



Treatment of grains through conservation cooling with the GRANIFRIGOR™

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1 GRANIFRIGOR™ grain cooling in steel silos

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Grain is one of our most vital staple foods. It is farmed and harvested with great care. According to the Food and Agriculture Organisation of the United Nations (FAO), the annual spoilage of the grain harvested worldwide is over 20%. The major part of this loss results from insect activity and mildew growth. Using the GRANIFRIGOR™ conservation cooling process effectively prevents these losses. Many million tonnes of grain, oil seed, rice, maize, and other cereals are conserved worldwide using this technology (fig. 1).

Why conservation cooling

Losses in freshly harvested grain are caused by the grain's cellular respiration and its consequent spontaneous heating. This process is dependent on the grain's moisture content and temperature. As the grain's temperature and moisture increase, its respiration becomes more intensive. The consequences of spontaneous heating are loss of substance and the propagation of insects and mildew. In temperate climate zones, it is well-known that during the cooler seasons there is appreciably less substance loss in grain storage than during the summer months. Conservation cooling means that winter climate conditions are brought forward to the post-harvest period, and are thus available immediately after the harvest. In tropical climates, the risk of spoilage through hot and humid climate conditions is particularly high. Thus conservation cooling is of especial significance here.

On account of its structure and surface properties and also low heat conduc-

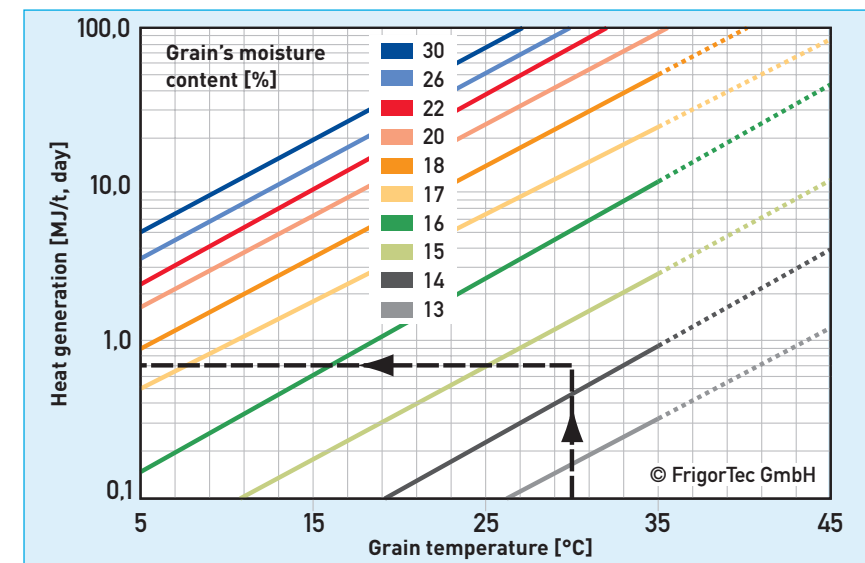
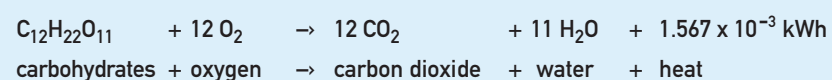
tance, grain offers the ideal conditions for the cooling process. Once grain has been cooled, it remains cold over a long period. Conservation cooling with the GRANIFRIGOR™ process has many advantages (ref. 1). The following text gives a detailed description of the benefits for the user.

Reduction of dry substance loss

The development process of grain attains peak maturity at harvest time. But grain goes on living after the harvest: it breathes. In cellular respiration, oxygen is absorbed and carbohydrates are then converted into carbon dioxide, water and heat. The consequence is loss of dry substance. The totals formula of the chemical process is illustrated below.

Fig. 2 shows the heat generation dependent on the grain's temperature and moisture content. In practice, this can be used to determine the dry substance loss of the stored crop.

The grain respiration – totals formula of the chemical process:



2 Heat generation during grain storage modified according to Jouin (ref. 2)

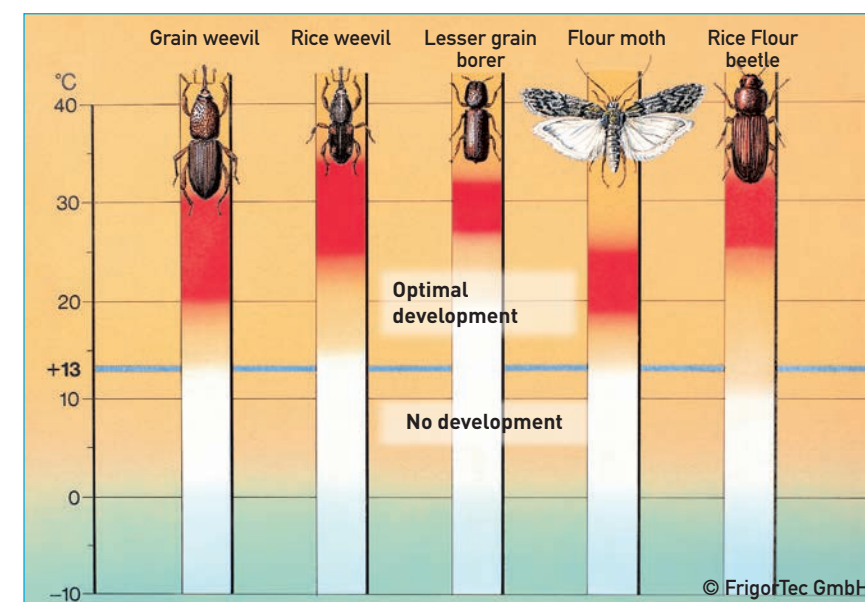
Sample calculation of respiration loss – dry substance loss

| Datum | | | |
|---|--------------------------|------------------------|---------------------------------|
| | Grain type | Wheat | |
| | Grain`s moisture content | 14.5% | |
| | Grain temperature | 30 °C * | |
| | Grain price | 200 EUR/t | |
| | Storage period | 4 months | |
| | Storage quantity | 10,000 t | |
| Formula | | | |
| Dry substance loss (t) = $\frac{\text{heat generation [MJ/t, day]} \times \text{storage period [day]} \times \text{storage quantity [t]}}{15,000 \text{ [MJ/t]}}$ | | | |
| Result | | | |
| | | Dry substance loss [t] | Loss/Cost [EUR] |
| | uncooled at 30 °C ** | 64 | 12.800 |
| | uncooled at 25 °C | 32 | 6,400 |
| | cooled at 10 °C | minimal (≤ 1) | 1.800 electricity consumption** |

* After drying or direct from the field in summer

** see fig. 2

*** Assuming: 4.5 kWh/t electricity consumption and 0.04 EUR/kWh electricity costs



3 Generation of relevant insect species dependent on temperature

Preventing weight and quality losses through insects

Originally, conservation cooling was developed for conserving moist grain, before drying. These days, however, more dry grain is cooled than moist – mainly to protect against feeding and proliferating insects. Fig. 3 shows some species of the most common insect pests and their optimal life and development conditions. Some pests prefer temperate climate zones, others find ideal conditions in tropical areas.

Losses through insect feeding can effectively cease by cooling the harvested crop to temperatures under 13 °C. If the temperatures are low enough, the insects go into diapause – hibernation – and cannot harm the stored crop.

But if insects find the optimal conditions of temperature and moisture, great losses occur through their feeding and excrement. The problem intensifies drastically, since insects reproduce dramatically in optimal conditions (fig. 4). Most beetle varieties have an extremely short developmental period. In ideal conditions, the grain weevil's generation cycle is already complete after 25 days.



Cooling without chemical protective measures

The chemical treatment of grain is today already subject to considerable official stipulations. Gassing involves high costs owing to the chemical substances used and the complicated and expensive procedure. Furthermore, it must be noted that in many countries the methyl bromide frequently used for gassing will be prohibited by the year 2005.

Prevention of mildew

Depending on climate, weather conditions, and crops rotation, an attack of fusaria fungi on the growing crops can occur regionally with varying intensity (ref. 4). Besides the considerable financial losses, there is also the risk of mycotoxin formation. Mycotoxins have a toxic effect on humans and animals. For instance, pigs are sensitive in reaction to deoxyvalenol DON or zearalenon ZEA. The consequences are loss of appetite, reduced growth and fertility disorders.

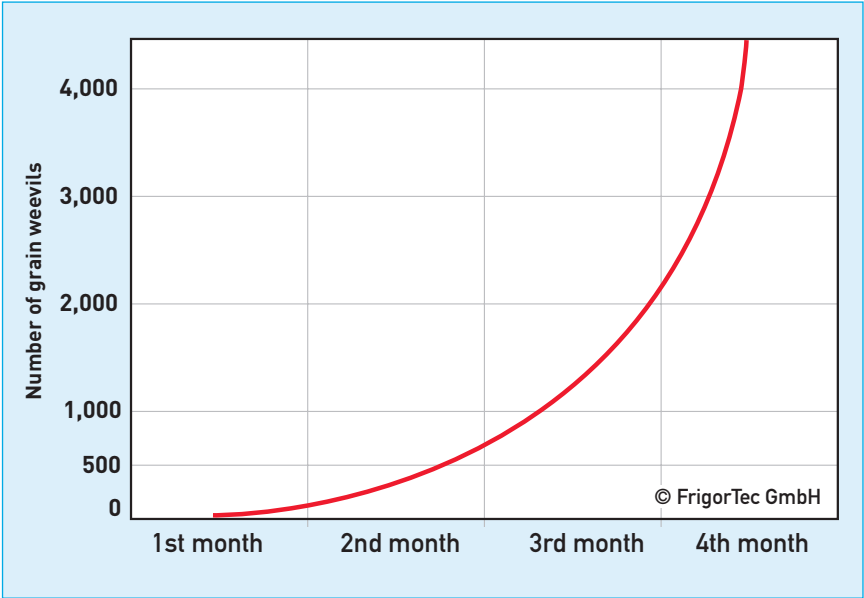
The development of mildew and its mycotoxins, e.g. aflatoxin, is supported among other things by heat. Cooling the grain with GRANIFRIGOR™ prevents this development (fig. 5).

Saving drying costs

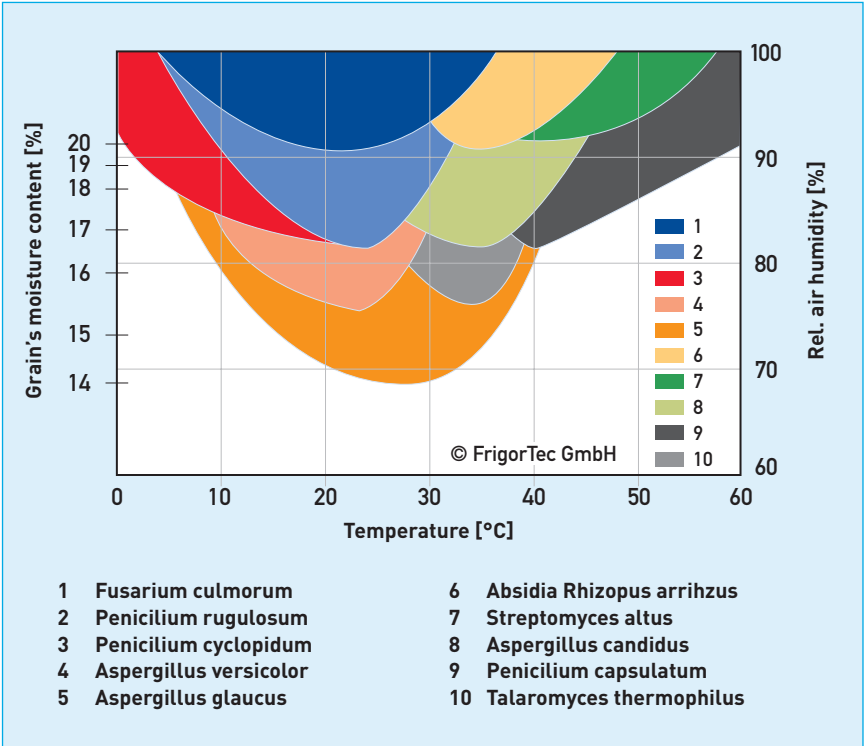
Depending on use, wheat that is harvested moist is dried to 14–16% moisture content, in Germany mainly to 15% (ref. 6). To do this, the ambient air is warmed in a special drying plant. This warm air extracts moisture from the grain and conveys it to the open air. The desired moisture content of maize, rice or oil seed is lower than of wheat.

Saving costs through conservation cooling is achieved through the following three conditions:

- Every cooling cycle produces an extra drying effect. This reduces the grain's moisture content by another 0.5–1.5% for each 20K cooling of the stored crop. For higher grain moisture levels (> 18% moisture), the extra drying effect can be greater, on the other



4 Proliferation of the grain weevil dependent on time in optimal conditions (ref. 3)



5 Generation of various organisms dependent on moisture and temperature (ref. 5)

hand, for dry grain (< 14% moisture) it is less.

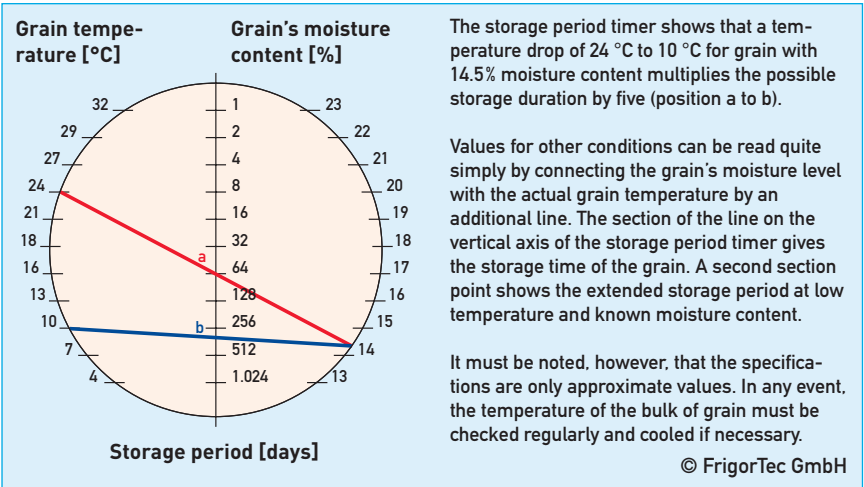
- The dwell time in the dryer can be shortened through suitable optimisation of drying and cooling processes, which saves energy and increases the drying capacity.
- Since there is less energy stressing the grain, the drying process is gentler. This means that fewer stress cracks occur.

Table 1: Storage periods for cooled grain in relation to climate zones and moisture content

| Moisture content [%] | Climate zone | temperate* [months] | tropics** [months] |
|----------------------|--------------|---------------------|--------------------|
| 12 – 15 | | 8 – 12 | 6 – 8 |
| 15 – 17 | | 6 – 10 | 3 – 5 |
| 17 – 19 | | 4 – 6 | 1 – 2 |
| 19 – 21 | | 1 – 4 | 0,5 – 1 |

* Primary cooling to 10 °C for Europe

** Primary cooling to 15 °C e.g. for Latin America and Asia



6 Storage period timer for grain

Table 2: Energy consumption for one cooling process of grain and oil seed

| Average temp. [°C] | 10 | 15 |
|-----------------------------|----------------|--------------------|
| Region | Europe | Latin America/Asia |
| Climate zone | Temperate zone | Tropics |
| Energy consumption in kWh/t | 2–4 | 6–8 |

No displacement costs

Conventional storage without cooling requires frequent grain displacement procedures. The intention is that by mixing the grain and thus exposing it to intensive air contact, heat zones can be eliminated. This always necessitates a free storage facility (silo compartment); moreover, every displacement procedure results in abrasion losses of around 0.03 % of the total quantity. On top of this, there is the energy needed for conveying equipment, which can be applied using around 1 to 3 kWh per ton of grain. GRANIFRIGOR™ cooled grain does not need displacing.

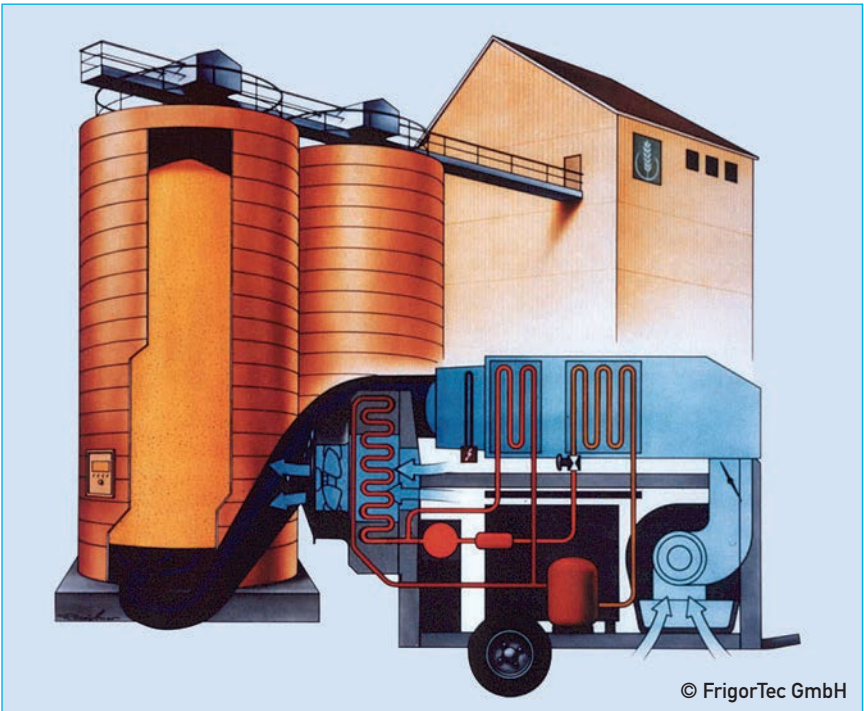
Cooled grain stays cold for a long period

A settled bulk of grain absorbs energy only very slowly, an effect deriving from the insulating effect of the air in the voids between the grains and the small contact surface of the grain. Thus, even when the outside temperature is cold, warm grain stays warm for a long time. The same effect, however, makes cooled grain remain cold over a long period. Table 1 lists the storage periods for cooled grain in relation to the moisture content. Fig. 6 shows the storage periods.

Energy consumption in conservation cooling

But the many advantages of conservation cooling also require certain investment resources. Apart from the investment involved in the cooling device, additional electricity is needed as drive energy. Energy consumption depends on the outside temperature, the humidity of the surrounding air, the grain's moisture content, and the grain temperature.

Table 2 shows the experienced values for energy consumption for one cooling process of grain and oil seed.



7 Process principle of the GRANIFRIGOR™ grain cooling device

The method

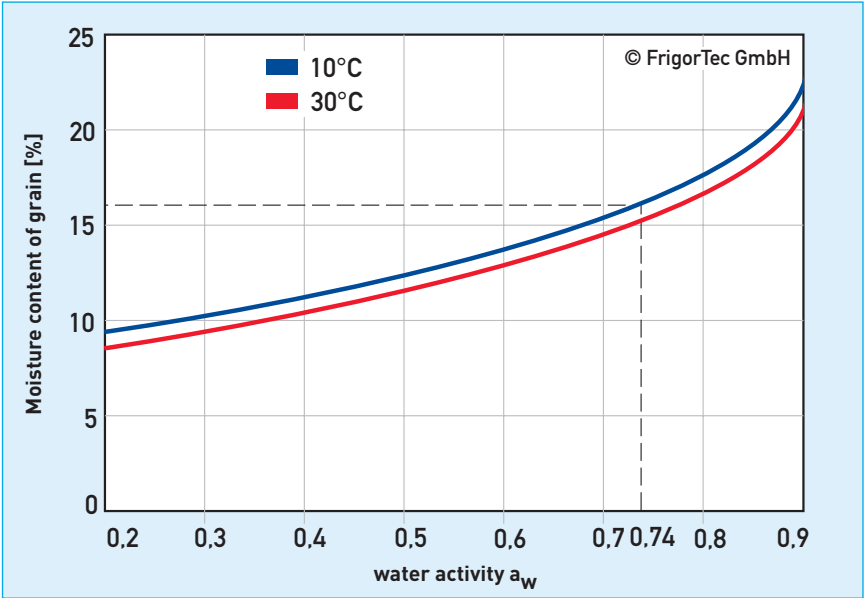
The fan of the GRANIFRIGOR™ grain cooler draws in the ambient air (fig. 7). This air is cooled by an air conditioner – the evaporator – to the desired temperature and is thereby dehumidified. Moisture is extracted. The downstream HYGROTHERM™ unit heats up the cold, moist air. This lowers the relative humidity. Since the HYGROTHERM™ heating unit uses energy from the refrigeration circuit, it involves no further energy costs. The air cooled and dried is fed through a hose in the ventilation system of the storage facility and is forced through the grain. This process can be employed in a warehouse or in a tower silo. The outgoing air is led outside via apertures, extracting absorbed heat and moisture from the grain.

Risks of ventilation with non-conditioned outside air

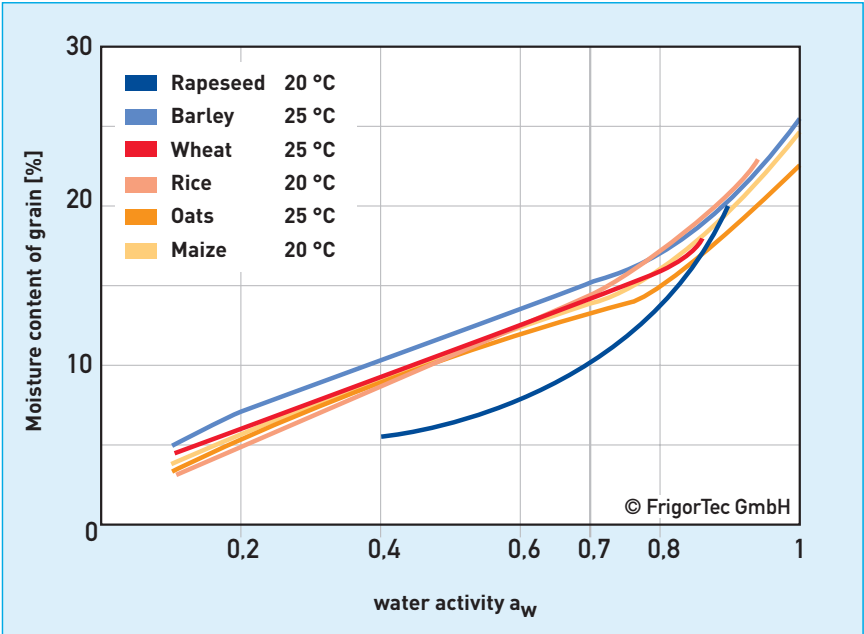
Depending on temperature, an equilibrium develops between the moisture content of the grain and the relative humidity of the ambient air. This dependency is defined by the absorption isotherms. Grain seeds are hygroscopic. If dry grain is exposed to humid air, then moisture develops. The grain spoils. Therefore ventilation with untreated ambient air is only permitted in certain weather conditions. The GRANIFRIGOR™ process operates independently of weather conditions. Even during rain or fog, the unit can be put into operation without the risk of humidification.

Moisture equilibrium of grain and air

The absorption isotherms of wheat at varying grain temperatures are shown in fig. 8. The registered example shows that when the crop's moisture level is 16%, the relative air humidity between the grains is around a_w 0.74. In this case, if air with a greater humidity level flowed in, it would generate moisture. This would perforce lead to spoilage of the stored crop. The moisture level would rise even more dramatically if the air temperature was in addition higher than the grain temperature.



8 Absorption isotherms of wheat at varying grain temperatures



9 Absorption isotherms of various grain types and rapeseed

So:

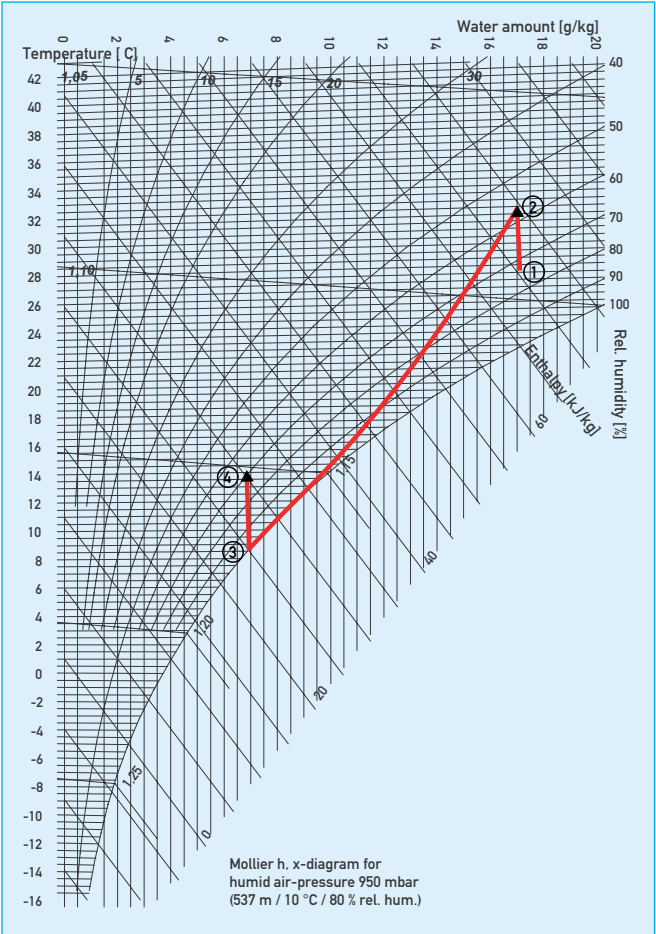
- Never introduce moist air into dry grain!
- Never introduce warm air into cooler grain!

This behaviour applies in the same way to all types of grain. Fig. 9 shows the absorption isotherms of several grain types.

Cooling and dehumidifying of the air with GRANIFRIGOR™

The air-cooling procedure is illustrated in the Mollier h-x diagram (fig. 10). The GRANIFRIGOR™ grain-cooler fan draws in the ambient air (fig. 10, point 1). The

ventilator heats the drawn-in air (fig. 10, point 2). This air is cooled by an air conditioner, the evaporator, to the desired temperature (fig. 10, point 3) and is thereby dehumidified. Moisture is extracted. Although the absolute moisture content drops, relative air humidity reaches almost 100%. For grain cooling, the following HYGROTHERM™ unit warms the cold, humid air again (fig. 10, point 4) to lower the relative humidity so that no moisture develops in the stored material. This renewed warming makes use of the energy from the cooling process; no further energy costs are incurred.



10 Principle of grain cooling based on the Mollier h, x-diagram (ref. 7)

Table 3: Criteria for the calculation of profitability of a GRANIFRIGOR™

| Criteria for the cooling | conventional | GRANIFRIGOR™'s benefits |
|---|-------------------|---|
| Dry substance loss (acc. Jouin) | high | low |
| Cooling device investment costs | – | depreciation |
| Energy consumption for cooling (averages) | – | 3 – 5 kWh/t (8 – 10 kWh/t in the tropics) |
| Energy consumption for drying | high | low, due to exploiting drying effect |
| Displacement/circulation | 0.03% loss | no |
| Energy consumption for circulation | yes | no |
| Chemical treatment | as required | no |
| Stress cracks in seeds | quality reduction | no |
| Quality/harvest freshness | drop in value | no drop |
| Oxidation for oleaginous products (soy beans, sesame, corn, rapeseed) | drop in value | no drop |
| Germination capacity of seeds and brewing barley | reduced | high |
| Rice yield (whole rice kernels) | low | high |
| Yellow discoloration of rice | quality reduction | no |

Optimal storage temperature

Grain should be cooled to below 13 °C immediately after going into storage. Insects go into diapause because of the cold environment. Their growth and proliferation ceases. Damage through insect feeding is prevented. Likewise, the development of mildew effectively ceases when the storage temperature is lowered.

Optimal profitability through the GRANIFRIGOR™ process

Using the GRANIFRIGOR™ grain-cooling method minimises dry substance losses and prevents loss of quality through insect feeding and the generation of mildew. The quality of the grain is conserved. Energy consumption for drying is reduced by the GRANIFRIGOR™ and the running time of the dryer is shortened. Moreover, no costs are incurred for chemical storage protection. A precise calculation of profitability will in most cases show an amortisation period of one to two years. Investing in a GRANIFRIGOR™ is therefore economical. The relevant criteria for calculating profitability are compiled in Table 3.

Operative range

Conservation cooling is just as feasible in a tower silo or in a warehouse. What matters is the expert management of air distribution. It is possible to cool all kinds of agricultural bulk produce with a GRANIFRIGOR™. These include wheat, brewing barley, rapeseed, maize, rice, paddy, soy beans, sunflower seed, peanuts, cotton seed, pellets, sorghum, sesame seed, linseed, legumes, potatoes, grass seed, cocoa beans, coffee beans, nuts, rye, spelt and many more.

Using conservation cooling

In view of the abundance of the various agricultural products, the most important uses will be described in brief.

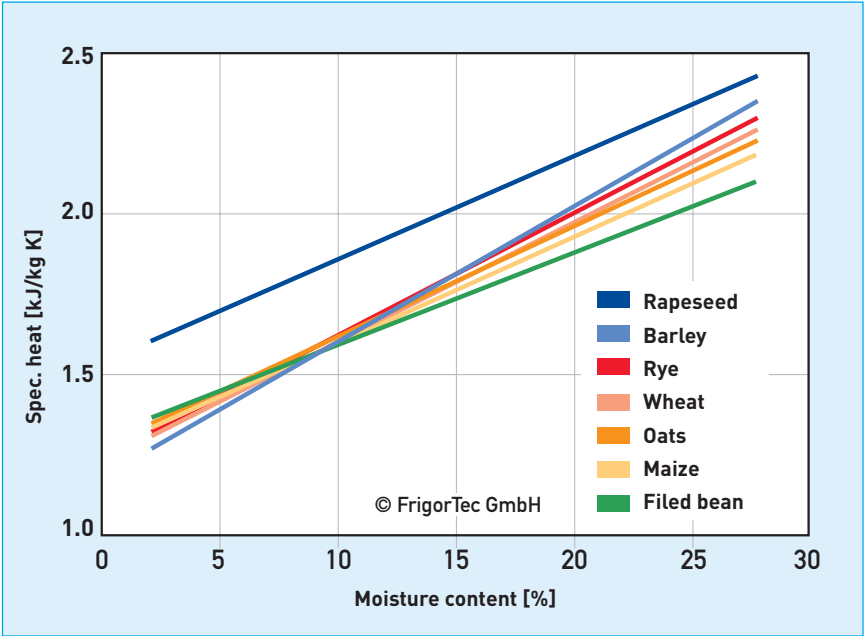
Rice/unpolished rice (paddy)

Rice is the major source of nourishment for many millions of people. 8,000 biologically different sorts of rice (ref. 8) are known world-wide. These are classified into long, medium and short. In common to them all is their sensitivity as a product. Rice should be dried in a particularly gentle manner – preferably in several stages. If the drying cycles are combined with the cooling process, it can save one – and frequently even three – drying cycles (ref. 9).

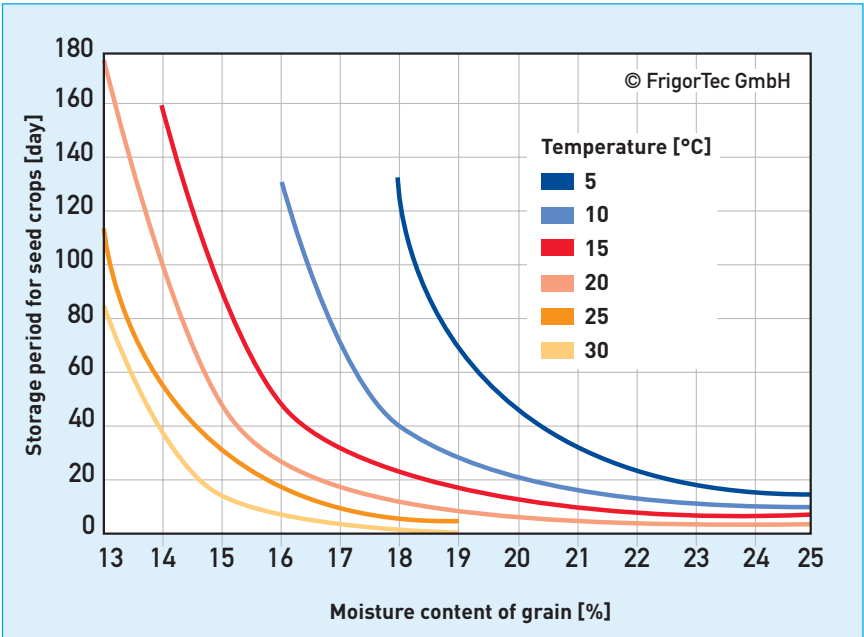
Besides the familiar advantages that have been described, conservation cooling means additional benefits for rice/paddy. Several studies in Central America and Asia have established conclusively that the yellow coloration of rice hardly ever occurs when it is cooled (ref. 10). Furthermore, cooled rice/paddy is less brittle. Conservation cooling yields around 3% more in quantity of head rice than without conservation cooling. Rice smells musty after a period of conventional storage. This does not apply to cold-stored rice. All these advantages present an important argument for the sustainment of quality and in the end for the level of the attainable price.

Rapeseed

The storage of rapeseed involves fundamental difficulties (ref. 11), even when moisture content is low (approx. 9%). Harvested rapeseed contains extensive amounts of pod and stem fragments, and also weed seeds. During threshing, the rapeseed can be slightly moistened by contact with moist vegetal parts; also, during harvesting, there is often contamination with microorganisms. Just one night's storage is sufficient for parts to warm up perceptibly, releasing the musty smell of microbiological conversion, a milieu that provides ideal conditions for mildew growth. This is why rapeseed is always cleaned as thoroughly as possible before storage. Nevertheless, since the possibility of mildew generation cannot be excluded by doing this, rapeseed should be cooled to 10 °C. This



11 Heat generation during rapeseed storage



12 Permissible storage period for seed crops acc. to Agena (ref. 13)

considerably reduces the germination count of the fungus. Rapeseed must maintain the quality of its oil throughout storage. With increasing storage temperature and moisture, oils split up and form free fatty acids. The water formed during the conversion and the heat released in the process must be conducted off without delay. This means that bulk rapeseed must be monitored and cooled. The bulk density of rapeseed is higher in comparison with that of wheat, for instance – because of the smaller seeds, which is why more air is lost in

the air flow through bulk rapeseed in comparison with other grain sorts. This is to be noted in the design of the cooling device.

Because of its higher lipid (fat) content, rapeseed can store less water than other grain sorts (ref. 12). The loss of dry substance in rapeseed during cellular respiration is only around 70% of the loss of grain; however, it generates around 33% more heat. Fig. 11 reveals that spontaneous heating is pre-programmed when dealing with

rapeseed. The specific heat generation is higher than for other grain sorts, therefore the storage temperature of rapeseed should lie clearly below 15 °C. If the rapeseed has an excess content of free fatty acids, which normally amount to 1%, problems occur when breaking the rapeseed. Free fatty acids are formed when rapeseed storage is too warm.

Oil seed

The generation of heat owing to oxidation processes in sunflower seed, peanuts, cotton seed, soy beans, rapeseed, maize and so forth, is intensified because of their oil and fat content. The consequences are a considerable loss of quality and agglomeration of the stored crop. Besides this, there are yet again losses in quality and weight through the increase in free fatty acids. Conservation cooling can maintain a 1–3% higher moisture content in comparison to conventional storage.

Seed/brewing barley

The maintenance of germinating quality is paramount with seed and brewing barley. Cooled seed crops with a moisture

content of 15–16% have a much higher average germination count than seed in very dry but warm storage. Fig. 12 shows the permissible storage period for seed crops dependent on temperature and moisture level. The reading is based on the original germinating capacity and is thus relevant for both seed crops and brewing barley. By punctually cooling the barley and/or seed to a protective temperature of around 10–12 °C, the possible storage period is extended considerably, thus shortening the germinating time.

Maize

Owing to its oil and fat content, maize tends to heat up rapidly, and the same applies when the maize is dried for safety reasons to 12–13% moisture content. This conventional procedure is exorbitant in energy and cost consumption, involves loss of quality and weight, and is not necessary for cooled maize. For example, the University of Hohenheim/Germany and the Michigan State University/USA proved that drying maize grains with a moisture content of under 17% with heated air causes a great loss in quality (ref. 14). These problems can



be effectively prevented through conservation cooling.

Pellets

Pellets are cooled in pellet coolers with untreated air from outside. Using this process, pellets of particularly large diameter are not cooled to the core. Stress fissures occur, which lead to increased proportions of meal and breakage, and so to loss of quality. Using the GRANIFRIGOR™ system cools stored pellets evenly to the core. The pellets become very hard; there is little bruising and breakage. This results in optimal flow characteristics when relocating.



Air distribution

Cooling in silo compartments

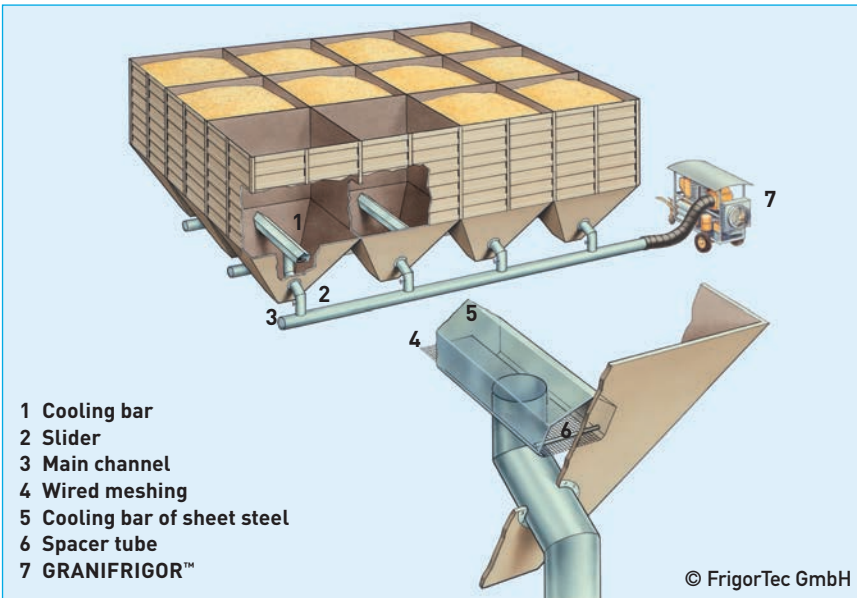
What matters most in cooling bulk products is excellent air distribution. A perforated floor has proved its worth for silos with a level ground area. Cooling bars of bevelled sheet steel are used for silos with a discharge cone. The cooling bars are open on the underside and are fitted with wire meshing to guard against swirling seeds and grains. The cold air is conducted into the cooling bars from the GRANIFRIGOR™ grain cooler along a piping system, and is then conveyed into the bulk grain via the underside opening, which is directed downwards (fig. 13).

Through air resistance from the bulk crop, the cold air is distributed across the entire cross section of the bulk produce and flows through the bulk produce in an upward direction. So that the warm exhaust air can escape from the bulk produce into the open, there must be a sufficient number of apertures provided under the silo roof. In autumn, condensation can occur in certain weather conditions. To prevent condensation, either the silo roof can be insulated or a suction ventilator installed. A suction ventilator is usually the most suitable solution. The ventilator must be capable of conveying a correspondingly large quantity of air, but only at low pressure.

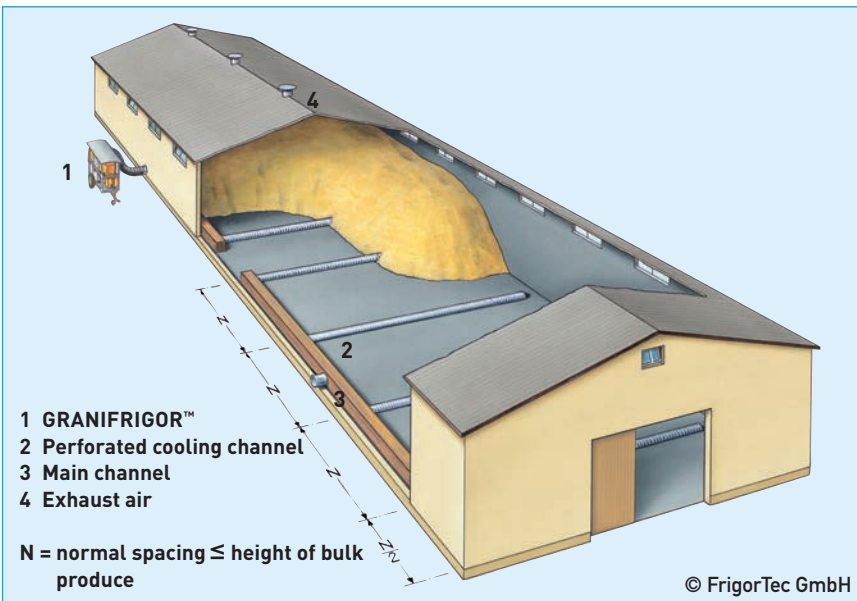
When dealing with tall silo systems, it must be noted that the possible bulk height of the stored material that is being ventilated creates a loss in pressure. The cooling device ventilator and its area of operation must be adjusted to this. Please note that rapeseed, for example, causes around three to four times more loss of pressure in the ventilating air-flow than wheat does.

Cooling procedure in the warehouse

In warehouses, the usual method is to install perforated sheet-steel cooling channels in half-shell form onto the floor. If the channels run underfloor,



13 Cooling bar course using the example of a honeycomb silo system



14 The principle of air distribution in a warehouse storage facility

they are covered with perforated metal panels. It is important that they are simple to clean, and that recesses and soiled edges occur as little as possible. The advantage of underfloor installation is that the storage facility can be more easily negotiated with a vehicle. This is a considerable help when removing material. The individual junction channels are combined together with a main channel outside or inside the building, or each channel emerges into the open separately. Long air pipes should be avoided as much as possible, and insulated against heat infeed. The distance of the cooling channels may not be larger

than the maximum height of the bulk produce and the maximum distance of the channels to the wall should be half the height of the bulk produce. If the mass of grain has a pile cone, this can be compensated for by varying the perforation of the air channels, or covering the surface of the bulk produce. Otherwise the cold air would flow the way of least air resistance and the tip of the pile cone would not be cooled. Ideally, a pile cone can be avoided to a great extent by a suitable distribution of the stored material.

In conclusion, a GRANIFRIGOR™ grain cooler presents many advantages that must be considered in terms of economic efficiency:

- Risk-free long-term storage without quality loss
- Protection from insect feed and proliferation
- Protection from mildew and their mycotoxins
- Avoiding expensive and unecological chemical treatment
- Minimising respiration losses
- No circulation required
- Lower drying costs
- Conservation of harvest freshness
- Conservation of germinating quality
- No yellow discoloration of rice
- Greater yield of head rice
- No stress cracks
- No oxidation of oleaginous produce
- Refrigeration can be implemented independently of weather conditions



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Models GRANIFRIGOR™ – Grain cooling units



GC 40 Europe



GC 60 Tropic / 80 Europe



GC 140 / 180 Europe



GC 220 Tropic / 240 Europe / 240 Subtropic



GC 310 Tropic / 320 Europe / 320 Subtropic



GC 460 Tropic / 500 Europe / 560 Tropic



GC 650 Tropic / 650 Desert / 700 Europe



GC 1000 Tropic / Desert

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