SOLAR THERMAL SYSTEM SIMULATION OF PEANUT DRYING DEVICE BASED ON TRNSYS
/
基于 TRNSYS 的花生干燥装置太阳能集热系统研究

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ABSTRACT

In order to solve the problems of natural drying peanut with long drying cycle, huge resource and vulnerable to pollution, a solar drying peanut device taking solar energy as the main energy source and electric energy as the auxiliary energy source is designed. The working principle, device structure, drying chamber and heat collector are also studied. The heat collector performance of solar collector system is simulated by utilizing TRNSYS. The simulation results show that the total solar heat collector inclined surface radiation, temperature of solar collector, and electric auxiliary heating rate and water layer changes with time.

摘要

为了解决花生传统自然晾晒干燥存在干燥周期长、晾晒场资源需求巨大、易受污染等问题，设计了一种以太阳能为主要能源、电能为辅助能源的太阳能干燥花生装置，并对其工作原理、装置结构、干燥室及集热器进行了相应的研究。利用 TRNSYS 软件对太阳能干燥花生装装置集热系统的集热性能进行了仿真，仿真结果分别显示了太阳能集热器倾斜面日总辐射量、太阳能集热器出口温度、电辅助加热率和水箱不同层随时间的变化.

INTRODUCTION

China is a big country of peanut cultivation. According to the statistics of the United Nations Food and Agriculture Organization, in recent years, the output value of peanut in China has reached about 40% of the world with first ranking *(Yan Jian-Chun et al. 2013; FAOSTAT 2012)* . At present, peanut drying in China is still mainly artificial, although it does not require inputting additional energy and the long drying period, huge area demand and weather conditions cause greater dependence. It has been unable to meet the development requirements of peanut industry in China. Solar drying refers to a drying operation using solar drying devices and solar radiation. Presently, the research and development of solar drying technology has made it possible to use solar energy for peanuts drying effectively.

The test place of solar peanut drying plant is Taishan District, Tai'an, Shandong Province, where, the annual radiation is 4806.72 MJ/(m^2a) and the sunshine duration is 2668 hours. Thereby, it has good solar energy utilization conditions.

MATERIALS AND METHODS

Design scheme of solar drying peanut

Combined with the advantages of various solar drying equipments and in view of the actual needs of peanut drying, we have developed a drying system using solar energy. The system combines solar energy with electric heating equipment for applying heat, which mainly dries the peanuts. Taking peanuts as an example, the design of a single loading capacity is 50-100 kg; the drying time is 20 hours and the power of the electric heating device is selected as 3 kW. The solar energy drying peanut equipment is used as small-sized drying equipment, and the following requirements should be met *(Lahnine L et al. 2016)*:

(1) Solar drying equipment has compact structure and small footprint;
(2) The material heating method is normal-pressure heat drying, and the drying temperature is controlled within 34^oC-52 ^oC;

(3) Good continuous drying operation: the use of solar energy and electric heating device, ensure material continuous drying;

(4) Drying chamber uniform distribution of air: air uniform design in the drying room, improve the uniformity of air flow drying chamber;

(5) Reasonable use of the drying chamber space: to ensure the loading of 50-100 kg, simple material loading is required.

1.1 The basic mechanism

We design peanut solar drying system with hot water according to the requirements mentioned above. The system is mainly composed of heat collecting system, drying system and control system. The basic structure of the solar drying system with hot water is shown in Fig.1

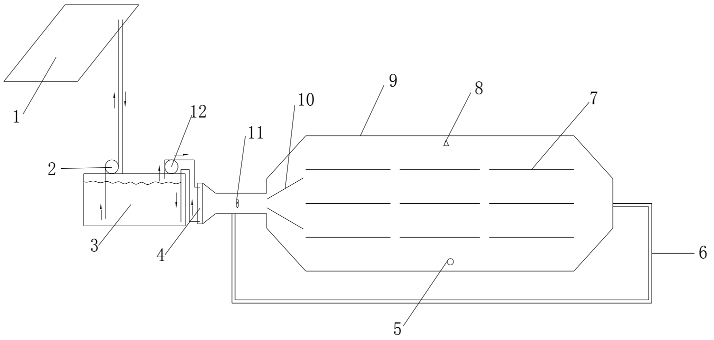

Fig. 1 - **Schematic diagram of peanut drying system using solar water heating**

1 - heat collector; 2 - heat collector circulation pump; 3 - water storage tank; 4 - heat exchanger; 5 - humidity sensor; 6 - circulation duct; 7 - material tray; 8 - temperature sensors; 9 - drying room; 10 – plate; 11 – blower; 12 - heat exchanger circulating pump

The heat collecting system consists of solar collector, water tank and electric heating device. The drying system is mainly composed of drying chamber, a fan and a windshield material tray. The control system includes temperature and humidity control and air volume control. Under the influence of the control system, heat collecting system supplies energy to input drying system meeting the needs of the drying system, which can improve the drying efficiency.

1.2 Working principle

Working principle of the drying system is that it heats the water through the heat collector during daytime and the hot water is circulated by a pump to the water storage tank. The tank and the drying chamber are connected through the heat exchanger transferring collected heat to the drying chamber, which is used in drying peanut. When the outside cold air is driven by the blower at the left of the drying chamber, the cold air is heated by the heat exchanger into the drying chamber for increasing peanuts temperature. The surface of the peanut is vaporized, lowering the moisture content of the peanut (*FAOSTAT, 2012*). In the drying process, the drying room temperature drops to a predetermined temperature; when solar energy is not enough, the electric heating device in the water tank operates to add the required heat to the drying chamber in order to maintain continuous drying. The storage tank electric heating device stops working when the indoor temperature is higher than a predetermined temperature.

1.3 Design of the drying room

The drying room is designed to dry peanuts; we have to consider the drying characteristics of peanut firstly, such as the initial moisture content and maximum allowable temperature. Secondly, the drying chamber not only achieves the heat and moisture transfer of hot air and peanut, it also needs a reasonable way of material bearing and releasing. The space can be fully utilized; the heat and water exchange can be fully carried out. At the same time, the convenience of the system operation and the access of materials are also considered *(Aktaş M.et al. 2016; Liu Mingle 2015).*

In order to be compatible with and solve the above-mentioned problems, the solar drying chamber adopts horizontal box structure; the drying room is a total of 1.2 m height, 2.1 m long and 1.4 m wide. Left end of the drying chamber is provided with a conical inlet; the right end is provided with a conical air outlet; the middle part of the drying chamber is a cuboid and the drying chamber side is provided with a door. As material access, the drying chamber is divided into 3 layers; each layer is provided with 3 material trays *(Zi Rou et al. 2011)*. The drying chamber structure diagram is shown in Fig.1.

1.4 Design of the heat collector system

The heat collector system is an important part of the solar drying peanut system. Electric heating device is composed of a solar collector and water tank. The performance of heat collector of the solar drying device has a great influence on the solar drying peanut effect.

1.4.1 Calculation of collector area

Solar collector and solar drying device of peanut are installed in Tai'an, Shandong province. The peanut harvest from late September to early October and the daily average temperature is 25 ^{o}C. The average daily solar radiation amount reaches 12.23*10^3 kJ/m^2.

(1) Calculation of total area of direct system heat collector *(Xie Shan-Zhu and Di Nan 2015)*

$$A_c = \frac{Q_w C_w (t_{end} - t_i) f}{J_t \eta_{cd} (1-\eta_L)} \tag{1}$$

A_C - the total area of the collector, m^2 ;
Q_W - the average daily water consumption, kg;
t_{end} - water temperature, K;
C_W - constant pressure heat capacity of water, 4.187 kJ/(kg·K);
t_i - the initial temperature of water, K;
f - solar fraction, GB range of value for 0.3～0.8;
J_t - the local daily average collector heating surface radiation, kJ/m2;
η_{cd} - the collector efficiency throughout the day, GB range of value from 0.4 to 0.55;
η_L - the pipeline and storage tank heat loss rate, range of value from 0.15 to 0.2.

(2) Indirect type system of the total area of the collector

$$A_{in} = A_c \left(1 + \frac{F_R U_L \bullet A_c}{U_{hx} \bullet A_{hx}}\right) \tag{2}$$

A_{in} - indirect heating system of the solar collector area, m^2
A_C -total area of solar collector in direct heating system, m^2
$F_R U_L$-total heat loss coefficient of collector, W/(m^2·K), Flat plate solar collector from 4 to 6W/(m^2·K);
U_{hx} --the heat loss coefficient of heat exchanger, W/(m^2·K)
A_{hx}—heat exchanger area, m^2;

The solar water heating system in this design adopts indirect systems and by the formula (1) and (2) we calculated the solar collector area of 5.99 m^2.

1.4.2 Collector installation

The project uses P-J-F-80/1.70/0.70-L type flat plate collector; the single collector area is 1.7 m2. As peanut collector area of the solar drying system necessary is 5.99 m^2, we select the 4 flat-plate collectors.

In order to make the solar collector to obtain the maximum heat, we need to select an optimum installation angle of solar collector. The installation of solar collector should not be less than 0.5 m in the ground level; the collector day lighting surface angle is the local latitude 5 degrees, and not less than 30 degrees *(Li Bian-Sheng et al 2011)*. The location of Tai'an latitude is: 113.13 degrees longitude, 36.18 degrees latitude. In the installation process, the heat collector should be installed in accordance with the best angle, select the tilt angle of 36 degrees, the gap at 5 degrees up and down, in order to obtain the best solar thermal effect. The installation of solar collector is shown in Fig.2.

1.5 Design of the water storage tank

The water tank is one of the most important parts of the solar heat collector system, as a storage device for hot and cold water. It should have good insulation properties. The water capacity, water tank insulation, shape, structure and material will directly affect the performance and operation of the solar collector system.

The volume of the water storage tank is related to the area of solar collector, the general per square meter solar collector area, tank volume needed for 40-100 liters, usually recommended by the proportion of heat exchanger area per square meter of the sun set corresponding to the 75 liters storage tank volume *(Guan Qiao-Li 2009)*. The collector area is 6.8 m^2, therefore, the volume of the storage tank should be 510 liters, and the volume of the storage tank is 750 liters .

Fig. 2 - **Collector installation schematic**

2. Simulation of the solar heating system using TRNSYS

2.1 TRNSYS Introduction

TRNSYS (Transient System Simulation) software was originally developed by Solar Energy laboratories Wisconsin-Madison University (SEL) and improved under the joint study of the European Institute gradually. TRNSYS simulation program that simulates solar system includes two parts: photoelectric and light. It includes a heat collector, water tank, water pump, auxiliary heater and other dozens of commonly used components. It can simulate the hot water, heating, refrigeration, air conditioning room and heat pump *(Liu Sheng-Yong et al. 2001)*.

2.2 Simulation model of solar collector system

Pic.1 is built in TRNSYS solar collector system component integration diagram, the simulation object for the flat plate collector forced circulation, water supply system with constant temperature control, solar energy as the main energy water heating, electric heating device, auxiliary heating, to maintain the water temperature at 60 degrees Celsius *(Wang An-Jian et al. 2014)*.

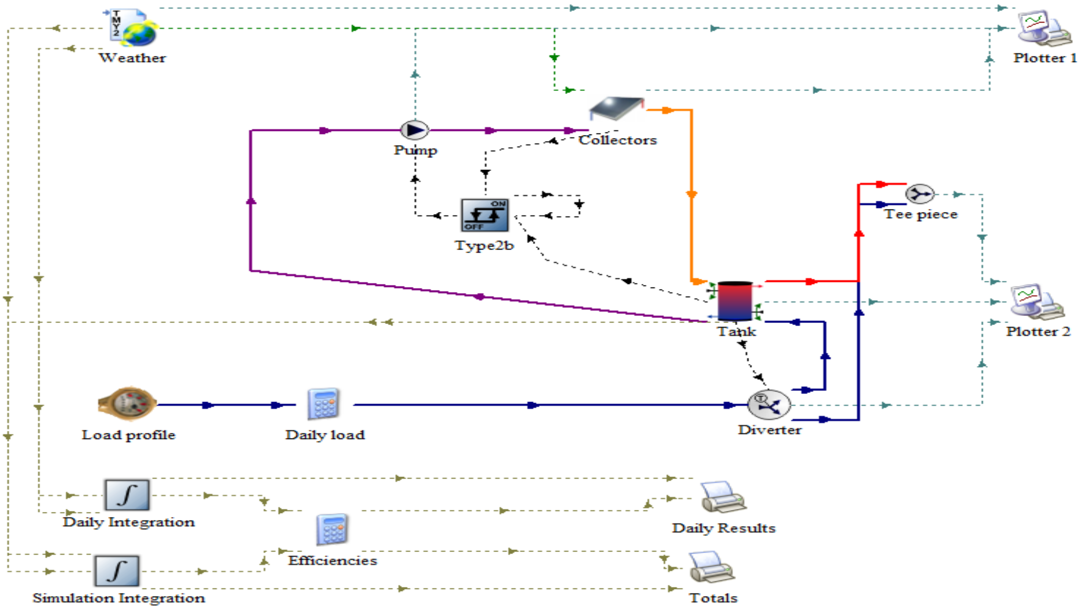

Fig.3 - **Pic.1 Simulation model of solar heat collector system**

The typical meteorological year is a set of meteorological parameters consisting of 8760 hours of hourly meteorological data, including dry, wet bulb temperature, solar radiation, and wind speed and wind direction. The typical meteorological year data of Tai'an using TRNSYS simulation derived from the latitude and longitude of Tai'an area by using Meteonorm7 software. Fig.4 and Fig.5 show the typical meteorological parameters of Tai'an region from the late September to early October *(Minaei S.et al., 2016).*

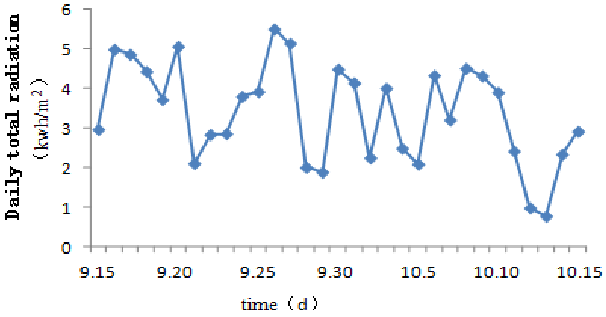

Fig. 4 - Total solar radiation changes

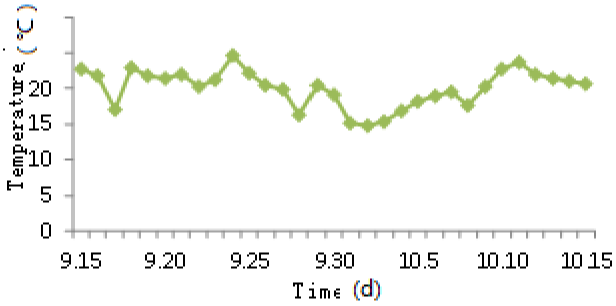

Fig. 5 - September 15th to October 15th temperature change

2.3. Typical weather simulation

In the simulation, we chose September 15th and October 15th from the typical meteorological year data, because the first one is the hottest and the second is the coldest from mid-September and mid-October.

2.3.1 The hottest weather simulation

The weather parameters for September 15th are shown in Fig.6, Fig.7, Fig.8 and Fig.9.

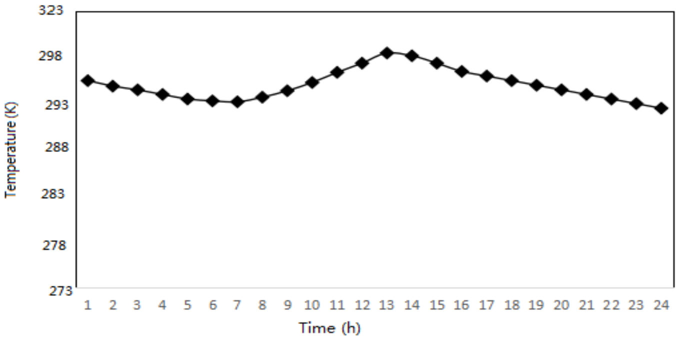

Fig. 6 - September 15th temperature change

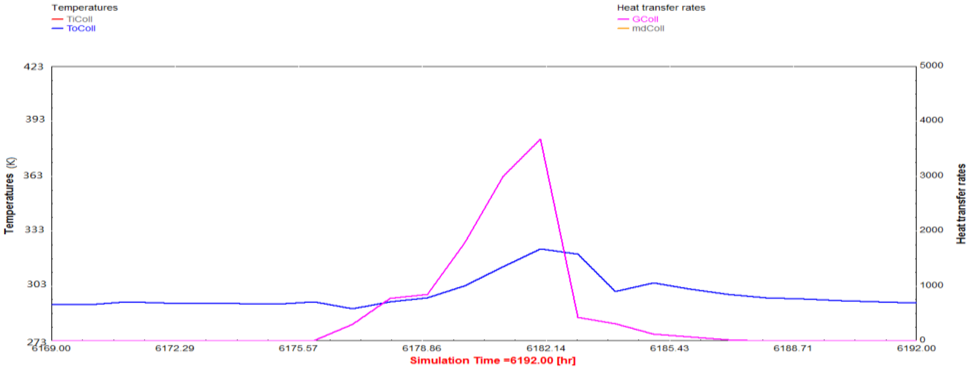

Fig. 7 - Variation of total radiation and outlet temperature of inclined surface of solar collector in September 15th

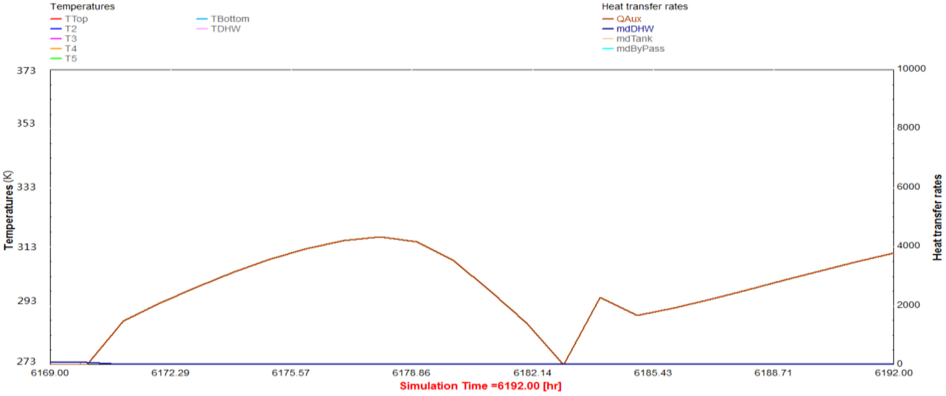

Fig. 8 - Electric heating rate change in September 15th

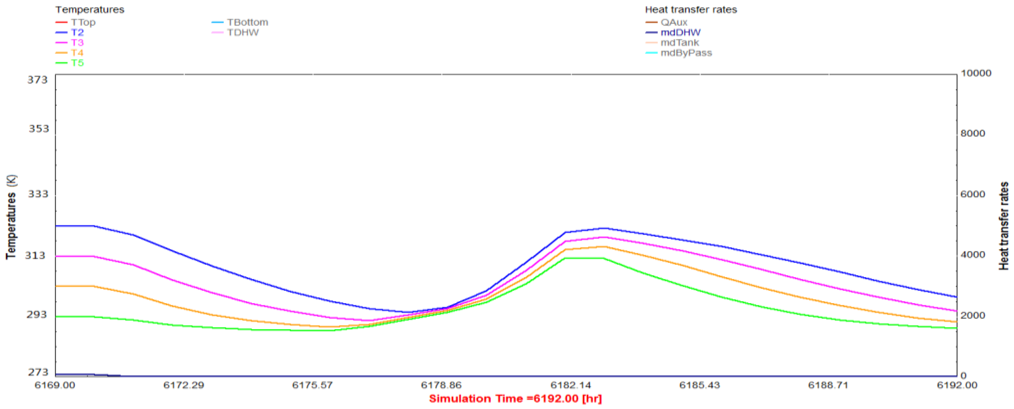

Fig. 9 - Variation of temperature in different layers of water tank in September 15th

2.3.2 The coldest weather simulation

In October 15th the weather parameters is shown in Fig.10, Fig.11, Fig.12 and Fig.13.

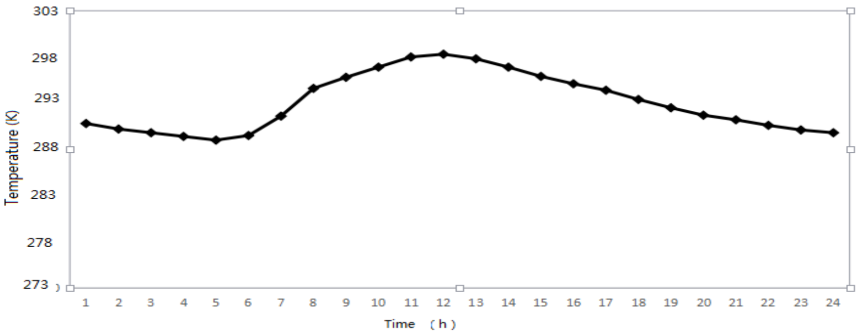

Fig. 10 - October 15th temperature change

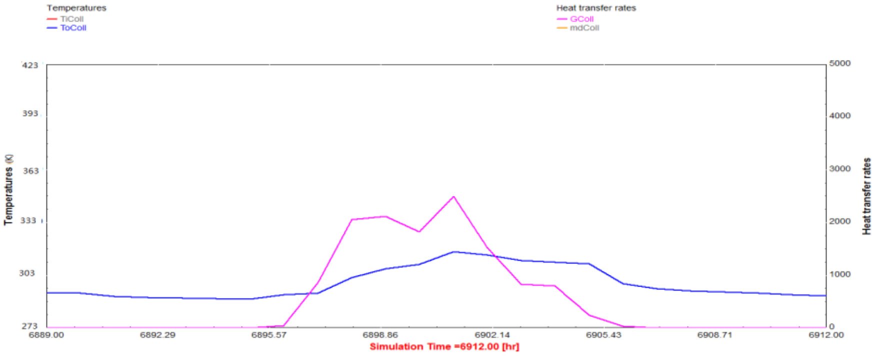

Fig. 11 - Variation of total radiation and outlet temperature of inclined surface of solar collector in October 15th

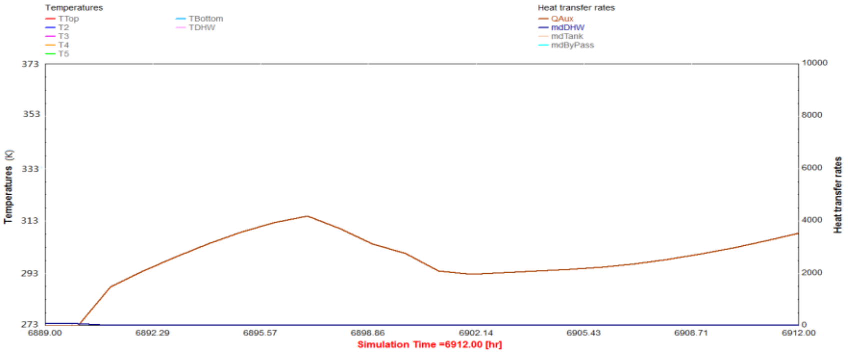

Fig. 12 - Electric heating rate change in October 15th

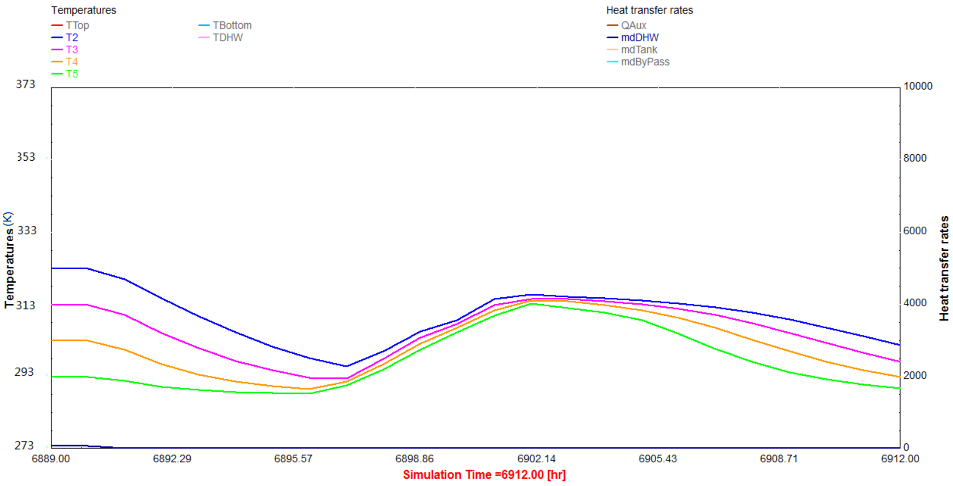

Fig. 13 - **Variation of temperature in different layers of water tank in October 15th**

3. Test Materials and methods

The test time is September 3, 2016, the test venue for Tai'an city of Shandong Province, P-J-F-80/1.70/0.70-L type flat type test by the collector, water tank and thermometer. The set temperature and simulation results of direct heat exchanger outlet through comparative test analysis of solar energy, solar thermal performance of dry peanut system heat collecting system were performed *(Wessapan T and Theerapong B, 2012; Tunde-Akintunde TY 2011; Gan XF 2011)*. We set the outlet temperature of heat exchanger by measuring the temperature once every hour and the results obtained are shown in Fig.14

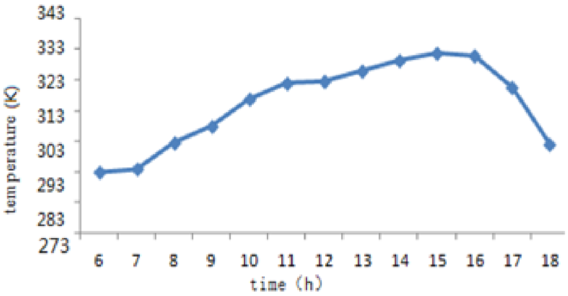

Fig.14 - **Variation of outlet temperature of solar collector**

CONCLUSIONS

(1) According to the simulation in September 15th, the solar tilt radiation began to increase from zero at 7: 00, the outlet temperature of the collector increases with the increase of radiation of the inclined plane. At 13:00, the maximum amount of solar tilt radiation is reached; the collector outlet temperature reaches the maximum value of 50.3 °C at the same time. At 18:00, the radiation changed to 0，the collector outlet temperature is no longer increased, and it is consistent with the actual situation, which shows that the simulation data is accurate.

(2) According to the simulation in October 15th, the solar tilt radiation began to increase from zero at 7: 08, the outlet temperature of the collector increases with the increase of the radiation of the inclined plane. At 12:00, the maximum amount of solar tilt radiation is reached; the collector outlet temperature reaches the maximum value of 43.4 °C at the same time. At 17:30, the radiation changed to 0，the collector outlet temperature is no longer increased, and it is consistent with the actual situation, which shows that the simulation data is accurate.

(3) With the use of TRNSYS simulation in the outlet temperature of heat exchanger consistent with the outlet temperature of the collector, the temperature is measured. The outlet temperature of the heat exchanger is up to 52°C, indicating that the collector performance of the peanut solar drying device meets well the design requirements.

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