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First application in France of heat disinfestation of a large wheat mill

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Abstract: Thermal disinfestations of flour mill structures and equipment were traditionally used before the 1960's, but they have been replaced by methyl bromide fumigation until the international ban of methyl bromide in 2005. During the last decade, heat disinfestation of flour mills was developed in Northern America and in some European countries from the 2000's workshops of heat disinfestation of wheat mills were carried out. In France, the first industrial application of this technology was attempted in 2010 for the disinfestation of a large wheat mill and was carried out by Agronet Company in collaboration with INRA Research Laboratory in Bordeaux. The heating of the flour mill was performed from electric heat generators of Thermonox® technology (Germany). The electric heaters are forced heat air ventilators enabling to reach the target temperature of 50 to 55 °C in about 10-12 h in all parts of the mill. Then, temperature is maintained at this level during 24 to 36 h and optimized from the indications of temperature sensors in order to obtain complete mortality of insects, whatever their development stage. Encaged insects (*Tribolium castaneum* and *Rhyzopertha dominica*) placed in the mill during mill heating were killed at more than 97%. Very few survivals were only observed on the floor at the ground level of the mill. The reproductive capacity of individuals surviving thermal exposure was severely reduced. This first industrial application of heat disinfestation process to a large wheat mill confirmed the results of laboratory studies performed earlier at INRA Laboratory. The economic evaluation of the heat treatment in the conditions described above revealed that it is competitive compared to fumigation with similar requirements in the preparation of the building before treatment. This technology seems very promising for periodic eradication of insect colonies in cereal processing industries without use of pesticide.

Key words: Wheat mill, electric heat generator, Thermonox® technology, heat disinfestation, industrial scale, stored-product insect, complete mortality.

Introduction

The use of heat treatment for mill disinfestation is an old technology (Mahroof *et al.*, 2003a, 2003b; Quarles, 2006; Mahroof, 2007; Beckett *et al.*, 2007) which gave way from the 1960s and 1970s to the treatment of facilities with insecticides or methyl bromide fumigation (which has been banned in French mills since the end of 2007). Over the last ten years, heat treatment techniques and equipment have initiated a new expansion of heat-based disinfestation in grain industry installations (Menon *et al.*, 2001; Klapal *et al.*, 2004; Hofmeir and Adler, 2004; Hasenböhler, 2010). Applications on a practical scale began in North America and Northern European countries well before the halt to the use of methyl bromide gas fumigation (Norstein, 1996; Dowdy, 2000; Dowdy and Fields, 2002; Roesli *et al.*, 2003). The new technology for "integrated" heating units in buildings in the early 2000s helped implementation progress rapidly in Europe, mainly in countries such as Germany, Austria, Switzerland and Benelux (Klapal *et al.*, 2004; Adler, 2007) (Thermonox® process).

In 2010 Agronet (Rouen) in conjunction with Semoulerie de Normandie Pastacorp (Rouen) and with assistance from the French agricultural research body INRA (UR MycSA Bordeaux) planned, organized and executed an initial mill disinfestation campaign at industrial scale using this process.

Material and methods

Disinfestation trial: milling plant characteristics

The disinfestation project was carried out in the mill run by Semoulerie de Normandie (Pastacorp-Lustucru). The treatment was applied to all mill areas, for a total volume of over 43,000 m^3. (Figure 1).

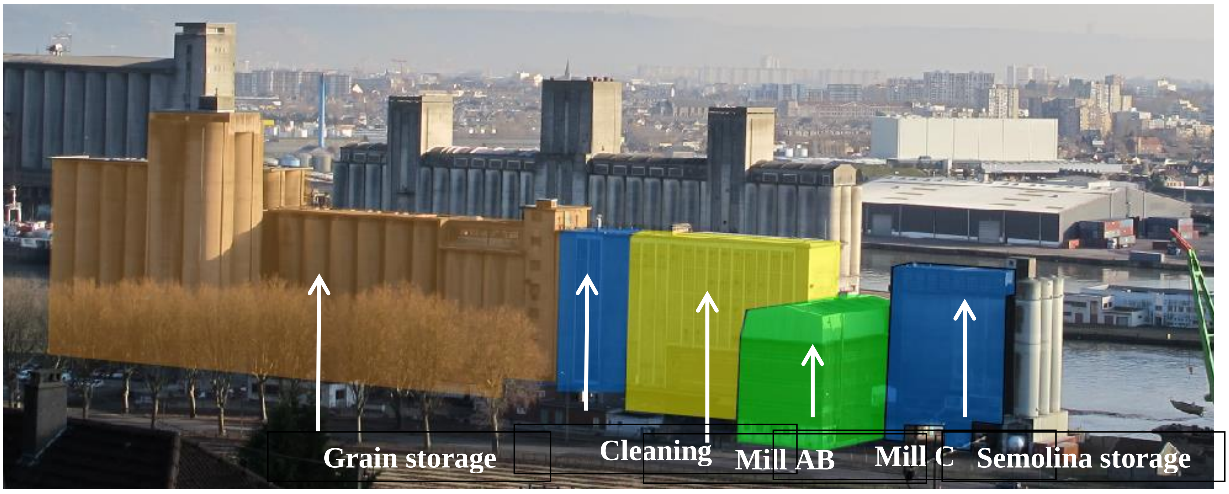

Figure 1. The 'Semoulerie de Normandie' plant in Rouen (Pastacorp) and its division into successive treatment areas.

Equipment

The equipment was the Thermonox® system developed in Germany (Hofmeir, 2002) and chosen for its effectiveness in producing the desired temperature while also reducing moisture levels. This equipment was used from the inside of the mill which saved on energy consumption by recycling heated air. The system improves control of reheating in critical areas by ensuring optimum directionality and spread of the equipment from the mill interior. Effective spread of the heat is supplemented by the use of ground fans to direct heat towards floor level. And lastly, running the equipment directly off the mill's electrical power guaranteed improved safety in use compared with systems using steam, gas or fuel-oil, all of which are energy-intensive and subject to specific regulatory safety constraints.

Temperature and moisture control

Three types of equipment for the measurement of ambient temperature and moisture levels were used: i. Sensor-transmitter units combined with a central data acquisition unit; ii. Heat/moisture probes with digital displays at critical locations in the mill (or assumed to be critical); iii. One manual infrared probe used to detect critical areas (Figure 2).

Figure 2. Infrared manual probe for surface temperature instant measurement.

Test insect species and mortality rate check

Two test insect species were chosen for the validation of efficacy on completion of the operation: the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae), which is more heat tolerant than the other species present in mills (Fleurat-Lessard *et al*., 2011a, 2001b; Hasenböhler, 2010) and the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), the most frequently encountered species in mills in France (Fleurat-Lessard, 1991). The grain borers were packaged in batches of 20 insects in fine brass wire gauze cages providing no heat protection. The red flour beetles (obtained from colonies taken from the test mill) were placed in plastic boxes containing a small amount of wheat flour at the bottom. One half of the 24 batches of grain borers were spread out in free space at the various levels in the mill and the other half in the machinery (left open). Four batches of borers were kept in an unheated room as a survival control group. Observed mortality in the batches of test insects at the end of the heating period was weighted by observed mortality in the control batches using Abbott's formula (1925).

Logistics available on site for heat treatment

Site preparation (thorough cleaning of mill with machine housings closed, building closed, protection of vulnerable equipment, scheduling of work by personnel, calculation of required heating power, distribution planning of layout of heaters to be installed (Figure 3) and estimation of energy, wiring and machine installation requirements, placing of test insects and measuring apparatus, all units of which had to be tested for correct operation, etc.) required 48 h with teams 4-7 strong according to task.

Temperature ramp-up following equipment start-up lasted between 12 and 18 h before reaching the target temperature in all disinfestation areas. During this phase, temperatures were measured at regular intervals in all parts of the mill in order optimize heating equipment coverage and direct hot air flows at critical locations. The "plateau" phase (52-55 °C throughout the mill) was maintained for at least 10 h before shutting down the equipment.

Indicators of disinfestation effectiveness

The temperature rise curves recorded in real time were used to validate effectiveness in eliminating insects (Figure 4). This was taken as the criterion for the minimum period for maintenance of a temperature at or above 50 °C (in the coolest mill area) for at least 12 hours.

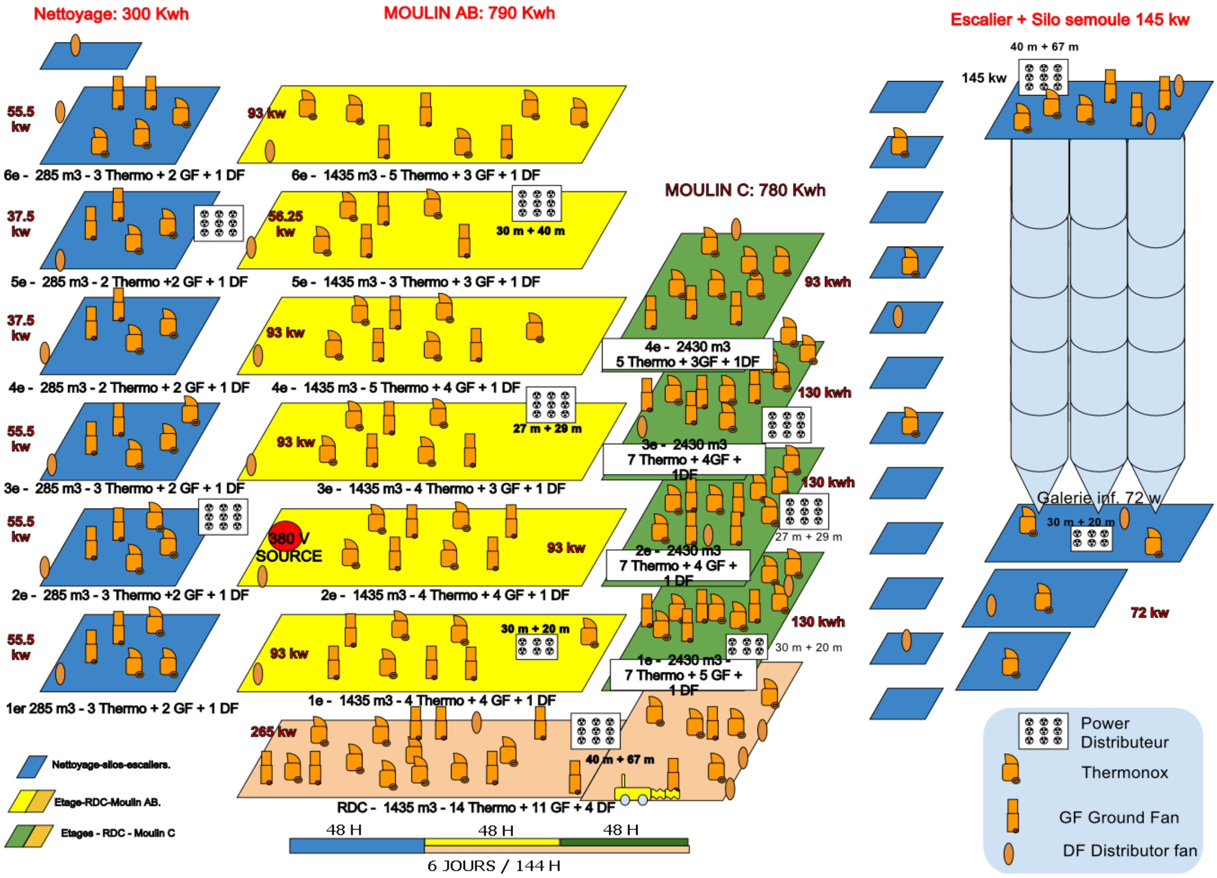

Figure 3. Thermonox® generator placing in the various mill areas.

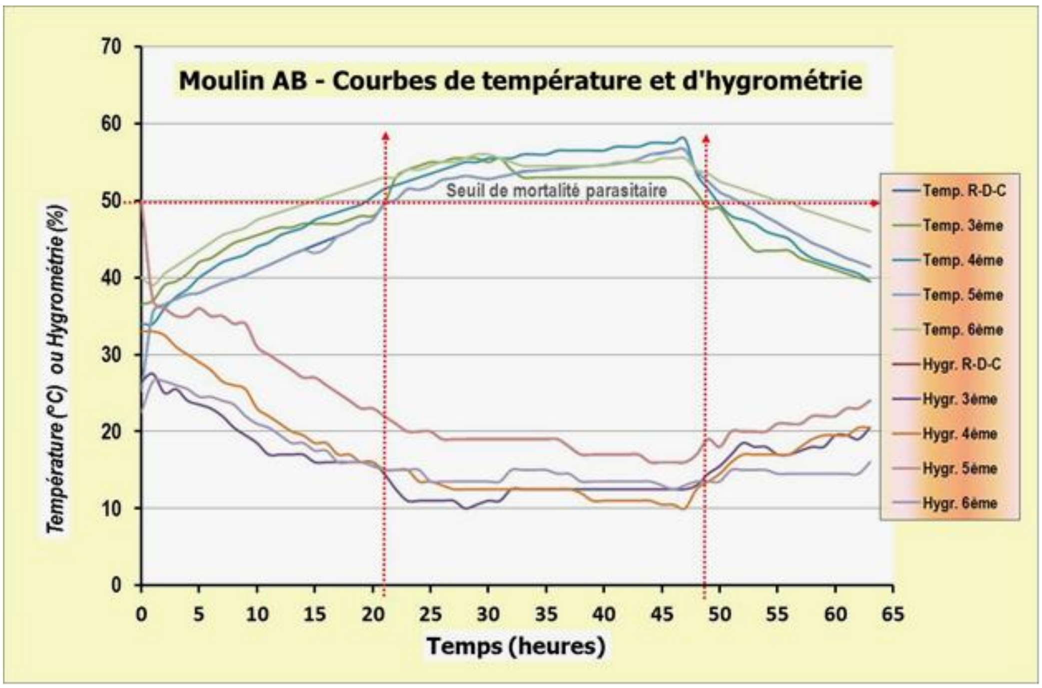

Figure 4. Model of the temperature ramp-up curve measured in real time in mill area AB.

Results and discussion

Temperature increase monitoring curves

Taking account of the various materials to be heated in the mill, the heating power to be installed was estimated at 45,000 kWh (or 48 units each max. 18 kW, running for 50 h in succession in the two mills AB and C) (Figure 5). The allocation of the installed heating power was as follows: i/ Cleaning tower: 300 kWh, ii/ AB mill: 790 kWh, iii/ C mill: 780 kWh, iv/ Semolina silo and stairway: 145 kWh. The real time temperature recordings in the various mill areas (Figure 4) enabled the minimum required “heat dose” to be achieved, expressed as a coupling of the target temperature (min. 50 °C) and the duration of that temperature (in hours). Only the gallery under the semolina cells did not reach the threshold for effective disinfestation.

Measuring insect mortality

The mortality of the test insects was 100%, with the exception of one sample placed at floor level on the ground floor (98% mortality; Table 1). Mortality was complete for all batches placed at machine level. Effectiveness was equivalent to fumigation with sulfuryl fluoride in optimum conditions (Delbonnel *et al*., 2005).

Observation of the effects of heat on the insects

During heating, the behaviour of the insects is dramatic: at a temperature of 42-46 °C and above, they flee the machines en masse seeking areas where the temperature is lower (corners, concrete stairways, floor cracks, bases of concrete pillars, etc.). Plant oil was sprayed in these areas to “trap” the insects active there and accelerate their mortality (Figure 5). At temperatures above 46-48 °C, the insects became torpid and began gradually to die off as the temperature rose to 50 °C.

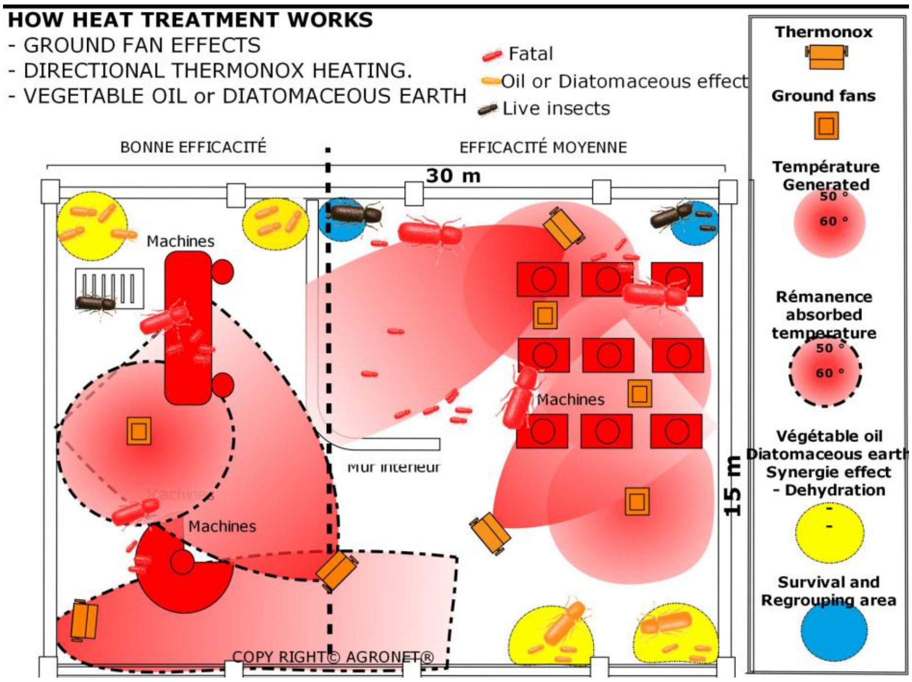

Figure 5. The “Thermonox® System” seen in its globality, with the mobile heat generators, floor heating and plant oil barriers in refuges.

Table 1. Mortality rate of test insect groups set at the different floors of the heated mill observed at the end of heat treatment.

Floor	Positions of test-insect cages	Insect number inside machinery	Insect number in free space	Mortality rate inside machinery (%)	Mortality rate in free space (%)
Ground floor	Placed on floor, near the wall		40		87.5
1st floor	Placed in height, inside the machinery	40	20	100	100
2nd floor	Placed in height in a pipe, near the wall inside a machine	40	40	100	100
3rd floor	Placed in height near the wall inside a machine	40	20	100	100
4th floor	Placed in height near the wall inside a machine (2)	40	40	100	100
5th floor	Placed in height near the wall inside a machine (3)	60	40	100	100
6th floor	Placed in height near the wall inside a machine	40	20	100	100
Total		260	220	100%	97.75%*

Energy consumption
A total volume of 43,000 cu. m. was heat treated for energy consumption of 86,000 kWh giving an energy requirement for “effective” treatment of 2 kWh/m^3. The average cost of the heat treatment in relation to the disinfestation volume was assessed at between € 1.5 and € 3.5 per m^3 taking into account the size of the facility (Table 2 and Figure 6).

Table 2. Applied energy and heating power and cost overview.

Building	Volume m^3	Duration (hours)	Energy (kWh)	kWh/m^3	Energy cost €/m^3 (July 2010 rate)
Cleaning + Semolina silo	4,750 +1,110	69	25,900	4.4	0.14
Mill AB	12,110	66	33,994	2.8	0.09
Mill C	13,220	67	26,870	2.0	0.07
TOTAL	43,430	202	86,773	2.0	0.06

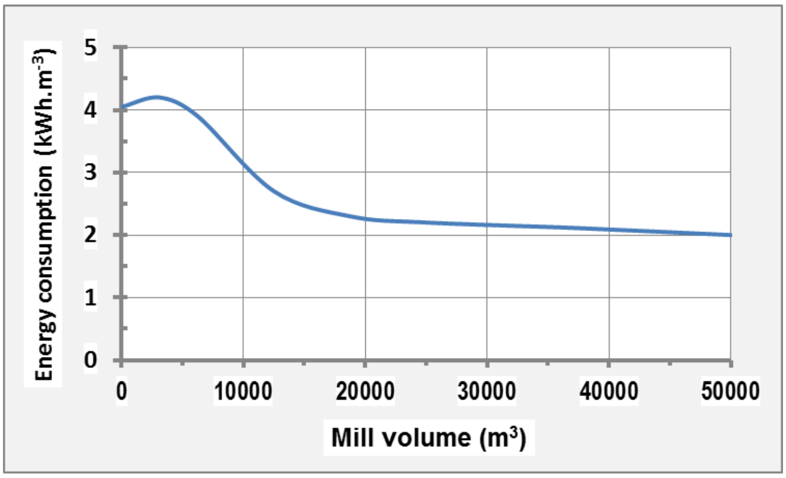

Figure 6. Level of energy consumed per cubic meter volume of the milling plant for heat disinfestation with the Thermonox® technology (H. Hofmeir, personal communication).

The match between estimated and observed results

The site preparation and the efficiency of the installed equipment matched the initial forecast estimates in all respects. The main findings and lessons from this full-scale trial of heat disinfestation of a large mill were as follows:

- Some plan sifter sieves bond became broken (in many cases old screens or screens insufficiently attached or glued). However, after several treatments this effect diminished and disappeared over time (due to the replacement of defective sieves): i/ 2010: 3% MPAD type without clips to be changed or repaired, ii/ 2011: 2% MPAD type without clips to be repaired.
- Some plastic floor may create a located bubble when no expansion joint has been created, or when a poor polymerization glued has been apply.
- Some grease from cylindrical roller bearing or oil bath lubricated ball bearing may drip.
- Humid or wet wood floor may also be deformed.

Discussion

The opinion of the mill managers

Mill preparation time is comparable with that required for fumigation. Less sealing work is required than for gas, but the connection of the heating units to switch cabinets, installation of generators, distribution boards and connection cabling needed at the various levels in the mill, their connection to the central electrical substation, require at least two whole days' work. The major difference is during the heating operation itself: it is possible to work in a heated area without any particular protective equipment in order to change the location of the units and measure temperatures to ensure a uniform spread of heat. It is also possible to observe the insects leave the machines and die off, which enables the heating to be shut down once they are seen to have been eliminated completely in the mill as a whole. The "damage" caused by the heat matches what was expected.

Conclusion

Offering a level of effectiveness at least equivalent to fumigation and with fewer constraints, heat-based mill disinfestation is a “new” technology that is likely to be increasingly developed in France for the total disinfestation on favorable cost terms of mills in the grain sector.

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