COLD PRESERVATION OF GRAIN

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Self-heating is doubtlessly the main reason for the loss of harvest-fresh grain. During colder seasons of the year, in northern regions, we encounter fewer problems in grain storage than in the hot seasons during and immediately after the harvest. The question is therefore asked why not transfer favourable winter conditions to the summer by means of cold storage of grain? The grain kernel offers the optimal conditions for being cooled in the bulk due to its structure, surface and physical properties (e.g. poor heat conduction).

Conditioned air (cold and relatively dry) is passed through silos and warehouses of any size. Normally, one-time cooling is sufficient for several months of storage and energy costs are low. SULZER ESCHER WYSS has 25 years of experience in the field of cold preservation of grain. Their grain cooling units (GRANIFRIGOR) are employed in more than 50 countries and are working successfully even under extreme climatic conditions. In the early 1960s cooling was applied mainly as a buffer storage of wet grain up to the moment drying could be started. Today, the trend is to cool dry-harvested grain in order to protect the product against insect activities. In general refrigeration is applied to agricultural products such as grain, oleaginous seeds, pellets, etc. In countries with extreme climatic conditions, ventilation with simple fans and reconditioned ambient air is often used. Ventilation prevents an extreme temperature rise, but low temperatures, necessary to protect stored products against harmful insects and to achieve optimum preservation of the grain quality cannot be obtained with this system in warmer regions. The most natural system of cold preservation with cooler and relatively dry air via cooling units has proved best to reduce considerably after-harvest losses. The question: why cold preservation, at what time and how to apply refrigeration is explained hereafter.

Why do we cool grain?

Reduction of the dry matter losses due to respiration of the grain

The grain kernel continues to live after the harvest and it breathes. Oxygen is consumed during respiration and carbohydrates are converted into carbon dioxide and water, and heat is generated. Loss of dry matter and consequently loss in weight result from this respiration process. Heat generation and thus respiration intensity depend on the moisture content (m.c.) of the stored grain and its temperature.

Fig. 1 shows the heat development in kcal/h and kg dry matter in dependence of the grain m.c. and temperature (Bauder 1969). This figure shows that the heat development with grain stored at 15% m.c. and 24.5 °C is about 6 times higher than with grain stored at the same m.c. but at 12.5 °C storage temperature.
Table 1 shows the reduction of dry matter losses with cold storage, where a mean grain price of US$ 160,--/ton is taken as basis. Cold storage of grain reduces the dry matter losses by approximately 80 to 90%.
Table 1: Dry matter losses due to respiration of the grain (after Jouin, 1964)

<table>
<thead>
<tr>
<th>Storage quantity</th>
<th>1000 t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain moisture</td>
<td>15 %</td>
</tr>
<tr>
<td>Storage time</td>
<td>1 month</td>
</tr>
<tr>
<td>Price of grain</td>
<td>160 US$ per t</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Losses</th>
<th>Value US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>(%)</td>
<td>t</td>
</tr>
<tr>
<td>25</td>
<td>0,12</td>
<td>1,2</td>
</tr>
<tr>
<td>35</td>
<td>0,54</td>
<td>5,4</td>
</tr>
<tr>
<td>10</td>
<td>0,02</td>
<td>0,2</td>
</tr>
</tbody>
</table>

With cooled grain the dry matter losses caused by respiration are reduced by 80-90 %.

Saving of drying costs

To achieve adequate storage conditions it is necessary to dry the moist grain, usually by means of fuel heated driers, or similar installations. Each cooling step has also a drying effect of an average of 0.5 to 0.8 % for about each 10 °C of cooling (e.g. from 20 °C to 10 °C) at an initial grain m.c. of approximately 16 %. This drying effect derived from cooling increases the higher the initial m.c. and temperature and it is less pronounced with dry grain (15 % m.c. and less ).

Drying effect by cooling is negligible with approx. 14 % m.c. of the grain. The combination of drying and cooling allows storage of grain with m.c.s. about 0.5 to 1.5 % higher than with common storage methods. The excess m.c. is removed during the cooling process. Energy savings for drying amount to approx. 20 to 25 %. Cold humid grain is stored safer than dry grain at high temperatures.

Avoiding weight and quality losses due to insect activity and microfloral growth

Originally, in the early sixties, grain cooling was developed for buffer storage of moist freshly harvested grain waiting to go through the drier. Nowadays more dry than moist grain is being cooled, simply for protection against insect activity and to prevent their development. The most important stored product insects are shown in Fig. 2.

Their lower threshold temperatures for adequate development (temperature at which the cycle from ovi position to full development takes about 100 days) is in the range of 17 °C to 21 °C. Insect activity and development is stopped at a temperature of approximately 13 °C. The insects fall into a state of dormancy and are no longer active. Therefore, cooling of grain to 10 °C is certainly a temperature which prevents insect activity. Cooled grain requires no chemical treatment. For example in Southern Italy very dry hard wheat coming from the fields with a m.c. of 8 to 10 % is cooled for protection from insects, no chemical treatments required, and the results are excellent. Storage of warm grain favours insect reproduction. Development of storage fungi and mycotoxins - the best known is aflatoxin - is favoured by high temperatures.

Mycotoxins in fodder can lead to severe diseases and to death of animals fed with infected products and can also be traced in the meat. Microfloral growth is accompanied...
by respiration and further contributes to the heat development mentioned before. Cooling does not kill fungi, but their development is prevented in most cases as they favour warm and moist grain.

**Fig. 2:** Development of the most important cereal-damaging pests as a function of the ambient temperature

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Elimination of grain movement with accompanying losses

Normal storage without cooling requires moving of the grain from one bin to another several times. Depending on the type of storage and conveying equipment, the abrasion losses for a one time moving are approximately 0.3 % and higher. In addition energy costs required to move the grain are estimated to be in the range of 1.0 to 3.0 kWh/ton of grain.

Cooled grain does not need to be moved. Once the grain is cooled it conserves its low temperature for a long period of time since the heat transfer capacity of grain is very
low compared with, for example, the heat transfer capacity of steel which is about 300 times higher than that of grain. Therefore, it is clear that grain has an excellent insulating property namely it has a self-insulating capacity. For this reason in uncooled grain heat developed in pockets cannot be dispersed in a short time by natural heat diffusion. Table 2 shows the range of storage time until the first re-cooling becomes necessary.

Table 2: Safe storage time of grain (initially cooled to 10 °C) at different moisture contents until the next re-cooling

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Storage time</th>
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<tbody>
<tr>
<td>12.5 - 15.5</td>
<td>8 - 12 months</td>
</tr>
<tr>
<td>15.5 - 17.5</td>
<td>6 - 10 months</td>
</tr>
<tr>
<td>17.5 - 18.5</td>
<td>4 - 6 months</td>
</tr>
<tr>
<td>18.5 - 20.0</td>
<td>1 - 4 months</td>
</tr>
<tr>
<td>20.0 - 23.0</td>
<td>2 - 8 weeks</td>
</tr>
<tr>
<td>23.0 - 25.5</td>
<td>1 - 2 weeks</td>
</tr>
<tr>
<td>over 30.0</td>
<td>apply continuous cooling</td>
</tr>
</tbody>
</table>

Avoiding condensation in steel silos

In Fig. 3 an example is given for wheat stored without cooling with 15 to 16 % m.c., storage temperature about 20 °C. According to the absorption isotherms the relative humidity (r.h.) of the air between the grain kernels is 70 to 75 %. If the ambient air temperature now drops to approx. +3 °C, the area around the walls inside the bin also cools down. The dewpoint is reached and water condensation at the inside silo wall occurs. Grain kernels in this area absorb the excess of water and thus permit microflora activity. The rotten grain sticks to the wall of the silo forming a caked layer. This damaged grain poses a problem at discharge, especially with large silos where it is located on surfaces difficult to clean. Also, it is an important source for microflora and insect activity. Cooling of the silo down to 10 °C to 12 °C avoids condensation since the temperature difference from the grain to the silo wall is reduced (Brunner 1980). Special information on cold storage in steel silos is available.
Avoiding breakage of pellets

Pellets having a large diameter are often discharged from the pellet cooler before their core cools. The heat in the core moves to the outside of the pellet and this leads to physical tensions, cracks, breakage and disintegration of the pellets. Additional cooling of the pellets in the storage facility makes the pellets stronger and less breakage and abrasion is obtained. The flow properties at discharge and transport are also improved.

Maintaining the quality of oleaginous products by cooling

Heat development is intensified due to oxidation of products such as rape seeds, sunflower seeds, peanuts, maize, soybeans with high oil and fat content. The consequences are deterioration of quality and caking of the product. There is also a rapid increase of free fatty acids leading to further quality and quantity losses. Processing of oleaginous products often requires a m.c. of the product higher than permissible for safe storage (e.g. soybeans). Cold storage generally permits storage at higher m.c. by approx. 1 to 3 % than conventional storage.

When do we cool grain?

Drying is superfluous in some years with a very dry harvest and also in countries having a hot dry climate (this does not apply for oleaginous products). However, to overcome the above mentioned adverse conditions, it is recommended to apply cooling every
year. In years with wet harvests cooling increases the safe storage capacities and in years
with dry harvests it permits protection from insects.

It is very important to start cooling the harvested product immediately when it is
stored, i.e. when high ambient temperatures still prevail to avoid weight losses, insect
activity, heating of the product and the consequent quality losses. This can be achieved
using grain coolers. Aeration of grain with simple fans and taking advantage of ambient
air will at best avoid considerable temperature increase in the grain pile, but the cooling ef-
fect will be limited to the available ambient temperature. This in addition to the problems
of specific dangers involved such as humidification of the product and rotting due to the
uncontrolled use of ventilation fans without cooling units.

How do we cool grain?

Fig. 4 shows the process of grain cooling, it is relevant for both silos and ware-
houses. The ambient air is drawn into the cooling unit (GRANIFRIGOR) by a high
pressure fan and its temperature is reduced in the cooling unit. The cold air, having a high
r.h., is reheated by the HYGROTHERM device, the r.h. is lowered and is thus adapted
to the m.c. of the product. This conditioned air obtained in the cooling units is blown
into the grain bulk through a simple air distribution system installed at the bottom of the
silo. The warm exhaust air is released from the top of the grain bulk. Cooling with
GRANIFRIGOR is entirely independent of weather conditions due to its HYGRO-
THERM device which permits the control of r.h. of the cooled air. Even when applying
cooling in rainy or foggy weather, there is no risk of rehumidification of the commodity.
Conditioning of the air in the chiller is extremely important to avoid hazardous rehumi-
dification around the air distribution systems and in the grain bulk itself (Donahaye et al.,
1973).
Cooling in upright silos

Cooling ducts as shown in Fig. 5 have given very good results. The resistance of the grain bulk to airflow - amongst other factors - depends on the surface area of the bin, the height of the bulk and the stored product.
Fig. 5: Cooling ducts for air distribution in silo bins for GRANIFRIGOR KK 140.

Fig. 6 gives the permissible height for the various products in relation to the surface area of the bin. The values shown in Fig. 6 are relevant for use with GRANIFRIGOR type KK 140. If, e.g. the surface at the base of a single bin is too small at a certain bulk height, it is possible to connect several silos simultaneously. Silo bins up to a bulk height of 60 m can be cooled without any problems.
Cooling a warehouse

In warehouses it is advisable to use cooling ducts made of half-round perforated galvanized steel plates which are placed on the ground. Cooling areas as shown in Fig. 7 are separated.
It is very important that the spacing from one duct to another is equal to or smaller than the bulk height in order to obtain uniform air distribution. It is recommended to consult an expert to determine the required cooling capacity and air distribution system for a silo or a warehouse. For new storage facilities the same consultation is recommended at the planning phase.

There are 5 GRANIFRIGOR models ranging from 30 to 550 tons grain cooling capacity in 24 hours. More than 30 million tons of grain per year and per harvest season are being cooled with GRANIFRIGOR units. Cooling offers the most natural preservation method and this storage system promises to gain more ground, also for ecological reasons.

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