# A Review of Software Used in Solar Dryer and PVT Systems

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***Abstract* --The paper provides an extensive analysis of recent studies focused on enhancing the efficiency and performance of solar thermal and photovoltaic (PV) systems through various computational methods and optimization techniques. The researchers explored the potential of using machine learning approaches, such as artificial neural networks (ANN) and Gaussian Process Regression (GPR), to model and predict key parameters in solar drying systems and PV/T systems. These studies highlighted the effectiveness of ANN and GPR inaccurately forecasting system behavior, emphasizing their importance in system optimization. Optimization techniques, including genetic algorithms (GA), evolutionary algorithms (EA), and soft-computing methods, were used to improve the efficiency of PV/T air collectors. The results showed significant enhancements in system performance through parameter optimization, further underscoring the critical role of optimizationin maximizing energy output. Moreover, computational fluid dynamics (CFD) simulations were employed to analyze the thermal performance of solar air heaters and PVT systems. Thesesimulations focused on optimizing system design and operational parameters to improve energy production and cooling processes, indicating the importance of numerical modeling in system optimization. These studies demonstrated the potential forsignificant enhancements in energy efficiency and thermal performance through experimental testing and validation.**

***Keywords* - Solar dryer, Photovoltaic/Thermal (PV/T) system.**

NOMENCLATURE

| | |
|---|---|
| $\beta_0$ | Temperature coefficients of efficiency (/K) |
| $L_f$ | Latent heat of fusion |
| $\lambda$ | Thermal conductivity |
| $\eta_{ele}$ | Electrical efficiency |
| $\eta_{Ex}$ | Exergy efficiency |
| $\eta_0$ | Efficiency at STC |
| $\eta_T$ | Overall efficiency |
| $\eta_{th}$ | Thermal efficiency |

ABBREVIATIONS

| | |
|---|---|
| ANN | Artificial neural network |
| COP | Coefficient of performance |
| ELM | Extreme learning machine |
| EVA | Ethylene-vinyl acetate |
| FPC | Flat-plate collector |
| HASS | Hybrid active solar still |
| GSA | Gravitational search algorithm |
| GA | Genetic algorithm |
| MPP | Maximum power point |
| NN | Neural network |
| PAP | Perforated absorber plate |
| PCM | Phase change material |
| PSS | Passive solar still |
| TMS | Thin metallic sheets |
| SVM | Support vector machine |
| TEG | Thermoelectric generator |
| STD | Solar tunnel dryer |
| SAHP | Solar-assisted heat pump |
| WOA | Whale optimization algorithm |

## I. INTRODUCTION

The world's population has increased and is expected to exceed 9.8 billion people by 2050. It leads to the intensification of food security in the world as one of the important subjects of sustainable development [1]. Also, the study of food security shows that the number of people suffering from malnutrition has increased from 784 million people in 2015 to 821 million people in 2017 which is proof of the main importance of investing in the agricultural sector to maintain food security and prevent the growth of hunger and poverty. By increasing the global demand for food, the intensity of using fossil fuels has increased in all stages of the human food chain.

Statistics show that global demand for energy and food will increase by 40 and 50% by 2030, respectively [2].

Simulation and mathematical modeling of the drying process of agricultural productions and drying systems is an important part of the drying process in post-harvest operations of agricultural products [3]. The modeling is based on a set of mathematical equations that satisfactorily explain the drying process and energy flow governing the dryer system. The purpose of modeling is to choose the best method and create the most suitable operating conditions for drying the desired product. Sometimes, it is not possible to conduct experimental tests and configure the system because of high cost. So, in the design and optimization of drying systems, modeling applications to predict the performance of the drying system and the drying behavior of agricultural products in different conditions is very useful and is known as a valuable tool [4]. Mathematical and machine learning models and simulation techniques such as Artificial Intelligence (AI), computational fluid dynamics, fuzzy, etc., can be effectively used to predict and analyze the effect of changes in input variables and their effects on outputs. Also, numerical modeling and simulation of the drying process are necessary for better control of system performance, overall improvement of final product quality, prediction of the product, and optimization of operating parameters and conditions [5].

Recently, some researchers applied AI methods to predict the final characteristics of Solar Dryer systems. Using AI models in most studies includes some advantages and disadvantages. One of the problems of cultivation in tropical regions is the needfor high energy consumption for ventilation and also cooling the internal environment of the structure in the hot seasons of theyear; which leads to the uneconomical cultivation of crops in hot seasons and these structures remain unused in thisperiod. Hence different software used in solar dryers and PVT systems are reviewed in this paper.

## II. MACHINE LEARNING APPROACH

### *1. Solar dryer*

Daliran et al. [25] modeled the temperature and mass of dried mint in a Quonset type of Greenhouse Solar Dryer (GSD). This study aimed to predict the temperature and mass of dried mint ($T_{dry}$ and $M_{dry}$) in a Greenhouse Solar Dryer (GSD). For this purpose, two types of ANN models (MLP and RBF) and Gaussian Process Regression (GPR) were used. The data was collected from a Quonset GSD located in Agricultural Sciences and Natural Resources University of Khuzestan, Iran. For the ANN models, Levenberg Marquardt learning algorithm, Sigmoid Tangent transfer function, and different combinations of neurons in the hidden layer (5–20) were assessed. During data analysis, the k-fold cross-validation method was used to create 100 random data sets in each step. The results showed that among all the models, the RBF with topologies 3-15-1 and 3-18-1 have the best and most accurate results for Tdry and Mdry modeling of dried mint, respectively (Mean Absolute Percentage Error (MAPE) was 1.4 and 1.82% for temperature and mass modeling, respectively). Among the 100 data sets that were created by the k-fold cross-validation method, sets 38 and 45 have the highest accuracy for Tdry and Mdry modeling, respectively. The statistical results (t, F, and Kolmogorov–Smirnov tests) of actual and predicted data by the RBF model showed that at the 95% probability level, there is no significant difference between the mean, variance and statistical distribution of the predicted data set with the actual values. Using the results of this research can help farmers and engineers in predicting the output of GSDs and achieving higher quality in drying agricultural products. Also, modeling other types of GSDs in this region and reaching a general and comprehensive model for use in all GSDs can be one of the important topics for future research. Also, Varol [6] developed the prediction model based on different soft-computing methods, viz., ANN, ANFIS, and SVM. ANN is emerging as the most popular among the various soft computing techniques because of its capability to deal with complex non-linear problems.

### *2. PV/T water collector*

Mojumder et al. [7] developed the prediction model based on a recently developed ELM algorithm to forecast the performance of the PV/T system. The results based on the ELM model are then compared with GP and ANN results. From the comparative analysis, it has been concluded that ELM is a promising approach to predicting the PV/T system's performance. Ammar et al. [8] developed the thermal energy distribution model based on ANN to calculate the optimum performance operating point of a PV/T water collector. Singh et al. [9] investigated the performance of PV/T air collector using GA by optimizing its four parameters particularly the length of the channel, depth of the channel, heat transfer coefficient, and fluid velocity. The overall $\eta_{Ex}$ of the system was reported 16.88% at the optimized value of parameters, as shown in Table 2. Therefore, the optimization of parameters is necessary to predict the performance. Singh and Agrawal [10] worked on a hybrid GA-FS approach to optimize the parameters of the PV/T air collector. The objective of the study is to maximize the $\eta_{Ex}$. The $\eta_{Ex}$ of the system was 15.82% when the parameters were optimized.

Table 1 Optimized value of parameters [9]

| S. no | Parameters to be optimized | Symbol | Optimized value |
|---|---|---|---|
| 1 | Channel length | L | 0.2083 m |
| 2 | Channel depth | D | 0.00069 m |
| 3 | Heat transfer coefficient | $h_{FA}$ | 1 W/m$^2$ K |
| 4 | Fluid velocity | V | 4.5 m/s |

using a hybrid GA-FS approach which is significantly higher than the result obtained using GA. Moreover, the convergence rate of the the GA-FS approach is faster as compared to GA and it takes much less time to recognize of optimum value of parameters to enhance its performance. Evolutionary algorithm (EA) was introduced for hybrid PV/T air collector by Singh et al. [11]. The performance of the PV/T system is significantly enhanced using EA. Diwania et al. [12] worked on a newly developed WOA to optimize the performance of a hybrid PV/T air collector by tuning its variable parameters. The result of WOA is then compared with GSA and GA and it has been concluded that $\eta_{Ex}$ and $\eta_{ele}$ of the PV/T system are significantly improved when the parameters are tuned using WOA. Hence, the parameter optimization using soft-computing techniques gives extremely encouraging outcomes and turns out to be imperative in predicting the performance of the hybrid PV/T module.

Gaur et al. [18] developed a mathematical model for a fully wetted absorber photovoltaic thermal (PVT) collector with and without phase change material (PCM) under its absorber channel. Thermal and electrical investigations were carried out using PCM OM37 for typical winter and summer days in Lyon, France. The system was analyzed under energy and exergy performances. PCM incorporation in a water PVT absorber improved the performance of the system in terms of electrical and thermal parameters. Enhanced electrical and thermal energy was attributed to the dissipation of excess heat of the PV module by a latent heat absorption mechanism that reduces the PV module temperature and releases heat at night as well, providing better electrical and thermal stabilities to the system. To solve the mathematical equation, an iteration method was used in the computer program Mathcad 15. A computer program was developed for the calculation of solar radiation on an inclinedsurface.

## III. ANALYSIS AND SIMULATION SOFTWARE

### *1. Ansys Software*

Hamad et al. [23] studied that adding artificial roughness or ribs to the surface of the wall of the absorber plate is an effective and promising method to increase heat transfer by interrupting the laminar sublayer. In this study, a trapezoidal rib was used to enhance the thermal performance of the solar air heater. Validation of experimental and numerical results was carried out. Eight different rib arrangements were considered and compared to determine the optimal configuration based on the thermal performance. The analysis was conducted in a 2D domain using ANSYS Fluent software, employing Reynolds numbers ranging from 5000 to 30000. The software utilized the RNG k-ε model and the finite volume technique to simulate turbulent flow. The governing equations, including Navier–Stokes, energy, and continuity equations, were solved separately. The results were obtained by describing the fluid flow and heat transfer within the model, utilizing a structured grid generated in the GAMBIT package. The model was subjected to specific boundary conditions and made certain assumptions, such as incompressible flow, Newtonian fluid behavior, steady state, and constant physical properties.

### *2. MATLAB software*

Alsaqoor et al. [24] examined the impact of incorporating phase change material (PCM) in photovoltaic thermal (PVT) systems on their electrical and thermal performance. Also studied was the effect of solar irradiation and coolant mass flow rateon the electrical and thermal output of both PVT and PVT-PCM systems. A graphical user interface was developed within the MATLAB Simulink under the weather conditions of Amman, Jordan. The results show that the incorporation of PCM in PVTsystems significantly reduces solar cell temperature and increases electrical efficiency. The highest electrical efficiency of a PVT system with PCM was found to be 14%, compared to 13.75% in a PVT system without PCM. Furthermore, the maximum achievable electrical power in a PVT system with PCM was 21 kW, while in the PVT system without PCM, it was 18 kW. The study also found that increasing the coolant mass flow rate in a PVT system with PCM further reduced PV cell temperature and increased electrical efficiency, while the electrical efficiency of both the PVT and PVT-PCM systems decreases as solar incident radiation flux increases, resulting in a significant rise in cell temperature. At an increased solar radiation level from 500 W/m2 to 1000 W/m2, the electrical efficiency of the PVT configuration decreases from 13.75% to 11.1%, while the electrical efficiency of the PVT-PCM configuration falls from 14% to 12%. The findings of this study indicate that the use of PCM in PVT systems can lead to significant improvements in energy production and cooling processes. The results provide valuable information for designing and optimizing PVT-PCM systems.


Fig.1. Flowchart diagram of MATLAB calculation procedure [24]

Embiale and Gunjo [19] carried out both the experimental study and numerical simulation to study the performance of the drying system and its components. In this study forced convection indirect solar drying system that has a double pass solar air heater (DPSAH), shell and tube type latent heat storage (LHS) with paraffin wax as phase change material (PCM), blower, and drying chamber is developed, and tested. The numericalstudy was conducted on the DPSAH to determine the effect of mass flow rate on its performance and an appropriate flow rate wasselected for the drying experiment. It was found that outlet temperatures of the DPSAH were higher at lower mass flow rates and lower at higher mass flow rates and mass flow rates of

0.01 kg/s gives the required outlet temperature. Whereas numerical simulation was done on the LHS to predict the charging and discharging behavior of the PCM and found that the storage can reach a fully charged state within 133 min, which can be achieved around the peak hours during the experiment. The DPSAH was simulated using the ANSYS R16.2 CFD software. As demonstrated in Fig. 2, the 3D geometry is created in SOLIDWORKS and imported into ANSYS R16.2. The model is made up of a glass cover, an absorber plate, a wooden box, and fluid inlet and outlet portions. Meshing was done on ANSYS meshing, as illustrated in Fig. 3.

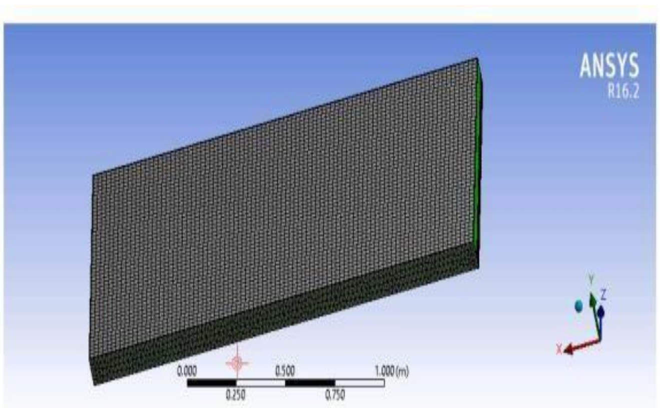


Fig. 2. Meshed view of Solar air heater[23]

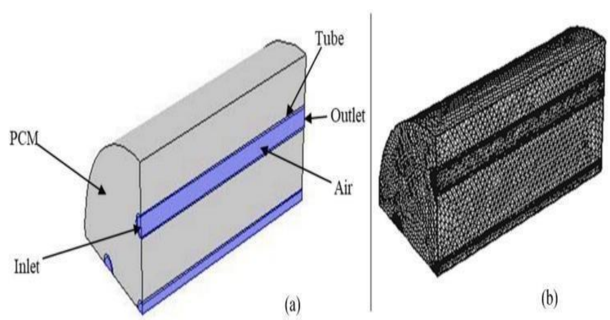


Fig. 3. Sectional and meshed view of latent heat storage [23]

Simulation procedure and boundary conditions ANSYS FLUENT was utilized to do a steady-state implicit pressure-based simulation and a SIMPLE method was employed for pressure velocity coupling. The simulation was carried outusing a normal epsilon model and a second-order upwindapproach for discretization. For the solution to converge, a residual convergency criterion of 10− 6 was chosen, and the solution was initialized using a typical solution initialization approach. The intake was designated as a “mass-flow inlet” while the outlet was designated as a pressure outlet with a gauge pressure of 0 pa. On the top, a steady heat flux of 800 W/m2 was provided, corresponding to the solar radiation falling on thesurface, while the sides were insulated. The mass flow rate of the air varied between 0.008 kg/s and 0.05 kg/s during the simulation and Kong et al. [22] performed a numerical method inwhich the ICEM module of commercial computational fluid dynamics (CFD) software Ansys Fluent was used to establish the geometric model and carry out the structural mesh division. Three-dimensional single precision was selected. The SIMPLE algorithm and an uncoupled implicit solver were used for the solution. The heat transfer surface grid encryption technology, boundary layer mesh technology, and general grid interface (GGI) mesh link technology were used. Grid independence verification was also conducted. When the number of grids is about 2.17 million, the outlet temperature error is less than 2%.

*3. COMSOL software*

Touti et al. [20] proposed to design a novel prototype of a PVT air collector, to improve the electrical and thermal performances. Numerical and Experimental studies werecarried out to evaluate the impact of the designed prototype onthe PVT efficiency. The essential goal of this work was to identify the optimal geometrical and operational PVT air collector parameters with a square tube channel. To achieve this goal, numerical simulation using COMSOL Multiphysics was combined with experimental validation of the PVT system. The objective of the optimization consists of improving the output temperature suitable for drying applications firstly, and cooling PV modules by reducing their temperature to improve the electrical characteristics such as power and voltage and thereby the efficiency of the photovoltaic modules. Therefore, the PV panel temperature dropped from 53.37 ◦C to 42.5 ◦C when the design varies from PVT-1 to PVT-6.

Naik et al. [21] performed experimental and numerical analysis of the thermal performance of pebble solar thermal collector (PSTC) was dealt with in detail using various parameters considered for the analysis on different days. The experimental setup with all the instrumentation was assembled and a series of tests were conducted by varying the operating variable viz.
1) Flow rate of heat absorbing medium 2) Shape of the pebbles and 3) Size of the pebbles, simultaneously analysis was also carried out using CFD software. A numerical simulation of PSTC is carried out to evaluate its thermal performance for varying operating conditions and also to ascertain its structural stability. The modeling is carried out using CATIA V5

modeling software. The data for the modeling, such as ambient temperature (Ta), inlet water temperature (Ti), and incident solar insolation(I) was derived from a few preliminary experimental trials. Next, the meshing of the proposed model was done using Hexa and Tetra dominant meshing methods. The meshed model was exported to ANSYS structural V19.2 software for analysis.

*4. GAMBIT software*

Alam and Kim [13] investigated the heat transfer and friction factor characteristics due to semi-ellipse-shaped obstacles in a rectangular solar air heater duct. The numerical study was performed to find the heat transfer and fluid flow using finite volume-based commercial fluent code in Ansys Fluent 16.0. to predict the effect of V arrangement of obstacles in staggered and inline form. The angle of attack of V was varied from $30^0$to $90^0$. The values of Reynolds number were varied from 6000 to 18,000. Nusselt number and friction factor were found to be strong functions of angle of attack (a) and obstacle arrangement. Bensaci et al. [14] performed a numerical and experimental study of the position of the baffles in a solar air heater to improve its thermal and hydraulic performance. The numerical study was performed on four casescorresponding to different placements of baffles with Reynolds numbers ranging from 2370 to 8340 using commercial mesh generator GAMBIT (version 2.4.6) which was used to create the geometry of the solar air heater (SAH) and to generate the computational domain mesh. The experimental model of the solar air heater was designed, manufactured, and used for the validation of the numerical model. The new baffle placements show that effective thermo-hydraulic performance is not just a function of the shape or changes in the geometric parameters ofthe baffles and found that the correct placement of baffles dramatically improves the thermo-hydraulic performance of solar air heaters. Chaube et al. [15] studied computational analysis of heat transfer augmentation and flow characteristics due to artificial roughness in the form of ribs on a broad, heated wall of a rectangular duct for turbulent flow (Reynolds number range 3000–20,000, which is relevant in solar air heater) has been carried out using FLUENT 6.1 software. A detailed analysis of heat transfer variation within inter rib region is doneby using the selected turbulence model. The analysis shows thata peak in the local heat transfer coefficient occurs at the point of reattachment of the separated flow as observed experimentally.The results predicted a significant enhancement of heat transfer in comparison to that for a smooth surface.

*5. CFDRC software.*

EI-Said and M. Emad [16] developed double-pass SAH with curved perforated baffles in forced convection utilizing numerical simulation of two-dimensional, steady, incompressible Navier-Stokes and energy equations utilizing CFDRC software. They found that the work combined the enhanced effect of perforated baffles and curved baffles which improved thermal performance. For different test conditions the outlet temperature, thermal efficiency, velocity, and pressure variation were numerically computed. Karmare and Tikekar. [17] performed CFD investigation of heat transfer and fluid flow in a rectangular duct with metal grit ribs as roughness elements employed on one broad wall of a solar air heater. To analyze the problem with CFD, the geometry of the flow domain of the solar air heater was prepared. For this purpose, Gambit 2.2.30 was used for modeling the flow domain with 60 60-rib angles, and Fluent 5/6 was selected as a solver. The whole geometry was then exported as a .msh file so that it was accessible in Fluent. It is a postprocessor for analyzing the CFD problems. The Fluent 6.2.16 version was used for this analysis. The circular, triangular, and square-shaped rib grits with angles of attack of 54, 56, 58, 60, and 62 were tested for the same Reynolds number. The broad wall was subjected to uniform heat flux.

## II. CONCLUSION

The paper presents the highlighted studies on different software used in solar dryers with PV/T systems integrated with PCM. According to the literature, the performance of a solar dryer strictly depends on many parameters such as inside temperatures, relative humidity, solar radiation, and the speed of hot air. The machine learning applications can be used to predict the future observations of crops which will enhance the drying rate and thermal efficiency. The numerical method also helps to forecast the deformations or changes which can take place within the system. It is established from the literature that the RBF gives the most accurate results as compared to other methods while Ansys is the best software to carry out any type of analysis along with CFD analysis. Still, more research is needed to build an energy-efficient and cost-effective solar drying system.

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