A simulation model for combined impingement and through drying

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SUMMARY

Air drying of various paper products such as newsprint, tissue grades, towelling. pulp sheets etc is recognized as viable alternative to the traditional process of contact drying on system heated cylinders. Several commercial installations using air drying systems are already in use worldwide. Hot air impingement drying and through drying are well developed processes with potential for improvement and additional applications not only in the paper industry but also in textile and nonwovens industries, Combination of impingement and through drying has been shown to be a technical feasible and attractive process for drying of newsprint and also textiles. The objective of this article is to present a summary of a mathematical model developed by the authors which demonstrates the technical advantages of the system. The results presented can be used. with suitable interpolation or judicious extrapolation to design of combined impingemet and through drying system. Limitations of the model are also pointed out despite the good agreement observed with published data on pilot and mill scale trials.

With continually escalating energy costs there is renewed impetus for finding newer ways of drying the paper web since drying is by far the most energy intensive step in the massive dehydration process that is conventional papermaking. For the Canadian newsprint industry the cost of drying newsprint is now in the neighbourhood of about half a billion dollars per annum. Even a marginal improvement in the drying economics, productivity of the machine or product quality can therefore pay rich dividends even in the short run. The traditional process of cylinder drying on a train of steam cans represents well over 85% of all dryers in the US paper industry; the percentage is much higher elsewhere, probably approaching 9 % in developing or less developed countries. The concept of contact drying was first patented in France some 160 years ago. No doubt, impressive gains have been made in the design and operation of contact dryers in the past few decades. However, it appears that the development has reached a saturation state; further improvements do not appear to be forthcoming at reasonable costs. Today, we can form paper web at speeds that today's contact dryers are unable to handle. It is thus a bottleneck in the papermaking process at least as far as the most modern papermachines are concerned. It is a problem which is, happily, not faced by most papermakers, and they are unlikely to face it in the near future.

The traditional cylinder dryer has a number of readily recognizable limitations. Among these are : slow drying rates requiring massive dryers which occupy large floor space; large thermal inertia of the system does not allow fast control or localized control of the drying rate; in most designs the product has a nonuniform moisture profile that cost additional energy and power to correct; at very high speeds the sheet is liable to undergo flutter resulting in wrinkling or breakage of the sheet and hence considerable downtime especially on faster machines; thermal efficiency is not very high etc. etc. Despite these limitations the century-long experience which papermakers have had with this dryer has made it a success.

With the advent of high speed formers coupled with increased costs of drying, which nearly quadrupled in less than a decade as far as Canada is concerned,

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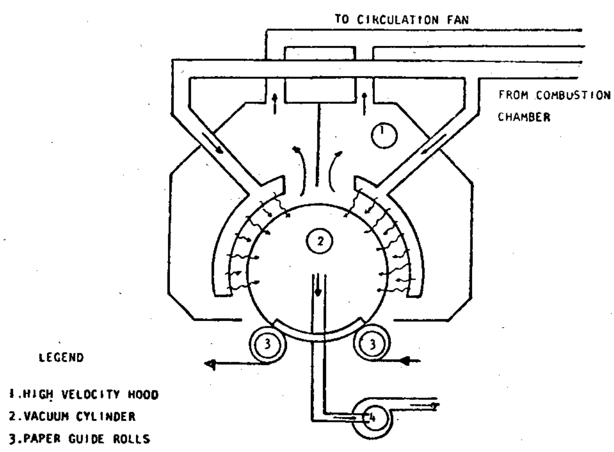
it is now necessary to examine alternate, more efficient and cost-effective, means of drying the paper web. Mujumdar has already reviewed the recent developments and trends in drying in the pulp and paper industry[1,2]. Specifically, the processes of press drying developed by the US Department of Agriculture, the most recent Convac process announced by Tampella Oy of Finland, a thermally-induced vacuum contact drying process under study at the Institute of Paper Chemistry at Appleton, Wisconsin, USA, and the Papridryer process developed and tested by the Pulp and Paper Research Institute of Canada in the late sixties, appear to have real commercialization potential. The interested reader is refferred to the references cited in[1,2] for further details. This paper will consider the Papridryer process exclusively since it has been verified in the pilot plant as well as a mill producing newsprint. This process is meant for newsprint which has reasonable permeability over certain moisture content range. Details of the process including operating data are available in reference[3,4].

Papridryer process is essentially a combined impingement and through drying process. Figure 1 is a schematic of the dryer. Hot air at temperatures up to 600 F impinges at velocities of up to 300 fps on to the paper web which is supported on a rotating perforated roll which is under suction of up to 20 inches of Hg. The jet slot width is about



Figuae 1—Schematic flow diagram of a simple Papridryer

1/8 in. while adjacent jets are about 1.50 in a part. The spent drying air is exhausted through round openings located strategically to minimize the adverse influence of crossflow on neighbouring jets The high velocity hood housing the multiple jet configuration covers about 270 degrees of the roll. Drying rates achieved by such a system are up to 10 times those obtained on a conventional cylinder dryer in the constant drying rate zone when unbound moisture is being vaporized. In the falling rate zone such a dryer is not recommended since the additional heat (which is not utilized for evaporation) is absorbed as sensible heat by the web leading to a significant fire hazard.

Simple calculations supported by pilot scale data show that a train of about fifty steam heated cylinder dryers on a typical newsprint machine today can be replaced with only about six or seven Papridryers. The space saving attained is easy to visualize. The capital cost saving unfortunately is not that dramatic; indeed preliminary calculations indicate that the cost of equipment and operation are at the present time comparable to those of steam dryers especially since the latter are a well developed technology. Indeed, since the Papridryer consumes considerable electrical power for air handling and generation of vacuum, the operating cost varies with location; the relative cost of fuel (natural gas or fuel oil) and electricity has a strong bearing on the cost of operation. Since higher thermal efficiencies can be attained the Papridryer process has a definite long term potential worldwide.

Among the advantages of the process one may cite: increased stability of the web due to suction high drying rates due to a synergistic effect of through drying on impingement drying, ability to operate the machine at higher speeds with less downtime, ability to couple the processes more readily with existing heat recovery processes etc. Another important advantage is the ability of the system to nearly instantaneous and highly localized control of drying rate. This makes the system easy to operate with the use of computer control.

The objective of this paper is to present some numerical results obtained by the authors using a simulation model they developed and published recently in Reference[5]. The interested reader is referred to that paper for details of the mathematical formulation including various assumptions and justification therefor. Only a few comments that have a direct bearing on the interpretation of the results, uncertainty and need for further refinement will be made in the following paragraphs.

Comments on the Mathematical Mode 1

It is basically a one dimensional transient formulation of the conservation equations for heat and mass utilizing a suggestion by Crotogino[6,7] that the overall drying rate is expressible as a linear combination of the two mechanisms of impingement and through drying acting independently. The two are weighted according to the amount of air involved in each process. Since application of suction produces a normal velocity into the sheet it is clear that impingement heat transfer should be increased by through flow. However, it is assumed that this effect is second order. Existing correlations, one due to Martin[8] and another due to Das[9] were used to evaluate the impingement heat transfer rate to the sheet and thus the impingement drying contribution in the wet bulb drying stage as well as the stage of removal of the bound moisture.

The through drying rate depends both on the sheet structure and the applied pressure differential (i.e. suction in the roll). A least squares fit of the permeability data of Brundette and Baines[10] was used to estimate the percolation velocity through the sheet. The air drawn through the sheet was assumed to leave saturated from the underside of the sheet, thus permitting calculation of the through drying rate. This is a good assumption for thick sheets which can be treated as thick packed bed; for thin beds good models are yet to be developed. A model proposed by Gummel[11] may be potentially superior to the simplistic approach taken here.

A correction was applied for the radiative heat transfer component. (See Crotogino and Allenger[7]. The vapour pressure exerted by the bound moisture in the wet sheet was estimated using a formula given by Wedel and Chance[12]; the falling vapour pressure of bound moisture is ascribed to a rise in the heat of adsorption of bound moisture as the web moisture decreases. Thus, the model also handles the falling rate calculations without any change in the formulation of the mathematical model. All fluid properties were corrected for effect of temperature and moisture content.

Since empirical equations are not available yet for heat transfer under impinging jets impacting on moving surfaces (as is the real case here) no correction is applied for this effect. There is reason to believe that the effect is small at high jet impact velocities and low surface speeds, which is the case here for the pilot and mill data. Extrapolation of this model to higher speeds or lower jet impact velocities may require correction for this effect. No correction is applied also for the effect of the through velocity on impingement. While the former effect tends to decrease the heat transfer rate the latter tends to enhance it. As will be seen from the results the good agreement attained with data is probably due, at least in part, to these and other compensating effects. It is noteworthy that Martin's correlation does not account for the influence of temperature dependent physical properties while that of Das does.

Colburn analogy was applied to estimate the mass transfer rate from the heat transfer correlations used. Since the Papridryer employs exhaust ports that minimize influence of cross flow, a new correlation due to Saad et al [13] which is for heat transfer under multiple slot jets impinging on a plane stationary surface with exhaust ports located midway between adjacent slot jets, was also used. This correlation gave results that were closer to the pilot results than those obtained using Martin's correlation for multiple slot jets with crossflow effects.

RESULTS AND DISCUSSION

Figures 2 and 3 compare the predicted drying rate performance published by Burgess et al for the pilot unit whose essential details are summarized below.

Vacuum cylinder diameter	380 mm
Dryer width	406 mm
Wrap of hood	300 degrees
Total dryer length	1000 mm
Nozzle or slot width	0.5 mm
Nozzle-web spacing	8.4 mm
Inter-nozzle spacing	3.8 mm
Normal machine speed	2.032 m/s

Note that all subsequent figures are in SI units.

A test run was made with a very slow machine speed to verify that the model predicted the drying behaviour accurately. This was successful as shown in Reference [2]. Previous paper used Martin's and Saad et al correlations which do not account for the effect of temperature dependent physical properties of air in evaluating the heat and hence the mass transfer coefficients.

Figure 2 must be looked at very carefully as it compresses a lot of information in one graph. Note that the stars refer to paper moisture at the beginning of each pass (or the end of previous pass) through the pilot Papridryer. Starting with initial moisture level of 1.92 kg/kg of bone dry paper, each pass through the same papridryer results in continually falling moisture content as shown in this figure. Whereas experimentally only the average drying rate in each pass could be measured, use of the transient model permitted us to account for the warm-up period for each pass and also the variation of the drying rate with distance (or time)

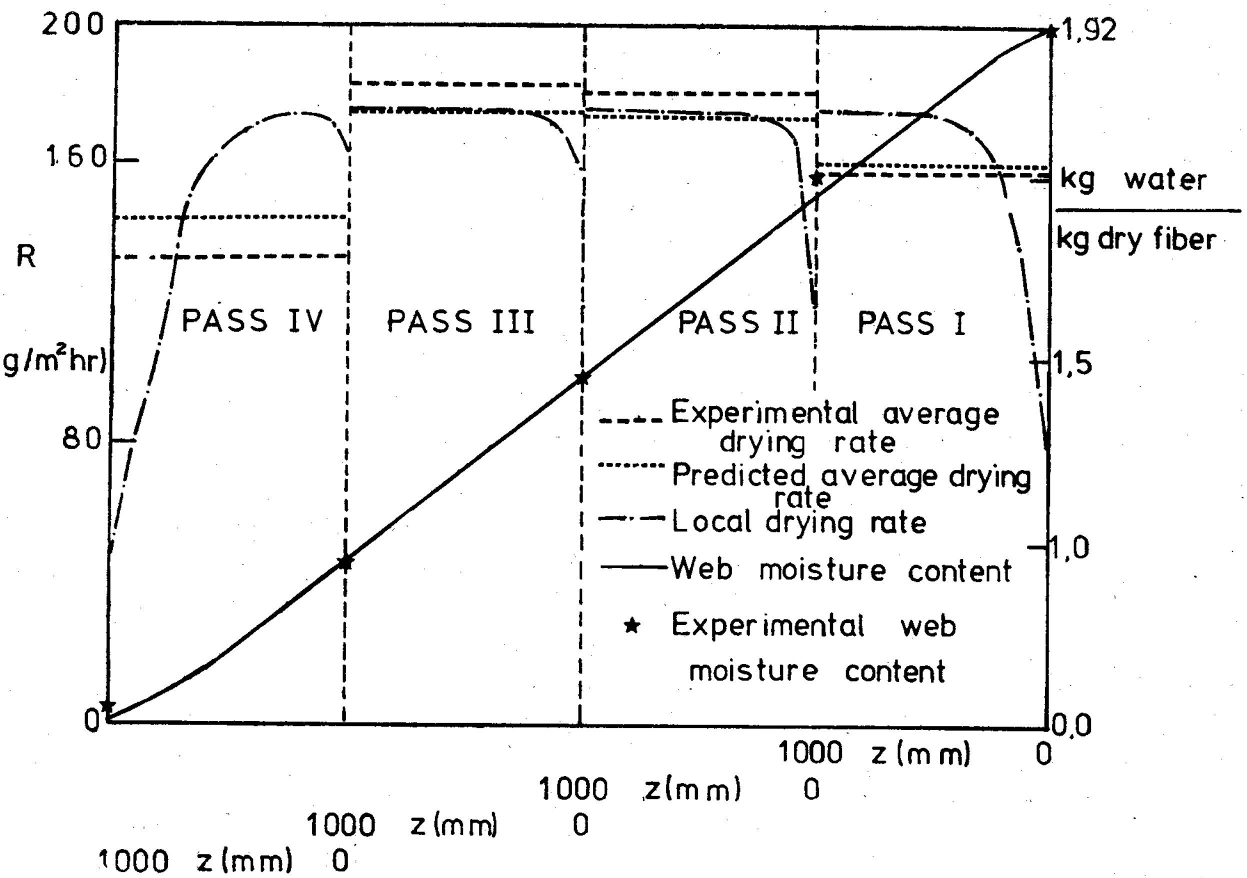
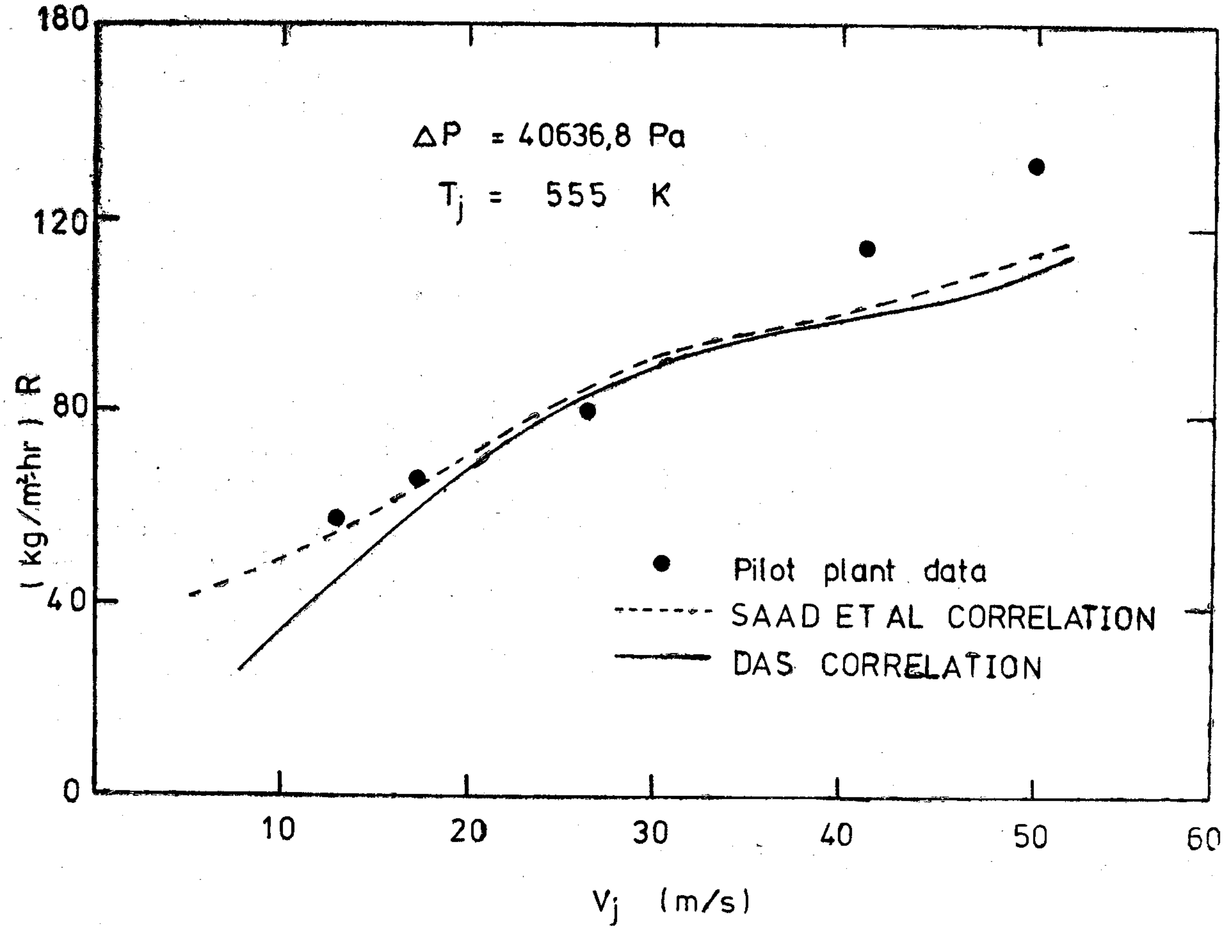


FIGURE 2

on each pass; these are shown as local rates of drying from which the average can be readily computed for comparison with data. In the first and fourth passes the model overpredicts the drying rate while the opposite is true in the middle two passes. The largest discrepancy is only about 10% on the average drying rate. It is understandably worst in the falling rate period. Also, part of the discrepancy is due to assumptions concerning the web temperature between passes. Prediction of the web moisture after each pass is almost exact. Accuracy of the experimental data is unfortunately not known.

Figure 3 shows the experimental effiect of jet velocity on the average drying rate for a jet exit temperature of 555 k and specified pressure differential across the web. Note that the permeability of the web is a function of moisture content and this is accounted for in the empirical fit of permeability versus moisture content fit used in the model. Two correlations were used in this simulation. Both performed well. Surprisingly the correlation which accounts more accurately for the effect of temperature dependent physical properties is marginally less accurate. This could be due to the fact that this correlation (due to Das) is for single jet while the Saad et al one is for multiple slot jets with exhaust ports between jets i.e. closer to the geometry of the Papridryer jets. It may be noted that the average drying rates attained are as high as 40-120 kg water evaporated/ m^2 h of dryer surface, which is well over an order of magnitude greater than what is obtained with steam cylinder dryers.

Figure 4 shows the effiect of pressure differential across the web on drying rate, other parameters being held fixed. A threefold increase in the overall drying rate is feasible over technically feasible range of suction that may be applied. However, since application of suction is an expensive process requiring electricity, it is doubtful if increase of suction to augment drying rates is an economic



FrGURE 3

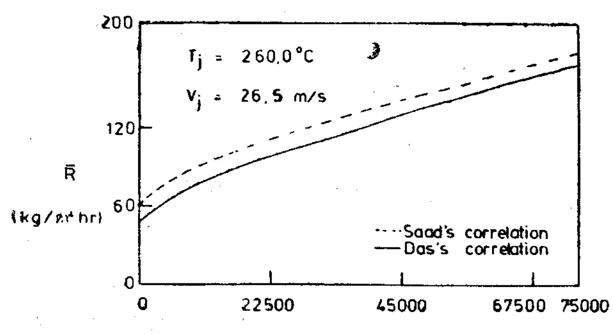


FIGURE 4

alternative. It is preferable to achieve shorter drying times through use of higher jet temperature initially and then through higher jet velocities.

Figure 5 shows the effect of jet temperature on the drying rate with suction pressure as a parameter. It is easy to see that the relative increase of drying rate with temperature is more siginificant at lower pressure drops across the web. A simplistic explanation for this phenomenon cannot be given because of the nonlinear nature of the problem. Use of data such as that displayed in figure 5 can allow a technoeconomic evaluation and possibly optimization of operating conditions for a combined impingement and through drying process. The permeability of the web is a very crucial consideration in choice of the suction pressure to be used. For example, a very low permeability mat will require application of considerable suction to obtain marginal gains in drying rates.

CLOSURE

In summary, it is shown that it is possible to predict the performance of a combined impingement and through drying process with the help of a simple mathematical model. It is shown that the predictions closely match the measured data on pilot scale. Although not shown in this paper this model was also found to give agreement with mill data which probably are less accurate in view of the difficulties in obtaining such data. In spite of the good agreement the authors believe that further studies are necessary to allow more accurate prediction of the drying rates in impingement and through drying systems.

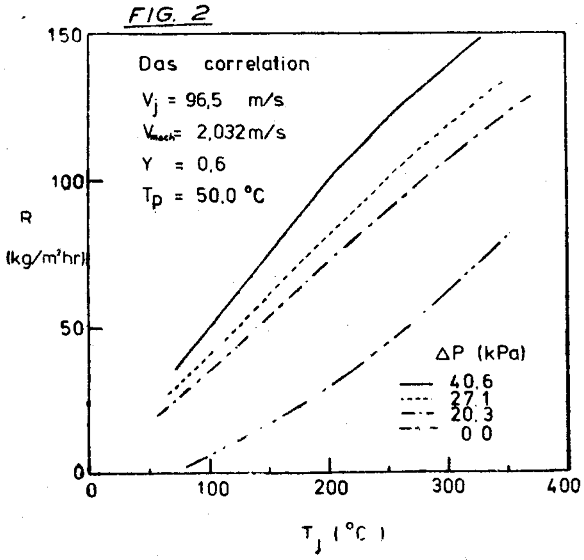


FIGURE 5

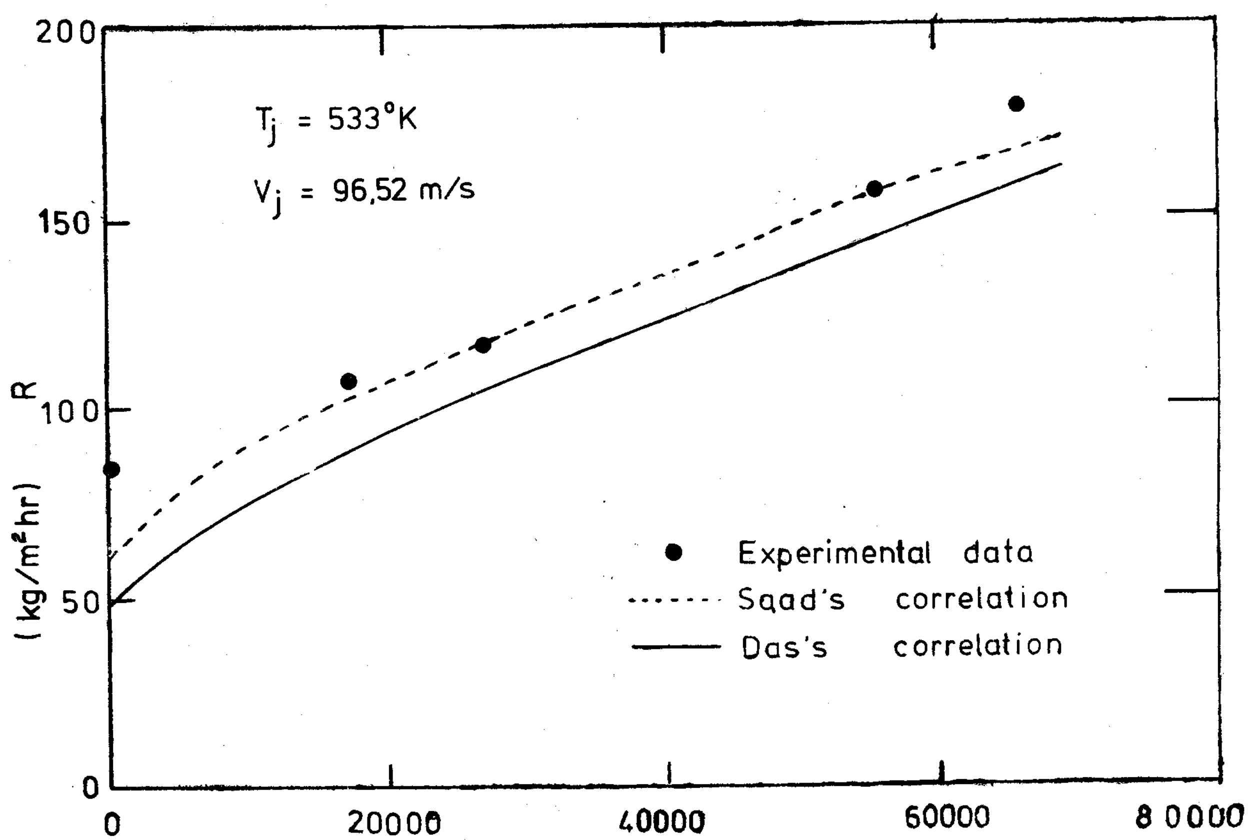


FIGURE 6

ACKNOWLEDGEMENTS

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