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Design of Mixed-mode Natural Convection for Solar Agricultural Crop Dryer

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Abstract -- Myanmar is an agricultural country and has a population of about 60 million. Various kinds of crops are grown in Myanmar. Among them, rice is one of the major crop and the drying facilities at the site of the rice production is essential if post production losses is to be kept to a minimum. So, many dryers are required for rice production. Some dryers are run by diesel or gasoline engines and natural source of sun. In this thesis, the drying system will be powered by solar energy sources. The dryer, so called, mixed-mode natural convection solar agricultural crop dryer is being designed. It was noted that the designed dryer had advantages over traditional sun drying, is that paddy was free from impurities such as dirt, there was a low incidence of losses from mold or insects; and paddy was not exposed to rain or dew. This dryer can reduce moisture content of 1.5 m^3 paddy, from 22 % to 12 % (w.b) in a day having the total solar energy of 15.87 MJ/m^2 falling on the dryer. Total volume of air is estimated to be 18155.32 m^3 with a flow rate of 0.6304 m^3/sec. The primary collector area is (7.88 m × 3.94 m) and the drying bed area is (3.81 m × 3.49 m). For human entry, a space (3.94 m × 1.63 m) is made in the drying chamber with a chimney having a height of one meter. And then, the solar dryers are analyzed by changing the drying capacity with same chimney height.

Indexed Terms: flat plate collector, moisture content, solar energy

I. INTRODUCTION

Agriculture is the ***mainstay*** of Myanmar's economy. Over 65 percent of the foreign exchange earnings come from agriculture. As such, future economic development will also be based upon the promotion of agriculture and agro-allied industries. Crop drying is a very simple, ancient skill. It is one of the most accessible and hence the most widespread processing technology. Sun drying of fruits and vegetables is still practiced largely unchanged from ancient times. Traditional sun drying takes place by storing the product under direct sunlight. Sun drying is only possible in areas where, in an average year, the weather allows foods to be dried immediately after harvest. The main advantages of sun drying are low capital and operating costs and the fact that little expertise is required. The main disadvantages of this method are as follows:

a) contamination, theft or damage by birds, rats or insects;
b) slow or intermittent drying and no protection from rain or dew that wets the product, encourages mould growth and may result in a relatively high final moisture content;
c) low and variable quality of products due to over - or under-drying;
d) large areas of land needed for the shallow layers of food;
e) laborious since the crop must be turned, moved if it rains;
f) Direct exposure to sunlight reduces the quality (color and vitamin content) of some fruits and vegetables.

Moreover, since sun drying depends on uncontrolled factors, production of uniform and standard products is not expected. The quality of sun dried foods can be improved by reducing the size of pieces to achieve faster drying and by drying on raised platforms, covered with cloth or netting to protect against insects and animals. Due to the current trends towards higher cost of fossil fuels and uncertainty regarding the future cost and availability, use of solar energy in food processing will probably increase and become more economically feasible in the near future. Solar dryers have some advantages over sun drying when correctly designed. They give faster drying rates by heating the air to 10-30°C above ambient, which causes the air to move faster through the dryer, reduces its humidity and deters insects. The faster drying reduces the risk of spoilage, improves quality of the product and gives a higher throughput, so reducing the drying area that is needed. However, care is needed when drying fruits to prevent too rapid drying, which will prevent complete drying and would result in case hardening and subsequent mould growth. Solar dryers also protect foods form dust, insects, birds and animals. They can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. Thus, they can be useful in areas where fuel or electricity are expensive, land for sun drying is in short supply or expensive, sunshine is plentiful but the air humidity is high. Moreover, they may be useful as a means of heating air for artificial dryers to reduce fuel costs.

II. OVERVIEW OF SOLAR ENERGY

The sun has been illuminating our little corner of the Universe. It is a massive ball with a diameter of about 1.4×10^6 km consisting mostly of hydrogen, which acts like a thermonuclear reactor. Deep in the interior there are two kinds of radiation, i.e;

1. The particle radiation
2. The electromagnetic radiation

The particle radiation consists of small particle; protons and electrons which leave from the sun with a very high velocity, 500 km/sec. The eccentricity of the earth's orbit is such that the distance between the sun and the earth varies by $\pm$ 1.7 %. At a distance of one astronomical unit, 1.495×10^{11} m. Data from Nimbus and Mariner satellites have also been included in the analysis and as of 1978, Frohlich recommends a new value of the solar constant of I_{sc} =1373 W/m^2,with a probable error of 1 % to 2 % . The World Radiation Center (WRC) has adopted a value of 1367 W/m^2, with an uncertainty of the order of the order of 1 %. A value of $I_{sc}$of 1373 W/m^2 (1.960 cal/cm^{2}min, 432 Btu/ft^{2}hr, or 4.921 MJ/m^{2}hr) is used in this thesis.

For solar energy design purposes, it is necessary to know the sun's position in the sky any given day of the year and time of the day. This knowledge is essential for designing either active system (for the location and orientation of solar array) or passive systems (orientation of the structure and placement of windows, fixed glass, and for estimating the shading effect of other building or nearby hills). In northern hemisphere, the sun moves in its daily traverse across the sky, reaching its greatest elevation at midway. An observer at point "O" will be able to note that, on June 21 (the northern hemisphere summer solstice) the sun has attained its most northerly track for its apparent passage around the earth. The sun rises earliest and sets latest on this day, and the sun's path is higher on this day than on any other day of the year. By September 21 (the fall equinox), its path has moved back south again and is directly over the equator. Now day and night are equal in length. By December 21, the sun's path is as far south as it will go, it is winter in the northern hemisphere, the sun is low in the sky all day, and the sun rises late and sets early, resulting in short days and long nights. All of this is reversed south of the equator, as shown in Fig. 1.

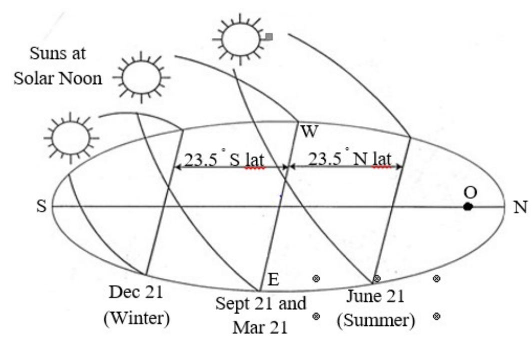

Fig. 1: Apparent Motion of the Sun (North Hemisphere)

Myanmar is situated between North latitude of 9°58′-28°31′ and the East Longitude of 92°10′-101°31′. The path of the sun is on equator on twenty-first March. On June twenty-second, the track of the sun is on "Tropic of Cancer". On September twenty-first, the sun reached over again on the equator and on December twenty-second, the sun is on "Tropic of Capricorn", then on March twenty-first, the sun is on equator again, making one complete cycle. In this rhythmic-nature the cycle orders in Myanmar, the weather is summer for first March to fifteen of May. The rainy season starts from fifteen May to end of October and winter is from November to end of February, thus creating three seasons in Myanmar.

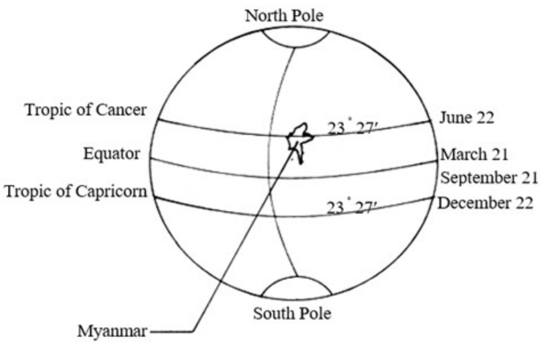

Fig. 2: The Trajectory of the Sun and Myanmar

A. Theories and Equations Used in Solar Energy Design:

Several definitions will be useful in understanding solar radiation. Some of the definitions useful in this thesis are described.

Recommended average days for months and values of “n” by months are shown in TABLE I.

Table 1: Recommended Average Days for Months

Month	n for i^{th} Day of Month	For the average Day of the Month		
		Date “i”	n, Day of Year	Declination
January	i	17	17	-20.9
February	31+i	16	47	-13.0
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
August	212+i	16	228	13.5
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	344	-23.0

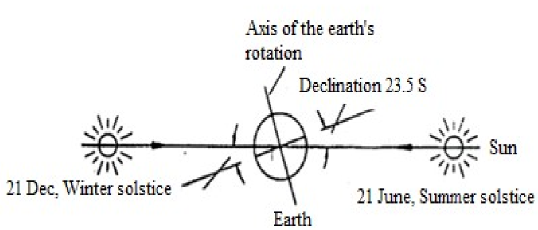

Fig. 3: The Tropic of the Sun

Declination (δ): Itδ is the angle made by the line joining the centers of the sun and the earth with its projection on the equatorial plane. The declination angle varies from a maximum value of +23.45° on June 21 to a minimum value of -23.45° on December 21. It is zero on the two equinox days of March 21 and September 22, shown in Fig. 3.

Cooper (1969) has given the following relation for calculating the declination:

$$\delta = 23.45 \times \sin\left[(284 + n)\frac{360}{365}\right] \qquad (1)$$

where, n = the number of day from first January

B. Hour Angle:

This is the angular displacement of the sun from noon and is equivalent to 15°per hour. It is based on local apparent time being negative in the morning and positive in the afternoon. It can be represented by the equation,

$$\omega = \frac{360}{24} \times t \text{ (hour)} \qquad (2)$$

C. Local Apparent Time (T_{local})

The time used for calculating the hour angle is the local apparent time. This can be obtained from the local standard time (T_{STD}) observed on a clock by applying two corrections.

$T_{local} = T_{SDT} + 4(M_{STD} - L_{local}) + E_t$ (3)

where,

T_{STD} = local standard time (min)

M_{STD} = standard meridian for local time zone, 97.05°

L_{local} = longitude of locality (degree)

E_t = equation of time correction (min)

$E_t = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B$

$$B = \frac{360 \times (n - 81)}{364} \qquad (4)$$

D. Slope(β)

The slope β is the angle made by the plane surface with the horizontal. It is taken to be positive for surfaces sloping towards the south and negative for surfaces sloping towards the north. It is also known as tilt angle.

E. Extra-terrestrial Solar Radiation (I_o)

Some variations in the extra-terrestrial radiation above the atmosphere are not due to solar changes but rather to the Earth-Sun distance throughout the year as stated in below,

$$I_0 = I_{sc} \times \left(1 + 0.033\cos\frac{360 \times n}{365}\right), \text{ (W/m}^2\text{)} \qquad (5)$$

F. Terrestrial Solar Radiation:

In space, solar radiation is practically constant; on Earth, it varies with the day of the year, time of the day, the latitude, and the state of the atmosphere and also on the position of the surface and on the local landscape. Three types of solar radiation are:

1. direct radiation,
2. diffuse radiation and
3. reflected radiation.

The available radiation on sloped surfaces can be obtained in two methods: isotropic sky and anisotropic method. Because the isotropic method is simpler than the anisotropic method, the isotropic method will be used in this paper. The radiation on the tilted surface was considered to include three components: beam, isotropic diffuse and solar radiation diffusely reflected from the ground. A surface tilted at slope β from the horizontal has a view factor to the skyF_{c-s}, which is given by (1+cos β)/2. (If the diffuse radiation is isotropic, this is also R_d, theratio of diffuse on the tilted surface to that on the horizontal surface). The surface has a view factor to the ground F_{c-g} of (1-cos β)/2. The equation of total solar radiation on the tilted surface for an hour is,

$$I_T = I_b R_b + I_d\left(\frac{1+\cos\beta}{2}\right) + I\rho_g\left(\frac{1-\cos\beta}{2}\right) \qquad (5)$$

where, I_b is beam irradiation for an hour, I_d is hourly diffuse irradiation, I is total irradiation (the sum of beam and diffuse irradiation), ρ_g is reflectance of the ground. For residential area, the value of the ground reflectance is 0.40.

By taking the required value from department of meteorology in Tauggyi and the time is from 8:30 morning to 4:30 evening, the calculated result of total solar energy incident of the collector surface is shown in TABLE II. The designed date is June 11, 2010.

Table 2: Hourly Total Solar Radiation Incident on the Collector for June 11, 2010

Time	ω	I_0, MJ/m^2	I	I_d	I_b	R_b	I_T, MJ/m^2
9:00	-56.86	2.9122	1.5670	0.9046	0.6625	0.7116	1.3574
10:00	-41.86	3.7258	2.0049	1.1573	0.8475	0.7868	1.8003
11:00	-26.86	4.3310	2.3305	1.3453	0.9852	0.8244	2.1298
12:00	-11.86	4.6864	2.5218	1.4557	1.0661	0.8419	2.3233
13:00	3.14	4.7679	2.5656	1.4810	1.0846	0.8456	2.3677
14:00	18.14	4.5699	2.4591	1.4195	1.0395	0.8365	2.2599
15:00	33.14	4.1058	2.2093	1.2754	0.9340	0.8117	2.0072
16:00	48.14	3.4074	1.8335	1.0584	0.7751	0.7616	1.6270
Total solar energy falling on collector (MJ/m^2)							15.876

III. OVERVIEW OF SOLAR DRYING AND DRYERS

Drying systems have not been classified systematically. However, drying methods can be broadly classified on the basis of heat transfer to the wet solid. According to mode of heat transfer, drying methods can be divided into:

1) Conduction drying,
2) Convection drying, and
3) Radiation drying.

Among these, convection drying is most popular in grain drying. In this drying, the drying agent (hot gases) in contact with wet solid is used to supply heat and carry away the vaporized moisture and the heat is transferred to the wet solid mainly by convection.

The structure of solar dryers is adjusted to the quantity, character, and designation of the material to be dried as well as to the energy sources used. Accordingly, a great variety of solar dryers has been developed and is in use. The following classification suggests three main groups for solar dryers on the basis of the energy sources used:

1. Solar natural dryers using ambient energy sources only
2. Semi-artificial solar dryers with a fan driven by an electric motor for keeping a continuous air flow through the drying space
3. Solar-assisted artificial dryers able to operate by using a conventional (auxiliary) energy source if needed.

A. Solar Natural Dryers:

In the main group of solar natural dryers, two subgroups are included: the subgroup of the passive, natural convection solar dryers (cabinet, tent type, greenhouse type, chimney-type dryers) and the subgroup of active, partly forced convection solar dryers having a fan driven by electric energy converted by photovoltaic solar cells or driven by a small wind turbine.

The natural convection solar crop dryers designs described include: direct, indirect and mixed-mode solar-dryers. Comparative studies on these three dryer designs suggested that the performance of the mixed mode natural convection solar crop-dryer (MNCSCD) is potentially most effective and it appears to be particularly promising in tropical humid areas where climatic conditions favour sun drying of agricultural products. The MNCSCD, basically a cabinet-type of solar dryer with transparent cover, an attached solar air heater and natural airflow, has been considered favourable since such a dryer utilizes solar energy directly, as well as the convective energy of the heated air.

The principal types of solar air heaters that can be coupled to the drying chamber of the MNCSCD are:

1. The single pass with front duct (SPFDSAH),
2. Single pass with rear duct (SPRDSAH),
3. Single pass with double duct (SPDDSAH), and
4. The double pass solar air heater (DPSAH).

It has been observed that the double pass solar air heaters perform better than the conventional single pass systems. However, their application in natural convective flow is limited, since air needs to be forced through the two channels for efficient utilization of the system. Studies on the three types of single pass solar air heaters employing solid absorbers have shown that performance of the SPDDSAH is superior to the other two. It has been shown that the SPDDSAH with a higher top to bottom ratio in the range 1.1~ 3.5, and a length to width ratio between 1.0 and 2.0 is recommended for optimum performance of the air-heater. It has also been shown that for collectors with tilt angle up to 60°, the length-to-depth ratio should between 20 and 200. Recent modelling work of a SPDDSAH by Hegazy showed that the channel depth-to-length ratio is an important parameter in determining the useful heat gain. His study suggested that for variable flow conditions, the optimum depth-to-length ratio should be 0.0025 for both natural and forced convection. Thus, the upper limit for the length-to-depth ratio of an air-heater can be assumed to be 400. The design constraints for sizing natural convection.Figure.4, shows a mixed-mode natural convection solar crop dryer.

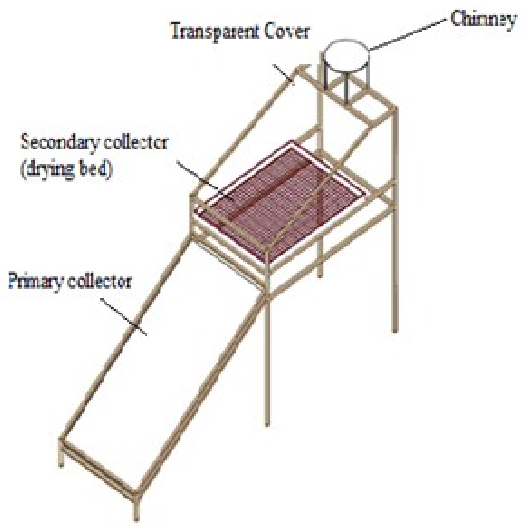

Fig. 4: Mixed-mode Natural Convection Solar Crop Dryer

B. Main Parts of Solar Dryers:
Solar dryers have the following main parts:

1. Daying space
2. Collector
3. Auxiliary energy source (optional)
4. Heat transfer equipment
5. Means for keeping the drying air in flow
6. Heat storage unit (optional)
7. Measuring and control equipment (optional)
8. Ducts, pipes, and other appliances.

C. Types of Solar Collector:
Any dark surface that faces the sun is a solar heat collector. Active or planned solar collection systems fall into two broad categories. They are:

1. Focusing collectors and
2. Flat-plate collectors.

For heating air, flat plate collector is the most common. The air heating flat plate collector is commonly subdivided into three main categories: bare-plate type solar collectors.

D. Collector Efficiency:
The efficiency of a solar collector is defined as the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any time period. Typical day-long efficiencies for different types of flat-plate collectors are presented in TABLE III.

Table 3: Collection Efficiencies for Flat-plate Collectors

Type	Day-long efficiency
Plastic tube type	25 %
Bare plate	30 %
Covered plate	35 %
Suspended plate	40 %
2-cover suspended plate	45 %

E. Construction of the Mixed-mode Solar Agricultural Crop Dryer:
The materials used for the construction of the mixed-mode solar dryer should be cheap and easily obtainable in the local market.The heat absorber of the solar air heater (collector) was constructed using black painted iron roofing sheet being mounted in the collector box built from well-seasoned woods. The solar collector assembly consists of air flow channel enclosed by transparent cover (glazing). One end of the solar collector has an air inlet vent, which is covered by a galvanized wire mesh to prevent entrance of rodents, the other end opens to the plenum chamber.

The drying cabinet together with the structural frame of the dryer was built from well-seasoned woods which could withstand termite and atmospheric attacks. Access door the drying chamber was also provided at the back of the cabinet.

The drying trays are contained inside the drying chamber and were constructed from a double layer of fine chicken wire mesh with a fairly open structure to allow drying air to pass through the food items.

IV. DESIGN CALCULATION

A. Design Constraints:
For airflow by natural convection, the average velocity of the drying air, u, at the exit (or outlet) of the collector is expected to be between 0.2 and 0.4 m/s.

The aggregate drying bed thickness, h_L, is not to exceed 200 mm, the maximum value expected for thin layer drying.

Ambient air temperature, T_a, in the environment where the dryer is to be placed is assumed to be 25ºC. Up to a two-layer drying bed arrangement is recommended for natural convection solar crop drying, the ratio of the air heater top to bottom channel depth ratio should range from 1.1 to 3.5.

For optimal performance of an air heater, the overall air duct channel depth of the air-heater must be greater than 90mm.

The drying surface area is about 60 ~ 80% of the drying chamber floor area, if the drying chamber is to be made for human entry for loading, unloading, and stirring.

Simulation studies on an MNCSCD showed that as the ratio drying chamber area to the collector surface area is increased the overall drying efficiency increase. However, it was observed that for the ratio in the range 1 to 2, there was no observable difference in the performance of the dryer. A value of 1.0 is therefore recommended as the ratio of the drying floor area to the collector surface area [5].

B. Required Data in Designing Solar Crop Dryer:

Latitude, φ 20°47' N(20.78°)
Longitude of location 97°02' E(97.02')
Standard meridian 97°05' (97.08°)
Crop name Paddy (k=0.03)
Initial Moisture Content, m_1 22% (Average)
Final Moisture Content, m_2 12% (Required)
Ambient Air Temperature 25°C (Assumed)
Required Drying Temperature 43°C (for Paddy)
Designed Date June 11, 2010 (n = 162)
Crop Volume to be tested, V_c 1.5 m^3
Tilt angle of solar collector- 30°

Type of collector suspended plate type flat plate collector

C. Design Calculation:

The calculated results are shown in TABLE IV.

V. RESULTS AND DISCUSSIONS

Table 4: Results of Solar Crop Dryer for Various Drying Capacity with the Same Chimney Height

Description	Values				
Crop volume, V_c (m^3)	2.5	2	1.5	1	0.5
Mass of crop, m (kg)	1606.25	1285	963.75	642.5	321.25
Moisture in crop, M_w (kg)	182.53	146.02	109.52	73.01	36.50
Required heat, Q_r (kJ/kg)	486.78	389.42	292.07	194.71	97.35
Heat gain, Q_g (kJ/kg)	6.349	6.349	6.349	6.349	6.349
Total area, A_T (m^2)	76.67	61.34	46.00	30.67	15.33
Collector area, A_c (m^2)	51.67	41.34	31.00	20.67	10.33
Collector width, W_c (m)	5.08	4.55	3.94	3.21	2.27
Collector length, L_c (m)	10.17	9.09	7.88	6.43	4.55
Drying bed area, A_d (m^2)	25	20	15	10	5
Bed length, L_d (m)	4.92	4.40	3.81	3.11	2.20
Area for human, A_{hu} (m^2)	10.71	8.57	6.43	4.28	2.14
Depth of air duct, s (cm)	33.89	30.31	26.25	21.43	15.15
Required air, V_a (m^3)	30258.05	24206.44	18154.83	12103.22	6051.61
Air flow rate, V (m^3/s)	1.0506	0.8405	0.6303	0.4202	0.2101

The calculated results are obtained from below, efficiency of collection, η=0.40 (from TABLE III)

Absorb energy from collector, $Q_g=\eta_c \times I_T$
Mass of moisture to remove moisture,

$M_W = m \times \frac{m_1 - m_2}{100 - m_2}$

Energy required to remove moisture, $Q_r = M_W L_S$
The required collector area is,

$$A = \frac{\text{energy required from the paddy}}{\text{absorbed energy from the collector}} = \frac{Q_r}{Q_g}$$

It is the total area (both primary collector and secondary collector areas) of the dryer. From the design constraints number eight, the area of the primary collector is taken as half of it.

VI. CONCLUSION

Myanmar is the agricultural country and many crops are grown in Myanmar. Among them, rice (paddy) is the major food in Myanmar society. Paddy post-harvest production includes harvesting, threshing, drying, storing and milling. Improvement in the quality of agricultural product is directly related to the drying. And then better storing conditions of the product is depended on the drying. So, crop drying is important.From the design calculation for 1.5 m^3 of paddy, it can be seen that the required energy to remove moisture content from 22 % to 12 % is 292.08 MJ. The received energy from the collector is 6.349 MJ/day m^2 for June 11. The depth of the paddy bed is 100 mm. So, the floor area of the paddy bed is 15 m^2. The required total collector area is 46 m^2.But the design dryer is using both direct and indirect method; the area of the actual collector is not the entire total requirement. The rest is considered directly to the crop floor. The size of the air inlet area is (3.94m×0.2626 m) and the chimney height is 1m. Without changing the chimney height, the new collector area form more heat to dry up and outlet air become slow which can cause overheat to the crop? The effect of overheated, due to the same chimney height, the grain can be broken and the quality of paddy can be poor. Hence to avoid overheat problem it should be suggested to change the outlet air move faster by increase of chimney height or by the use of turbo ventilator at the chimney.

REFERENCES

[1] Shailendra Kumar Bohidar, Prakash Kumar Sen, Ravi Bharadwaj, Study of Turbo Charging, 2015.

[2] Anonymous: "Design Study Of Grain Dryer", (2011).

[3] C. C. Myint, Institute of Agriculture, Pyimana, the Union of Myanmar, "Nature Farming in Myanmar", 2011.

[4] Bukola O. Bolaji and Ayoola P. Olalusi: "Performance Evaluation of a Mixed-Mode Solar Dryer", Department of Mechanical Engineering, University of Agriculture, Abeokuta, Ogun State, Nigeria, 2007.

[5] F.K. Forson, M.A.A. Nazha, F.P. Akuffo, H.Rajakaruna: "Design of mixed-mode natural convection solar crop dryer: Application of principles and rules of thumb", 2007.

[6] Nay Min Zaw, Maung: "Design Of Solar Dryer (Beans)",ME Thesis, Mechanical Engineering Department, Mandalay Technological University, June, 2007.

[7] PhyuPhyuHtun, Ma: "Design And Construction Of Intermittent Solar Adsorption Refrigeration System Using Water-Carbon (Adsorber And Condenser)", Ph.DThisis, Mechanical Engineering Department, Mandalay Technological University, March, 2007.

[8] La´szlo´ Imre: "Solar Drying", "HAND BOOK OF INDUSTRIAL DRYING", third edition, edited by Arun S. Mujumdar, Singapore, 2006.

[9] Zin Mar Htun, Ma: "Design and Performance Analysis of Solar Water Heating System for 435 Liter Water Tank", ME Thesis, Mechanical Engineering Department, Yangon Technological University, May, 2004.