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AN ENERGY ANALYSIS ON GRAIN DRYING SYSTEMS IN CHINA

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ABSTRACT

There will be about 0.25 to 0.3 billion tons of grain product including rice, wheat and corn etc. each year in China. An energy analysis on grain drying systems on which electricity, oil, coal or sun power and batch, tower with thick or thin layer of grain, infra red radiation, fluidized flowing types grain drying systems were made and compared for the sake of energy saving is shown in this paper.

Key word: Energy analysis, Grain drying systems, Rate of Energy consumption, Rate of heat consumption, Rate of power consumption.

INTRODUCTION

Drying is the final process link for post harvest of farm grain production. Attention to grain drying system has been paid since the establishment of new China. The theory, the test, the experiment, and the characteristic of grain drying system have been studied, and some fruitful results have been made. Many types of grain drying system have been developed and used on farms in China including fixed bed, heated air spraying, fluidized flow, mixed flow recirculating heated air tower with the use of different fuel including wood, husk of rough grain, coal, gas, electricity,diesel fuel, and solar energy.

There will be about 0.25 - 0.35 billion ton of grain product including rice, wheat, corn and barley each year in China. All of them are dried mainly by solar energy on sunny ground. According to a rough calculation to the fuel consumption on drying 0.275 billion ton of grain with initial moisture content 25% to final moisture content 13.5%, ten million tons of coal or 5 million tons of diesel or ten billion kwh of electrical power will be needed. This is a very huge sum and cost of fuel and energy consumption on grain drying if commodity fuel is used, but all this fuel is spared in China because of using solar energy and sunny ground instead of commodity fuel.

In calculation, the heat value of above fuel or energy is taken as:

coal, standard -- 20934KJ/kg,
diesel fuel -- 41868KJ/kg,
electricity -- 3600KJ/kwh.

It is a burden to a developing country to supply such a large sum of commodity fuel for grain drying usage. The Chinese farmers cannot afford the high cost on fuel consumption while the price of grain is comparatively low with respect to that of fuel such as coal, diesel and electricity. It is too much difficult to supply more coal, diesel fuel or electricity to rural area for grain drying usage.

The object of this paper is to give an energy analysis on grain drying systems, to see how to save fuel consumption for them, and which is the best system and cost less in fuel consumption and suitable for Chinese farmers. From the point of view in energy analysis, grain drying is very large energy consumption work in experience of all developed countries. In mechanized grain production, irrigation and drainage will possess the first place in energy consumption, grain drying will be the second place, while tractor ploughing, harrowing and soil preparation will have the third place.

Shao etc. (1985) had written a reference book of "Theory and construction on grain dryers" published by Chinese Machinery Industry Press in which there was a section to illustrate the energy analysis on different types of grain drying systems. (1)

The world known reference book of grain dryers by Brooker, Bakker-Arkema and Hall (1974), (1992) pressed by AVI had no section to analyze the energy consumption on grain drying systems but the heat balance equation in these two books would be the theoretical basis in this paper. (2, 3)

THEORETICAL ENERGY ANALYSIS ON GRAIN DRYING SYSTEMS

The drying medium used in drying cereal grain for all drying systems except infra red radiation is moist air, which is a mixture of dry air and vapor. The moist air is heated and then pass through the grain. The sensible heat surrendered by the air is equal to the latent heat of evaporization required to vaporize the water from the grain. This heat exchange is the main heat consumption process.

1. Heat balance for drying using air as medium

The simplified heat balance equation for the drying process can be written as in the following equation:

$$60\, q_a\ c_a\, (Ta - Tg)t\, /v\ = h_{fg}\ (md)\, (Mo - Me) \qquad (1)$$

where:

q_a -- air flow rate (m /min)

v -- specific volume of air (m /kg)

c_a -- specific heat of air (KJ/kg. C)

(Ta-Tg) -- temperature drop of air through grain mass (C)

t -- drying time (h)

h_{fg} -- latent heat of evaporation, in some instance it may be considered as constant as 2970 KJ/kg.(H_2O)

md -- dry matter of grain (kg)

(Mo-Me) -- moisture content of grain at initial (Mo), and final or equilibrium m.c. (Me), (in decimal)

2. The heat consumption rate h_r

In practical, the rate of heat consumption (h_r) may be used to calculate the heat to evaporate the water while drying, $h_r > h_{fg}$. Thus, the necessary heat used in in drying for a specified type of drying system will be as follows:

$$Qt\ =\ h_r\ m_w\ = h_r\ (md)\, (Mo - Me) \qquad (2)$$

where:

h -- rate of heat consumption ($KJ/kg.H_2O$)

Q -- total heat used for evaporate the water while drying (KJ)

m -- mass of water removed while drying (kg)

3. Heat balance of infrared ray radiation or solar grain drying system

In infrared radiation or solar drying, the heating of grain is mainly through the radiation and not by air-grain heat transfer.The heat balance of this two system will be as follows:

$$3600 W_i \, t / \eta_i = h_r \, m_w = h_r \, (md)(Mo - Me), \text{ for infrared drying} \quad (3)$$

where:

Wi -- the power of infrared radiation (kw)

t -- the time of drying (h)

η_i -- efficiency of infrared radiator on grain drying, (in decimal)

$$I \, A \, t / \eta_s = h_r \, m_w = h_r \, (md)(Mo - Me), \text{ for solar drying} \quad (4)$$

where:

I -- mean intensity of infrared radiation or solar radiation ($KJ/m^2.h$)

t -- total time of drying (h)

A -- total area of solar collector projecting in horizontal plane (m^2)

η_s -- efficiency of solar grain dryer of specified type (in decimal)

4. The mechanical power consumption

The mechanical power consumption used on fan, auger and elevator, stirrer will be as follows:

$$Pm = Pmf + Pme + Pms \quad (5)$$

where:

Pm -- total power consumed when drying (KJ)

Pmf -- recorded power consumed on fan for air flowing exchanged into (KJ)

Pme -- recorded power consumed on transportating grain while drying (KJ)

Pms -- recorded power consumed on stirring grain while drying (KJ)

5. Rate of energy consumption e_r, rate of heat consumption h_r , rate of power consumption p_r in $KJ/kg.H_2O$.

$$e_r = h_r + p_r \quad (6)$$

where:

$h_r = Q_t / m_w$; $p_r = P_m / m_w$.

EXPERIMENTS

In this paper, there will be eight main types of grain dryers on tests in heat, power or energy consumption in which seven types No.1 - 7 were tested under Chinese National approval and would be reliable in their experimental data. The No.8 test on solar barn grain drying systems was conducted in the laboratory at SCAU (South China Agricultural University).

These eight types of grain drying systems were as follows:

1. Fixed bed using coal as fuel with heat exchanger to obtain heated air for grain drying;
2. Fixed bed using coal as fuel and heated flue gas in furnace for drying;
3. Fixed bed using diesel fuel injector and burner to obtain heated air for drying;
4. Bin type using coal as fuel and gas generator to obtain flue gas for drying;
5. Tower type using coal as fuel and furnace to obtain mixed flow low temperature heated air for drying;
6. Rotary drum dryer using infrared ray and electricity (15kw) for drying;
7. Fluidized bed and flow of flue gas through perforated and inclined channel;
8. Solar barn fixed bed grain dryer using air-water heat collector to obtain heated air for drying.(4)

All systems were using heated air for evaporating the water on or in grain except infrared ray radiation drying. This was the main energy consumption in grain drying systems. About 89% to 98% of the energy in drying was used on this purpose.

No stirring machine was used in the above eight types of grain drying systems. All systems had blowing fan to propel heated air or flue gas for grain drying. It was not necessary to move or recirculate the grain in fixed bed while drying, but others drying systems had augers, elevators, or drums to recirculate the grain in drying. There would be electric power consumption for blowing fans, augers and elevators and watt-hour meters were used to record it and then changed it into power consumption in KJ. Power consumption was the second main energy consumption in drying, about 2% to 11% of the energy was used.

EXPERIMENTAL RESULTS AND DISCUSSION

The comparative heat and energy consumption experiments for eight types of grain drying systems is shown in Table 1.

As shown in Table 1, the average rate of heat consumption for all drying systems using heated air as drying medium was rather high, at 5686 - 13517 KJ/kg H_2O. The lower figure represented fixed bed grain drying systems at 5686 - 8006 KJ/kg H_2O; and the higher figure represented the heated air spraying and fluidized flowing channel drying systems at 13062 - 13517 KJ/kg H_2O.

The infrared drying systems belonged to the radiation heating systems,its average rate of electricity consumption exchanged into rate of heat consumption was as low as 5090 - 5125 KJ/kg.H_2O, approximately a little more than the theoretical heat value to evaporate one kg mass of water (5024 KJ). They costed at about ¥1.2/kg H_2O. when the the price of electricity was ¥0.06 per kilowatt hour. This cost was two or three times higher than that of other drying systems using coal as fuel(¥1.08-1.20/t% H_2O).

The average rate of power consumption of drying systems for air blowing fan,grain moving machines such as augers or elevators, and stirring machines was at about 152 - 1139 KJ/kg.H_2O. The lower figure represented the fixed bed drying systems which is not necessary to move the grain while drying, so they would have the less power consumption. The higher figure represented the spraying heat heated air drying 1139 KJ/kg.H_2O.

The main heat consumption for all eight types of drying systems was used on drying the grain by heated air. 89% to 98% of heat was consumed on this purpose. The power consumption for air blowing, grain transportation and stirring shared only 2% to 11%. It was interesting to note that the fixed bed drying systems had the less power consumption because the grain kept staying on bed and it is not necessary to move them while drying, and that the fixed bed drying systems did have even lower rate of heat consumption than mixed flow heated air grain bin drying systems.

The solar barn grain dryer belonged to fixed bed drying system, it consumed the equivalent heat with fixed bed drying systems. All the heat was from solar radiation and its cost is free. In experiment, the average cost of electricity and labor for solar barn dryer designed by the authors was only ¥0.07 - 0.11/t.1% H_2O.

CONCLUSION

From experiments and analysis on energy consumption of grain drying systems, we may draw out the following conclusion:

1. Grain drying is a very huge energy consumption processing.
2. Fixed bed drying systems do have less energy consumption than other systems. The most energy consumed drying systems lie on heated air spraying and fluidized bed air flow drying systems.
3. Coal is preferable commodity fuel in China for grain drying systems because it is plenty and cheaper than diesel fuel and electricity.
4. Solar energy should be used and developed in China and developing countries for energy saving on grain drying systems. It is necessary to improve the sunny ground drying method and to design high efficiency solar collector for air heating to use on grain drying systems. The solar barn dryer designed by the authors costs the lest in experiments.

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TABLE

Table 1. Experimental results on energy analysis for different grain drying systems

No	Type of grain drying	Variety of grain	Mo Me (%)	Fuel or energy used medium	Rate of drying production (t/h.1%)	Average heat consumption (KJ/kg)	Average power consumption (KJ/kg)	Average energy consumption (KJ/kg)	Water removed per hr. (kg/h)	Average cost in drying (¥/t%)
1.	Fixed bed	Wheat	18.5 / 13.5	Coal Heated air	3.63	5686.4	174.4	5860.8	41.91	0.22
		Rice	27.1 / 13.5		2.17	10432.7	334.6	10767.3	25.4	0.44
2.	Fixed bed	Wheat	19.0 / 13.5	Coal flue gas	2.42	6566.9	214.8	6771.7	27.9	0.32
		Rice	24.6 / 13.5		3.36	8006.8	151.6	8158.4	38.8	0.30
3.	Fixed bed	Wheat	18.0 / 13.5	Diesel fuel	2.16	4484.9	314.9	4799.8	25.3	0.51
		Rice	19.1 / 13.5		2.36	6994.7	292.2	7286.9	27.5	0.77
4.	Heated air spray	Rice	18.5 / 13.5	Coal Cas	4.01	13517.5	1139.4	14656.9	47.3	0.60
5.	Low temp mixed flow tower	Wheat	20.4 / 13.5	Coal furnace flue gas	2.18	9065.4	493.6	9559.0	24.5	0.34
		Rice	22.8 / 13.5		3.09	10023.0	525.7	10548.7	35.9	0.40
6.	Infra red radiation	Wheat	23.8 / 13.5	Electricity	1.13	5090.2	505.5	5595.7	13.0	1.08
		Rice	22.9 / 13.5		1.25	5125.0	347.3	5472.3	14.7	1.20
7.	Fluidized bed	Wheat	19.3 / 13.5	Coal furnace flue gas	1.02	7950.9	269.4	8220.3	10.68	0.94
		Rice	25.8 / 13.5		0.61	13062.8	320.6	13383.4	37.66	1.02
8.	Solar radiation fixed bed	Rice	25.7 / 13.5	Solar energy	1.03	5870.0	538.6	6408.6	11.8	0.11
		Rice	22.7 / 13.5		2.21	5723.0	291.2	6014.2	25.6	0.07