



Design and Development of Seed Storage System based on Earth Tube Heat Exchanger

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ABSTRACT

Diurnal fluctuations cannot penetrate at certain depth of ground. Ground at this depth gives stable thermal environment. Utilizing the soil for heat dissipation purpose, ETHE (Earth Tube Heat Exchanger) system was designed and developed for a typical space in closed loop mode for storage of high value seeds maintaining RH in addition to cooling the air. Seed storage structure based on ETHE of 54 m³ was constructed as per design calculations. ETHE was made of PVC pipe 0.16 m outer diameter and 42 m in length, buried 2.7 m deep below soil surface in loop mode. Different seeds were stored in storage structure. Seed storage studies under ETHE indicated higher germination compared to ambient condition storage. However, there was no appreciable change in vigor index. The average relative humidity inside was relatively stable and temperature was considerably different as compared to ambient over the entire year. The work of ETHE was in heating mode from mid July to November and in cooling mode from November to mid July.

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Introduction

Seed is an important and essential input for attaining sustainable agricultural production. Seed poses maximum viability, vigor and germination at physiological maturity. It starts deteriorating just after attaining the maturity whether it is in plant, stored in soil banks, warehouses or liquid nitrogen or in transit; all seeds succumb with time and die. The deterioration process cannot be eliminated but it can be minimized by safe storage.

For safe storage of seed, moisture content and temperature are the principal factors to determine the storability of the seeds in bulk storage (Mudgal, 2002; Singh, 2002). The amount of moisture in the seed tends to fluctuate according to temperature and relative humidity of the surrounding air. The storage of the seeds involves several ecological systems comprising of physical, chemical and biological variables. Important variables are temperature, moisture, oxygen, storage structures, properties of seeds and its quality, microorganisms, insect, mites, rodents and birds. It is the understanding of the physico-chemical environment in the background of the interaction or the biotic and abiotic variables operating in a seed grain bulk, which helps in proper management in seed stores.

Scientifically visualized controls bring ideal balance in the relationship of the abiotic variables i.e. moisture and temperature with the biotic variables i.e. the presence of microorganisms, insects and mites and the properties of the seed which ensure proper seed preservation and soundness. The effects of these two abiotic variables in the safe storage of seed are interrelated. When these relationships get disturbed due to unfavorable storage condition or defective practices, spoilage occurs which influence seed viability and vigor during storage (Garg, 2002). Control on this abiotic factor may be achieved by ventilating air through proper designed an earth tube heat exchanger system connected with storage system or structure. The earth tube heat exchanger is well suited for maintaining RH in addition to cooling the air (Ma-Chengwei *et al.*, 1997; Pangavhane, 2003; Sharan, 2003). This advantage is suitable for use as environmental cooling and other storage buildings for high valued seed and other materials where low RH and lower temperatures are desirable. A closed loop systems is more efficient than an open loop design as it does not exchange air with the outside, therefore it does not require as high degree of dehumidification as an open loop system.

In the present contest of sufficient seed production in the country, scientific storage of seed is of paramount importance. This study was therefore undertaken with a view to design and development of the ETHE for the purpose of creating an appropriate environment for seed storage.

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Materials and methods:

Theoretical design of ETHE storage system

Heat transfer analysis for seed storage room

The seed storage room was considered as closed chamber in which cool air in summer and warm air in winter was circulated using the ETHE system. The room was almost sealed and there was no entry or escape of air from door and window. Inside relative humidity of air was considered to be nearly stable and was useful to maintain low relative humidity inside the room. Heat transfer through seed storage room structure (Walls, roof) was referred as transmission load (Sinha 2000). The load was calculated by following equations and expressed as kW.

$$Q = u \cdot A \cdot (T_o - T_i) \quad \text{Where,}$$

$$u = \frac{1}{\frac{1}{h_0} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \dots + \frac{x_n}{k_n} + \frac{1}{h_i}}$$

Determination of buried pipe depth

Buried depth was determined from the concept of semi-infinite solid. Semi-infinite solid was characterized by a single identifiable surface. If a sudden change of conditions was imposed at this surface, transient, one-dimensional conduction will occur within the solid. The semi-infinite solid provides a useful idealization for many practical problems. It was used to determine transient heat transfer near the surface of earth. For typical ETHE system was installed under climatic conditions of Anand (India) and the following design input data were considered as shown in Table 1.

Table 1. ETHE design input data

S. No	Parameters	Data
1	Location	Anand (Gujarat State) Latitude: 22° 35' N Longitude: 72° 55' E
2	Space size (to be cooled or heated)	54 m ³
3	Capacity (heat load of seed storage chamber)	1176 watt
4	Storage room inlet air temperature during peak summer (Maximum permissible)	34 °C
5	Storage room outlet air temperature desirable	30 °C
6	Average ambient temperature (summer)	38 °C
7	Undisturbed soil temperature	25 °C
8	Initial soil surface temperature	22 °C
9	Soil surface temperature during peak summer	44 °C
10	Velocity inside the pipe	12-13 m/s
11	Time zone	120 days

The heat transfer equation for transient conduction in a semi-infinite solid was given by

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

Applying boundary conditions and using separable variable of variable solution, this equation can be reduce to

$$\frac{T - T_{0s}}{T_s - T_{0s}} = \operatorname{erfc} \left(\frac{x}{(4\alpha t)^{1/2}} \right)$$

Using this equation, the minimum buried depth required was estimated taking 10 % safety factor.

Mass flow rate of air

To transfer the heat from the air to be cooled or heated to the soil and from the soil to the air, certain mass flow has to be circulated. Considering heat load of 1176 watt for seed storage room required mass flow rate could be calculated from the following equation:

$$Q_{\text{total}} = M_{\text{total}} \times c_p \times T_{\text{mean}}$$

Diameter of pipe

The velocity of air has profound effect on the heat transfer. Velocity of air depends on the total mass flow in the system. Keeping the air velocity inside the pipe at 12-13 m/s, the diameter of pipe was calculated by the equation

$$M_{\text{total}} = \delta_{\text{air}} \times A \times V$$

Heat transfer from the cylindrical body of ETHE

Conduction mode of heat transfer can be viewed as the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles. Higher temperatures are associated with higher molecular energy and when neighboring molecules collide, as they are constantly doing, a transfer of energy from the more energetic to the less energetic molecules must occur. In presence of temperature gradient, energy transfer therefore, occurs in the direction of dropping temperature.

Considering a hollow cylinder having inner radius r_i and outer radius r_o . For steady-state conditions with no heat generation, the appropriate form of heat transfer equation is

$$\frac{1}{r} \frac{d}{dr} \left(Kr \frac{dT}{dr} \right) = 0$$

The physical significance of this equation becomes evident if we consider the appropriate form of Fourier's Law. The rate at which energy is conducted across any cylindrical surface in the solid may be expressed as

$$q = -KA \frac{dT}{dr} \quad \text{Where, } A = (\pi \times d_i \times L)$$

$$q = -K(2\pi L) \frac{dT}{dr}$$

It is the area normal to the direction of heat transfer. Now using temperature distribution equation and Fourier's Law the expression for the heat transfer rate can be obtained as follows

$$q = \frac{2\pi L(T_1 - T_2)}{\ln\left(\frac{r_o}{r_i}\right)}$$

From this equation it was evident that, for radial conduction in a cylinder wall, the thermal resistance was of the form

$$R_{\text{cond}} = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi KL}$$

Now considering a cylinder which was buried in the soil at a certain depth the exposed outer wall of the pipe depends not only on the resistance between the hot and cold surfaces but also on the capacity of surrounding atmosphere to remove the heat arriving at the outer surface. Here, a cylinder was covered with the soil and carrying hot air at inlet at around 34 °C in summer and undisturbed soil temperature of around 25 °C.

Thus overall temperature difference driving heat out of the pipe is $(T_{\text{mean}} - T_{\text{und}})$.

Where,

$$T_{\text{mean}} = \frac{(T_{\text{in}} + T_{\text{out}})}{2}$$

If we consider the radial heat flow only in the one direction there will be three resistances across the heat flow path.

- 1 The convective resistance inside the pipe surface due to flow of the air (R_1).
- 2 The conduction resistance of the pipe material which is found much less compared to other resistance (R_2)
- 3 The conduction resistance offered by the soil, which is much higher (R_3).

Sectional view of the cylinder surrounded by the soil is given in Fig. 1 with thermal circuit diagram.

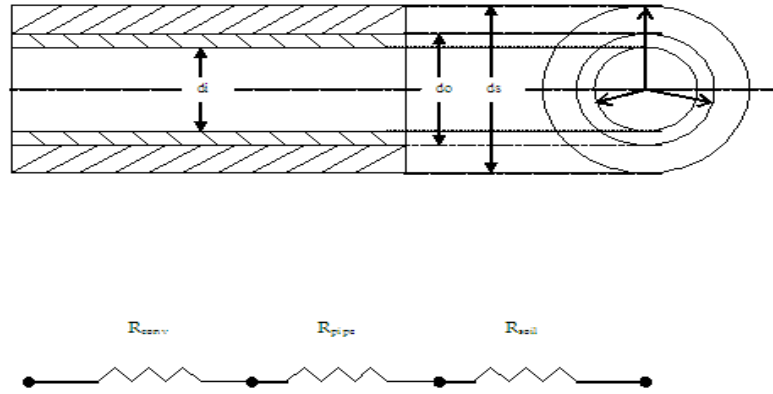


Fig. 1 Cross sectional view of ETHE buried pipe and different resistances

Total resistance offered to the flow of heat will be summation of all these three resistances.

$$R_{total} = \frac{1}{h_i \pi d_i l} + \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi K_p L} + \frac{\ln\left(\frac{r_s}{r_o}\right)}{2\pi K_s L}$$

Airside convective heat transfer coefficient

To estimate an airside convective heat transfer coefficient, Reynolds Number for the design velocity of the air can be calculated as under:

$$Re = \frac{(\delta_{air} v d_i)}{\mu}$$

As flow is turbulent, Dittus-Boelter correlation can be used to estimate Nusset number, Nu .

$$Nu = 0.023x(Re)^{0.8} x(Pr)^{0.33}$$

Therefore, heat transfer coefficient inside the pipe (h_i) was given by following equation

$$h_i = \frac{Nu.K_{air}}{d_i}$$

Length of pipe

The length of pipe was calculated considering the minimum soil radius under steady- state radial heat flow from ETHE pipe to soil at buried temperature at 25 °C considering the temperatures around the pipe at radial distance of one pipe diameter away were very much affected and beyond this limit remain unaffected (Sharan and Madhavan 2003).

Assuming ETHE pipe length, the total resistance offered by the system including the soil at the buried depth can be estimated for the heat transfer per meter length (q_1) of total load and it will be,

$$q_1 = \frac{\text{Total load}}{\text{Length of pipe}}$$

The temperature drop of the air in one-meter length of pipe was calculated considering internal energy lost by air as it flows axially:

$$q_1 = m \times c_p \times (T_{in} - T_{out})$$

By equating the internal energy lost by air as it flows through the pipe section with the heat transfer in the radial direction to soil, the minimum radius of the soil layer wherein this temperature gradient exists were estimated as follows:

Radial heat flow through the pipe thickness and soil is,

$$q_1 = \frac{\Delta T}{R_{total}} \quad \text{Where, } \Delta T = T_{mean} + T_{und} \quad \text{and} \quad R_{total} = R_1 + R_2 + R_3$$

Using above equation; total soil resistance per meter length was calculated and soil radius was calculated as per recommendation given by (Sharan and Madhavan 2003). Putting the value of total resistant (watt per meter length); the length of pipe was calculated by application of following equation considering 10 % safety margin.

$$L = \frac{Q_{total} \times R_{total}}{\Delta T}$$

Development of ETHE storage system:

Experimental set up

The experimental set up consists of a seed storage room, an earth tube heat exchanger, a blower and appropriate instrumentation. The set up has been designed based on the theoretical considerations mentioned in the previous sub sections. The dimensions of the room have been considered for storage of seeds at approximately 34 °C and relative humidity of 50-65 %, which correspondence to an appropriate environment for seed storage (Agarwal R. 1997). The ETHE system works in a closed loop wherein the room air is reticulated, thereby maintaining proper temperature and relative humidity. This closed loop also ensures that there is negligible increase in relative humidity during the rainy season. The temperature of the entire system was monitored using dedicated data logger.

Storage systems

The seed storage room (Fig. 2) was constructed adjusting to the Agricultural Product Process Engineering Unit building taking support of one of its existing wall. The overall dimension of the structure was 6.1 m (length) x 3.65 m (width) x 2.51 m (height). The total volume of the chamber was 54 cubic meters. Closed loop ETHE system was installed with appropriate blower and pipe connections. The blower pumps in conditioned air into the room through a distribution system (manifold) fitted at the lower level of the room. Similar distribution system at a higher level is fixed at the other end of the room through which the air gets sucked and enters the closed loop ETHE. A timer device is connected to blower to operate the blower intermittently.

Construction of seed storage room

With proper design and careful construction virtually any type of building will function as efficient seed storage. Tight controlled atmosphere was easier to obtain in buildings, which had smooth interior walls and ceilings. The room was made up of bricks and cement construction in 0.23m wall thickness with appropriate cement-sand plaster. The roof was made up of pre-fabricated reinforced cement concrete slabs and joint together on supporting beams. Door and window were made up of single piece plywood to avoid air leakage.

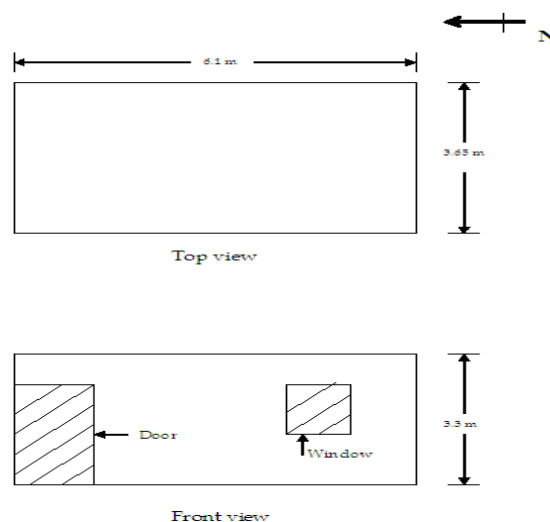


Fig. 2 Different views of seed storage room

Earth tube heat exchanger

A 7 m x 2.6 m x 2.8 m pit was excavated in front of the constructed room. After excavation, the pit floor was properly leveled and PVC pipe 0.16 m outer diameter and 42 m in length was laid down and connected forming a continuous loop. Five PVC pipes each measuring 6.1 m were laid keeping a distance of 0.45 m between them. The pipes were connected using appropriate bend and pipe sections. Two-riser pipes were taken out from both ends and one connected to the room (Lower level) through blower assembly and another connected to room (Upper end) for circulating the air. All joints of pipe were fixed with appropriate adhesive solution and then synthetic putty applied over the joints to prevent moisture penetration inside it. The pit was then filled with the original soil up to ground level.

Blower house and blower

A blower coupled with motor (direct drive, industrial type, 0.5 hp with radial blade) was fixed on a small constructed foundation with necessary nut-bolts inside the blower house. Blower was connected to the underground PVC pipe and delivery end of blower was connected with room. Three-phase electric connection was provided to operate the electric motor of blower through a timer assisted starter.

Seed Storage

Seed samples of cowpea (GFC-2), sorghum (S-1049) and fodder bajra (GFC-1) were stored in 1 kg cloth bags while onion seed was stored in polyethylene bag of 400 gauge under normal conditions (control) as well as ETHE assisted seed storage room. The percentage germination was determined to study the change in seed viability during storage. The temperature of the stored seeds was also monitored.

Instrumentation

A dedicated multichannel digital data logger (data taker Make, DT-600) consisting of 30 input channels and programmable through a computer software was used to continuously monitor the temperature of the system. The temperature sensors used were J type thermocouples (appropriate by calibrated). The sensors were connected to the data logger through appropriate wires and compensated for signal strength. Additionally two small data loggers (make: Tiny tech) were also used. One of them was dedicated to measuring relative humidity of the surrounding air and storing it in its internal memory. The other data logger was used for measuring temperature of surrounding air and was also programmable to collect data at appropriate intervals of time. Both these data logger were placed inside the storage room to monitor relative humidity and temperature. The placements of sensors are shown in (Fig. 3).

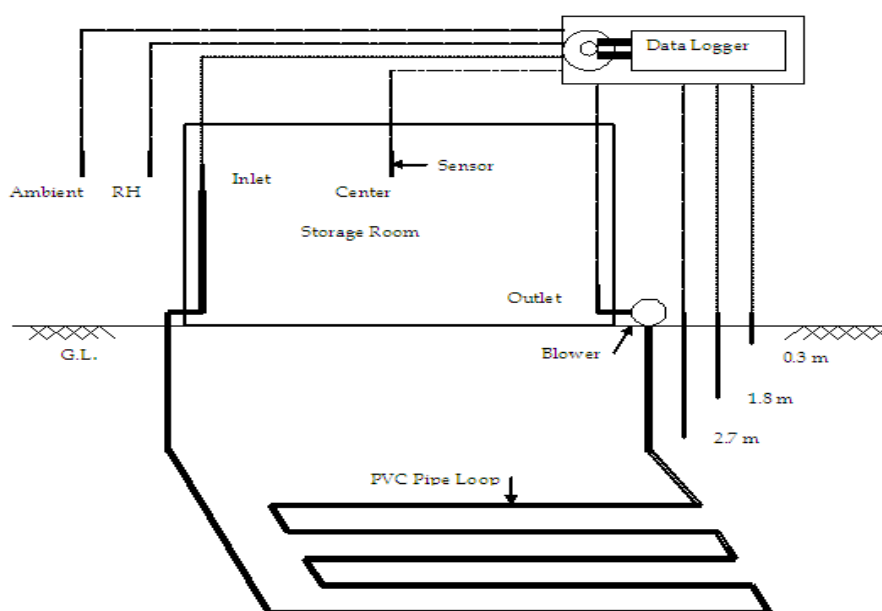


Fig.3 ETHE instrumentation

Results and discussion:

Seed germination test

To study the seed storage viability, cow pea (GFC-2), sorghum (S-1049), bajra (GFC-1) and onion (GWO-1) in small quantities (one Kg sample of each) were stored in earth tube heat exchanger storage room as well as under ambient storage (as control). All samples were stored for a period 8-month. Pre-storage and post-storage germination was conducted in the laboratory of Main Vegetable Research Unit, Anand Agricultural University, Anand. Germination data after two replications for cowpea, sorghum, bajra and onion showed germination of 95 %, 98 %, 92 % and 98% respectively for pre-storage (Table 2). Data for ambient condition storage (control) showed germination of 78 %, 80 %, 62 % and 54 %, while that of earth tube heat exchanger storage showed 78 %, 83 %, 68 % and 62% respectively. There was slightly higher germination compared to control. Vigor index for all samples does not show appreciable change post-storage (Table 3). The increase in germination might be due to the relative humidity inside the storage room was not affected by change in relative humidity outside due to small weather changes.

Table 2. Seed germination data

Crop (variety)	Pre-storage germination, %	Post-storage germination, %	
		Control room	ETHE room
Cowpea (GFC-2)	95	78	78
Sorghum (S-1049)	98	80	83
Bajra (GFC-1)	92	62	68
Onion (GWO-1)	98	54	62

During a typical rainy week when variation in relative humidity of ambient was very high; for ETHE room, it was not fluctuating as much. The average relative humidity inside was relatively stable as compared to ambient over the year. Another reason might be of storage room temperature follows the ground bottom temperature over the entire year, and was considerably different from ambient temperature. The annual temperature showed that the ETHE had worked in heating mode from mid July to November and in cooling mode from November to mid July.

Table 3. Seed germination vigor index data

Crop (variety)	Pre-storage germination vigor index	Post-storage germination vigor index	
		Control room	ETHE room
Cowpea (GFC-2)	4.2	3.4	3.4
Sorghum (S-1049)	4.6	3.9	4.0
Bajra (GFC-1)	5.8	3.8	4.2
Onion (GWO-1)	5.8	3.4	3.9

Conclusions

The low humidity storage system based on ETHE is a safe, clean, environmental friendly air heating and cooling system. The system is simple in construction, consumes less electric energy as compared to air cooling/conditioning and can therefore, is used for special applications even in rural areas. If the storage room is made sufficiently air tight, the air re-circulation is very effective and is successful in maintaining temperature and relative humidity inside the room which will be necessary for seed viability.

Nomenclature

Q	Heat load, k.cal/hr
Q_{total}	Total heat load required to be removed, w
T	Temperature at buried depth, °c
T_{0s}	Temperature of surface, °c
T_s	Initial soil temperature, °c
t	Time zone, days
x	Buried depth of pipe, m
α	Thermal diffusivity of soil, m ² /day
$erf.c$	Error function

M_{total}	Total mass flow rate of system, kg/s
c_p	Specific heat of air, kj/kg
T_{mean}	Bulk mean temperature of air, $^{\circ}\text{C}$
T_{in}	Inlet temperature of air, $^{\circ}\text{C}$
T_{out}	Outlet temperature of air, $^{\circ}\text{C}$
δ_{air}	Density of air, kg/m^3
V	Velocity of air inside the pipe, m/s
r_i	Inner radius of buried pipe, m
r_0	Outer radius of buried pipe, m
r_s	Soil radius, m
T_{und}	Undisturbed soil temperature, $^{\circ}\text{C}$
A_i	Cross sectional area of pipe normal to the heat flow, m^2
k_p	Thermal conductivity of pipe, $\text{w/m } ^{\circ}\text{C}$
k_s	Thermal conductivity of soil, $\text{w/m } ^{\circ}\text{C}$
R_e	Reynolds Number
P_r	Prandtle Number
N_u	Nusset Number
k_{air}	Thermal conductivity of air, $\text{w/m } ^{\circ}\text{C}$
q_l	Heat load per meter of pipe length, k.cal/hr
ΔT	Axial temperature drop per meter of pipe length, $^{\circ}\text{C}$
Δt	Radial temperature drop per meter of pipe length, $^{\circ}\text{C}$

References

- Agarwal, R.L. (1997). Seed Technology, Scientific Publishers, Jodhpur.
- Garg, M.K. (2002). Temperature and relative humidity management, Machinery Management for Quality Seed, Department of Seed Science and Technology, CCS Haryana Agricultural University, Hissar, pp: 222-229.
- Ma-ChengWei. and Cw -Ma (1997). A study on earth cooling of ventilation air for animal housing in south China in summer. Transactions-of-the-Chinese-Society-of-Agricultural-Engineering, 13:173-176.
- Mudgal, V.D. (2002). Different operations in post harvest processing of food grains. National Training Course on Post Harvest Technology for Grains, Udaipur, December 1-8, pp: 14-18.
- Pangavhane, D.R. (2003). Experimental study on buried earth tube heat exchanger for cooling of buildings. Advances in Renewable Energy Technologies, Narosa Publishing House, New Delhi, pp: 57-63.
- Sharan, G. (2003). Development and application of earth tube heat exchanger. Research Newsletter, Indian Institute of Management, Ahmedabad, December 2003.
- Sharan G. and T. Madhavan (2003). Simulation of performance of earth tube heat exchanger using a mathematical model. Journal of Agricultural Engineering, Vol. 40(3): 8-15.

Singh, R.P. (2002). Role of temperature and moisture in safe storage of food grains. National Training Course on Post Harvest Technology for Grains, Udaipur, December 1-8, pp. 56-60.

Sinha, J.P. (2000). Controlled condition seed store for temperature climate. Advanced Course on Post harvest Handling and Management of Seeds, Indian Agricultural Research Institute, Regional Station, Karnal, pp: 12-27.