

# Regulation and Thermal Compensation of Continuous Forced Convection Indirect Solar Dryer for the Drying of Agricultural Products: Maize, Mahogany Nuts, Shea Nuts, By-products Derived from the Processing of Mango

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**Abstract:** In this work; we were interested in the respect of the drying parameters, namely the recommended temperature range and the extraction of the moisture content during the drying of maize, mahogany nuts, shea nuts or by-products resulting from the processing of the mango. The thermal analysis of the drying system leads us to develop a system of regulation and thermal compensation in order to avoid the calcinations of the finished product and to respect the physicochemical parameters of the material. It must be emphasized that there are several agricultural products and their physicochemical parameters are not the same. Therefore the temperature ranges will be selected from the control system and compensation while taking into account the quality of said products. Note also that this study is conducted in a Sahelian country where sunshine is important and it becomes interesting to proceed to a regulation and a thermal compensation. To do this, we designed the control system and thermal compensation while taking into account the drying temperature.

**Keywords:** Thermal Regulation, Thermal Compensation, Solar Drying, Agricultural Products and by-Products, Temperature, Humidity

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## 1. Introduction

One of the primary means of drying agricultural produce is direct sun exposure, but this method is not without drawbacks due to bad weather. Such bad weather has adverse effects on the quality of these agricultural products.

Drying with solar driers is one of the best alternatives to maintain the intrinsic qualities of dried agricultural products [2-3]. This drying system also recommends the respect of certain parameters so as not to harm the products during drying [4-7].

In view of the foregoing, the regulation of these parameters becomes a need during the drying process as well as the compensation of the coolant for drying.

This work aims to develop a device for regulating and thermally compensating the indirect forced convection solar dryers.

## 2. Devices Description for Regulating the Drying System [1, 8-13]

### 2.1. The Temperature Sensor

Temperature control and monitoring are among the most important applications of automation and process [1]. The temperature sensor is an apparatus for determining the temperature of a component or a body at a given time. This converts the measured temperature into an analog electrical

signal resulting from the variation of resistance. A microprocessor controls and exploits the electrical signal. The current temperature of the system is displayed by LED's directly on the electronic box. The microprocessor and the display simplify the use considerably [1].



Figure 1. The temperature sensor.

### 2.2. The Solenoid Valve

The solenoid valve will be used to regulate the flow and pressure of the heat transfer fluid and is controlled by an electromagnet.



Figure 2. Solenoid valve with pilot control integrated, membrane not coupled 3/8to2.

### 2.3. The Relief Valve

The relief valve allows the protection of the equipment against the effects of overpressure when the supply of the installation is from a pressure much higher than the maximum operating pressure.



Figure 3. Relief valve.

## 3. Thermal Sizing of the Heating System

The drying temperature of the products is of the order of  $T_s \in [\theta^\circ\text{C}; \theta' ^\circ\text{C}]$  with  $\theta^\circ\text{C} < \theta' ^\circ\text{C}$  while taking into account calcination.

The volume of water extracted per hour during the drying time is obtained by the following formula:

$$V_{\text{water}} = m_h \cdot (\%e_r - \%e_{\text{water}}) / (1000 - \%e_{\text{water}}) / T_s$$

- a)  $m_h$ : Product mass when wet, ie 1kg;
- b)  $\%e_{\text{water}}$ : Moisture content of the product when wet, 95%;
- c)  $\%e_r$ : Recommended moisture content for the finished product, 12%;
- d)  $T_s$ : Drying time depending on the quality of the material.

The flow rate of the coolant is determined by the blower or the air compressor which is of the order:

$$D_{fc} = 12 \text{ dm}^3 / \text{mn}$$

- i.  $Q_{p1} = M_a \cdot C_{p_a} \cdot (T_{as} - T_{ac}) - \Sigma(\text{convective losses of the ducts})$  In case it is the solar source, only, that works.  
 $Q_{p1}$ : Power produced by the solar source in Joule (J)  
 $M_a$ : Mass flow rate of air in kg/s  
 $C_{p_a}$ : Thermal capacity of the air in J/kg.°C  
 $T_{as}$ : Air temperature at the outlet of the generating source (Solar thermal).  
 $T_{ac}$ : Air temperature at the input of the producing source (Solar thermal).
- ii.  $Q_{p2} = RI^2 \cdot T_r - \Sigma(\text{convective losses of the ducts})$  In case it is the heating resistor, only, that works.  
 $Q_{p2}$ : Power produced by the source of the heating resistance in Joule (J)  
 $R$ : System resistance in ohm ( $\Omega$ )  
 $I$ : Intensity crossing the resistance in ampere (A)  
 $T_r$ : Heating time(s).  
 $Q_p = Q_{p1} + Q_{p2} = M_a \cdot C_{p_a} \cdot (T_{as} - T_{ac}) + RI^2 \cdot T_r - \Sigma(\text{convective losses of the ducts})$  In case both sources are recommended.  
 The flow of heat received by the material is:

$$\Phi = \lambda_1 \cdot \left(\frac{A}{Dl}\right) \cdot (U_m \cdot D_l \cdot \left(\frac{\rho}{\mu}\right)^m) \cdot S \cdot (T_{\text{pext}} - T_{\text{pint}}) \text{ car } \Phi = h \cdot S \cdot (T_{\text{pext}} - T_{\text{pint}})$$

The temperature required for drying which is of the order of  $T_s$  will be programmed from a display. But this temperature is obtained before hand by the formula:

$$\lambda_1 \cdot \left(\frac{A}{Dl}\right) \cdot (U_m \cdot D_l \cdot \left(\frac{\rho}{\mu}\right)^m) \cdot S \cdot (T_{\text{pext}} - T_{\text{pint}}) = M_a \cdot C_{p_a} \cdot (T_{as} - T_{ac}) + RI^2 \cdot T_r - \Sigma(\text{convective losses of the ducts})$$

Finally, we get the following formula:

$$T_{pint} = T_{pext} - [M_a \cdot C_{p_a} \cdot (T_{as} - T_{ac}) + RI^2 \cdot T_r - \Sigma(\text{convective losses of the ducts})] / \lambda_1 \cdot \left(\frac{A}{D_i}\right) \cdot (U_m \cdot D_i \cdot \left(\frac{L}{\mu}\right))^m \cdot S$$

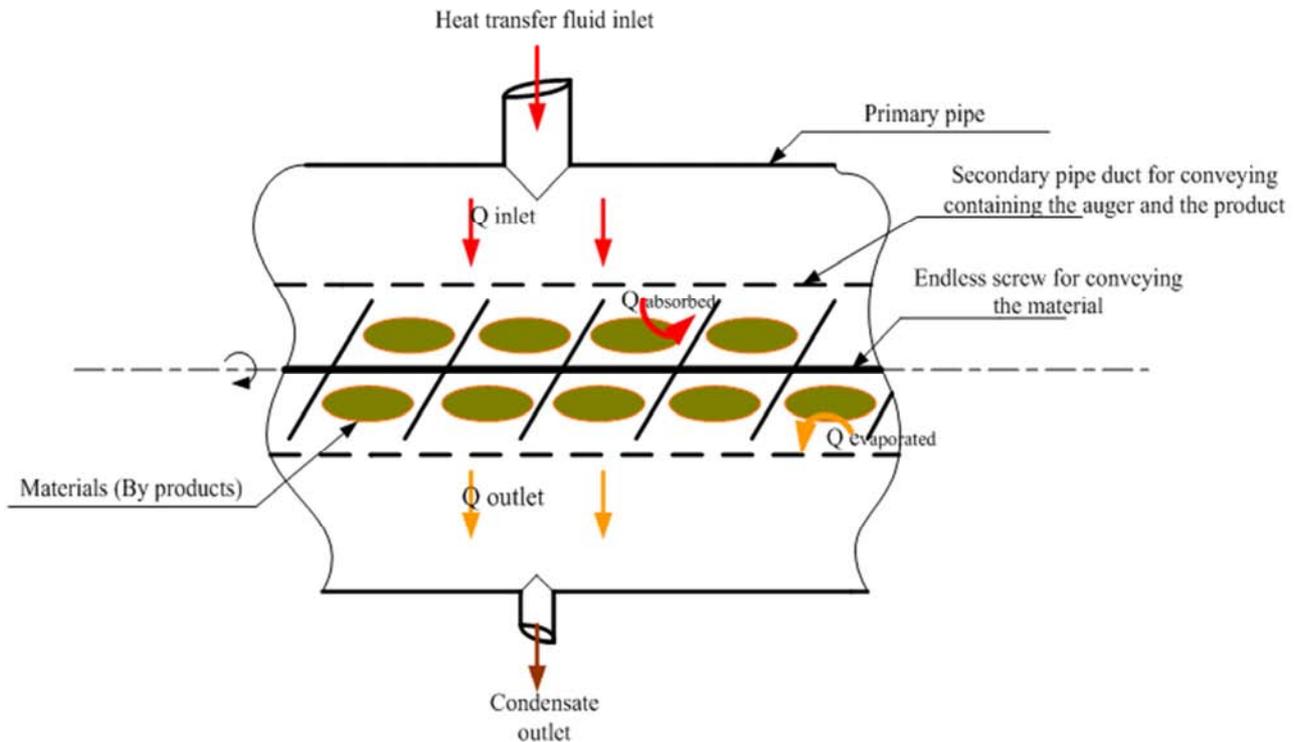


Figure 4. Materialization of the different flows in the ducts.

Table 1. Identification of the different parameters.

| Designations   | Symbols        |
|--|----------------|
| Coefficient taking into account the radiative and emissive properties of the body (Ar) | A              |
| Convective heat exchange coefficient (W/m <sup>2</sup> . K)                            | h              |
| Thermal conductivity of liquid   | $\lambda_1$    |
| External diameter of the tube(duct)  | $D_{ext}$      |
| Inner diameter of the tube(duct)   | $D_i$          |
| Diameter of the worm   | $D_{arbre}$    |
| Heat flow that attacks the drying duct   | $\Phi$         |
| Length of the duct(tunnel)drying   | L              |
| Density of the liquid  | $\rho$         |
| Nusselt number   | Nu             |
| Reynold number   | Re             |
| Surface attacked by the coolant  | S              |
| External body temperature of drying pipe   | $T_{pext}$     |
| Temperature received by material   | $T_{pint}$     |
| Dynamic viscosity of the liquid  | $\mu$          |
| Average speed of the liquid  | $U_m$          |
| Volume of duct(tube)drying   | $V_{pipe}$     |
| Material volume  | $V_{material}$ |
| Volume of the worm   | $V_{vsf}$      |

### 4. Results and Discussion

The heating system used in this study is a combined system of solar thermal and heating resistance that will serve to over heat the compressed air produced. In this system the heating resistor will serve as compensation or replacement in case of failure to reach the ideal temperature between [0°C; 0°C] with 0°C < 0°C.

The heat transfer fluid from the solar thermal interconnection system-heating resistor will be regulated according to demand.

To do this, the recommended temperature range [0°C; 0°C] is programmed on a display. This display will be in connection with a temperature sensor and a motorized valve. The temperature sensor installed in the chamber of the drying chamber will send information on the display regarding the heating state of the drying chamber. The display will control the opening of the motorized valve to allow the passage of the material when the temperature range [0°C; 0°C] is reached, and the closing of said valve in case the temperature will be above said desired range in order to avoid the calcinations of the product (see Figures 5 & 6) since we are in the case of a continuous indirect convection dryer with forced convection.

In addition, another probe will control the startor stop of the heating resistor if the temperature is below respectively above the desired range (see Figures 5 & 6).

Table 2. Actions and commands.

| Actions   | Commands        |
|---|-----------------|
| Heat transfer fluid production  | KM <sub>D</sub> |
| Sends heat transfer fluid into the heating chamber                          | KM1             |
| Continuous drying of the product  | KM2             |
| Starting the heating resistor after time t to compensate for the deficiency | KM3             |
| Closure VC1   | KM4             |

| Actions              | Commands |
|----------------------|----------|
| Closure VC2          | KM5      |
| Closure VC3          | KM6      |
| Hopper valve closure | KM7      |

Table 3. Informations et sensors.

| Informations   | Sensors        |
|--|----------------|
| Initialization   | m              |
| Presence heat transfer fluid                                   | n <sub>1</sub> |
| Absence heat transfer fluid                                    | n <sub>0</sub> |
| Open valves  | a <sub>1</sub> |
| Closed valves  | a <sub>0</sub> |
| Drying temperature reached                                     | b <sub>1</sub> |
| Drying temperature not reached                                 | b <sub>0</sub> |
| Products or by-products being dried                            | c <sub>1</sub> |
| Products or by-products not in the course of drying            | c <sub>0</sub> |
| Heating resistance running to compensate for the insufficiency | d <sub>1</sub> |
| Heating resistance at standstill                               | d <sub>0</sub> |
| Closed hopper valve  | e <sub>1</sub> |
| Open hopper valve  | e <sub>0</sub> |
| Chamber valve1 (VC1) closed drying                             | f <sub>1</sub> |
| Chamber valve1 (VC1) open drying                               | f <sub>0</sub> |
| Chamber valve2 (VC2) closed drying                             | g <sub>1</sub> |
| Chamber valve2 (VC2) open drying                               | g <sub>0</sub> |
| Chamber valve3 (VC3) closed drying                             | h <sub>1</sub> |
| Chamber valve3 (VC3) open drying                               | h <sub>0</sub> |
| Material presence at VC1 level                                 | i <sub>1</sub> |
| Material absence at level VC1                                  | i <sub>0</sub> |
| Material presence at VC2 level                                 | j <sub>1</sub> |
| Material absence at level VC2                                  | j <sub>0</sub> |
| Material presence at VC3 level                                 | k <sub>1</sub> |
| Absence of material at the level of VC3                        | k <sub>0</sub> |

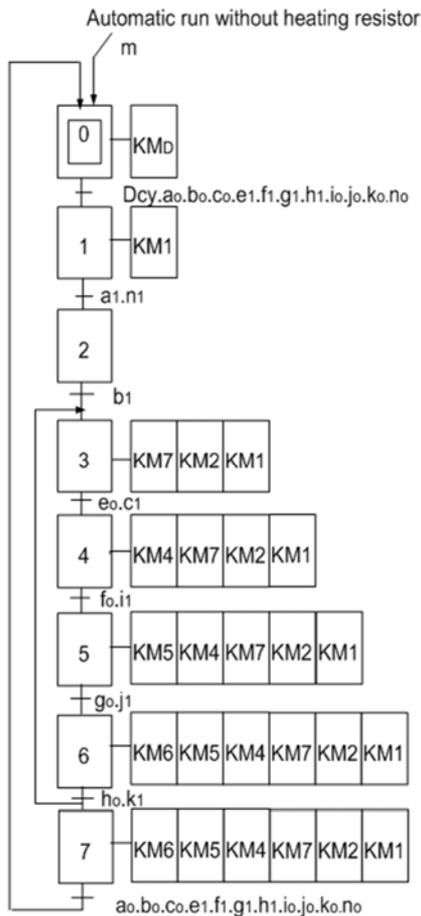
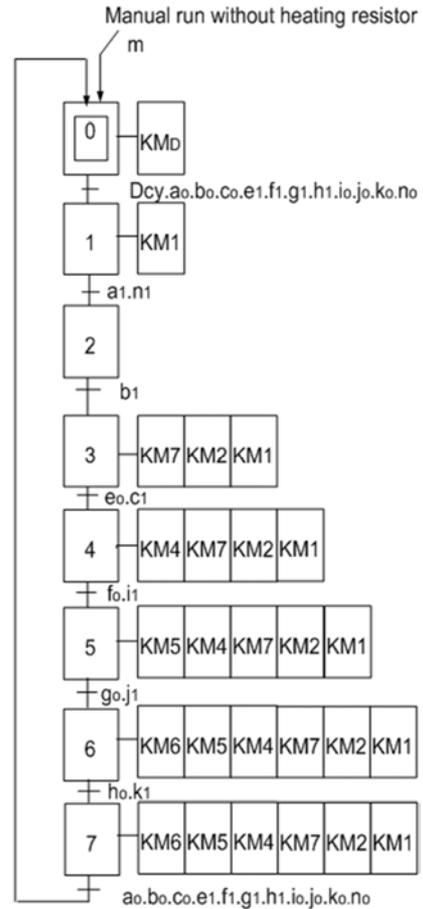
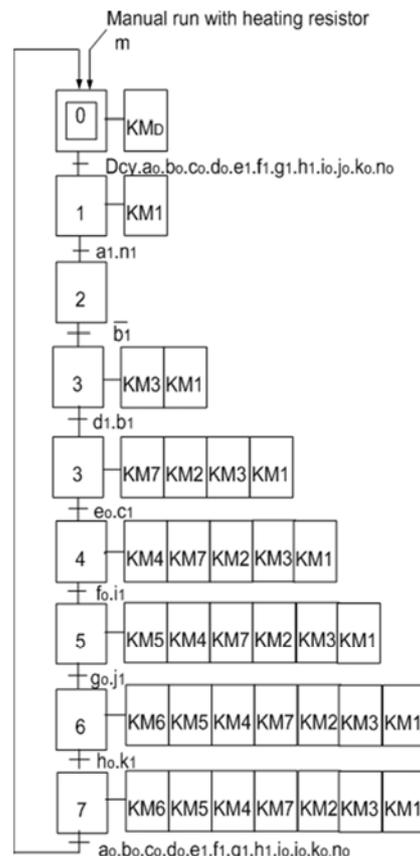


Figure 5. Grafset manual and automatic controls without heating resistor.



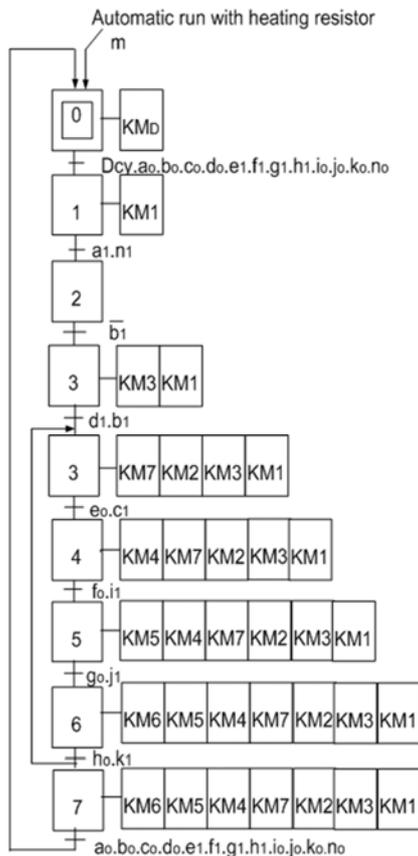


Figure 6. Grafset manual and automatic controls with heating resistor.

We did not speak specifically about the pressure and the flow rate of the coolant because they depend on the blower or the air compressor used.

Note also that the recommended pressure will be of the order of 10 bars and the flow of said heat transfer fluid will be of the order of 12dm<sup>3</sup>/min.

In our design there are three stages of drying ducts, so we will have probes for each compartment. This will allow us to correctly follow the behavior (Temperature in degrees Celsius and the pressure in bars as a function of time in minutes) of the different drying ducts.

## 5. Conclusion

The thermal analysis of the continuous forced convection indirect solar dryer has led to the development of a rigorous system for monitoring temperature and humidity, which are the crucial parameters in the drying process.

The thermal regulation of the drying system also makes it possible to avoid the calcinations of the finished product and to respect the recommended quality. The direct connection of this drying system to the mango processing line at the plant and processing plant levels will reduce production costs and the regulation of the coolant.

The forced convection indirect solar dryer would perform better in the northern, Sahel and central regions (Burkina Faso) as solar rays are more intense in these areas. But the disadvantage at this level will be the acquisition of the raw material which is available in quantity only in the western part of the country.

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## Biography



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