Super heated Steam drying of paper and board

MUJUMDAR ARUN S.,* CUI WEN-KONG*

SUMMARY

The author proposes steam drying as a technically feasible and economically attractive process for drying of various paper grades This novel idea is based essentially on substitution of hot air with superheated steam as the drying medium. This paper summarizes possible steam dryers found to be technically feasible on the basis of simple mathematical models. Experimental verification of the model results is under way in author's laboratory.

INTRODUCTION

Use of superheated steam as the drying medium has already been demonstrated as a technoeconomically viable and highly energy-efficient process, eitber at pilot plant or commercial scale, in various industries. Steam drying of pulp and hog fuel are notable industrial-scale processes already in operation in many countries. Another important drying operation in the forest products industries is superheated steam drying of vaneer and timber. This process has been tested at the pilot plant level. Aside from very significant energy savings, this process also yields better product quality while reducing the drying times. Stenter dryers using steam as the drying medium[1] have been developed in India for drying and curing of textiles at an energy savings of at least 35%. Considering that such a significant energy savings is attained by simply total recycle of the exhaust stream after impingement in the dryer (i.e.) no attempt made to make the system air-tight) it is entirely possible to obtain greater savings with superheated steam and optimized impingement systems.

Other applications for superheated steam as the drying medium include : steam fluidized bed drying of granular foodstuffs and of pulverized coal. Absence of oxygen avoids undesirable oxidation or denaturation reactions in foods and organic materials, thus giving a better quality product free of discoloration. Another highly important advantage is the elimination of fire and explosion hazard in a steam medium.

The Principal advantage of steam drying over air drying is the fact that the exhaust steam is also steam, albeit at a lower specific enthalpy, which can be reused more efficiently and at a much lower cost than humid air. In air drying over thirty percent of the thermal energy loss is accounted for the heat lost in the exhaust as economically unrecoverable. The exhaust steam from steam drying can be partially recycled as is or after compression or reheating or mixing with high pressure steam. Since the heat of vaporization of water in the wet product is not lost in the exhaust (as is the case in typical air drying without heat recovery systems) the thermal efficiencies of steam dryers defined in terms of a ratio of the latent heat of vaporization per kg of water to tbe heat input to remove 1 kg of water from the product, reach astonishingly high levels. For example, heat consumption of the order of only 20 percent of the latent heat of vaporization has been estimated for combined impingement and conduction drying in a Yankee type configuration[2]. Heat losses from the dryer and ancillary equipment become the major sources of inefficiency.

On the other hand considerable laboratory scale tests, mathematical modelling followed by pilot and mill scale trials are needed to justify the commericial potential of steam drying of paper. At a more fundamental level equilibrium data for paper-steam system need to be obtained at various pressures. As well, critical moisture contents of paper in steam environment is unknown. Further-

Department of Chemical Engg.
McGill University, Montreal Quebec, Canada
*Tianjin paper Co , Tianjin, people's Republic of China

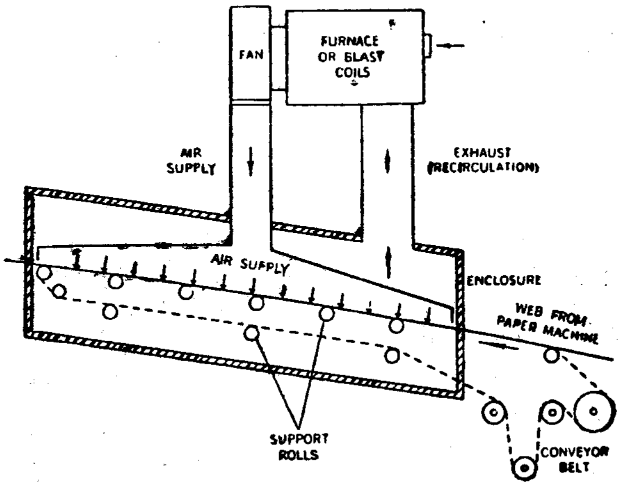
more, effect of steam drying on paper properties must also be tested.

SOME STEAM DRYING CONFIGURATIONS

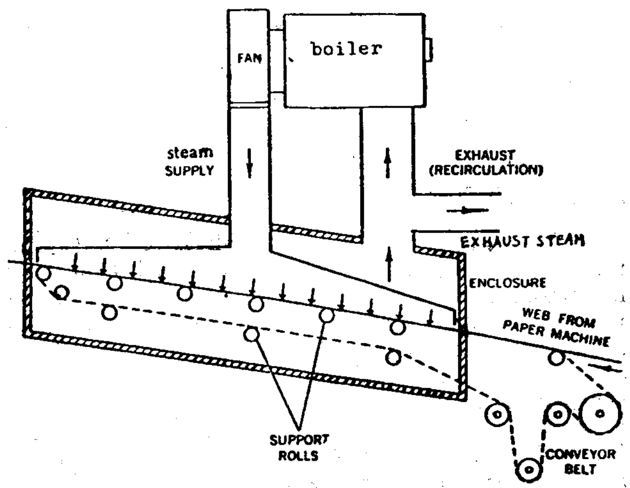
There are two principal air drying processes which can be adopted for steam drying viz. impingement and through drying. Figure-1 shows these concepts schematically. Impingement drying is highly efficient when removing surface or unbound moisture. Here the drying rate is externally (i. e. heat/mass transfer exterior to the web) controlled. Higher heat input generally means higher drying rates until the critical moisture content is reached. For air drying the critical moisture level is on the order of 35 per cent on dry basis. Below this level the drying rate falls under otherwise constant drying conditions while the web temperature rises due to reduced evaporative cooling. In this case the drying rate is controlled by internal transfer of heat and moisture. Through drying (as well as other exotic methods of valumetric heating of water such as RF or micro-wave drying) is particularly suited in this region while the effectiveness of impingement drying drops significantly.

Figure-2 shows schematically the following possible configurations for steam drying of thin paper which is permeable to steam at reasonable pressure differentials.

A. Pure impingement.



(a)



(A) Impingment steam dryer

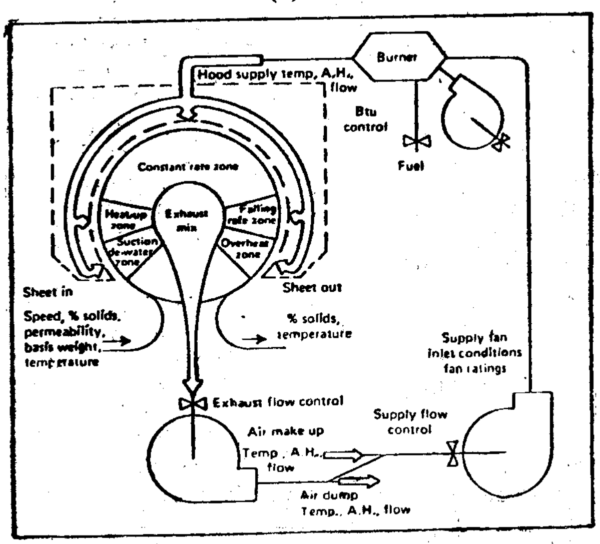
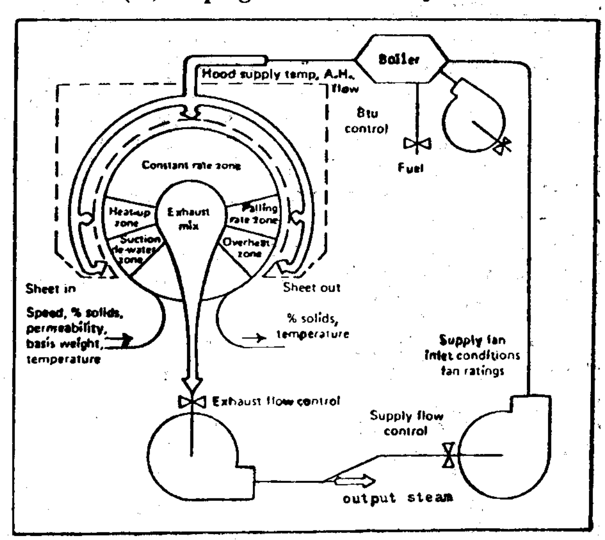
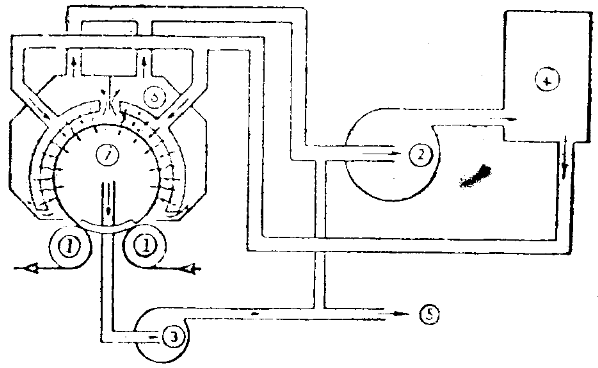


Fig. 1 Schematics of (a) impingement air dryer and (b) through air dryer



(B) Through Steam dryer



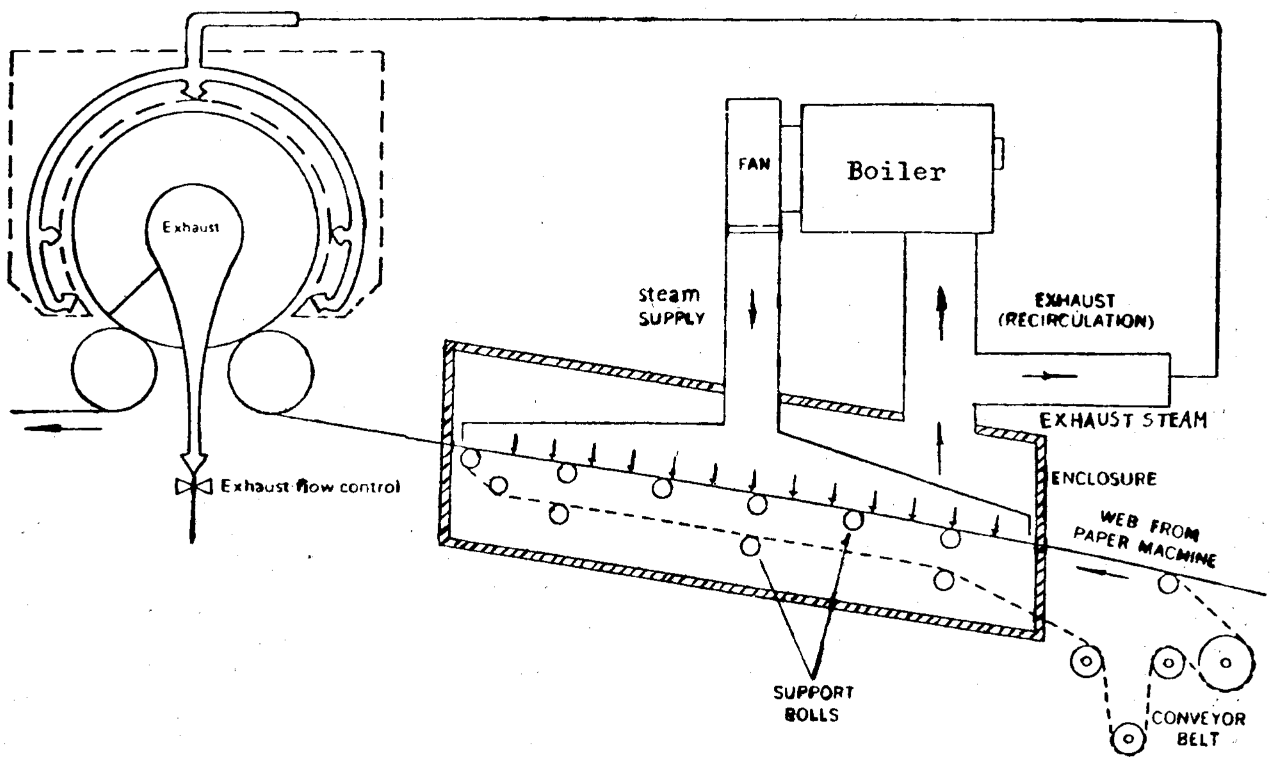
(C) Steam Papridryer; 1. Paper guide rolls; 2. Circulation fan; 3. Vacuum fan; 4. Boiler; 5. Exhaust steam; 6; High velocity hood; 7. Vacuum cylinder.

B. Pure through drying

C. Combined impingement and through drying

D. Impingement followed by through drying.

The estimated drying rates attained under these drying configurations are tabulated in Table-1. This table also contains a comparison with air drying. Note that the operating parameters such as temperature, pressure, velocity of jet or percolation flow rates in the case of through drying, cannot be the same for steam drying as in air drying. For estimation purposes only "reasonable" ranges of parameters are considered for the novel processes involving use of steam. The main point of this exercise is to point out the strong potential and prospects of the proposed steam drying processes.



(D) Impingement steam drying followed by through steam drying system.

Fig. 2 Possible configurations for steam drying of paper

TABLE—1 ESTIMATED AVERAGE DRYING RATES OF SEVERAL DRYERS, (kg/m^{2}h)

Conditions	Impingement steam	Impingement air	Through steam	Through air	Papri steam	Papri air	Impingement + through (steam)	Impingement + double-(steam)
Jet temperature T_j=580 K Jet velocity V_j=104 m/s hood open area A_{hoa}=2.6% hood pressure P_h=0.105 mPa ($\triangle P$=27 kPa, for papri only)	95 tissue	100 tissue			205 newsprint (3)	140	215	
T_j=580 K; Ph=0.105 mPa; $\triangle P$=28 kPa.			120 tissue	130 tissue				
T_j=600 K; V_j=100 m/s A_{hoa}=2%; P_h=0.4 mPa Pressure of steam for heating cylinder P=0.72 mPa								370 (2) tissue

Option D i. e. sequential impingement and through drying is a process which has roots in the essential feature of the drying rate curve. It is intuitively obvious that the optimal drying configuration is unlikely to be also optimal in the falling rate period. When internal heat and mass transfer rates dictate the overall drying rate it is reasonable to expect a different drying process to be optimal. In this case through drying is recommended since the drying medium then reaches the interior where heat is transferred and the moisture carried off under an applied hydrodynamic gradient. It turns out that combined impingement and through drying, as used in the Papridryer process for newsprint, is also good for removal of surface moisture. The thinning of external boundary layer by suction augments the impingement heat/mass transfer rates too. A technoeconomic evaluation and comparison is needed to choose between options C and D. Volumetric heating techniques such as RF or microwave heating are based on high levels of electrical energy consumption and hence are not considered here despite their merit in correcting moisture profiles towards the final stages of drying. Loo and Mujumdar[3] have developed an approximate mathematical model of option (C) which shows the high potential for use of such a system.

Figure 3 again a new concept due to Cui and Mujumdar[2]. It is based on the classical multiple effect evaporation concept. The idea is to utilize the exhaust from one part of the dryer as the drying medium for another part of the dryer without additional input of energy (or work).

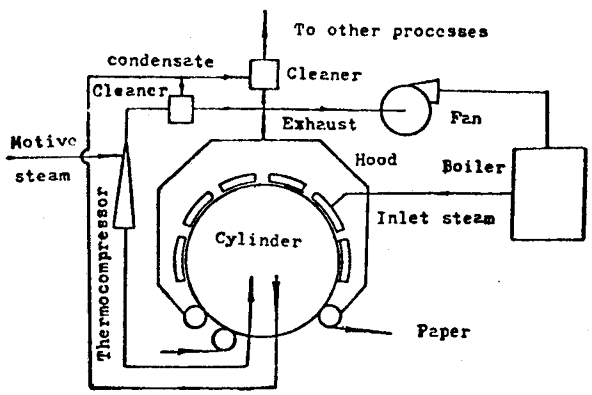


Fig. 3 Flow diegram of combined steam jet and double-effect evaporation dryer.

Thus the exhaust from the high velocity hood is used partially to heat the cylinder as condensing steam-very similarly to what is done in the conventional Yankee system. This is combined convection-conduction drying; the contribution due to radiation is only marginal. Perhaps a better concept is to utilize exhaust upon impingement as the heating medium in the following dryer which is operated at a lower pressure (or temperature).

It should be noted that impingement drying rates are always extremely high while the contact time between the jet and the wet web extremely small. This results in a requirement for high levels of recycle of the exhaust stream as jet flow in the same dryer. Excess steam equivalent to that

TABLE—2. ESTIMATED VALUES OF THE ENERGY CONSUMPTION AND ENERGY COSTS FOR STEAM DRYING

Conditions	Heat Consumption (kj/kg water)		Total energy consumption (kj/kg water)		Heat Cost U$/ton water)		Total energy Cost (U$/ton water)	
	Papri dryer	Impingement + double-effect	Papri dryer	Impingement + double-eff·ct	Papri dryer	Impiegement + double-effect	Papri dryer	Impingement + double-effect
Jet temperature $T_j = 580$ K Jet Velocity $V_j = 104$ m/s hood open area $A_{hoa} = 2\ 6\%$ hood pressure $P_h = 0\ 105$ mPa $\triangle P = 27$ kPa	2445		2880		8.10		13.8	
$T_j = 600$ K. $V_j = 100$ m/s $P_h = 0.4$ mPa Pressure of steam for heating Cylinder P=0. 72 mPa	583		966		1.94		6.95	

* Data for superheated steam combined impingement and through drying, from, Ref. (3).

** Data for combined steam impingement and double-effect evaporation dryer, from Ref. (2).

produced by drying in the dryer must be bled off and used elsewhere as process steam. If the exhaust steam is utilized efficiently the overall thermal efficiency of the process can be very high.

Table 2 shows estimated values of the thermal energy consumption and energy costs (U.S.A. figures for 1982) for combined through–impingement drying as well as the double-effect Yankee-type dryer proposed by Cui and Mujumdr[2]. When compared with conventional dryer efficiencies the levels are indeed extremely high. It must be noted, however, that the costs of capital investment required for steam compression equipment are not included in this analysis. Furthermore, the cost figures and hence technoeconomic assessment of the various dryer concepts proposed here are highly dependent on the geography too.

CONCLUDING REMARKS

Several novel concepts are proposed which are based on nearly total utilization of the drying medium (which is ateam) as well as the steam pro duced as a result of evaporation in the dryer. Experimental data are needed to verify the mathematical models upon which are based the conclusions reported here. Details of the models are available elsewhere (2,3). An experimental program has been initiated in the laboratories of the principal author to evaluate the basic concept of steam drying. The authors believe that steam drying of paper is the technology of the twenty first century when energy supply constraints will demand an entirely new drying technology in the paper industry of the future.

ACKNOWLEDGEMENTS

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