# Selection of Optimum Temperature and Thin Layer Drying Kinetics of Maize for Production of Quality Seeds

Mosharaf Hossain, Abu Sayed, Awal, M.A Hossain, M.A. and Mahdi Hasan

**Abstract-** This thesis presents the drying characteristics of maize seeds (*Zea mays L.)* using a hybrid drier. The hybrid drier provided with a flat plate concentrating solar collector and an air heater performed better than sun drying method as well as any other solar drier. The average air temperatures at collector outlet and inside the drier were found about 22.71℃ and 17.22℃ higher than the average ambient air temperature, respectively. The collector efficiency varied from 20% to 32% depending on the global solar radiation. The experimental data was fitted to nine thin layer drying equations. A non-linear regression analysis was used to fit the thin layer drying equations. The models were compared using the coefficient of determination, mean relative percent error, root mean square error and the reduced chi-square. The Page model showed a better fit to the experimental data as compared to other models. Here, the highest $R^2$ (close to 1) and the lowest RMSE values indicate the highest grade point and highest average grade point ranked first. Samples dried in the hybrid drier were completely protected from insects, rain and dusts, and the dried samples were hygienic.

**Index terms:** Drying, Hybrid Dryer, Thin layer, Optimum temperature and Maize

## 1. INTRODUCTION

Drying of agricultural products has always been of great importance for the preservation of food by human beings. Drying is a complex thermo physical and to some extent biochemical process comprising simultaneous heat and mass transfer. The basic concept of drying is water removal. The surface water of the product is changed to vapor and removed in the first stage, the inside water will than migrate to the surface and be subsequently removed. In Bangladesh, drying is normally carried out by traditional sun drying method. Its offers a cheap and easy method of drying but the drying rate is very slow and it often results inferior quality due to dependence of weather conditions [1].

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If continuous adverse weather exits for a couple of days together then the whole amount of products are spoiled. This creates serious negative economic impact on the farmers or processors to continue their further activities. As an alternative to sun drying, solar drying is a promising alternative for crop drying in developing countries, because solar energy for crop drying is environmentally friendly and economically viable due to low initial and operating cost [2]. All the areas of Bangladesh receive abundant solar radiation almost all round the year. The type of drier used and the way in which it is operated has a significant influence on the quality of the product. Solar drying system must be properly designed in order to meet particular drying requirements of specific crops and to give satisfactory performance with respect to energy requirements.

The natural convection solar drier appears to have potential for adoption and application in the tropics and subtropics. It is suitable at a household level for drying of 10 to 15 kg of fruits and vegetables. But the natural convection solar drier suffers from limitations due to extremely low buoyancy induced airflow inside the driers [3]. On the other hand, hybrid solar drier is one in which drying is continued in off sun shine hours by back up heat energy or storage heat energy. Therefore drying is continued and product is saved from possible deterioration by microbial infestation [4] grains in Bangladesh. Among them maize is gaining popularity in the country very quickly due to its high yield potential [6]. At present, the low quality of the seeds of these crops is an important problem facing a large number of farmers. After harvesting, farmers generally store a proportion of their crops for sowing in the next growing season. Some varieties of rice and corn are harvested in rainy season, leading to high moisture content and risk of degradation. As a consequence, a large number of farmers in Bangladesh experiences seed quality losses due to delayed or improper drying caused by the lack of knowledge and adequate drying facilities. Hien [7] reported that germination was 85% for grain seed dried in the dryer, compared with 70% for sun drying. So adoption and application of mechanical dryers for drying of grain seed is an important need. This study was carried out to determine the optimum drying temperature of maize seeds in terms of drying rate and germination to fit the experimental data in thin layer drying equations and to evaluate the performance of hybrid dryer for production quality maize seeds.

## 2. MATERIALS AND METHODS

### 2.1 DESCRIPTION OF DRYER

This experiment was conducted in the lab dryer. This laboratory dryer was designed and fabricated at the Farm Machinery and Post harvest Process Engineering Division, Bangladesh Agricultural Research Institute, Gazipur. The dryer basically consisted of a heating unit and a drying unit. A schematic view of a laboratory dryer is shown in Figure 1. A brief description of laboratory dryer is given below. The overall dimension of the dryer was 2.47 m x .5 m x 1.18 m. A 0.50 kW axial type blower was connected in side of the dryer to draw the atmospheric air in the dryer and to push out the heated air to the dryer with a desired air velocity. Air flow was controlled by a variance connected to the blower. For heating, two electric heaters (1600Wx2=3200W) were installed at the entry part of the dryer. A temperature controller along with a sensor was set to maintain constant temperature in the dryer. The drying tray was located at the extreme end of the dryer. The drying air was passed through the product spread in thin layer. The tray was made aluminum frame and

[5]. Maize, rice and wheat are the major cereal

iron net with dimensions, 304.8 mm x 304.8 mm. The drying air was heated up in the heating unit. The drying air came from the heated unit through some pipes of small diameter and turning towards the drying unit, flew through the drying tray and exhausted from the outlet.

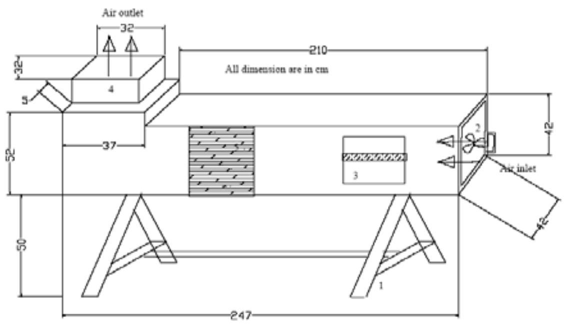


Fig 1: Schematic view of a laboratory dryer: (1) Leg/ stand (2) Axial type blower (3) Electric heater (4) Drying chamber (5) Straw box for straight air flow.

### 2.2 TREATMENTS AND EXPERIMENTAL DESIGNS

Six different temperatures i.e. 38, 40, 42, 44, 46 and 48$^{o}$C were used as temperature treatments. Different lengths of time were tested for different temperatures. At the lowest temperature i.e. at 38$^{o}$C up to 21 h and at 40, 42, 44, 46 and 48$^{o}$C drying times up to17, 15, 12, 11 and 10 h, respectively were tested.

**2.3 DRYING IN LABORATORY DRYERm**aize seeds (*BARI Bhutta-7*) were obtained from Bangladesh Agricultural Research Institute and the whole experiment was conducted in Farm Machinery and Post Harvest Engineering Division. Initial seed moisture content was determined taking six samples of seeds (which were randomly collected from the bulk harvest) straight away and by drying at 105$^{o}$C in an oven for 24 h. Moisture percentage was calculated following the procedures described by ISTA [8,9]. The remaining seeds were then immediately dried at different amounts of time according to the design. The initial seed moisture content was around 25 % fresh wet bases. The duration of experiment was June to December, 2013 respectively. Drying experiments were performed at different drying temperature to determine the optimum drying temperature of maize seeds. Before starting an

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experimental run, the whole apparatus was operated for at least one hour to stabilize the drying air temperature and air velocity in the dryer. Drying was started and continued until it reached the constant moisture content. Weight losses of the samples in the dryer were recorded during the drying period at half an hour interval with an electronic balance (CP423S, Sartorius, Germany). The temperature of ambient air and drying air temperatures were measured with a digital thermometer (K202, Volt craft digital thermometer, Germany) connected with k type thermocouples. Air velocity affects the drying rate over a certain range and above this range drying rate becomes independent of air velocity. Constant drying air velocity was maintained at 0.5 m/s. Velocity of drying air was measured with a thermo-anemometer (AM-3848, England). Relative humidity of the ambient air was measured by a thermo hygrometer (E200, Lufft, Germany). After completion of drying, the dried samples were collected, cooled in a desiccators to the ambient temperature and then sealed it in the plastic bags.

## 2.4 THIN LAYER DRYING EQUATIONS

Mathematical models for thin-layer drying of maize seeds were analyzed by using direct least square method between moisture ratios (*MR*) and drying time (*t*). Moisture ratio was defined as follows:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad \text{.....................(1)}$$

Where *Mo*, *Me* and *Mt* are initial moisture content, equilibrium moisture content and moisture content at any time respectively. *Me* values were obtained from drying curves and were set equal to moisture content at which sample weight became constant with drying time. Nine commonly used thin layer equations were selected to fit the experimental data of drying of maize seeds by the direct least square method using SPSS 11.5. The equations were evaluated in terms of coefficients of determination ($R^2$) was a primary criterion for the selecting the best equation to describe the drying curve equation. In addition to ($R^2$) root mean square errors (RMSE), $\chi^2$ (Chi-square) and these are defined as:

$$R^2 = \frac{\left(\sum M_{exp} M_{pred}\right)^2}{\sum M_{exp}{}^2 \sum M_{pred}{}^2} \quad \text{..................( 2)}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]^{1/2} \quad \text{...................(3)}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - n} \quad \text{...................(4)}$$

Where *i MR* exp, is the experimentally observed moisture ratio, *i pre MR*, is the *it* predicted moisture ratio, *N* is the number of data and *n* is the number of constants in drying model.

Table 1: Mathematical models applied to the drying curve

| Model no. | Model name | Model equation |
|---|---|---|
| 1 | Newton Equation (O'Callaghan *et al.*, 1971 and Bala and Woods, 1992) | *MR=exp(-k t)* |
| 2 | Page Equa.(Page,1949 and Bala and Woods, 1992) | *MR=exp(-k t* $^{n}$*)* |
| 3 | Modified page (Overhults et al. 1973) | *MR= exp [(-k t)*$^{n}$*]* |
| 4 | Henderson and Pabis (1969) | *MR= a exp (-k t)* |
| 5 | Geometic (Chandra and Singh, 1995) | *MR= at*$^{-n}$ |
| 6 | Wang and Singh (Wang and Singh, 1978) | *MR=1+at+bt*$^{2}$ |
| 7 | Two term exponential (Sharaf-Eldeen *et al.*, 1980) | *MR= a exp(-k t)+(1-a)exp(-ka t)* |
| 8 | Logarithmic (Yaldiz and Ertekin, 2001) | *MR= a0+ a exp(-k t)* |
| 9 | Midilli Equation (Midilli *et al.*, 2002) | *MR= a exp(-k t*$^{n}$*)+b t* |

Residuals of each model were plotted with experimental moisture contents. If residual plots indicate a systematic pattern, there is a systematic error in model prediction [10] [11]. A model was considered to be the best when the residual plots indicated uniformly scattered points i.e. random; RMSE is a minimum value and $R^2$ is a maximum value (close to 1.0). 2.5 EFFICIENCY CALCULATION

The thermal efficiency of the solar collector was calculated using following formula: Considering global solar radiation, Collector efficiency,

$$\text{Collector efficiency, } \eta_{cdg} = \frac{\dot{m}_a C_{pa}(T_i - T_o)}{A_c I_g}$$

(5)

Where,

$M\ a$ = mass flow rate of air, kg/s

$Cp\ a$ = specific heat of air, kJ/kg K

Ti = inside the drier air temperature, °C

To = outside the drier air temperature, °C

Ac = area of collector, m2

I g = global solar radiation, W/m2

## 2.6 SEED QUALITY TEST

A germination test was performed on the seeds in Farm Machinery and Post harvest Engineering Division Lab and subjected to six different drying temperatures i.e.38, 40, 42, 44, 46 and 48 $^{o}$C. Tetrazolium test and standard germination test were carried out to determine viability and germination percentage respectively. In tetrazolium test viability of maize seed was determined by using 0.1-0.5% tetrazolium solution. Three replications of 10 seeds were taken for each sample. The trays with samples were left under room temperature to germinate. The seeds that had root or shoot longer than 2 mm were considered as germinated seeds.

## 3. DISCUSSIONS

The maize seeds were dried in 38, 40, 42, 44, 46 and 48$^{0}$C. The initial moisture content of seeds after harvest was 24.86 % (fresh weight basis). And it was dried up to equilibrium moisture content at 38, 40, 42, 44, 46 and 48$^{0}$C respectively. Figure 2 shows the effects of drying time and temperatures on the moisture content of maize seeds. It showed that times required for drying at 38, 40, 42, 44, 46 and 48$^{0}$C were 21, 17, 15, 12, 11 and10 h respectively.

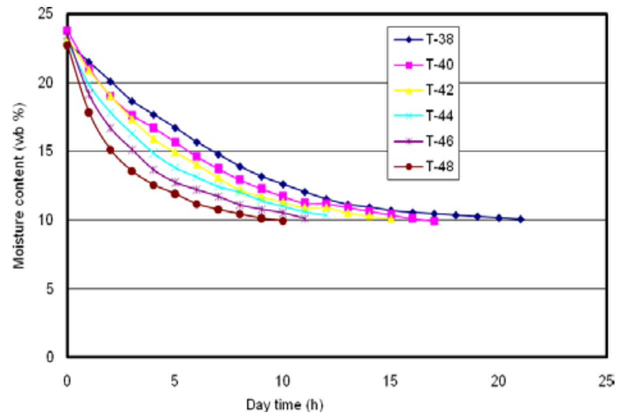


Fig 2: Effect of different drying temperature on moisture content (%, wb) of maize seeds

## 3.1 FITTING OF EXPERIMENTAL DATA TO THE MODELS

Maize seeds were dried in the Laboratory dryer at varying temperature of 38, 40, 42, 44, 46 and 48$^{0}$c in thin layer. Therefore, the drying characteristics of maize seeds were fitted to the thin layer drying equations to estimate the parameters of the best fitted equation at that temperature. However, it would be better to run the experiment at varying temperature to find out the effect of temperature on the drying of maize seeds. Nine thin layer equations were fitted to the experimental data of drying of maize seeds by the direct least square procedure. Model parameters, coefficient of determination ($R^2$), root mean square error (RMSE) and $\chi2$ (Chi-square) of thin layer drying models are presented in Table 1. From the Table 2 the highest $R^2$ and the lowest RMSE values indicated that Page model is the best fitted model. Midilli [12] ranked two followed by the Logarithmic, Two term exponential model, Henderson and Pabis model, Geometric, Newton and Modified Page model. Therefore, the fitting of Page model was found better than those of, other models.

Table 2: Mean values of model parameters, coefficient of determination (R2), root mean standard error (RMSE), $\chi2$ (Chi-square) and rank of thin layer drying models.

| Model Name | Temperature °C | k | a | b | n | a0 | R2 | RMSE | χ2 | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| Newton | 38 | 0.21253 | | | | | 0.9158 | 1.356 | 1.859 | |
| | 40 | 0.23243 | | | | | 0.9253 | 1.516 | 1.961 | |
| | 42 | 0.26239 | | | | | 0.9029 | 1.729 | 2.272 | 5 |
| | 44 | 0.28861 | | | | | 0.8887 | 1.883 | 2.561 | |
| | 46 | 0.30609 | | | | | 0.877 | 1.993 | 2.63 | |
| | 48 | 0.34331 | | | | | 0.879 | 2 | 2.463 | |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Page | 38 | -3.41435 | | | -.105089 | | 0.92317 | .29495 | .09569 | |
| | 40 | -3.35725 | | | -.105891 | | 0.94310 | .26525 | .07915 | |
| | 42 | -3.34273 | | | -.109523 | | 0.95288 | .25696 | .07546 | 1 |
| | 44 | -3.25691 | | | -.104233 | | 0.96726 | .20983 | .05203 | |
| | 46 | -3.1935 | | | -.108735 | | .98616 | .13297 | .02122 | |
| | 48 | -3.08883 | | | -.108428 | | .99749 | .05154 | .00324 | |
| Page Modified | 38 | .0548419 | | | 27.37540 | | .94277 | .29815 | .09778 | |
| | 40 | .0670221 | | | 27.64771 | | .93556 | .36039 | .14611 | |
| | 42 | .0745030 | | | 27.53673 | | .94179 | .36293 | .15052 | 8 |
| | 44 | .0849875 | | | 26.8518 | | .93517 | .40928 | .19797 | |
| | 46 | .0986432 | | | 26.57349 | | .89034 | .58252 | .40720 | |
| | 48 | .1081546 | | | 25.08158 | | .85123 | .68899 | .58021 | |
| *Henderson. & Pabis* | 38 | .0548419 | 27.37540 | | | | .94277 | .29815 | .097785 | |
| | 40 | .0670221 | 27.64771 | | | | .93556 | .36039 | .14611 | |
| | 42 | .0745030 | 27.53673 | | | | .94179 | .36293 | .15052 | 9 |
| | 44 | .0849875 | 26.85185 | | | | .93517 | 40928 | .19797 | |
| | 46 | .0986432 | 26.57349 | | | | .89034 | .58252 | .40720 | |
| | 48 | .1081546 | 25.08158 | | | | .85123 | .68899 | .58021 | |
| *Geometric* | 38 | | -.812295 | | -24.9382 | | .85491 | .474720 | .24789 | |
| | 40 | | -1.00875 | | -25.2486 | | .84936 | .55101 | .34156 | |
| | 42 | | -1.13014 | | -25.2376 | | .85677 | .56929 | .37039 | 7 |
| | 44 | | -1.31997 | | -24.9288 | | .85826 | .60515 | .43279 | |
| | 46 | | -1.43710 | | -24.3452 | | .79534 | .79579 | .75994 | |
| | 48 | | -1.46616 | | -22.8981 | | .74853 | .89578 | .98075 | |
| *Logarithmic* | 38 | .1451763 | 20.19516 | | | 9.894632 | .99796 | .05773 | .00386 | |
| | 40 | .1914257 | 20.15207 | | | 10.45289 | .99704 | .07981 | .00764 | 6 |
| | 42 | .2061919 | 19.85245 | | | 10.34811 | .99944 | .03685 | .00167 | |
| | 44 | .6190523 | 18.34485 | | | 11.08802 | .99793 | .07678 | .00766 | |
| | 46 | 26.61618 | 15.42118 | | | 15.15609 | .58707 | 1.19152 | 1.89297 | |
| | 48 | 32.14729 | 15.24318 | | | 14.18152 | .66866 | 1.09061 | 1.63547 | |
| | 38 | | -0.212 | 0.0156 | | | 0.9133 | 1.25 | 1.289 | |
| | 40 | | -0.231 | 0.018 | | | 0.9398 | 1.36 | 1.389 | |
| Two-Terms Exp. | 42 | | -0.267 | 0.025 | | | 0.9274 | 1.496 | 1.502 | |
| | 44 | | 0.296 | 0.03 | | | 0.9178 | 1.618 | 1.643 | 4 |
| | 46 | | -0.317 | 0.035 | | | 0.9102 | 1.704 | 1.682 | |
| | 48 | | -0.346 | 0.042 | | | 0.9112 | 1.712 | 1.594 | |
| | 38 | -2.1708 | 27.03147 | .382017 | 71.83489 | | .98954 | .13434 | .02206 | |
| Midilli | 40 | -5.68731 | 31.22942 | -4.55093 | 81.75364 | | .951410 | .00000 | .00000 | |
| | 42 | -355.137 | 30.21176 | -.405161 | 9395.449 | | .998900 | .00000 | .00000 | 3 |
| | 44 | -.167691 | 21.76088 | -.945940 | -190.718 | | .95541 | .27074 | .10588 | |
| | 46 | -.201421 | 20.10756 | -.893226 | -180.990 | | .95312 | .27364 | .11232 | |
| | 48 | -.219716 | 18.07571 | -.788797 | -172.357 | | .86128 | .22942 | .08271 | |



**3.2 COLLECTOR PERFORMANCE**

The concentrating solar collector as well as solar drier was tested during drying of maize. The variations of ambient air temperature, air temperature at the outlet and inlet of the collector and inlet of the drier with global solar radiation for the experimental run are shown in Figure 3. During this drying period, highest global solar radiation was found to be about 465W/m2 and absorber plate temperature was about 61.5°C at the mid noon of the day. But, the highest collector outlet air temperature was about 49.1°C. Average ambient air temperature in day was found to be 26.38°C. In day time (9:30 am to 5:30 pm) collector outlet air temperature was about 22.72°C higher than the ambient air temperature.

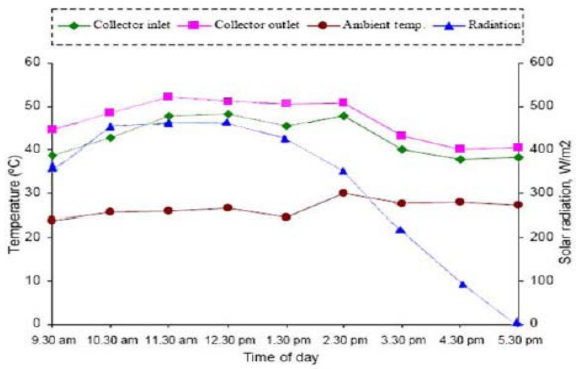


Fig 3: The variations of ambient air temperature, air temperature at the outlet and inlet of the collector with global solar radiation for the experimental run. The solar collector was completely insulated with 25 mm thick cork sheet; as a result, the air temperature in the collector did not drop drastically at the time of low solar radiation. Air temperature developed in the day time at the outlet of the collector was sufficient for maize seed drying.

**3.3 DRIER PERFORMANCE**

Drier air temperatures were measured at inlet, outlet and inside of the drier during solar drying of maize seed. The temperature of the drier was maintained at 43°C by 6 kW (3 x 2 kW) air heaters when the solar radiation was low in afternoon or adverse environmental condition (cloudy-rainy sky). The internal temperature of the drier was found highest 44.1°C and it was varied from 39.6°C to 44.1°C whereas, the average ambient air temperature was found 26.38°C (Table 3). In day time (9:00am to 5:00pm) the average drier temperature was about 17.22°C higher than the average ambient air temperature.

Table 3: The variations of ambient air temperature and average air temperature inside the drier with global solar radiation for the experimental run

| Time | Drier average temp.°c | Ambient average temp.°c | Solar radiation, W/m² |
|---|---|---|---|
| 9.30 am | 42.9 | 23.2 | 427.5 |
| 10.30 am | 43.1 | 25.7 | 489 |
| 11.30 am | 44.1 | 26.1 | 522.5 |
| 12.30 pm | 43.9 | 26.4 | 454.2 |
| 1.30 pm | 43.2 | 27.2 | 477.3 |
| 2.30 pm | 42.7 | 29.4 | 498 |
| 3.30 pm | 43.4 | 26.8 | 382 |
| 4.30 pm | 42.4 | 27.5 | 132.8 |
| 5.30 pm | 42.8 | 25.2 | 16 |
| Average | 43.17 | 26.38 | 377.7 |

**3.4 COLLECTOR EFFICIENCY**

Collector efficiency followed a similar pattern of the solar radiations. In sunny days, collector efficiency with global radiation 450 W/m2 was found highest 32% at mid noon and it was varied from 20% to 32% (Table 4). Then the internal temperature of the collector was found around 55.8°C with the ambient temperature was only 22°C. This is due to the contribution of flat reflector effect. The collector was a concentrating type with a flat reflector. So, the solar radiation on the plastic cover was the sum of direct global radiation on the cover and incoming reflected radiation from the reflector. An average increase in total radiation was found to be 28.26% over the global radiation on the plastic cover due to the use of the reflector in a typical day during the experimental run. The relationship between total radiation (global + reflected from reflector) and global radiation on the plastic cover of a typical day is shown in Figure 4. The following regression equation was developed to calculated total radiation from the global radiation. $I_t = 1.1392\, I_g + 50.012$ ($R^2 = 0.97$).

Table 4: Variation of collector efficiency at different times of a typical day

| Time | Global solar radiatio n, W/m² | Inside tem.°c | Outside tem.°c | Collector efficiency,% |
|---|---|---|---|---|
| 9.30 am | 300 | 39.66 | 23.6 | 22.41 |
| 10.30 am | 400 | 46.08 | 25.3 | 21.75 |
| 11.30 am | 420 | 49.1 | 24.2 | 24.82 |
| 12.30 pm | 450 | 55.8 | 22 | 31.44 |
| 1.30 pm | 420 | 48.61 | 26.6 | 21.94 |
| 2.30 pm | 325 | 43.64 | 26.1 | 22.59 |
| 3.30 pm | 265 | 37.18 | 27.5 | 15.29 |
| 4.30 pm | 225 | 36.3 | 24.9 | 21.21 |
| 5.30 pm | 200 | 31.9 | 22.2 | 20.30 |
| Average | | | | |

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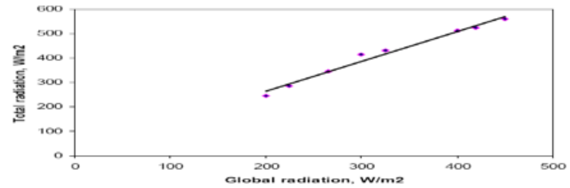



Fig 4: Relationship between total radiation and global radiation

### 3.5 ESTIMATION OF DIFFERENT DRYING PARAMETERS

The parameters of Page model at variable temperatures (38°C to 48°C) are found to be a linear function of air temperature. Following regression equations were developed for the parameters of Page model as a function of temperature.

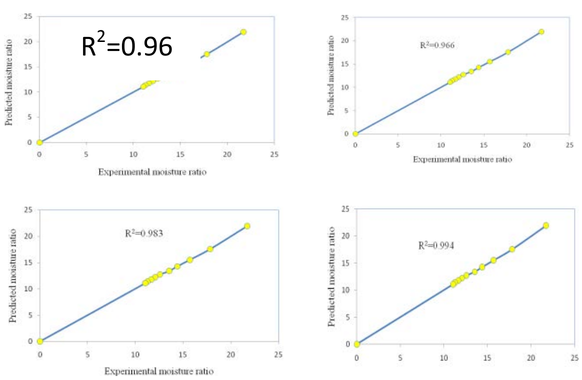
$k = 0.0173T_a - 0.3167$ (R2= 0.9718) …………(7)

$n = 17.292Ta^{-0.8822}$ (R2= 0.9808) …………..(8)

Substituting the values of k and n from the equations (6) and (7) into the Page equation in Table 2, we get the following equation in terms of temperature

$M = Me+(Mo-Me)\ \exp(-(0.0173Ta-0.3167)t^{(17.292Ta-0.8822)}$ ……(9)

Figure 5 show the comparison between the experimental moisture content and moisture content predicted from the Page model for the drying temperature of 38, 40, 42, 44, 46 and 48$^0$C respectively. The predicted data mainly banded around the straight line which showed the suitability of the model in describing single layer drying behavior of maize seeds.



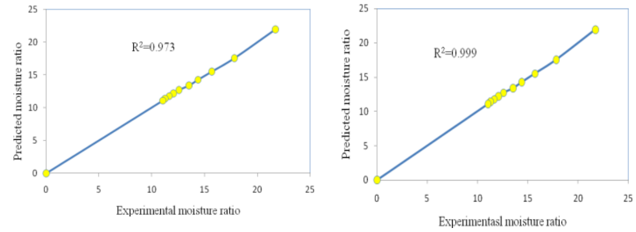




Fig 5: Experimental and predicted moisture content for single layer drying of maize seeds at 38$^0$C, 40$^0$C, 42$^0$C, 44$^0$C, 46$^0$C and 48$^0$C.

### 3.6 EFFECT OF TEMPERATURE ON SEED GERMINATION

As drying temperature increased, germination percentage decreased and it shows after at the temperature of 42$^o$C. The maximum germination percentage recorded 91.47% at 42$^o$C. The effect of drying air temperature on germination of maize seeds shown in Figure 6. Above the temperature of 44°C, the germination reduced drastically. As germination is the main purpose of seed, it should dry at the optimum temperature of 42°C. McDonald and Copeland [13] suggested that a drying air temperature of 43°C is accepted as the safe upper limit for drying most seeds without damage which is closely similar with study temperature.

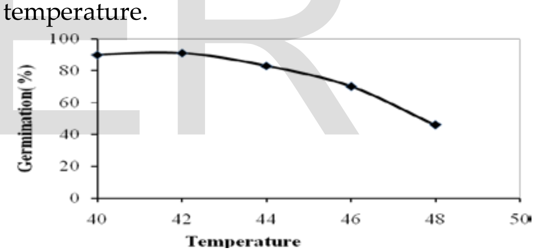



Fig 6: Effect of drying air temperature on seed germination.

## 4. CONCLUSIONS

Nine thin layer drying models were fitted to the experimental data of maize seed drying in this hybrid drier. The models were compared using the coefficient of determination, mean relative percent error, root mean square error and the reduced chi-square. The Page model was considered the best for describing the thin layer solar drying behavior of maize. The agreement between the predicted and experimental results was excellent. The average air temperatures at collector outlet and inside the drier were found about 22.71°C and 17.22°C higher than the average ambient air temperature respectively. The collector efficiency varied from 20% to 32% depending on the global solar radiation. The optimum drying temperature for the selected seed grains have been established. It was found that $42^0C$ was completely safe for maize seeds. An increase in drying temperature decreased the drying time and final moisture content of dried maize seed. The maximum average germination percentage of dried maize seed was 91.47% respectively. The hybrid drier provided with a flat plate concentrating solar collector and an air heater performed better than sun drying method as well as any other solar drier.

**References**

[1] A. Wahab, "Development and Adaptation of Hybrid Dryer for Quality Grain Seed", Technical Bulletin, Krishi Gobeshona Foundation, no. 24, 2011.

[2] A. Esper and W. Mühlbauer, "Solar tunnel drier for fruits", Agricultural Engineering, Band 4, Heft 3/4, pp. 27- 40, 1998.

[3] B.K. Bala and J.L. Woods, "Simulation of the indirect natural convection solar drying of rough rice", *Journal of Solar Energy*, Vol. 53, no. 3, pp. 259-266, 1994.

[4] Gauhar, Mastekbayeva, chandika, Bhatta, L. Augustus and kumar, "Gujrat energy development agency", vadodara, gujrat on december 11-13, 1999.

[5] M.A. Hossain, and K. Gottschalk, "Experimental studies and mathematical modeling of solar drying system for production of high quality dried tomato", Postdoctoral Research Report published in Bornimer Agrartechnische Berichte, Vol.59, pp. 172, 2007.

[6] M. R. Karim, Moniruzzaman and Q. M. Alam, "Economics of Hybrid Maize Production In Some Selected Areas of Bangladesh". *Bangladesh Journal of Agricultural Research*, Vol. 35, no. 1, pp. 83-93, 2010.

[7] P.H. Hien, L.V. Van, and B.N. Hung, "The SRR-1 dryer: An application of low temperature in-bin drying and storage systems in Vietnam", Paper presented at the 18th Association of South-East Asian Nations. 1997.

[10] Chen And morey, "Comparison of four emc/erh equations", *Transactions of* Coefficient. *Journal of agriculture engineering research*, Vol. 6, no. 3, pp. 169-174, 1989.

[11] S. Kaleemullah, and R. Kailappan, "Moisture sorption isotherms of red chillies", *Bio-system Engineering*, Vol. 88, n.1, pp. 95-104, 2004.

[12] A. Midilli, H. Kucuk, and Z. Yapar, "A new model for single layer drying", *Drying Technology*, Vol. 20, pp.1503-1520, 2002.

[13] M.B. McDonald and L.O. Copeland, "Seed Production: Principles and Practicec", Chapman and Hall, New York. 1997.