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Technical and economic study of the drying of maize of the Anketrakabe rural commune in Madagascar

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ABSTRACT: *This paper is a modest contribution to the analysis of the complex phenomena of coupled heat and mass transfers occurring between a moving gas and a wet solid. The scientific literature on the drying of agro materials is unanimous on the positive effect of the air temperature, the negative effect of the relative humidity of the air and the thickness of the products as regards in the drying time. The aim of this work is to study the energy efficiency of solar drying processes, it appears necessary to establish less empirical design rules and taking better account of the processes involved. For the purpose of predicting the evolution of the water contents until reaching the desired value.*
The product used is corn. To achieve this result, two solar double pass sensors are used. The output temperature of a double pass sensor is higher (favorable for maize drying) compared to the single pass sensor. We also do the economic study of all the materials used. Finally, we are interested in the economic study, the depreciation of appliances and the maize drying efficiency in the rural commune Anketrakabe (DIANA Region in Madagascar).

KEY WORDS*: drying, thick layer, yield, damping, dryer*

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Nomenclature

Ta	Confined air temperature (°C)
Tae	Room temperature(°C)
Tc:	Temperature of the sky(°C)
Tie:	Temperature of the outer face of the insulation(°C)
Tii:	Temperature of the inner face of the insulation(°C)
Tni:	Temperature of the underside of the absorber(°C)
Tns:	Temperature of the upper side of the absorber(°C)
Ts:	Soil temperature(°C)
Tve:	Temperature of the outside face of the glass(°C)
Tvi:	Temperature of the inner face of the window(°C)
Pv:	Solar power received by the window(W/m^2)
Pn:	Power received by the absorber(W/m^2)
hcfi:	Coefficient of heat exchange by convection between the fluid and the insulator ($W.m^{-2}.K^{-1}$)
hcfn:	Coefficient of heat exchange by convection between the fluid and the absorber ($W.m^{-2}.K^{-1}$)
hcvn:	Coefficient of heat exchange by convection between the glass and the absorber ($W.m^{-2}.K^{-1}$)
hki:	Coefficient of heat exchange by conduction in the insulation ($W.m^{-2}.K^{-1}$)
hkn:	Coefficient of heat exchange by conduction in the absorber (W.m-2.K-1)
hkv:	Coefficient of convection heat exchange in the glass ($W.m^{-2}.K^{-1}$)
hris:	Coefficient of heat exchange by radiation between the insulator and the ground ($W.m^{-2}.K^{-1}$)
hrni:	Coefficient of heat exchange by radiation between glass and absorber ($W.m^{-2}.K^{-1}$)
hrvc:	Coefficient of heat exchange by radiation between window and sky ($W.m^{-2}.K^{-1}$)
hvv:	Coefficient of heat exchange between the glass and the outside air due to the wind ($W.m^{-2}.K^{-1}$)
Tfs:	Sensor output temperature (K)
ΔHv (Tp):	mass latent heat of water vaporization of the product
I:	Solar constant (w/m^2)
Io:	Radiation received by a horizontal surface ($J/m^2.day$)
J:	Number of the day of the year
Q:	Mass flow rate of the fluid (kg/s)
Mv:	Half of the mass of the glass for Δx (kg)
Mn:	Mass of the absorber Δx (kg)
Mi:	Half of the mass of the insulator Δx (kg)
Pv:	Power absorbed by the window (W/m^2)
Pn:	Power absorbed by the absorber (W/m^2)
Ta:	Ambient temperature (° C)

I- INTRODUCTION

Agriculture occupies 70% of the active population and accounts for 20% of exports. The quality of a product has in itself a subjective dimension left to the appreciation of each.

Drying is either a means of preservation or a stage in the processing of certain products. It is used both in the rural world in the industrial world through the food industry, textiles ... etc. Solar dryers are easy to build with locally available tools and materials. This fonctionnement is generate through by the free convection. Obviously, the amount of sun and humidity will affect the performance of the dryer. Solar dryers are divided in two models, direct and indirect type. however, these systems can be active or passive. All opinions considered agree on drying temperatures between 35°C to 82°C.

In this work, we will see the modeling and numerical simulation of a double pass solar collector and also the techno-economic study of corn drying in the DIANA region, Madagascar. Finally, we apport the advantage for dryer with the double pass solar collector. Much of work has already been published on the drying of agricultural products. Among them, Khama R et al. Studied the drying process and coupled heat and mass transfer phenomena that occur between the drying air and the wet product to be dried. A. Boulemtafes et al. presented the results of a study on energy analysis of the solar drying process of medicinal and aromatic plants and in particular peppermint.

Dryer used is indirect type, passive, without extra energy and which operates in batch mode. R. Romule et al. presented the drying and smoking of agricultural and fish products. They found alternative sources of drying energy and conservation techniques for local and fishery products in the Sambirano district in DIANA region. L. Fridolin A. et al. is studying the modeling of the drying speed of maize. They determined the speed of drying of the hygroscopic product by using of the different models.

Having regard to all these works and despite some resemblance to the references given, it would be almost better to identify from the beginning the technico-economic study of maize drying that we will discuss in an investigation. Indeed, this technique is mainly done using the principle of forced convection. Finally we calculate the cost of manufacture of the dryer to use and their life.

II- MATERIALS AND METHODS

1) System Overview

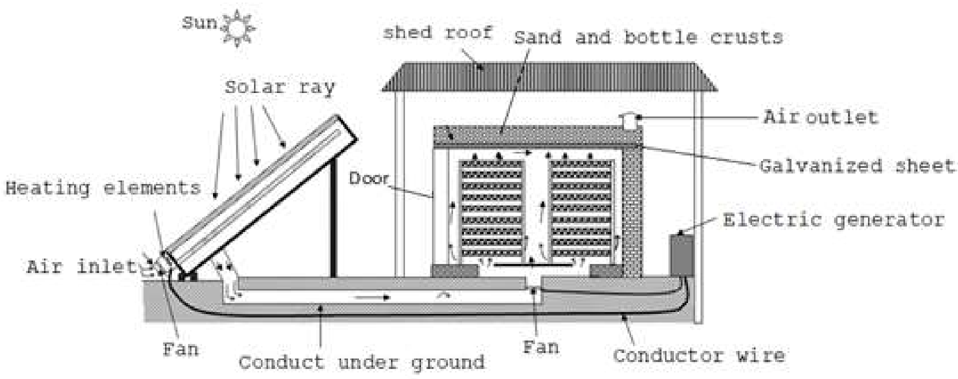

Figure 1: System studyed

2) Description of the dryer

The convective driers and especially tunnel driers are widespread in the various industrial sectors [10]. These are dryers operating in the forced convection mode. They use a circulator to ensure the flow of hot air and they allow changing the operating conditions to ensure a good performance. Considering only the sun makes the system dependent on the climate, which requires the use of a heat source around 1500W.

III- MATHEMATICAL FORMULATION

1- Double pass sensor

In this study of the energy system (solar collectors, driers, solar water heaters, ...), we are sometimes led to the development of mathematical models [2], [5], [7], [8].

a) Work assumptions

In our calculations, we adapt the simplifying assumptions are often commonly accepted:

- The flow of heat transfer fluid inside is one-dimensional.
- The solar collector is the seat of heat transfer only.
- The different solid media have a uniform temperature in a normal plane of the flow.
- The thermal inertia of the fluid is negligible in front of the convection term.

b) Basic diagram and ratings

The different heat exchanges, in the case of the model (1), are illustrated by the following figure:

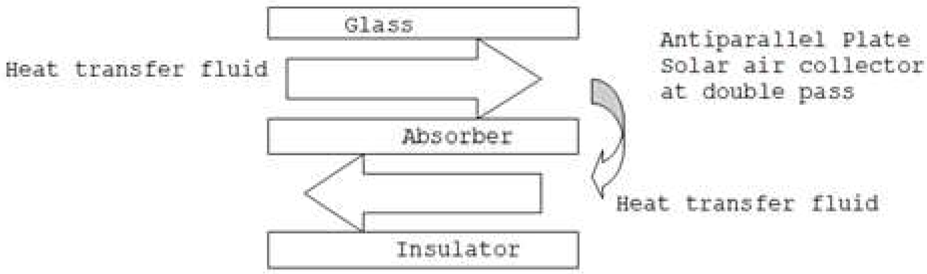

Figure 2: Schematic representation of the studied models

c) Thermal balance in each of the elements of the insolator

The different thermal transfers between the various components of the hot air generator in the figure above, allow us to write the thermal balances of each the slices of the sensor.

Outside face of the glass

$$\rho_v.Cp_v.e_v.\frac{\partial T_{ve}}{\partial t} = P_v + h_{rvc}(T_c - T_{ve}) + h_{rvs}(T_s - T_{ve}) + h_{cvv}(T_e - T_{ve}) + h_{kv}(T_{vi} - T_{ve}) \quad (1)$$

Inside face of the glass

$$\rho_v.Cp_v.e_v.\frac{\partial T_{vi}}{\partial t} = h_{rvn}(T_{ns} - T_{vi}) + h_{cv}(T - T_{vi}) + h_{kv}(T_{ve} - T_{vi}) \quad (2)$$

Outside face of the absorber

$$\rho_n.Cp_n.e_n\frac{\partial T_{ns}}{\partial t} = P_n + h_{rvn}(T_{vi} - T_{ns}) + h_{cfn}(T - T_{ns}) + h_{kn}(T_{ni} - T_{ns}) \quad (3)$$

Inside face of the absorber

$$\rho_n.Cp_i.e_n\frac{\partial T_{ni}}{\partial t} = h_{rni}(T_{ii} - T_{ni}) + h_{cfn}(T_f - T_{ni}) + h_{kn}(T_{ns} - T_{ni}) \quad (4)$$

Inside face of the insulation

$$\rho_i.Cp_i.e_i.\frac{\partial T_{ii}}{\partial t} = h_{rni}(T_{ni} - T_{ii}) + h_{cfn}(T_f - T_{ii}) + h_{ki}(T_{ie} - T_{ii}) \quad (5)$$

Outside face of the insulation

$$\rho_i.Cp_i.e_i.\frac{\partial T_{ie}}{\partial t} = h_{ris}(T_s - T_{ie}) + h_{cvi}(T_e - T_{ie}) + h_{ki}(T_{ii} - T_{ie}) + h_{ric}(T_c - T_{ie}) \quad (6)$$

Puissance absorbed by the absorber

$$P_n = \alpha_n \frac{P_{dir}.\alpha_{dirv} + P_{dif}.\alpha_{difv}}{1 - (1 - \alpha_n)\rho_{dif}} \quad (7)$$

Power absorbed by the glass

$$P_n = P_{dir}.\alpha_{dirv} + P_{dif}.\alpha_{difv} \quad (8)$$

Heat transfer fluid

Conduit 1 :

$$\rho_f.Cp_f.S_f.\Delta x.\frac{\partial T_f}{\partial x} = S_{fn}.h_{cfn}.(T_{ns} - T_f) + S_{fv}.h_{cfv}(T_{vi} - T_f) \quad (9)$$

Conduit 2 :

$$\rho_f.Cp_f.S_f.\Delta x.\frac{\partial T_f}{\partial x}=S_{fn}.h_{cfn}\left(T_{ns}-T_f\right)+S_{fv}.h_{cfv}\left(T_{vi}-T_f\right) \quad (10)$$

Limit conditions

For x = 0:$Tf_{01} = T_a$ (11)

For x = Lc:$Tf_1 = Tf_2$ (12)

2- Drying equations

Product Characteristic (Corn) [6]

Characteristic	Equation
Initial water content (M)	40
Final water content	6,4
Drying temperature	75 °C
Hre	1 – exp-K(T + 460)M^n
Density	1397 – 205Ce
Cp	0,35 + 0,0085Ce
Thermal conductivity	0,114+0,133Ce – 0,125Ce^2
ΔHv (Tp)	Lv(1+ 4,35 exp(28,25M))

According to references [3] and [13], we consider the following equations:

Gaseous phase

$$\rho_a.V_a.\frac{\partial C_v}{\partial x}=\frac{A}{\varepsilon}\rho_a.h_{map}\left(C_{vp}-C_v\right) \quad (13)$$

$$\rho_a.C_{pa}.V_a.\frac{\partial C_v}{\partial x}=-\frac{A}{\varepsilon}\rho_a.h_{cap}\left(T_a-T_p\right) \quad (14)$$

Solid phase

$$\rho_p.\frac{\partial C_e}{\partial t}=-\frac{A}{1-\varepsilon}\rho_a.h_{map}\left(C_{vp}-C_v\right) \quad (15)$$

$$\rho_p.C_{pp}.\frac{\partial T_p}{\partial t}=\lambda_p^{eff}\frac{\partial^2 T_p}{\partial x^2}+\frac{A}{1-\varepsilon}\left[h_{cap}\left(T_a-T_p\right)-\rho_a h_{map}\,\Delta H_v^{eff}(T_p)(C_{vp}-C_v)\right] \quad (16)$$

Initial conditions

$$C_e(x,t=0)=\frac{X_0}{1+X_0}=C_{e0} \quad (17)$$

$$T_p(x,t=0)=T_{a0} \quad (18)$$

Limit Condition for (x = 0)

$$\rho_p.C_{pp}.\frac{\Delta x}{2}.\frac{\partial T_p}{\partial t}=2\lambda_p^{eff}\frac{\partial^2 T_p}{\partial x^2}+\frac{A}{1-\varepsilon}h_{cap}\left(T_a-T_p\right) \quad (19)$$

IV- TECHNICAL STUDY

We used the following materials:

a) Dryer

Wall: Clay brick

External dimensions: Height - Width - Length 2 m - 4 m - 4 m

Dimensions of racks: Length - width - thickness 3,6m - 1,8 m - 0,15 m

b) Solar captor

Glass wool insulation

Dimension: Length - Width - Thickness 2m - 1,5m - 0,22m

Glass thickness : 5mm

Absorber: 0.1mm

V- ECONOMIC STUDY

1-Material Number Unit Price, Total Price

Materials	Number	Unit Price ($)	Total Price ($)
Supply for solar collector	2	155	310,00
Clay brick	7500	0,0184	138,16
Sand of river	$3m^3$	6,578	19,74
Board	10	4,21	42,11
grilling	260	1,315	342,11
Metal door	1	39,473	9,47
Sheet metal (0,40mm)	20	3,684	3,68
honey	20 litre	2,631	2,63
Driving (100 PVC)	1 barre	7,105	7,11
Fan (75W)	6	13,157	8,95
2x2.5 thread	10m	0,473	4,74
1500 W resistor	8	1,578	2,63
Shipping costs			105,26
Installation costs			526,32
TOTAL			1 752,89

Table 2: Lit of materials and prices in Antsiranana

2- Calculation of depreciation rate

According to references [6], [10], we used:

The expected lifetime is D = 5 years

Depreciation rate is given by the expression:

$$t = \frac{100}{D} \quad \text{With D = 5 years} \qquad (20)$$

3-Amortization period

$$a = \frac{V_o}{D} \qquad (21)$$

With Vo is original value

$$t = \frac{1752,895}{5} = 350,5789 \ \$ / year$$

4- Linear depreciation method

C.F.M: Monthly fixed cost

$$C.F.M = \frac{t}{12 \ mois} = \frac{350,5789}{12} = 29,215 \ \$ / month \qquad (22)$$

- Rental cost: 0,015 $ / kg dry maize
- Room capacity 2.5 t maize
- Drying time 6 h
- Dry maize yield 66%

With regard to the drying time, we had 5 tons of maize can be dried per day.

There are three peaks of maize production in Madagascar: March, july and november. The campaign duration is 25 days.

The total product dries for 25 days is 82.5 t;

The monthly income is 1302,632$/ month;

The annual revenue will be 3907,895$/ years.

5- Economic study

a) Cash flow

The cash flow is given by the following expression:

FT = Revenue - Expenditure (23)

b) Discounting factor

The discount rate is 50%:

$C.A = (1 + TA)^{-n}$ (24)

With TA is discount rate

n: year of exercise

c) Net cash flow
FNTA = Updated TNF = FT x CA (25)

VI- RESULTS AND DISCUSSIONS

The behavior of the insolator following the emission solar radiation during a day is presented in Figure 3. Figure shows us the value of direct, diffuse and global powers varies with the positioning of the sun. More the distance between the sun and the sensor is reduced, as is generally the case at 12 o'clock, the radiation is very important. On the other hand, if the sensor is in an inclined position, the solar radiation became less important.

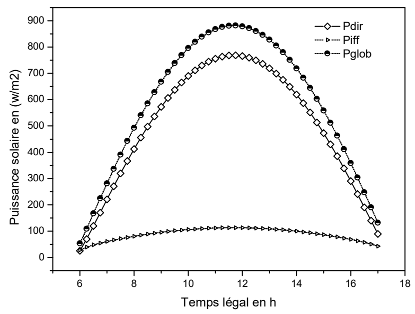

Figure 3: *Evolution of solar radiation as a function of legal time*

Figure 4 illustrates the curves representing the variation of the glass and absorber powers. Importance of the absorber curve is due to its higher absorption coefficient than for glass, because of its optical properties, allowing the heat to pass at a high transmission coefficient.

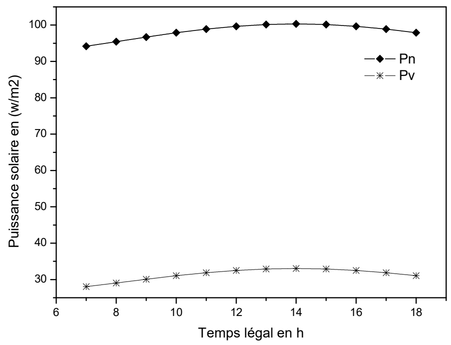

Figure 4: *Evolution of absorbers and glass powers as against time*

The evolution of the output temperature of the double pass sensor is shown in figure 5. The evolution of temperature field within this medium (dryer room) is the key to the drying phenomenon, since an increase in evaporation rate leads decrease the water content.

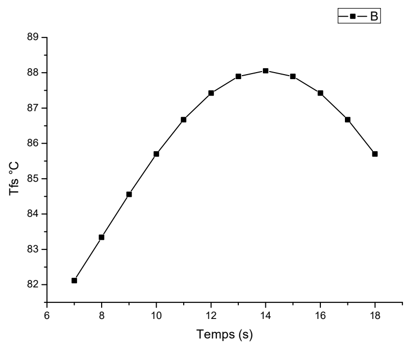

Figure 5: *Evolution of the temperature of the double-pass sensor output*

a) Summary table of depreciation and profitability of the dryer

	Year 1 (In Dollar)	Year 2 (In Dollar)	Year 3 (In Dollar)	Year 4 (In Dollar)	Year 5 (In Dollar)
Recipe	3907,895	3907,895	3907,895	3907,895	3907,895
Total recipe	3907,895	3907,895	3907,895	3907,895	3907,895
Spent					
Hardware purchase	2404,211				
Maintenance cost	26,31579	26,31579	26,31579	26,31579	26,31579
Billing (Energy)	89,28053	89,28053	89,28053	89,28053	89,28053
Staff	592,1053	592,1053	592,1053	592,1053	592,1053
Amortization	350,5789	350,5789	350,5789	350,5789	350,5789
Total expenditure	3462,491	1058,281	1058,281	1058,281	1058,281
FT	445,4037	2849,614	2849,614	2849,614	2849,614
Cumulative FT	-2159,86	689,7547	3539,369	6388,983	9238,597
Discounting coefficient	0,000263	0,000175	0,000117	7,79E-05	5,18E-05
FNTA	445,4037	1897,843	1265,229	843,4858	561,374
Cumulative FNTA	-2159,86	-262,016	1003,212	1846,698	2408,072

Table 3: Profit Summary of maize Dryer

The analysis is based on prices in May 2018 and concerns only tunnel dryers. Quantities dried annually are extrapolated from May data. We see that the dryers are clearly used the other months with other product.

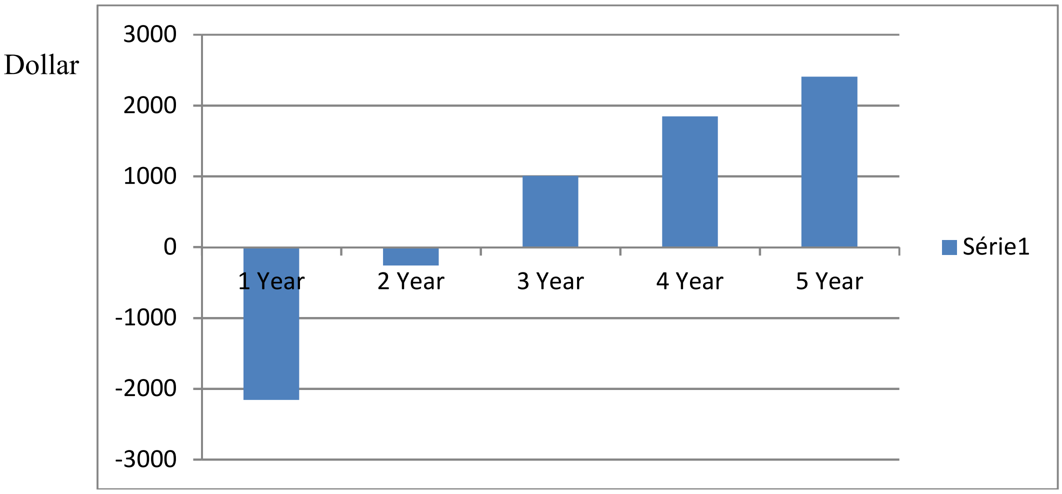

Figure 5: Benefit during the year

The benefit of the maize sector in the rural municipality Anketrakabe entrain the economic development in this village. Majorities population is farmer. In general, the local products founding in this village are maize, groundnuts and others.

The table below presents the annual revenue of the municipality.

	2014	2015	2016	2017	2018
Number of producers	150	130	200	300	500
Products sold (Ton)	2 250	2 000	4 000	6 500	10500
Corn price for 1 ton (September month)	236,842$	263,157$	342,105$	394,736$	263,157$
Rebate collected (4%)	21315,789$	21052,631$	54736,842$	102631,578$	110526,315$

Table 4: Annual Rebate Revenue

Source: Rural Municipality of Anketrakabe.

According to the table, maize production accounts for 60% on the development of the rural commune Anketrakabe. But, compared to the number of populations, only 18% are maize producers. The population is estimated at 2933 inhabitants, in 2017.
In 2018, maize production decreases due to cyclone damage (heavy rain).

VII- CONCLUSION

The behavior of solar air collectors has been studied in natural and artificial sunshine so as to better control the parameters on which the yield depends.

The modeling made it possible to highlight the interest of the selective absorbers for the double pass sensors, which allow a considerable improvement of the yields when the temperature of entry of the air is high. The climatic context of the DIANA region lends itself well to the practice of drying, which has been applied since month March to a large number of products.

To conclude, we can say in the one hand that the technical feasibility of solar drying is demonstrated for some products, it remains to prove for others. On the other hand, the socio-economic impact of solar dryers still requires a lot of investigation to be known. Finally, the results of the NPV show us this system is profitable in the DIANA region.

The future program of research foresees the consolidation of the results already acquired, notably by the reduction of the costs and the use of the local materials. Better knowledge of physiological characteristics of the products to be dried, as well as the development of complete processes for products insufficiently studied or not yet studied.

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