on narrow web systems.

For polymeric films on steel coating drums the web to drum heat transfer is significantly affected by the conduction through the small amount of gas trapped between web and drum where the mean free path of the molecules is much bigger than the gap. Radiation is a small component and direct conduction is limited relating to the surface roughness of the two surfaces. Previous work has made estimates of heat transfer but based on gas conductivity where intermolecular collisions dominate. Our (theoretical) analysis, based on free molecular transport of heat (kinetic energy) confirms the size of the coefficients and dependence on gas density (pressure) but not gap size and suggests that higher values might occur.

We have an estimate of the molecular flux due to density-gradients also based on free molecular flow (like Knudsen flow) in a small gap. Using this, we have an analytic model (solution of PDE) of the gas density distribution in the gap as a function of position along and across the moving web, which then defines the spatial variation in heat transfer.

The model shows the potential effects of molecular properties, web width, web speed and injected gas density on heat transfer and friction.

It appears that as speeds are lowered, gas leakage from the edges could cause significant drops in heat transfer and the effect will be worse with narrow webs.

Summary.

It is expected that the presentation will follow the path taken in exploring this problem. Taking account of some of the earlier work (e.g. ref 8) and answering the questions initially posed. Thus highlighting the speed & width at which the benefits are marginal.

Also the presentation will compare performance difference of different gases such as argon versus air or water as the injected gas.

This work also demonstrates that in systems where injecting the gas is not appropriate there will be an uncontrolled variable that is likely to affect the process. This variable is the water content of the polymer. This will lead to a rate of diffusion of the moisture out of the back surface of the web that is related to the water content & the time the polymer is under the high heat load. This in turn will affect the heat transfer coefficient and thus the effectiveness of the cooling of the web & thus the maximum temperature the web will reach.

For those interested in the light reading that was used by Mike McCann in developing this work some of the key references are listed below.

References.

1. Tabor, D. 'Gases, liquids & solids & other solid states of matter' 3rd Edn
   Cambridge University Press 1991 ISBN 0-521-40488-6

2. Bird, R Byron, Stewart & Lightfoot. 'Transport Phenomena' 2nd Edn
   John Wiley 2002 ISBN 0-471-41077-2

3. Gombosi, Tamas I. 'Gaskinetic Theory'
   Cambridge University Press 1994 ISBN 0-521-43349-5

4. Bird, G.A. 'Molecular gas dynamics & the direct simulation of gas flows'
   Clarendon Press, Oxford 1994 ISBN 0-19-856195-4

5. Bennett, C.O., Meyers, J.E. 'Momentum heat & mass transfer' 3rd Edn.
   McGraw Hill 1998 ISBN 0-07-050207-2

6. Pitts,D., Sissom, L. 'Heat transfer' 2nd Edn.
   Schaum's Outline Series. McGraw Hill 1998 ISBN 0-07-004671-9

7. Gatreau, R., Savin, W., 'Modern Physics' 2nd Edn
   Schaum's Outline Series. McGraw Hill 1999 ISBN 0-07-024830-3

8. Schwartz, W., Wagner,W., 'Thermal limitations in roll coating processes'
   Proc. 28th Annual Technical Conf. Soc. Of Vacuum Coaters 1985 13- S11.2

9. McCann, M.J. 'Control of distributed parameter systems'
   PhD Thesis Imperial College. London.

10. Clow. H. et al 'Coating apparatus for thin plastic webs'
    Application Serial No 07/254,088 filed Oct 6th 1988 now abandoned
    Continued as application No 626,320 - Patent No. US 5,076,203

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