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A Methodology for Determination of Waste Heat and Water Recovery Potential from the Dryer Section of a Pulp and Paper Factory

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Abstract— Pulp and Paper factories consume large amount of thermal energy at their dryer sections for evaporation. The vapor is released into a hood that covers all the drums of the dryer. Knowing the recoverable values of heat and condensate is essential for the design and/or selection of a proper waste heat recovery system and for the evaluation of its cost effectiveness. This paper presents a methodology developed to determine the amounts that could be recovered from the dryer section of a typical pulp and paper factory. It consists of a series of mathematical models established based on the laws of thermo-fluid dynamics and heat transfer, and that closely represent the various stages of the drying process. The series of equations, together with the actual measured operating parameters can be used for the calculation of the recoverable amounts of the two resources. The methodology was applied to one of the dryers of the Ethiopian Pulp and Paper Factory, and 930 kW thermal power and 1.26 m^3/hr. condensate water were found to be available for recovery. In other words 72.6% of the heat supplied by the steam to the dryer can be recovered. Therefore, it can be concluded that the method is very useful for addressing the issues of energy and water efficiency of paper factories.

Index terms*:* Drum, Dryer section, Energy balance, Felt, Mass balance, Paper-web, Waste heat recovery.

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1 INTRODUCTION

Paper is a very common product used at every corner of the globe. Its contribution to the civilization of mankind is immense. Paper is manufactured mainly by processing various types of trees. Unfortunately, the various processes required to transform the raw material into paper require large amount of energy input. This is mainly because of the large amount of heat energy required at the drying section of a paper factory for the removal of the large quantity of water present in the paper web by evaporation. Pulp and paper factories are listed among the energy intensive manufacturing industries at global level [3].

In the drying section of a paper factory, a huge amount of heat is utilized for drying the paper web. The majority of the heat then would be available as latent heat of vaporization. Apparently, the means of recovery of the waste heat and its cost effectiveness can only be established if one can quantify the amount of the heat with an acceptable degree of accuracy. This paper presents a methodology developed to estimate the recoverable amounts of the waste heat and the associated condensate water at the drying section of a paper factory based on its actual and measured operating parameters.

1.1 Brief Description of Paper Manufacturing Processes

Wood is processed to produce pulp in a separate plant. First the size of the wood is reduced by chopping it in to fine pieces. Then it is thermally and chemically treated to alter its composition. Wood is predominantly composed of 30% lignin, 45% cellulose, and 20% hemicelluloses; whereas, pulp is composed of, 85% cellulose, about 10% lignin and 5% hemicelluloses. Hence pulp is refined and chemically treated forms of wood [2].Factories that prepare their own pulp are known as integrated paper mills. Whereas those that receive the pulp by purchasing from other mills are known as non-integrated mills [3].

The subsequent standard operations conducted to produce paper from pulp are: disintegration, de-flaking, refining, adding chemicals/additives, cleaning, paper sheet (paper web) formation, wet pressing, drying, and finishing works. Obviously, many different types of machines, each run by consuming energy, are needed to carry out these operations [3].

Our main focus is the drying process. This process removes about 60% water remaining in the paper web. The removal is done by heating and evaporating the water. It is worth noting that, at this stage, the water present in the web is at ambient state, and it has to be heated first. The latent heat of evaporation for water is naturally high and hence, one can clearly see why a paper factory consumes large amount of thermal energy for the drying process.

This thermal energy can be recovered and used for various purposes. The main objective of this paper is to present a

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methodology by which one can estimate the amount of heat energy which could be recovered from the dryer section of a paper factory. Obviously, quantification of the recoverable amount is very essential to design and/or select the means of recovering the resource and making financial evaluations. Since the recovery is accomplished by condensing the vapor, one can tap and reuse the condensate. Hence, the waste heat recovery process offers dual advantage. The methodology developed is, therefore, very useful for improving the resource efficiency of paper factories deprived of waste heat recovery systems.

2 METHODOLOGY

2.1 Description of the Drying Process

The working principle of the drying section of a typical paper factory can be described using the schematic diagram given in Fig.1. In the figure are shown a number of drums, to which steam from boiler is injected. Then the drums got heated up and the water present in the paper web is heated and evaporated. The vapor produced during the drying process is sucked into the hood covering all the drums.

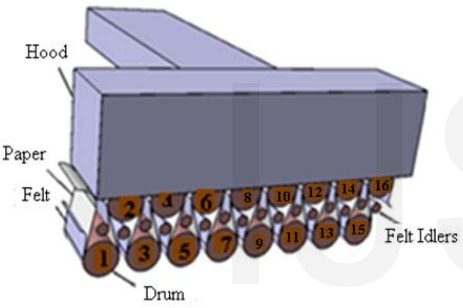

Fig.1 The dryer section

As illustrated in the schematic diagram, the delicate paper web is supported by means of a heat resistant material, called felt, is made to pass continuously around each of the rotating drums. As it moves past the drums, the paper web gets sandwiched in between the external circumferential surface of the drum and the felt. The heat is transferred by conduction across the wall of the drum to the web. A small part of this heat is inherently lost to the ambient across the felt.

Heating of the web takes place (not only at high temperature but also) at high pressure above that of the ambient because of the sandwiching and the force exerted on it by the felt. This condition is very useful for the drying purpose because, the moment the web leaves the drum during its forward motion, there will be sudden drop in the pressure of the hot compressed moisture embedded in it. This sudden expansion gives rise to a spontaneous transformation of the medium into a flash steam, which therefore results in the removal of the moisture from the product. The flash steam so formed is released to the space under the hood. The same phenomenon takes place again and again as the web passes from one drum to the next. The 60% water is removed in this manner to ultimately obtain dry paper [6]. Typical paper factories are equipped with two dryer sections, named primary dryer and secondary dryer, to perform the drying.

Apart from the latent and sensible heat loss with the vapor, there will be some amount of heat loss to the ambient from the surfaces of each of the drums not covered by the web-felt pair, the two ends of each of the drums, and from the outside surface of the felt because each of these surfaces are at a relatively higher temperature than that of the ambient. Moreover, some amount of heat will be lost from the web-felt pair to the ambient while the pair passes from one drum to the next. As will be seen in the next section, all such losses have been considered during the mathematical modeling of the drying process.

2.2 Mathematical Modeling of the Drying Process at One of the Drums

The drying process at a specific drum is expressed mathematically by applying energy & mass conservation principles and relevant heat transfer equations to the control volumes enclosing the paper web and the felt. The symbols used to represent the parameters, properties and dimensions relevant to the mathematical modeling are as listed below.

Nomenclature:

ρ_a = Air density *(kg/m^3), D = Diameter of drum (m),* V_{rel} *= Relative velocity (m/s),* ω *= Angular speed (rps),* l_g *= Gap between two neighboring drums (m),* S_f *= Span/width of felt (m),* m_a *= Mass per unit area of felt (kg/m^2),* t_f *= Thickness of felt, (m),* S_f *= Span/width of paper-web(m),* g_p*=Mass per unit area of paper (kg/m^2),* $\dot{m}_c$*=Mass transportation rate of cellulose in the paper-web(kg/s),* C_{pw}*=Specific heat capacity of water (kJ/kg-K),* C_{pc}*=Specific heat capacity of cellulose(kJ/kg-K),* T_∞ *=Ambient temperature (K),* C_{pf} *=Specific heat capacity of felt (kJ/kg-K),* $\dot{m}_f$ *=Mass transportation rate of felt (kg/s),* θ*=Angle of drum surface exposed to air (rad/s),* S_d*=Span of drum (m),* h_D *= Convective heat transfer coefficient for drum circumferential surface (W/m^2), hDs=Convective heat transfer coefficient for drum side/end surface (W/m^2),* h_p*=Convective heat transfer coefficient for paper web surface (W/m^2),* h_f*=Convective heat transfer coefficient for felt surface (W/m^2), Ø =Relative humidity (%),* T_{db}*=Dry bulb temperature (K),* P_l*=Local pressure (Pa),* W_i*=Absolute humidity of air entering the hood (kg/kg),* W_o*=Absolute humidity of air exiting the hood (kg/kg),* $\dot{m}_d$*=Mass flow rate of dry air (kg/s),* $\dot{Q}_g$*=The rate at which heat is lost from paper web in CV shown in Fig 4 (W),* A_p*=Surface area of the paper web enclosed in the CV shown in Fig 4,* $\dot{M}$*=Moisture evaporation rate from paper web in between neighboring drum (kg/s),* h_{fg}*=Latent heat of vaporization for water (kJ/kg),* $\dot{m}_{wgi}$*=The rate of transportation moisture in paper web at inlet of CV shown in Fig 4 (kg/s),* $\dot{m}_{wgo}$*=The rate of transportation moisture in paper web at outlet of CV shown in Fig 4 (kg/s),* H_{gi}*=Specific enthalpy of moisture in paper web at inlet of CV shown in Fig 4 (kJ/kg),* H_{go}*=Specific enthalpy of moisture in paper web at outlet of CV shown in Fig 4 (kJ/kg),* T_{gi}*=Temperature of paper web at inlet of CV shown in Fig 4 (K),* T_{go}*=Temperature of paper web at outlet of CV shown in Fig 4 (K),* $\dot{m}_{ev}$*=Total evaporation rate from dryer section (kg/s),* $\dot{m}_{v1}$ *=Moisture mass flow rate of air at inlet of the hood (kg/s),* $\dot{m}_{v2}$ *=Moisture mass flow rate with outgoing air from the hood (kg/s),* $\dot{Q}_T$*=Total heat supply rate to a drum (W),* T_{pi}*=Paper web temperature at inlet to CV (see Fig.2) (K),* T_{po}*=Paper web outlet temperature at outlet from CV (see Fig.2) (K),* T_D *=Drum surface temperature (K),* T_{fi}*=Felt inlet temperature at inlet to CV (see Fig.3) (K),* T_{fo}*=Felt out let temperature at outlet from CV (see Fig.3) (K),* T_{Ds}

=Drum side end surface temperature (K), T_{ni}*=Paper web temperature as it gets into the next drum (K), v=Drum surface speed (m/s), C =Moisture content of paper web as gets in to a drum (%)*

The simplifying assumptions used for the modeling are as follows:

- The plant has already passed the start-up phase and is in the phase of continuous operation at steady state conditions.
- The cellulose and water content of the paper web is uniformly distributed over its area.
- The paper web and the felt that support it move with the same uniform speed over the circumference of the drum and there is no slippage.
- Supply of steam to the drums takes place at a steady state steady flow condition.
- Evaporation takes place in the gap between consecutive drums.

These assumptions are not far from the reality. The various physical phenomena taking place at one of the drums of a dryer section are expressed mathematically as follows.

2.2.1 Heat gain by the paper web as it passes over part of the circumference of a drum

Applying steady state energy conservation principle to the control volume enclosing the paper web only, the net heat gain can be expressed as [6]:

$$\dot{Q}_d - \dot{Q}_f = (\dot{m}_w c_{pw} + \dot{m}_c c_{pc})(T_{po} - T_{pi}) = a1 \qquad (1)$$

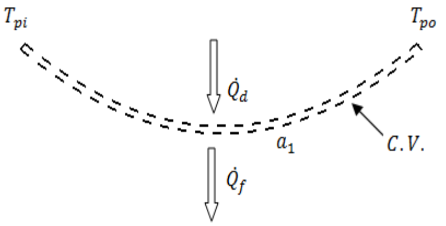

Fig.2: Control Volume enclosing only the paper web

In the expression, $\dot{m}_w$ stands for the rate at which the moisture embedded in the web are being transported across the CV. Since no evaporation takes place in between the inlet and exit of the control volume, $\dot{m}_{wi} = \dot{m}_{wo} = \dot{m}_w$ for the drum under analysis. The subscripts i and o respectively designate the inlet and outlet of the CV. Moreover, the same $\dot{m}_w$ can also be expressed as:

$$\dot{m}_w = C * \dot{m}_c/(1 - C) \qquad (2)$$

Where C stands for the moisture content of the web in % and it gets into the CV. It is to be noted that the value of C is different for different drums because of the evaporation that takes place in between them. The symbol $\dot{m}_c$ represents the rate at which the cellulose part of the web is being transported across the CV, and is given by:

$$\dot{m}_c = v * S_p * g_p \qquad (3)$$

2.2.2 Heat gain by the felt as it passes over part of the circumference of a drum

Applying the steady state energy equation to the Control Volume (CV) enclosing the felt only, the net heat gain can be expressed as [6]:

$$\dot{Q}_c - \dot{Q}_f = \dot{m}_f c_{pf}(T_{fo} - T_{fi}) = a2 \qquad (4)$$

Where $\dot{Q}_c$ = rate of heat which is lost from the external surface of the felt to the ambient.

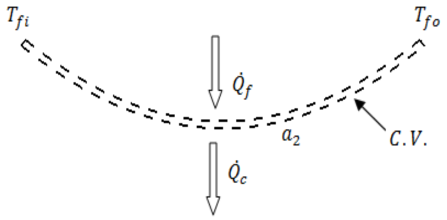

Fig.3: Control Volume enclosing only the felt

The symbol $\dot{m}_f$ used in Eqn. (4) stands for the rate at which the felt's mass is transported steadily across the CV and, it is given by:

$$\dot{m}_f = m_a * S_f * v \qquad (5)$$

$\dot{Q}_c$ can be determined based on its mean temperature T_f and the ambient temperature T_∞ using this expression:

$$\dot{Q}_c = h_f A_f (T_f - T_\infty) = a3 \qquad (6)$$

Where A_f = area of the felt and, $T_f = (T_{fi} + T_{fo})/2$

2.2.3 Heat balance for the paper web-felt pair as it passes over a drum

Equations (1), (4) and (6), written for the web-felt pair, constitute systems of simultaneous equations which can be rewritten in matrix form as follows and then solved:

$$\begin{pmatrix} 0 & 1 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} \dot{Q}_c \\ \dot{Q}_d \\ \dot{Q}_f \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \qquad (7)$$

2.2.4 Heat loss from the surfaces of one drum to the ambient

The rate at which heat is lost from that part of the circumferential surface of the drum not covered by the paper web can be expressed as:

$$\dot{Q}_e = h_D A_c (T_D - T_\infty) = a4 \qquad (8)$$

Where Ac is the area of the surface exposed to the ambient.

The rate at which heat is lost from the two sides of the drum that are exposed to the ambient, $\dot{Q}_s$ can be expressed as:

$$\dot{Q}_s = h_{Ds}A_{Ds}(T_{Ds} - T_\infty) = a5 \qquad (9)$$

Where T_{DS} is the surface temperature and A_{Ds} is the total area of the two sides of the drum [2].

The total heat loss rate from the surfaces of the drum exposed to the ambient, Q_{TA} can, therefore, be obtained from:

$$\dot{Q}_{Ta} = \dot{Q}_e + \dot{Q}_s \qquad (10)$$

2.2.5 Total heat transferred from the drum to the paper web and the ambient

The total heat transfer rate from one drum to the paper web and the ambient $\dot{Q}_T$ is equal to the sum of the heat supplied to the web ($\dot{Q}_d$) and that lost to the ambient ($\dot{Q}_{Ta}$). That is,

$$\dot{Q}_T = \dot{Q}_d + \dot{Q}_e + \dot{Q}_s = a6 \qquad (11)$$

Under steady conditions, $\dot{Q}_T$ is equal to the rate at which heat is extracted from the steam ejected into the drum.

2.2.6 Heat transfer from the paper web to the ambient as it passes from one drum to the next

As the paper web leaves one drum and passes to the next, there will be evaporation of the moisture to the ambient. Enthalpy possessed by the vapor will also be lost to the ambient. Besides, there will be transfer of heat from the web to the ambient. These physical phenomena can be expressed mathematically by applying the conservation principles and laws of heat transfer to a control volume enclosing the paper web momentarily located in between the drum under analysis and the next one (see Fig. 4).

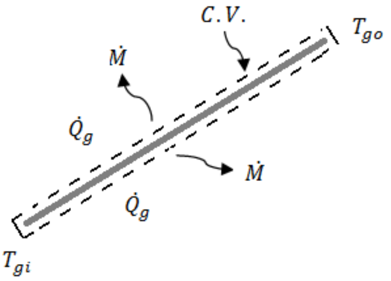

Fig.4: Paper web momentarily located in between the drum under consideration and the next one

The following expression gives the energy balance per unit time for the CV:

$$\dot{Q}_g + \dot{M}(h_{fg}) + \dot{m}_{wgo}(H_{go}) - \dot{m}_{wgi}(H_{gi}) + \dot{m}_c C_{pc}(T_{go} - T_{gi}) = 0 \qquad (12)$$

The rate, at which heat is lost from both surfaces of the paper web in the CV, $\dot{Q}_g$ can be determined based on the average temperature of the paper web at the inlet and outlet of the CV and, on the ambient temperature. That is,

$$\dot{Q}_g = 2h_p A_p(T_g - T_\infty) = a9 \qquad (13)$$

Where $T_g = (T_{gi} + T_{go})/2\ldots$ and T_∞ stands for the ambient temperature.

The rate, at which moisture is evaporated from the paper web while it is in the CV, $\dot{M}$ can be determined from:

$$\dot{M} = \dot{m}_{wgi} - \dot{m}_{wgo} \qquad (14)$$

$$\text{Where} \quad \dot{m}_{wgi} = \dot{m}_w = a7 \qquad (15)$$

For convenience, the set of equations describing the physical phenomenon occurring in the CV, Eqn. (12) is reorganized and written as follows:

$$\dot{Q}_g + b_2\dot{M} + b_3\dot{m}_{wgo} + b_4\dot{m}_{wgi} = a_8 \qquad (16)$$

Where: $b_2 = h_{fg}$, $b_3 = H_{go}$, $b_4 = H_{gi}$ and

$$a_8 = \dot{m}_c C_{pc}(T_{gi} - T_{go}) \qquad (17)$$

The set of Equations (13) to (17) are all written for the paper web momentarily located in between the drum under consideration and the next one. They can be summarized in matrix form as given in Eqn.18 and solved simultaneously based on measured data.

$$\begin{pmatrix} 0 & 1 & 1 & -1 \\ 0 & 0 & 0 & 1 \\ 1 & b_2 & b_3 & b_4 \\ 1 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} \dot{Q}_g \\ \dot{M} \\ \dot{m}_{wgo} \\ \dot{m}_{wgi} \end{pmatrix} = \begin{pmatrix} 0 \\ a_7 \\ a_8 \\ a_9 \end{pmatrix} \qquad (18)$$

2.2.7 Moisture content of paper web at entry point to the next drum

The percentage of moisture embedded in the paper web at the outlet of the CV shown in Fig. 4, C can be expressed as:

$$C = \dot{m}_{wgo}/(\dot{m}_{wgo} + \dot{m}_c) \qquad (19)$$

Since the outlet of the CV is at the inlet to the next drum, the value of C at the inlet to the next drum is the same as the one computed from Equation 19.

3 THE COMPUTATION PROCEDURE

It is to be noted that the equations (1) to (19) are written for one drum. Some of them can be solved, as simultaneous equations, using actual measured data of the parameters, properties and dimensions for the drum under consideration. In other words, the computations are done for one drum at a time. Some of the values calculated for one drum will serve as an input data for the next drum to perform similar computation. The same set of equations will be employed in the subsequent computations but, of course, one should use measured data for the respective drums. The same procedure is repeated for all the drums of the dryer section to finally obtain the total amount of recoverable heat and of condensate water.

3.1 Overall heat supply and rate of evaporation at all drums of the primary dryer

The total rate of heat consumption and that of moisture evaporation at all the drums of the primary dryer (or, the secondary dryer) can be determined by summing up the values obtained for each drum using the expressions discussed in the preceding sections. Accordingly, the total rate of heat consumption at a dryer section can be determined from:

$$\dot{Q}_{TT} = \sum_{j=1}^{jmax} \dot{Q}_{Tj} \qquad (20)$$

The total rate of evaporation from the paper web at a dryer section,

$$\dot{m}_{ev} = \sum_{j=1}^{jmax} \dot{M}_j \qquad (21)$$

Where j stands for the number of drums in a dryer section and, jmax is the total number of drums in the dryer section (e.g, sixteen).It is assumed that the whole moisture evaporated from the dryer section is collected under the hood. So, the space within the hood will be filled by hot moist air containing significant amount of thermal energy in the form of latent heat and sensible heat.

3.2 Estimate of Recoverable Waste Heat and Condensate

Fig. 5 shows the schematic of a dryer section (primary or secondary), together with its hood. In general, the whole moisture evaporated from all the drums ($\dot{m}_{ev}$) is assumed to be collected under the hood. In addition, there would be air entrainment from the ambient as the fan of the hood runs. So, there exists recoverable thermal energy under the hood.

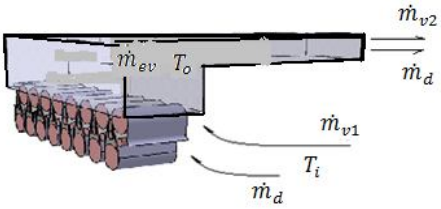

Fig. 5: Hot moist air in the hood.

The principles of psychometrics can be applied to Fig. 5 for estimating the recoverable amount of this energy from measured thermodynamic properties at the inlet and outlet sections of the hood .The absolute humidity of the air at the inlet of the hood, W_i can be determined from its relative humidity, dry bulb temperature, and local pressure. The absolute humidity at the outlet of the hood, W_o can also be obtained in a similar manner. Thus, the moisture contained by the air entrained into the hood can be determined. This quantity plus the evaporation rate from all the drums under the hood constitute the total flow rate of the moisture part at the inlet of the hood. The rate, at which moisture enters the hood with the entrained air, $\dot{m}_{v1}$can be expressed as:

$$\dot{m}_{v1} = W_i * \dot{m}_d \qquad (22)$$

Where $\dot{m}_d$ = mass flow rate of the dry part of the air.

Similarly, the rate at which moisture leaves with the air at the exit section of the hood is given by:

$$\dot{m}_{v2} = W_o * \dot{m}_d \qquad (23)$$

Applying mass conservation law, one can also express $\dot{m}_{v2}$as:

$$\dot{m}_{v2} = \dot{m}_{v1} + \dot{m}_{ev} \qquad (24)$$

Observe that $\dot{m}_{v2}$ would have been equal to $\dot{m}_{ev}$ if the air entrained into the hood were moisture free.

The sensible heat and latent heat of the hot moist air inside the hood is extracted by cooling it. The recovered amount would be maximum when the medium is cooled down to the ambient temperature. The recoverable amount of sensible- & latent heat and that of the condensate can be estimated as follows.

The sensible heat recovery rate, $\dot{Q}_s$ can be estimated from,

$$\dot{Q}_s = \left(\dot{m}_{v2} C_{pw} + \dot{m}_d C_{pa}\right) \Delta T \qquad (25)$$

Where ΔT equals the temperature difference at the inlet and outlet of the hood. The latent heat recovery rate, $\dot{Q}_L$ can be estimated from:

$$\dot{Q}_L = \dot{m}_{cr} * h_{fg} \qquad (26)$$

Where $\dot{m}_{cr}$ = the condensation rate. This can be determined from:

$$\dot{m}_{cr} = (W_o - W_i) * \dot{m}_d \qquad (27)$$

Finally, the total recoverable waste heat per unit time is obtained by taking the sum of $\dot{Q}_L$ and$\dot{Q}_s$. The recovery rate of the other precious resource, water, is equals to$\dot{m}_{cr}$.

4 RESULTS AND DISCUSSION

The Methodology has been applied to assess and quantify the amounts of waste heat and condensate available for recovery from the primary dryer of an Ethiopian Pulp and Paper Factory, found at about 100 Km south east of the capital Addis Ababa. The primary dryer of the Factory consists of 16 drums. The moisture evaporated from the paper web is released to a hood covering all the drums. The Factory does not have a heat recovery system [1].

The parameters needed to apply the method (such as, the physical dimensions of the drums, the paper web and the felt; rotational speed of the drums; thermal properties of the paper web and the felt; paper-web temperatures at the entrance to and exit from each drum; the surface temperatures of part of the circumference exposed to the ambient and of the end surfaces of each drum; the local ambient temperature, relative humidity and pressure, etc) have been measured while the Factory was carrying out its normal manufacturing operation under a steady condition. Thereafter, using the last expressions in Section 3, the sensible heat and latent heat available for recovery have been calculated. The values obtained are, respectively, 137.8 kW and 793 kW. The amount of condensate water that would be obtained per unit time during the recovery process, by cooling the hot moist air in the hood, is equal to 0.35 kg/s. That means a total of about 930.86 KW thermal powers was available for recovery. This is a lot. It has been checked that this thermal power is equal to 72.6% of that supplied by the steam to all the 16 drums of the primary dryer. Apparently, about three-quarter of the power supplied by the steam is recoverable. The condensate water resulting from the cooling equals 1260 liters per hour.

The figures given above are for the case in which the cooling is done up to the ambient temperature. In practice, however, the cooling is practicable up to a temperature slightly higher than that of the ambient (say, 100^0C). It follows then that the actually recoverable values will be less but still, it can be concluded with a high degree of confidence that the major part of the resources can practically be recovered. Moreover, standard paper factories are equipped with other secondary dryer, with a design similar to the primary dryer, for further drying of the same paper web. It follows then that there is an opportunity of recovering more thermal energy and more condensate water. The same methodology can be followed to determine the additional amounts of the recoverable resources from the secondary dryer

5 CONCLUSION

As pointed out in the introduction part, pulp and paper factories are energy intensive industries. This is mainly because of the very high thermal energy required to get rid of the huge amount of water present in the paper web. In the absence of waste heat recovery system, about three-quarter of the heat supplied to the dryers goes, together with the valuable resource (water), into the atmosphere. Obviously, recovery and reuse of these two precious resources is simply good for the factories as it cuts fuel and water bills and enables efficient and rationale use of the resources. Moreover, recovery and reuse of the energy is good for the environment simply because it would mean less fuel combustion and, therefore, less CO_2 emission. And, to design and/or select an appropriate waste heat recovery system for a factory, the first data one would need to know is the amount of waste heat available for recovery. The methodology is developed to address this task.

As discussed in the preceding sections, the methodology is developed applying the well-established concepts of thermo-fluid dynamics and heat transfer. This is done after a thorough investigation of the physical phenomena of the paper-web drying processes in standard paper factories. The simplifying assumptions imposed for the modeling are not far from reality. The method enables to find the data required for the design and/or selection of a waste heat recovery system and for evaluation of its cost effectiveness. It has been successfully applied to determine such data for an actual paper factory. Therefore, it can be concluded that the method is very useful for energy managers and the like in their effort of addressing energy and water efficiency issues in paper factories.

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