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Design of a hybrid solar collector with a flat plate solar collector and induction heating: evaluation and modelling with principal components regression

Diseño de un captador solar híbrido con captador solar de placa plana y calentamiento por inducción: evaluación y modelado con regresión de componentes principales

E. Figueroa-Garcia[1], M.A. Segura-Castruita[2], F.M. Luna-Olea[2], O.F. Vázquez-Vuelvas[3], A.M. Chávez-Rodríguez[2*]

[1]*Tecnológico Nacional de México/Instituto Tecnológico José Mario Molina Pasquel y Henríquez domicilio, Campus Cocula, Calle Tecnológico No. 1000, Col. Lomas de Cocula, C.P. 48500, Cocula, Jalisco, México.*
[2]*Tecnológico Nacional de México/Instituto Tecnológico de Tlajomulco. Km 10 Carr. San Miguel Cuyutlán, Tlajomulco de Zúñiga, Jalisco, C.P. 45640, México.*
[3]*Biochemical Engineering and Bioprocessing Laboratory. Chemical Science Faculty. University of Colima. Campus Coquimatlán. Carr. Km 9 Carretera Colima - Coquimatlán s/n. Coquimatlán, Colima. 28400. Mexico.*

Abstract

Food drying is one of the main food preservation processes, which are supplied with electrical energy (EE). Recently, the EE has had constant increases in its costs, prompting the integration of renewable energy sources for these processes. Therefore, the objective of this research was to design, build and model a hybrid solar collector (HSC-IH) for drying food, made up of solar energy (SE) through a solar collector and EE by means of induction heating. (IH), this work prioritizes the incorporation of an auxiliary heating system for the solar collectors, minimizing temperature variability and increasing its heat capacity, the HSC-IH has a collection surface of 1 m^2, adjustable flow of 0.3 - 4 CMM and maxim of 80 ° C, the prediction model developed with PCR, to determine the outlet temperature (OT) provided by the HSC-IH with only the use of solar energy and to estimate the energy provided by the EE with the IH, the final model it has an R^2 of 0.934 and can be used to understand the OT of HSC-IH.
Keywords: solar dry, hybrid solar collector, flat plate collector, induction heating, principal components regression.

Resumen

El secado de alimentos es uno de los principales procesos de conservación de alimentos, los cuales, se abastecen de energía eléctrica (EE). Recientemente la EE ha tenido constantes incrementos en sus costos, suscitando la integración de fuentes de energía renovables para estos procesos. Por lo que, el objetivo de esta investigación fue diseñar, construir y modelar un captador solar hibrido (HSC-IH) para secado de alimentos, conformado por energía solar (SE) a través de un captador solar y EE por medio de calentamiento por inducción (IH), este trabajo prioriza la incorporación de un sistema auxiliar de calentamiento para los captadores solar minimizando la variabilidad de temperatura y aumentando su capacidad calorífica, el HSC-IH cuenta con una superficie de captación de 1 m^2 flujo regulable de 0.3-4 CMM y temperatura máxima de 80 °C, el modelo de predicción desarrollado con PCR, para determinar la temperatura de salida (OT) que aporta el HSC-IH con solo el uso de energía solar y estimar la energía que aportara la EE con el IH, el modelo final presenta una R^2 de 0.934 y se puede utilizar para comprender la OT del HSC-IH.
Palabras clave: energía solar, captador solar hibrido, captador solar de placa plana, calentamiento por inducción, regresión sobre componentes principales.

1   Introduction

Currently, the depletion of fossil fuel sources has caused the constant to increase in electrical energy (EE) prices (Prada *et al*., 2019); which directly influences the operating expenses of the food industries since these industries use between 10 and 15% of the total EE used by the entire industrial sector in the world (Bennamoun *et al*., 2011). Given the importance of reducing energy costs in the drying process, the integration of renewable energy (RE) sources has been sought as they offer a promising approach to this challenge. Some options that are used to replace or minimize the use of EE are solar energy (SE), combustion energy (biomass), geothermal energy, etc., (Fudholi and Sopian, 2019), mainly solar energy. The average solar radiation that the earth receives is 1,366 W/m², being able to take advantage of 1,000 W/m², so solar drying is currently a promising alternative (Montero *et al*., 2015).

Solar energy is used in solar drying systems that can be direct type (DT) or indirect type (IT) (Téllez *et al*., 2019), but indirect systems avoid quality degradation in the foods, have better quality of photosensitive dry products and better drying control compared to DT (Montoya-Ballesteros., *et al* 2017); but it is limited by the climatic conditions in which it can operate, so its use cannot be continuous (El-Hage *et al*., 2018) in addition to the low efficiency in relation to electric dryers (Bokor *et al*., 2019), IT drying uses solar collectors (SC) and drying cabinets (El Hage *et al*., 2018). The most widely used SC are flat plate solar collectors (FPC), FPC have great applicability in sectors of society, where cost factor is more important than efficiency, they have been widely used around the world due to their simple structure, reliable operation, low cost, and favorable performance (Lingayat *et al*., 2017); however, temperatures and efficiency achieved by FPC are low and require a longer drying time (Karki *et al*., 2019). In this sense, to increase efficiency, different designs and materials have been proposed for the elaboration of these solar collectors; for example, FPC with phase change materials (FPCPCM) that have heat storage in their materials during the day and release heat when there is little or no radiation; in addition, they can be used for a period longer than four hours longer than an FPC. This type of system shows efficiency of 45 to 54%, compared to the conventional system, due to the storage of heat, the reduction in

drying time and the quality of the products (Essalhi *et al*., 2017; Natarajan *et al*., 2017; Tlatelpa-Becerro., *et al* 2020). This is achieved by the type of materials that can be used in its manufacture, among which we can mention waxes, nanofluids, among others (El-Khadraoui *et al*., 2017; El-Sebaii and Shalaby, 2017). Specifically, SC with nanofluids (SCN) improve the rate of heat transfer from the absorbent plate to the transfer fluid, where the fluid stores the heat and from there the transfer is made to the end point, the medium of this fluid can be water or oil and concentrations vary due to the stability achieved by the nanoparticles (El-Khadraoui *et al*., 2017; El-Sebaii and Shalaby, 2017; Abuşka *et al*., 2019; Borode *et al*., 2019; Charvát *et al*., 2019; Zhou *et al*., 2019; Simonetti *et al*., 2020); actually, there is a tendency to use hybrid systems that allow greater control of the process and higher drying speeds due to the use of thermal energy sources complementary to solar radiation (Torres-Gallo *et al*., 2017), such as hybrid solar collectors (HSC). This type of collector works with two sources of thermal energy; the first is solar, through a FPC and the other, a type of auxiliary energy, which can be electrical, geothermal, combustion (LP gas, biomass), etc., (Torres-Gallo *et al*., 2017); so that, have higher efficiency, higher temperature and availability of use compared to those mentioned above, reaching an efficiency of up to 42.2%, higher than in conventional drying, depending on the geographical and climatic conditions and the established mass flow (Abubakar *et al*., 2018; Rizal and Muhammad, 2018; Murali *et al*., 2020), which makes them a viable option to reduce spending on EE (Bokor *et al*., 2019); as different researchers have shown when drying foods of animal and vegetable origin (Rizal and Muhammad, 2018; Murali *et al*., 2020).

Another viable option for the food drying industry is induction heating (IH), among which we can mention electromagnetic induction, which can shorten the drying time up to 2.5 times and obtain quality products (Ortiz-Hernández *et al*., 2020). The above allows us to assume that the new developments of solar-electric HSC with induction heating (HSC-IH) can improve the efficiency of HSC and use them in industrial drying processes; however, this aspect has been little reported.

Moreover, the prediction of the thermal behavior of drying systems, through mathematical models, is an aspect of utmost importance for the efficient management of this type of drying systems (Hao *et al*., 2021). About, black box models are generally used, which describe empirical correlations (based on

experiences or measurements) (Salat *et al.*, 2017), such as the use of multiple linear regression models that have been used to predict the behavior of some variable of interest of the solar collector (Kicsiny, 2014). Nevertheless, these models present problems of multicollinearity between the predictor variables, which could lead to misidentification of the most important predictors (Sharma, 1996; Hoe and Kim, 2004). Principal Component Analysis (PCA) is a method that is used intensively to find the relationship between various parameters, avoids multicollinearity problems and helps develop more robust prediction models (Camdevyren *et al.*, 2005; Wuttichaikitcharoen and Babel, 2014). Principal components regression (PCR) methods have been used successfully to analyze data and improve the precision of models generated with multivariate characteristics (Devangad *et al.*, 2016). PCR is a robust machine learning method that has been widely applied to obtain prediction models (Shi *et al.*, 2017: Luan *et al.*, 2018: Li *et al.*, 2020). The objective of this work was divided into 3 sections, to determine the climatic feasibility for the use of solar energy in Tlajomulco de Zuñiga, Jalisco, the second was to design, build and model a HSC-IH for air heating, with a double FPC step and an alternative thermal energy source with EE by HI and finally to develop a multivariate statistical approach to classify the predictor variables, according to their interrelationships and predict the outlet temperature (OT) of the HSC-HI by PCR.

2 Materials and methods

2.1 Design and construction of the HSC-IH

The hybrid solar-electric, solar collector was designed with an induction heating system (HSC-IH), which was integrated with a double pass FPC and an IH system using EE. In this way, air at room temperature is supplied to the HSC-IH, which is filtered at the inlet to prevent the accumulation of bacteria and particulate matter inside. Inside the FPC the heat exchanger generated by the IH (composed of two steel bars surrounded by helical copper coils and an IH module) was placed; in addition, the FPC consists of two air passages, which seek a greater permanence of the air inside the collector and create turbulence, it is then directed towards the outlet through an isolated flow channel at a depth of the required temperature gradient, for which a radial flow extractor is used
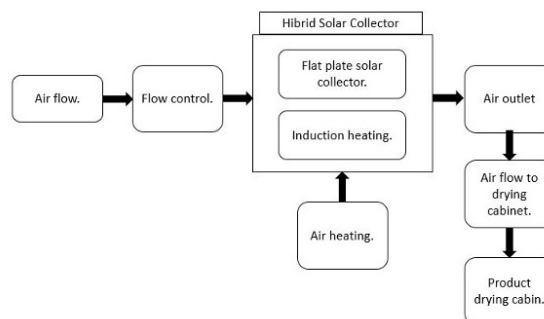

Figure 1. HSC-IH- flow chart.

Figure 2. HSC-IH.

to maintain the necessary mass flow and release it into the drying chamber as we can see in figure 1.

As can be seen in figure 2, the design description consists of FPC with the following characteristics: open at the top, configured and manufactured with materials resistant to temperatures around 1370 to 1400 ºC; with an internal dividing wall partially divides the FPC in two; where the internal dividing wall has the same height as the container , but a shorter length, and is vertically fixed in the central part of the bottom of the collector , but making perpendicular contact only with one of the vertical walls of the flat plate solar collector to leave a space between the free end of the dividing wall and the wall

opposite the wall that makes contact with the dividing wall; in such a way that they form a channel in the shape of a "U", through which the air to be heated circulates; the conventional electromagnetic induction heating system was placed externally to the flat plate solar collector ; where its steel bars, together with its helical copper coils that surround the heating parts, are inserted horizontally inside the FPC , crossing the wall opposite the wall where the dividing wall makes contact, each bar housed in a circulation channel of the FPC.

It has a transparent glass that hermetically closes the open upper part of the FPC, a "U" shaped tunnel inside the FPC, formed by the "U" shaped channel covered by the glass transparent, where the air to be heated flows; the inlet of the air to be heated is connected to one of the ends of the FPC in a "U" shape with the outside, where the inlet is provided towards one of the ends of the wall that makes contact with the wall dividing to generate turbulence and homogenization of the temperature, the flow is introduced by means of an extractor (SOLER PALAU, 5HXM-200) and a hot air outlet is provided at the other end of the tunnel "U", which is located towards the other end of the same wall where the dividing wall makes contact, and from this point a metallic structure configured to support the HSC-IH with all its components is connected, the structure of the HSC-IH is manufactured with a first heat-insulating plate made of a fiber insulating material made of glass, has a thermal conductivity of 0.04 W/(m·K) at 24 °C, a second heat-insulating plate adhered to each flat face of the first heat-insulating plate, made of MDF, with a thermal conductivity of 0.04 W/(m·K) at 24 °C, a protective plate adhered to each flat face of the sandwich formed with the heat-insulating plates (3 and 4); the stainless steel protective plate is resistant to corrosion and has a melting temperature of around 1370 to 1400 ºC. The HSC-IH is covered on the inside with a layer of black paint to capture radiation and maintain heat inside said container, this collector feeds through a thermal hose to the drying chamber where the product is placed on dry.

The dimensions, characteristics, and types of materials used in the manufacture of the HSC-IH are shown in tables 1-3.

Table 1. HSC-IH parameters.

Parameter	Dimension	Parameter	Dimension
Width of the solar collector.	.72 m	Insulation thickness	.03 m
Length of the solar collector.	1.42 m	Solar collector outlet diameter.	0.10 m
Collector area	1 m2	Solar collector inlet diameter.	0.20 m
Channels.	2	Collector slope	45°
Length of space between glass and absorbent plate.	.3 m	Absorbent plate thickness.	0.006 m
Length of the space between channels.	.32 m	Insulating plate thickness.	0.003 m

Table 2. IH parameters.

Parameter	Dimension	Parameter	Dimension
Induction heating module	Input voltage: 220 V Plate input: 12 V-54 V Maximum power: 2100 W. Length: 155 mm Width: 70 mm Weight: 3kg	Number of induction heating rods.	2
Length of induction heating rods.	.75 m	Number of turns of helical coil.	38
Induction heating rod diameter.	3 mm	Number of helical coils.	2

Table 3. HSC-IH materials.

Parameter	Material
Collector structure	PTR 3 mm
Absorbent plate	Stainless steel sheet
Insulating plate	Tempered glass
Internal structure cover	Stainless steel sheet
External structure cover	Galvanized sheet
Insulator 1	MDF
Insulator 2	Fiberglass
Bar used for induction heating	Steel
Helical coil	Copper 6 mm
Painting	Oil paint, matte black color

2.2 Climatology analysis

The variables radiation (R) (W/m^2), ambient temperature (AT) (° C) were analyzed, these data were obtained monthly from the year 2019 - 2020 and precipitation (%) and light hours were analyzed only in 2020, in the town of Tlajomulco de Zúñiga, Jalisco, Mexico, the data were provided by the automatic meteorological station (AMS) of the National Water Commission located at coordinates 20 ° 26'32 "N 103 ° 25 '14" W at 1566 meters above sea level, to determine the viability of solar thermal energy in the region.

2.3 Experimental setup

The HSC-IH was placed at the Technological Institute of Tlajomulco, Jalisco, Mexico, with an inclination angle of 35 °. First, a thermal evaluation of the HSC-IH was performed without using the second energy source (IH), to evaluate the efficiency and the outlet temperature (OT) in a period of eight hours (8:30 - 16:30 hours) in three constant flows (F) of the HSC-IH (0.3, 2 and 4 cubic meters per minute (CMM), only SE was used. OT, R, AT, wind speed (WS), ambient humidity (H) and humidity (HI) in the HSC-IH were recorded as outputs, as well as time (M), the reading of these variables was taken every 10 minutes for 10 repetitions of each treatment, generating a total of 1440 treatments. It is important to highlight that the R,

AT, WS and H data were recorded in the AMS; while OT and HI were obtained with a temperature sensor (ASAIR, DHT22) that was placed in the collector.

The efficiency of the flat plate solar collector is estimated without using induction heating this to determine the efficiency of the FPC using equation (1).

$$n = \frac{mc_p(T_o - T_i)}{A_a G_t} \quad (1)$$

Where: n is the efficiency, G_t es global solar radiation at the collector plane (W/m^2), m is the fluid flow rate, c_p is the specific heat at constant pressure (J/Kg-°C), A_a is an absorbent area (m^2), T_o Ambient air temperature and T_i Fluid temperature at the collector inlet.

2.4 Modelling with principal components regression (PCR)

The model developed to predict the outlet temperature of the HSC-IH without the use of the IH to determine the thermal energy that the IH provides in the HSC-IH was fed with 80% of the experimental data and 20% was used to validate. A principal component analysis was used to obtain the model; since, it uses a multivariate approach that converts several correlated variables into linearly uncorrelated variables, which are called principal components (Mahmoudi *et al.*, 2020). With the first principal components contain the greatest amount of information, it transforms the correlated variables into a smaller number of variables constructed as linear combinations of the originals. This methodology applied to regression allows finding associations between variables and reducing their number to facilitate their analysis and interpretation (Zheng *et al.*, 2018). The values of the principal components of the predictor variables for each observation are given by the equation (2):

$$Z = XA \quad (2)$$

Where:

Z: matrix whose (i, k)-th element represents the value of the k-th principal component in the i-th observation.

X: matrix ($n \times p$) whose (i, j)-th element represents the value of the j-th predictor variable in i-th observation.

A: matrix whose k-th column is the unit eigenvector associated with k-th greater eigenvalue of $\frac{1}{n}X'X$.

The PCR method is an estimation technique to combat multicollinearity. If the matrix X is centered and scaled, it is denoted X´ the model is as follows:

$$Y = \beta_0 + \beta_1 Z_1 + \beta_n Z_n + \varepsilon$$

Where Y is the dependent variable, β_0 is the intercept, β_n is the coefficient of the component and Z_n is the PC. The process for making the OT prediction model (MPCR) is as follows:

1. Data cleaning is done to remove missing values.

2. Correlation analysis of the data set.

3. Principal component analysis to determine the components that will be taken to feed the model.

4. The model on principal components regression (PCR) is established, the mentioned before variables are used as predictors and the OT as response (Y), (Alibuhtto and Peiris, 2015: Kawano, 2016: Qi *et al.*, 2016).

2.5 Statistical analysis

- Correlation research aims to calculate and understand the impact of a linear or non-linear relationship between two continuous variables. Association coefficients assume values ranging from negative correlations (-1) uncorrelated (0) to positive correlations (+1). The sign of the correlation coefficient (that is, positive or negative) determines the direction of the relationship (Rath and Tripathy, 2020).

- An analysis of variance ($P \leq 0.05$) of the experimental results of the study variables was performed to establish the differences between treatments and interactions between variables that affect the OT of HSC-IH.

- Likewise, predictions were made with the model obtained for validation, where the determination coefficient (R^2), Fc value ($P \leq 0.05$) of the independent variables. On the other hand, the performance of these models was obtained through statistical indices with cross-validation with 20% of the data, such as the square root of the mean error of bias, the RMSE and the mean absolute error (MAE), with the following equations. 3 - 4 (Douglas *et al.*, 2009):

$$RMSE = \sqrt{\left(\frac{1}{n}\right)\sum_{i=1}^{n}(Xe_i - Xp_i)^2} \qquad (3)$$

where $RMSE$ is the square root of the mean of the error; n is the number of tests, Xe_i is the experimental result of the outlet temperature of the HSC-IH y Xp_i is the output temperature result of MPCR.

$$MAE = \left(\frac{1}{n}\right)\sum_{i=1}^{n}(|Xe_i - Xp_i|) \qquad (4)$$

where MAE is the absolute mean error; the rest of the symbols indicate the same as in the eq. (3).

- The RCME is an indicator of the performance of a model in each period and its value is always positive; while the MAE provides information on the long-term behavior of the correlations, which allows a comparison of the real deviation between the predicted and measured values, term by term in both cases, zero is ideal (Wang and Lu, 2018).

- Data processing was carried out in statistical software RStudio and Minitab18 (2018).

3 Results and discussion

3.1 Climatology analysis of the Tlajomulco de Zúñiga region for the use of solar energy

The solar radiation that occurs in the region during the year 2019 was relatively lower (677 ± 104.7 W/m^2) than the 698.26 ± 85.84 W/m^2 of the year 2020. Although the distribution of radiation was not uniform since in 2019 the maximum monthly average value was 826.24 W/m^2 in the month of May and the lowest was in December (533.11 W/m^2); while, in 2020 the maximum monthly average value was presented in April (838.96 W/m^2) and in January there were 546 W/m^2 (figures 3-4). This behavior can be explained by two reasons, the first is the solar declination, due to the position of the planet during its translational movement, which in spring has an angle close to zero, so that in the northern hemisphere there could be a longer time radiation; while in winter the declination angle is approximately 23 °, which translates into shorter days and longer nights in the northern hemisphere (Diez *et al.*, 2019). The second could be the cloudiness that occurs during the year, which would cause changes in radiation in the different months (Parreño *et al.*, 2020).
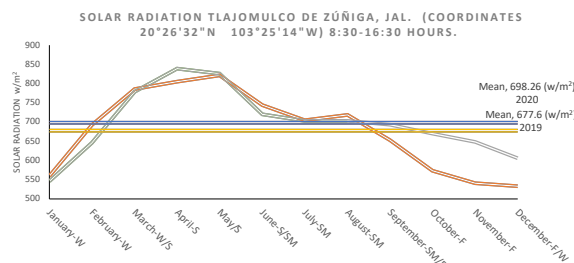
Figure 3. Solar radiation in Tlajomulco de Zuñiga, Jalisco, Mexico. (Winter (W), Spring (S), Summer (SM), Fall (F)).
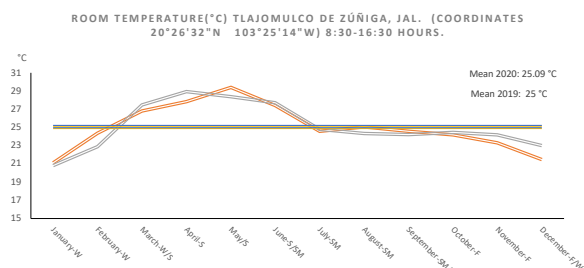

Figure 4. Room temperatures in Tlajomulco de Zuñiga, Jalisco, Mexico. (Line blue year 2020, line orange 2019, line, yellow, mean 2019, line green, mean 2020), (Winter (W), Spring (S), Summer (SM), Fall (F)).
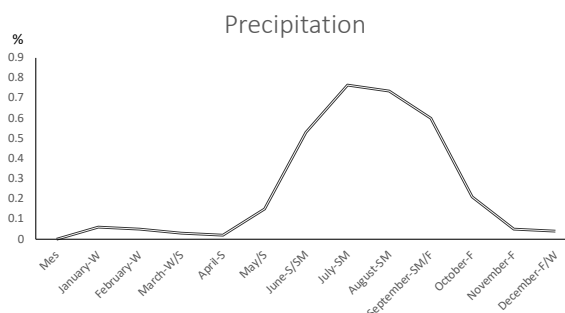

Figure 5. Precipitation in Tlajomulco de Zuñiga, Jalisco, Mexico, (Winter (W), Spring (S), Summer (SM), Fall (F)).
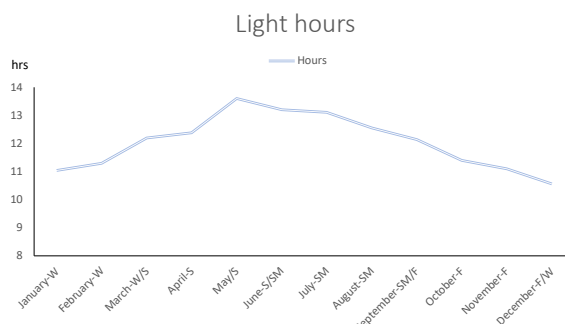

Figure 6. Light hours in Tlajomulco de Zuñiga, Jalisco, Mexico, (Winter (W), Spring (S), Summer (SM), Fall (F)).

The ambient temperature averaged 25 ± 2.49 °C for 2019, being like that which occurred in 2020 (25.09 ± 2.49 °C). The normal monthly maximum in 2019 was in the month of May (29.39 °C) and the normal minimum in January (21.11 °C). On the other hand, in 2020, the normal maximum monthly temperature was in April (28.93 °C) and the normal minimum in January (20.81 °C). The above reflects a normal behavior in radiation and temperature, which means that the use of solar energy is viable due to the parameters presented in the literature (Ulloa *et al*., 2011: IRENA, 2016: Sultan *et al*., 2020).

Regarding precipitation, the rainy season lasted 3.8 months (June 6 to September 30), with a probability of more than 40% that a certain day will be a rainy day. The maximum probability of a rainy day was 80% on July 9 and the behavior throughout the year, as we can see in figure 5; another important factor is the light days, which establish the hours that we can use solar energy, obtaining an average of 12.04 ± 0.9 hours of light and we can observe its behavior in figure 6.

3.2 Thermal evaluation of HSC-IH

The thermal evaluation of the HSC-IH established with three flows, presented differences in OT ($P < 0.05$), obtaining a higher OT at lower flow; in such a way that, by increasing the flow, the OT is reduced, as can be seen in figure 7- 8. Nonetheless, having low airflows can present problems with the humidity output of the HSC-IH and prolong the drying time (Rani and Tripathy, 2021). Otherwise, when OT was compared with the other study variables (figure 9), multicollinearity was observed. Although AT was the one that presented a greater relationship with an r of 0.92; while the variable that had the lowest relationship was the wind direction with are about 0.24, which can be explained because the HSC-IH was subjected to a constant flow and blocking of this variable.

The efficiency of HSC-IH was determined with the aforementioned method and without using induction heating, the efficiency for the three flows used can be observed in table 4; The lowest efficiency was found with the lowest flow, this due to the null use
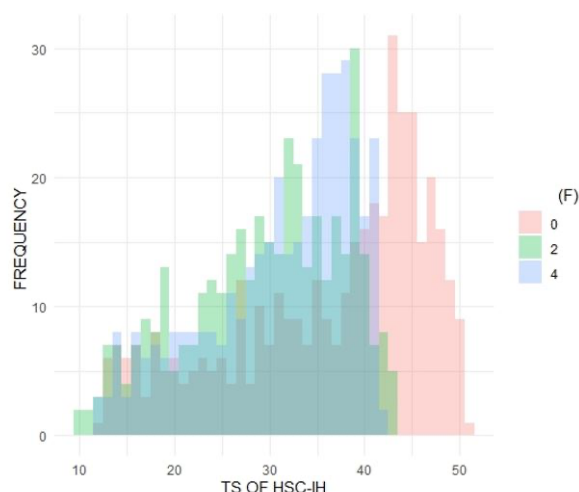
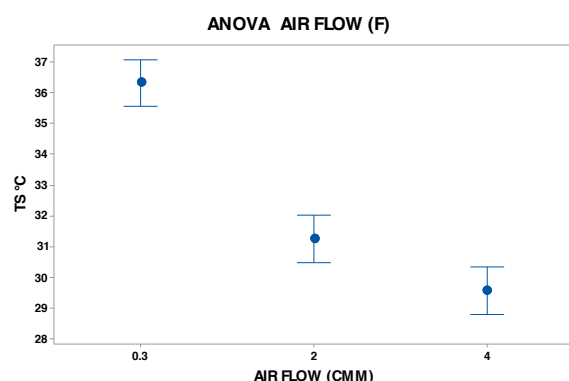Figure 7. Histogram of different air flows vs TS.

Figure 8. ANOVA of different feed airflows of the HSC-IH.

of useful heat, similar to that reported (Gómez *et al.*, 2010) where greater efficiency occurs when the flow is increased, but this parameter is also related to radiation present in the evaluation carried out.

3.3 Modelling with principal components regression

The results of the extraction of the principal components (PC) and evaluation parameters of the MPCR model are shown in table 5, resulting in eight principal components and the importance provided by each PC.

After the PC analysis, the MPCR model is established, eliminating the non-significant PCs, by the PC they were reduced from eight PC to six linearly uncorrelated PC since the cumulative contribution rate of the main eigenvalues of the factors reached 98.22%, which indicated that the selected principal components covered almost all the information of the indicators, which solved the multicollinearity problem. The MPCR generated with six PC to predict the OT of HSC-IH is shown in equation (5):

$$Y = 32.402 + 4.288(PC1) - 0.570(PC2)$$
$$+ 0.009(PC3) + 1.031(PC4)$$
$$- 2.48(PC5) - 3.436(PC6) \quad (5)$$

The model presents a value of R^2 of 0.9348, which means that the proportion of silver can explain 93.48% of the behavior of the outlet temperature. On the other hand, when verifying the precision of the prediction model, it should have a good performance since the RMSE was close to zero (2.37); while, if the MAE (5.63) is positive, it indicates that the model could underestimate the OT of the HSC-IH. However, the PCR model that comprises six PC with eight independent variables, can predict the output OT provided by the HSC-IH with only the SE, the remaining temperature is provided by the HI to reach a temperature of 80 °C for what we can describe the total temperature (TT) of the HSC-IH with equation (6):

$$TT = TY + TI \quad (6)$$

Table 4. HSC-IH efficiency.

Airflow (CMM)	Inlet temperature	Outlet temperature (TS)	Efficiency (%)
0.3	23.93 °C	36.31 °C	6
2	21.3 °C	31.24 °C	42
4	23.92 °C	29.55 °C	38

Table 5. Importance of principal components.

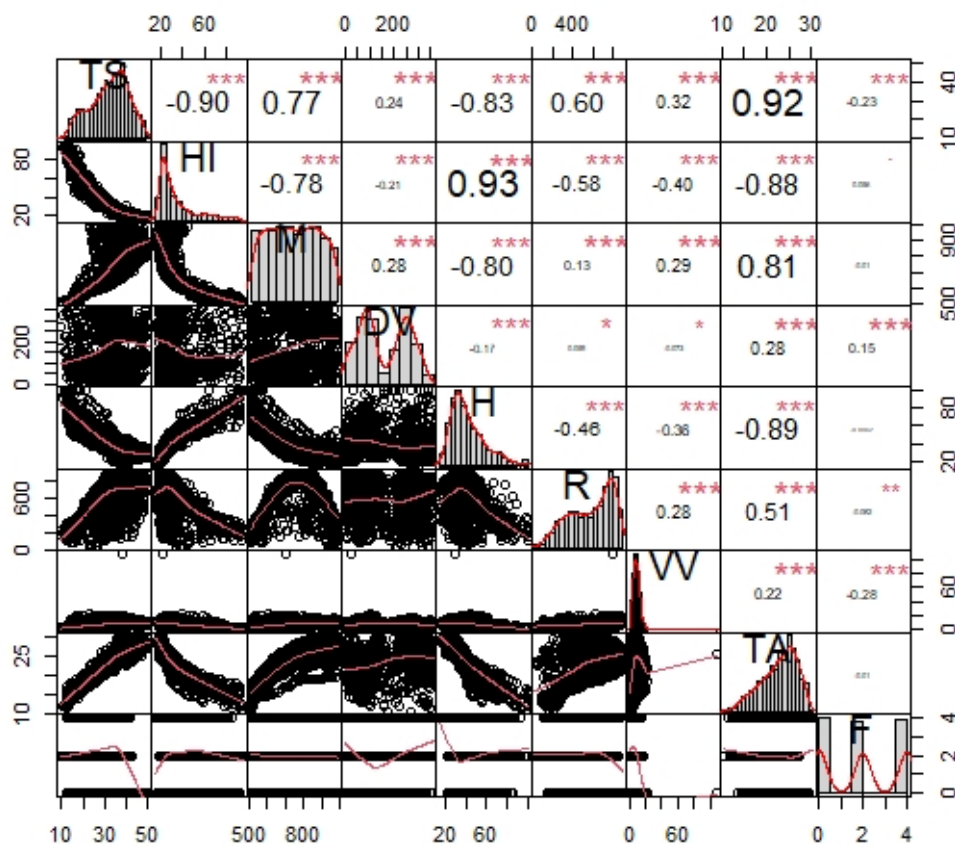|	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Standard deviation	2.0072	1.1765	0.9372	0.89002	0.80577	0.35419	0.3047	0.22107
Proportion of variance	0.5036	0.173	0.1098	0.09902	0.08116	0.01568	0.0116	0.00611
Cumulative proportion	0.5036	0.6766	0.7864	0.88545	0.96661	0.98229	0.9939	1

Figure 9. Correlogram of variables that interact in the HSC-IH .

Where TY is the temperature provided by the HSC-IH only with SE (80 °C), TI is the temperature that the IH will generate to complete the TT, from which equation (7) follows:

$$TI = 80 - TY \qquad (7)$$

With which we can determine the temperature at which each type of energy contributes to the HSC-IH.

Conclusions

The use of renewable energies plays a fundamental role in the development of the food industry, mainly solar energy, highlighting that it is a cheaper energy source compared to electrical energy. The results of the study show that the use of solar energy in Tlajomulco de Zúñiga, Jalisco, Mexico, is feasible due to its geographical location and meteorological conditions, mainly due to the available solar radiation; also, the proposal of a hybrid solar collector consisting

of integrated FPC with an auxiliary heating system, through induction heating (HSC-IH), achieve that hybridization increases the temperature that produces a SC and keeps it constant to be used in continuous drying processes, reducing the variability that SC presents due to climatic conditions; besides, to reduce the consumption of electrical energy, which is the source of energy with which these drying processes are mainly carried out. The proposed HSC-IH has a satisfactory thermal performance, with an efficiency of 42% in a flow of two CMM only with the use of SE; too, a statistical regression model with main components was developed that allows predicting the temperature provided by the HSC-IH only with SE in the course of the year, under the meteorological conditions used with a R^2 of 0.9348 and the constant monitoring of this parameter is eliminated, in conclusion, it is HSC-IH with the results obtained, it can be an option for the use of drying processes, however, experimental drying tests with the HSC-IH are still lacking for the evaluation of the drying process of a food.

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