

Energy efficiency measurements in grain drying

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Abstract. Grain drying is one of the most energy consuming processes on farms. It has also a lot of potential for energy savings. Grain drying can be divided into different processes: heat generation, heat transport, and drying.

Heat generation is done with furnaces and these are either air or water heating furnaces. The easiest way to determine furnace efficiency is to measure its burning efficiency. This can be done with good accuracy with portable flue gas analyzers.

The hot pipes are not normally heat insulated causing heat losses during hot air transfer to the drying silos. Pipe heat losses depend on pipe area, temperature difference between the hot air, and the surroundings. Heat losses from pipes can be measured easily with heat flow sensors.

Drying process energy efficiency depends on the dryer heat losses, which are caused by the hot dryer surfaces; furthermore, it also depends on the design of the dryer, the air distribution inside the dryer, and on air volume flow amount. By measuring the air conditions before and after the drying process and the air flow through the dryer we can calculate the drying parameters and the dryer efficiency.

Key words: Energy, drying.

INTRODUCTION

Grain drying is one of the most energy consuming processes on farms. If the grain is wet as it can be after a rainy harvesting period, drying can consume as much energy as all field works together. Grain drying has a lot of potential in energy savings. Savings could be more than 50% with proper process control and heat recovery systems.

Grain drying can be divided into different processes: heat generation, heat transport, and drying. Heat generation is done with furnaces which are either air or water heating furnaces. Air heating furnaces are more common for instance in Finland and Estonia because of their simplicity and easy maintenance. Efficiencies on both types are about the same. When direct air heating furnaces are used, hot air is transferred with air pipes and ducts from the furnace to the dryer. Because of the fire safety regulations the furnace is situated in fire isolated room with some distance from the dryer. In good cases the pipes are only a couple of meters long but they can also be about 10m long. The pipes are not normally isolated making heat losses to the surrounding and decreasing the energy efficiency.

In furnaces maintenance is important. During burning the inner parts of furnace will be covered by soot, which decreases the heat flow through the heat exchanger. For instance 3mm thick soot can reduce the efficiency about 13% (Bohm et al., 1989). It is also important that nozzles are in good conditions in oil burners and the burning air amount is adjusted correctly. In correct adjustments flue gas analyzers are needed. It can easily lead to 5-10% losses if the air amount is incorrectly adjusted.

The dryers are normally mixed flow dryers with separate hot and cold air channels. The structures of the dryers are quite alike. Drying process energy efficiency depends on the dryer heat losses, which are caused by the hot dryer surfaces and it also depends on the design of the dryer and the air distribution inside the dryer and also on air volume flow amount.

Piltti (1979) used insulation material on the hot surfaces of the dryer and got a 10% decrease in energy consumption. At the same time the capacity of the dryer was also improved. The same kinds of results were obtained by Peltola (1985). In Sweden Aas (ref. Bohm et al., 1989) measured over 30% heat losses in air dryer air ducts.

Peltola (1985) and Suomi et al. (2003) have measured specific energy consumptions in grain drying. The specific energy consumption was according to their studies 103-164g of burning oil per evaporated water kilogram. This corresponds to 4.4-7.1 MJ per evaporated water kilogram. These figures include heat generation, transport, and drying process.

The authors have started to develop energy efficiency measurements for grain dryers. The methods are chosen so that the instrumentation could be easily moved during the drying season from one dryer to another.

MATERIALS AND METHODS

Furnace efficiency

The easiest way to determine furnace efficiency is to measure its burning efficiency. This can be done with good accuracy with portable flue gas analyzers. By measuring the flue gas CO₂ and CO content and temperature the analyzer shows directly the burning efficiency. This kind of measurement is based on flue gas loss measurements. Normally the fuel needs more air than it is theoretically needed for burning. The necessary excess air is expressed by air ratio, which is the ratio of air amount needed for clean burning divided by the theoretical air need. Normally air ratios are for gas burning 1.05-1.1, for oil burning 1.1-1.2, for wood chip burning 1.2-1.5 and for firewood burning 1.5-2.0. Only oxygen is needed for burning; air nitrogen flows through the furnace which results in heat losses. If the furnace structure and air mixing in the burning gases is poor, also unburned fuel can be found in the flue gases. CO content shows the amount of unburned gases in analyzers. Besides CO also unburned hydro carbons can be found in the flue gases. The total flue gas loss is shown in the equation (1).

$$Q_{tot} = Q_{heatloss} + Q_{inburned} \quad (1)$$

Q_{tot} - Total heat loss of flue gases;

$Q_{heat loss}$ - Heat loss due to flue gas heat content;

$Q_{unburned}$ - Heat loss due to unburned fuel in flue gas.

In oil furnaces the heat loss due to flue gas heat content can be calculated with equation (2) (Vuorelainen, 1980). As can be seen from equation (2), flue gas CO₂ and flue gas temperature have an effect on burning efficiency. The theoretical CO₂ content changes with the fuel. It is normally between 12 and 20%. The burning air distribution and amount in the furnace affects the CO₂ content. The temperature of flue gases is controlled by the size of the furnace heat exchanger. The burning efficiency can be optimized by adjusting the burning air amount and distribution and by keeping the flue gas temperature low. The latter can be controlled with the proper size of heat exchanger but also with the fuel feeding amount.

$$Q_{oil} = \left(0.006 + \frac{0.479}{CO_2} \right) (T_f - T_a) \quad (2)$$

Q_{oil} - Heat loss due to flue gas heat content in oil burning;
 CO_2 - Carbon dioxide content of flue gases;
 T_f - Temperature of flue gases;
 T_a - Temperature of burning air.

Fuel gas analyzers have normally the burning efficiency equations built into. By choosing the right fuel and analyzing the flue gases the analyzer shows directly the efficiency. Telegan Sprint V 4 analyzer was used in our tests. The analyzer measures oxygen, carbon monoxide, nitrogen monoxide, and flue gas temperature. It calculates from these carbon dioxide content and burning efficiency. The inaccuracy of carbon dioxide figure is $\pm 0.2\%$, carbon monoxide $\pm 5\%$ and temperature $\pm 1^\circ\text{C}$.

Heat losses in hot air flow

From air heating furnaces hot air is transferred to the dryer by air pipes or ducts. The pipes are not normally heat insulated causing heat losses to the surroundings. Pipe or duct heat losses depend on their area, temperature difference between the hot air and the surroundings.

Heat losses can be measured with heat flow sensors. Ahlborn FQA017C heat flow sensor was used in the tests. It is attached to the pipe surface and the instrument shows heat flow from the hot surface to the surroundings. The inaccuracy of the sensor is according to the manufacturer 5%.

Dryer efficiency

Figure 1 shows the changes in air values during the drying process. The process starts at point 1, which are the intake air conditions before the dryer furnace. When the air is heated we move to point 2. In point 1 the enthalpy of the intake air was 37.9kJ kg^{-1} . After heating the enthalpy is 94.1kJ kg^{-1} . The furnace has increased the enthalpy 56.2kJ kg^{-1} . When the air flows through the dryer it engages moisture from the grain, which means that the specific humidity increases and the temperature decreases. If the process continues without heat losses (adiabatic process), then we end up in point 3. The specific humidity at point 3 is 25g of water in every dry kilogram of air. In point 2 it was $9\text{gH}_2\text{O kg}^{-1}$ dry air. The water amount in the air has increased $16\text{gH}_2\text{O kg}^{-1}$ dry air. In reality there are heat losses in the dryer surfaces and also a part

of the air can leak from the dryer. The exhaust air relative humidity is normally lower than theoretical 100%. Point 4 is an example where the exhaust air condition can be at the exhaust of the dryer.

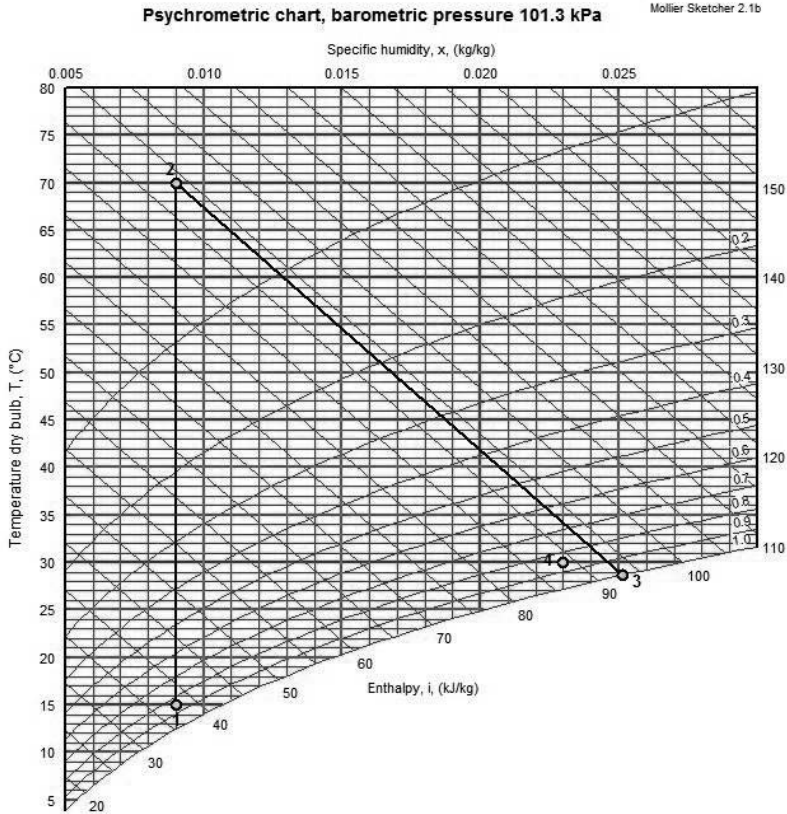


Figure 1. Example drying process (software 4 Product).

Figure 2 shows the measurements needed for the drying process measurements. By measuring the air conditions before and after the process and the air flow through the dryer we can calculate the drying parameters. The grain dryer at the University of Helsinki was instrumented according to Table 1. The data was collected with the Agilent 34970 data logger and the results were calculated with Matlab program.

Heat flow power to the dryer can be calculated with equation (3). In the equation the temperature difference between the furnace intake and dryer intake (input) are used and with this the air pipe heat losses can be neglected.

$$P = c_a \Delta T q_m \tag{3}$$

P - Heat power;

c_a - Specific heat value of air, 1.0 kJ/(kgK);

ΔT - Temperature difference between furnace intake and dryer intake;

q_m - air mass flow.

Table 1. Sensor at the dryer.

Measuring point	Sensor
Furnace air intake	K-type thermocouple and Honeywell HIH 4000 humidity sensor at the blower intake
Dryer intake	K-type thermocouple and Halton MSD 630 air flow sensor
Dryer air exhaust	K-type thermocouple and Honeywell HIH 4000 humidity sensor at the exhaust pipe

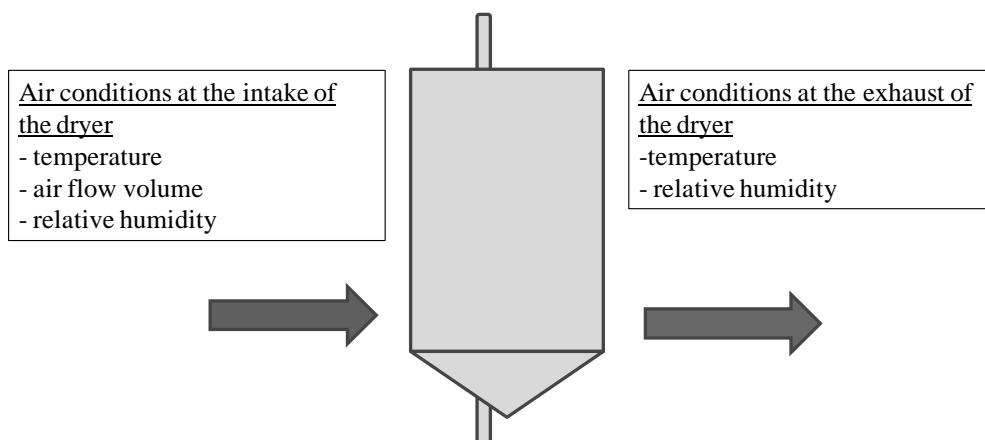


Figure 2. Principle of drying process measurements.

The losses of the process can be calculated from the enthalpy figures of the intake and exhaust air, equation (4).

$$P_{hl} = (i_{in} - i_{out})q_m \quad (4)$$

P_{hl} - Heat loss in the dryer;

i_{in} - Air enthalpy at the dryer intake;

q_m - air mass flow.

The specific consumption of the dryer can be calculated by integrating the energy use and by calculating the moisture removal amount, equation (5). Specific energy consumption depends on the dryer efficiency, grain, and somewhat also on grain initial moisture content. The grain moisture near the storing water content needs more energy because the moisture flow from the grain center to the surface slows down.

$$E_{sd} = \frac{E_d}{m_w} \quad (5)$$

E_{sd} - Specific energy consumption of drying;

E_d - Energy consumption of drying air;

m_w - Removed water amount from the grain during drying.

RESULTS

Normally hot air furnace burning efficiencies are over 80% and the best ones have about 90% burning efficiencies. Table 2 shows results of grain dryer measurements. As can be seen from the results the burning efficiencies have been high. In oil and gas burners when the burner is properly adjusted and the nozzles are in a good condition the burning efficiencies are high.

Table 2. Results of furnace flue gas measurements.

Furnace	Fuel	CO ppm	CO ₂ %	Flue gas Temp. °C	Burning efficiency %
Heating furnace	Oil	303	12.1	122	95
Dryer furnace 1	Oil	0	12.0	254	89
Dryer furnace 2	Oil	18	10.3	241	88
Dryer furnace 2	Natural gas	0	9.3	200	91

The air pipe heat losses were measured at the University of Helsinki grain dryer. The pipe surface temperatures were 50-60°C when the ambient temperature was 18°C and the air temperature inside the pipe was 69°C. The heat flow from the pipe surface to the surrounding was 300 500W m⁻² depending on the measurement place. The pipe diameter was 0.63m and length was 8m. The surface area of the pipe was 15.8m² causing an average heat loss of 6.5 kW. The heat power of the furnace was 160kW, so the heat loss of the pipe was 4.1%.

Figure 3 shows a typical drying process. At the beginning the heat losses are high due to the warming up of the dryer structures and grain inside the dryer. After warming up period the heat loss has been quite constant, according to Figure 3 about 15 kW.

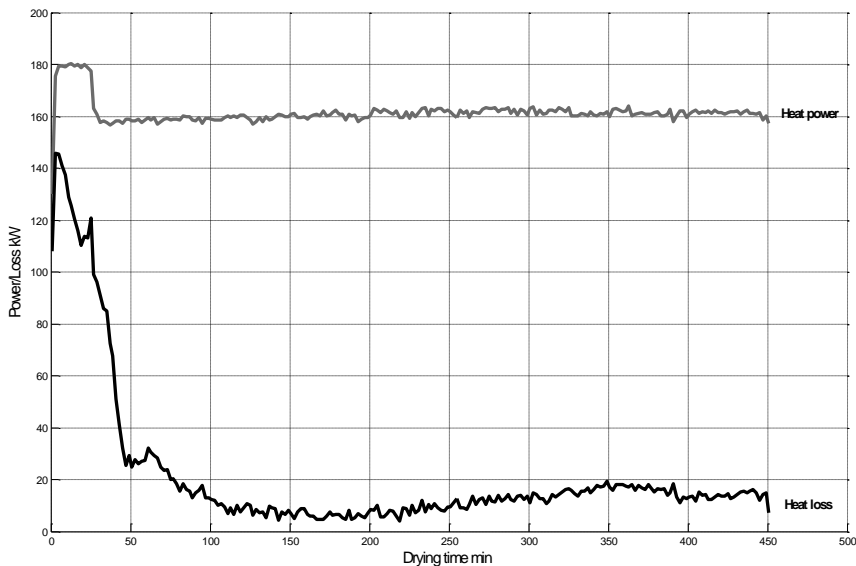


Figure 3. Example of a test result, red = heat power, black = heat loss.

Table 3 shows the figures calculated from the drying process.

The accessory equipments, elevator and blower, are normally operated by electricity and their energy consumption is low compared to the whole energy consumption. Their good maintenance will insure an energy efficient use.

Table 3. Example of measured energy consumption during drying.

Water removed during the process	836kg
Mean water removal speed	111 kg h ⁻¹
Heat energy used during the process	1216 kWh
Specific energy consumption of the process	1.5 kWh kg ⁻¹ removed water kg 5.2 MJ kg ⁻¹ removed water kg

CONCLUSIONS

Grain dryer efficiency measurements can be divided into three different parts, furnace, heat transfer and drying process. With methods represented in this study these parts can be measured so that the for instance the reason for poor efficiency can be shown. This measurement method will be utilized in the coming grain dryer efficiency measurements.

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