Recent Developments in paper drying

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SUMMARY

Recent developments in drying of paper and board are reviewed with emphasis on novel concepts which are still in their infancy as far as commarcialization is concerned. Specific topics included are : through drying, air drying, combined impingement and through drying, press drying and vacuum contact drying. Advantages, limitations and current status of each process are noted where appropriate.

Papermaking is essentially a massive dehydration operation. Efficient removal of water is thus the key function of a good papermachine. Water is removed more cheaply by mechanical means (e g. pressing) than by thermal means. Traditionally, cost ratios of pressing/drying of about 1 : 5 have been used for economic studies With soaring energy costs a ratio of 1 : 10 is rather conservative by today's standards In energy terms it is estimated that steam usage in mills is 4 to 6 times the total electrical consumption. Clearly, strong incentive for improvement of the drying system and its thermal efficiency already exists.

It is obvious that it is desirable first to improve the press section since a 5 percent increase in moisture going into the dryers can increase the drying requirement by 25 percent. The final moisture content is also important. Because of crossmachine direction moisture profiles most mills are required to overdry paper. Since this takes place at low moisture levels laws of thermodynamics require an exponential increase in energy requirement to get rid of the moisture at such low levels. It is generally accepted that one percent increase in (average) reel moisture results in 1.5 to 3 percent increase in dryer capacity. In the opinion of the author this is an understatement.

Papermaking is a highly capital-intensive process. Thus, the industry worldwide is understandably reluctant to invest in machines based on entirely new technology however well-proven and economic on the pilot scale. The dryer section on most paper machines currently installed is thus based on the same drying technology as the machine installed several decades ago. Of course improvements have been made on efficient condensate removal systems to improve heat transfer performance, better pocket ventilation systems, better dryer clothing to minimize sheet flutter problems in the open draws, better control of the drying process etc. However, the basic concept of contact drying is unchanged. As machine speeds have increased the dryer train has become longer to permit adequate dwell time. Without undermining the importance of finding ways of improving the steam can dryers (which do over 80 percent of drying in the USA) and their performance it is the opinion of the author that it is high time the industry pays adequate attention to the newer concepts that are being developed at a painfully slow pace.

The objective of this paper, is to review some of the recent work on drying of paper principally work presented at DRYING '80, the Second International Symposium on Drying held at McGill University in July 1980. Both fundamentals and applications were discussed. Areview of the fundamental and simulation studies is beyond the scope and intent of this article. The texts of papers presented at this conference are available in DRYING '80, Vol. 1 and 2, available from Hemisphere in North America and from McGraw-Hill elsewhere in the world[1].

CLASSIFICATION OF RECENT DEVELOPMENTS

Recent published reports on drying of paper can be classified in one of the following categories :

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a) Papers dealing with conventional multi cylinder dryer;

b) Papers dealing with relatively new drying technology already in use commercially;

c) Papers dealing with novel concepts which are at laboratory or pilot scale stage, and

d) Papers dealing with modelling or simulation of paper drying and paper dryers.

It is the prime objective of this paper to introduce the reader to the sources of recent literature and to present some details on recent papers in Categories (b) and (c .

Through drying and air floater drying are relatively new technologies which have found considerable applications industrially (Category (b)). Combined through and impingement drying, press drying and the most recent Convac drying process first unveiled publicly at DRYING '80 by Tampella of Finland belong to Category (c). While the first two processes combine well established concepts to enhance drying rates the Convac process is an entirely novel concept. It is still at a laboratory stage and continuous pilot testing is expected to be underway currently. If successful this process shows the potential for a real breakthrough in drying technology since it can yield drying rates up to 30 times those attained in steam cans. Press drying is particularly suited for board grades while the Papridryer process is ideal for permeable grades such as newsprint.

THROUGH DRYING

Through drying is a process of drying a wet, porous medium by the passage of hot air through its mass. Since the heat and mass transfer areas are increased due to the intimate contact of flowing air with the fiber surface, the heat required per pound of water evaporated and the operating costs compare favourably with those of conventional methods[2].

The thermal efficiencies of through dryers were increased up to 90% by various workers, with use of several drying stages and air recycling[3] or using cascade systems[4]. There is also the possibility of operating the through dryers at low temperatures by using low grade waste energy. Honeycomb vacuum cylinders of diameters in excess of 6 metres are now operating at speeds greater than 4000 fpm.

Use of through drying for drying of tissue paper, toweling etc. has increased due to (a) the extremely high forming speeds achieved by twin-wire formers outstripping the capacity of the largest Yankee dryers; (b) consumer preference for soft, high-bulk products; (c) manufacturing advantages of single-ply products; (d) little or no press dewatering needed in through drying, and (e) better, increased productivity coupled with higher thermal performance of through dryers.

Although through drying has become the dominant method of drying for porous grades (e.g. tissue, towelings, filters, blottings, non-wovens) in recent years, there is not a reliable and generally applicable approach for the prediction of the heat and mass transfer rates. It is known that there is a minimum pressure difference (threshold pressure) which can be related to the surface tension forces, below which no flow occurs. Once this pressure is achieved, the drying process take place. Chu and Kuo[5] divide this process into three different periods in which drying rates are principally controlled by three different mechanisms of water movement, i.e., simultaneous two-phase flow, capillary action, and diffusion. These drying phases are called mechanical dewatering, first and second falling rate periods, respectively. Chu and Kuo derived different expressions for drying rates for each period which agreed with an average deviation of 11% with their own experimental results.

In recent years, different mechanisms were proposed by various workers in order to estimate the heat and mass transfer rates in through drying. Rohrer and Gardiner[6] considered the air flow through the web to be analogous to the turbulent flow through ducts. Wedel and Chance[7] tried to analyse the air flow as an external flow over a cylinder. Both approaches agreed well enough with their own experimental results.

In his study of textiles and very thin tissue products, Gummel[8] compared his experimental findings with the heat and mass transfer equations derived for similar flow conditions for laminar flow through pipes with entrance effects. This comparison showed that the experimental values are substantially lower than the theoretical ones.

Further fundamental studies and experimental data are required to describe the through drying mechanism since its value is proved by commercial applications. Current studies at McGill University are aimed at improving the understanding of the through drying process for thin sheets.

AIR DRYING

Use of air dryers or air floater dryers as an alternative to cylinder drying has been on the increase especially for drying of pulp sheets, coated papers and board. Here the web is supported on strategically located and directed air jets which perform the dual role of conveying the sheet untouched by solid surfaces, and drying it in transit. Since drying takes place tension-free (and hence allowing unrestrained shrinkage) such a dryer can produce sack paper with notably better properties i.e. higher modulus of elasticity, stiffness and ultimate tensile strength-properties desirable in board grades.

Richardson[9] has reviewed and compared the thermal, production and cost performance of infrared, dryer cans, air caps and air foils for drying of coated paper. Since the drying technology considered is conventional these units will not be discussed here.

Bennet[10] has presented operating principles and applications of floatation of air foil dryers. Since there is no mechanical contact between the dryer and the web they have become well-established for drying coated papers and for products like bag paper and toweling. Advantages claimed are: high drying rates, uniformity of moisture profile across width and favourable energy efficiency.

COMBINED THROUGH AND IMPINGEMENT DRYING

It is well known that the conventional "steam can" drying method makes it difficult to achieve higher capacity and better performance as the machine speed and width increase. It has been proven experimentally that by combining impingement drying with through drying the drying rate (in the constant rate period) can be increased several fold (Burgess *et al.*[11]). Clearly this process (also called Papridryer, after the original development at the Pulp & Paper Research Institute of Canada) can only be used for permeable sheets such as newsprint. Such a drying unit consists essentially of a high velocity hood wrapped around a vacuum cylinder. Hot air jets (up to 300°C) impinge against the web supported on the vacuum roll causing high rates of heat and mass transfer at the surface of the moving web. The vapour formed within the sheet is removed by suction thus maintaining high levels of concentration gradients for mass transfer to occur within the sheet. Application of suction has a synergestic effect. Firstly, it accomplishes through drying. Secondly, suction causes a steepening temperature gradient at the web surface enhancing the external heat transfer coefficient. The magnitude of this enhancement can be measured more readily only for impingement on stationary surfaces. Saad[12] has shown that suction does improve the impingement heat transfer rate, relatively more significantly away from stagnation zone.

In the design of an impingement dryer with or without suction (e. g. a Yankee dryer for tissue paper) it is important to be able to assess the effects of multi-jet arrangement, cross-flow effects, effects of web motion, effect of large temperature difference between the air jet and the web (which is at the wet bulb temperature under constant rate drying condition) etc. Several projects are at various stages of completion in the Department of Chemical Engineering at McGill University under the direction of Professor W.J.M. Douglas and the author. Both analytical and experimental studies have been carried out. Das[13] has developed heat transfer correlations for impingement under temperature differences of up to 300°C. Van Heiningen[14] has measured the effect of surface motion on slot jet impingement heat transfer. This work is being extended by B. Huang[15] to obliquely impinging jets.

Cross-flow effects have been investigated by Saad[12]. P. G Huang[16] has examined numerically the effects of cross-flow and wall motion. Numerous other studies in our laboratories have covered single and multiple round jets, effects of confinement, effects of curvature, flows in semiconfined impinging jet configurations etc. Huang and Mujumdar[17] have utilized some of the correlations developed in our laboratory to formulate a transient model for combined impingement and through drying. Comparison of results of these simulations with data obtained on pilot-scale and mill scale dryer units is excellent, despite a number of assumptions built in to circumvent our ignorance of this complex convective heat/mass transfer problem. This simulation could be used to optimize the design of a Papridryer-type process.

On the basis of preliminary design calculations it has been shown that only six Papridryers (2 m diameter) would replace a train of about sixty steam can dryers in today's high speed newsprint machines. Although the resulting space savings are obvious the energy costs depend on the geographic location of the mill and must be evaluated carefully for each individual case. Among the numerous advantages of the Papridryer process are: fast response to control action, ability to correct moisture profile and better energy efficiency. It is noteworthy that this dryer can be designed and fabricated using known technology.

Very recently Attwood and White[22] surveyed the prospects and possibilities of press drying wherein external pressure is applied to the wet web while the sheet temperature is above 100°C. At elevated temperatures the fibre components are softer and the moist sheet is more compressible; this results in increased bonding and strength. Improved contact between the drying cylinder and the sheet also results in significantly higher drying rates. Most of the work in press drying is directed towards use of high yield pulps in production of linerboard with emphasis on use of hardwoods in order to lessen demand for softwood species. Work is currently under way in the USA, UK and Sweden on press drying development. Attwood and White have enumerated a dozen major advantages of the press drying process, on the basis of laboratory and pilot tests. Design of a more energy efficient papermachine that is also simpler is one of the potential spin-offs of this novel process. It is important to point out that press drying can, in principle, be applied at each or all of the three stages in the papermaking process after the web is dewatered to between 85 and 55 per cent; from 60 to 40 per cent moisture content; and from 40 to 20 per cent moisture or less. The last stage is the most important from the point of view of strength development.

This process is still in the stage of development. A number of problems remain to be solved. Among these: operation at higher speeds and outputs, design of fabrics to withstand relatively high pressures in the nips; drying cylinder design to permit the high drying rates attainable; problems of keeping cylinder surface clean and prevention of web adhesion to the cylinder.

A number of possible machine configurations have been proposed by Attwood and White[22]. These have the advantage of better energy utilization since unrefined stock and different furnishes can apparently be used. Without additional studies with higher speed machines it appears that such machines can be designed today only to run at moderate speeds. In view of the above it appears that papermachines using press drying are particularly desirable for developing countries. Indeed, as a pleasant reversal of the direction of technology transfer, developing countries can contribute to the papermaking technology of developed countries by generating mill scale data for use in improved design and operation of newer machines in the future.

PRESS DRYING

The FPL (*Forest Products Laboratory, US Dept. of Agriculture*) press drying process combines the mechanical and thermal means of water removal by simultaneously pressing and drying the wet sheet. It has been shown that press drying improves interfibre bonding which allows use of high-yield hardwood and softwood pulps for strong, stiff paper products such as linerboard. Press drying requires less energy because the paper sheet has lower moisture entering the drying section. According to a 1980 economic evaluation of the process by Ince[18] press drying could result in a saving of about US $32. per metric ton of linerboard.

Currently this process is still at laboratory stage. Static bench scale tests are being performed at FPL to obtain drying and heat transfer data needed for a design calculation. Byrd[19] has summarized the results of recent bench-scale studies of press drying of linerboard He has presented a figure to estimate dryer size needed for paper machine speeds ranging from 50 to 2000 fpm. Clearly, increasing press pressure and drying temperature result in significant reduction in dryer size. Results of the static tests are being applied to the design of a continuous press drying apparatus for use in design of a full-scale continuous process. It is likely that press drying will reduce equipment requirements in drying as well as pulping processes.

CONVAC DRYING

Lehtinen[20] has described the Convac dryer which is really a vacuum drying technique for paper. Here the paper is pressed against a heated metal surface with a permeable felt and an impermeable metal backing which is water cooled. Before drying commences air is removed from the felt by application of vacuum. Once drying starts this vacuum is maintained by continually condensing water vapour which evaporates from the web and percolates through the felt, on the cold surface. This concept has been tried on a static laboratory dryer with encouraging results. Drying rates exceeding 145 kg m^{2}h were attained with metal temperature of 170°C. This properties of paper and board dried in Convac dryer resemble those of press dried webs (i.e. high stiffness, tensile strength etc).

In convac drying the web surface contact with the hot surface becomes smooth. By drying in two stages and exposing each side to the hot surface both sides can be smoothened. In a proposed commercial dryer design the Convac design resembles an MG cylinder covered with a felt and a steel band. Instead of a convection hood (for the MG cylinder) the Convac unit would have spray nozzles for water to cool the steel band.

CLOSURE

In the interest of brevity several important subtopics have not been included in this survey. The interested reader is referred to DRYING '80 (Volumes 1 and 2) and DRYING '81 volumes for articles relating to conventional drying, simulation and energy saving potential in papermaking. Drying of pulp and wood products is also an area of peripheral interest to the papermaker. References to these topics are also included in these volumes. For a brief and interesting report on the DRYING '80 proceedings relevant to the pulp and paper industry the reader is referred to Crotogino[21].

It ts hoped that this paper will stimulate the interest of the reader in the field of drying. Spurred by the sky-rocketing energy costs this energy-intensive operation is bound to receive increasing and closer scrutiny in the years to come.

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