Efficiency of air dehumidification on the drying process in a food plant

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ABSTRACT

To reduce the proliferation of bacteria inside a food plant, cleaning and disinfection are performed every day. These operations are followed by drying which has to be as quick as possible. This study shows the influence of a dehumidifier on the water mass evolutions on the surfaces such as floor, wall and equipment during the drying of a food plant. The temperature, relative humidity and water mass evolution during drying period were monitored in a food plant running under two conditions: with and without dehumidifier. The results comparison shows that drying rate is about 1.5 times higher with dehumidifier.

Keywords: dehumidifier, food plant, mass transfer, relative humidity

1. INTRODUCTION

Listeria monocytogenes is a serious food-borne pathogen that can cause severe infection called listeriosis and mainly appears in ready-to-eat food products. The products contamination is caused at first by the contamination inside the premises of the food processing plant (Autio et al. 1999, Vogel et al. 2001a, Wulff et al. 2006). Then the contamination can increase along the cold chain depending on the temperature and residence time in the refrigeration equipment (Duret et al. 2014). Inside a food plant, damaged equipment, crack on the floor, etc… allow the bacteria to take refuge (Carpentier & Cerf 2011). The presence of water and nutriment allows the bacteria to adapt to the disinfection products, which make them harder to eradicate (Muhterem-Uyar et al. 2015). Remaining water and humidity in the premises are determining factors to microbial development which can be reduced using a dehumidifier. There are many dehumidifier types for different applications. For human comfort, the use of dehumidifier allows slightly reduction and homogenization of the relative humidity inside a building (Teodosiu et al. 2003). Kim et al. (2008) carried out an experimental and numerical (3D CFD) study and show the influence of a dehumidifier in greenhouse on the relative humidity: reduction of about 10% (from ~70% to ~60%). The use of dehumidifier in a food production plant allows the increase of the drying rate. However, from our literature review, there are few studies reporting the influence of dehumidifier on the relative humidity in air and on the rate of water evaporation. To our knowledge, there are no published data about the water load inside a food processing plant after cleaning and during drying. In most of the food processing plants, there is no dehumidifier, and when one is used, it is most often designed in an empirical way. In a previous study (Lecoq et al. 2015), an experiment was performed in a food production plant without dehumidifier to study the water evaporation on the surfaces (wall, floor and equipment). The relative humidity was rather important (~85%) which induced a low evaporation rate during the drying period of two hours, thus, water still remained on certain surfaces.

The main objective of this study is to present the influence of a dehumidifier installation on the humidity and the water evaporation rate at different positions in an industrial food plant.

2. EXPERIMENT IN FOOD PLANT

The experiments were carried out in a production plant of chilled foods during the drying period. The ambient conditions (temperature, relative humidity, air velocity) and the water weight on several surfaces were measured in two cases: with and without a dehumidifier in the room.

2.1. Production room

The dimension of the production room of chilled products was 17.1m long, 8.2m wide and 3.6m high (Figure 1). Low temperature is maintained in this room using two evaporators located at the ceiling. Air from two evaporators is blown inside air ducts located at the ceiling, and the air is diffused to the left and right. The two evaporators are referred as evaporator 1 and evaporator 2 (Figure 1).

In this study it is considered that the drying process starts when the cleaning period ends which means that no additional water is provided in the room during drying.

The following conditions set by the manufacturer were observed. During the cleaning process, the evaporators were stopped.

For the experiment with dehumidifier, both evaporators restarted 50 min after the beginning of the drying period. The dehumidifier (desiccant wheel) was always working, even during the cleaning process. Its characteristics are shown in table 1.

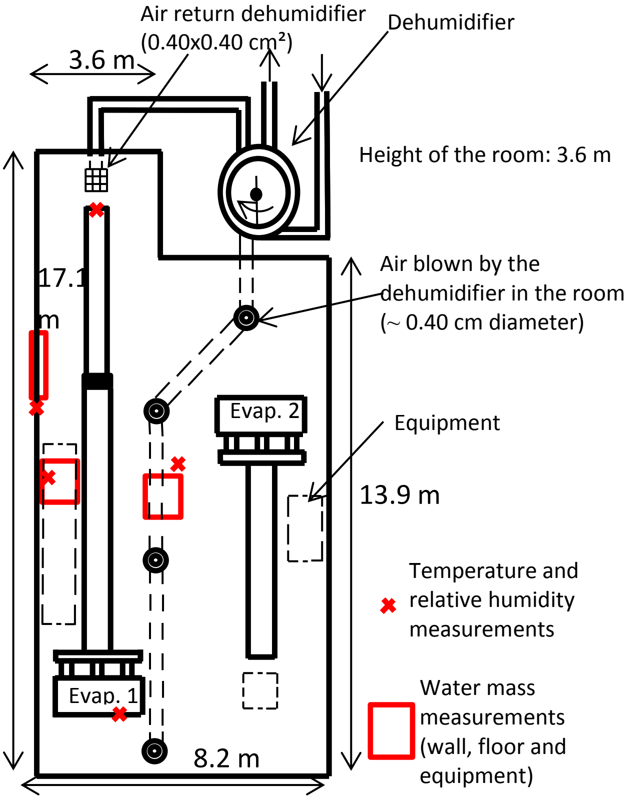


Figure 1: Scheme of the food production room with the measurement points (top view).

For the experiment without dehumidifier the first evaporator restarted directly after the end of the cleaning process and the second one after 45 min. The first evaporator was "on" from 0 min to 20 min, then, it was defrosting from 20 min to 45 min. During this period the ventilator of the evaporator was working but without cold production.

Table 1: Characteristic of the dehumidifier (Recusorb RZ-081):

Dehumidification capacity [kg/h] For inlet condition of 20°C and 60%HR	19
Dry air flow rate [m^3/h] External static pressure [Pa]	2800 400
Moist air flow rate [m^3/h] External static pressure [Pa]	1000 200
Battery power [kW]	24
Motor power [kW]	3

2.2. Water weight, temperature, relative humidity and air velocity measurements

The air and surfaces temperatures, the relative humidity and the water weight on the surfaces (wall, floor and equipment) were measured during the drying process in both experiments (with and without dehumidifier).

After the cleaning process in the production room, the water weight was measured at different times at various surfaces: floor, wall and equipment. To measure it, paper towelettes were used to wipe a 25cm x 50cm surface area on the floor. Because there is less water on the wall and on the equipment compared to that of the floor, the wiping was done on a 50cm x 50cm surface area on these surfaces. A square frame (25cm x 50cm or 50cm x 50cm) was placed on the measurement position before the water swabbing. After swabbing, the towelettes were deposited in a plastic bag, air inside the bag was eliminated by pressing before the bag closing. The towelettes in the bag were weighted, as soon as possible, using an electronic balance (Sartorius, CPA34001P, +/- 0.1 g). On the floor and on the wall, one repetition was performed. The same manipulation was repeated every 30 min on neighboring surfaces until 2 hours. The evolution of water weight at different positions was followed by weighting the towelettes. Because of the difficulty to carry out measurements in a real food plant, only one location, considered as "representative", could be analyzed for each surface (wall, floor, and equipment) in spite that the initial water load and the transfer intensity can vary from one position to another. The analysis of such heterogeneities is out of the scope of the present study.

Temperature was recorded every 30 seconds from the beginning until the end of the drying process using thermistor (Testo 171, +/- 0.2°C). Due to the sensor installation, some temperatures were taken only 30 min after the beginning of the drying period. The sensors were put at the air inlet and outlet (near the outlet of the air duct) of the first evaporator and also in the middle of the room at several heights: 0.2m, 2.6m, 3.2m (Figure 1). In addition, surfaces temperatures were recorded by sticking the sensors to the wall, floor and equipment. For better accuracy of the surfaces temperatures measurement, thermal insulation of 4 mm thickness of was placed on the sensors.

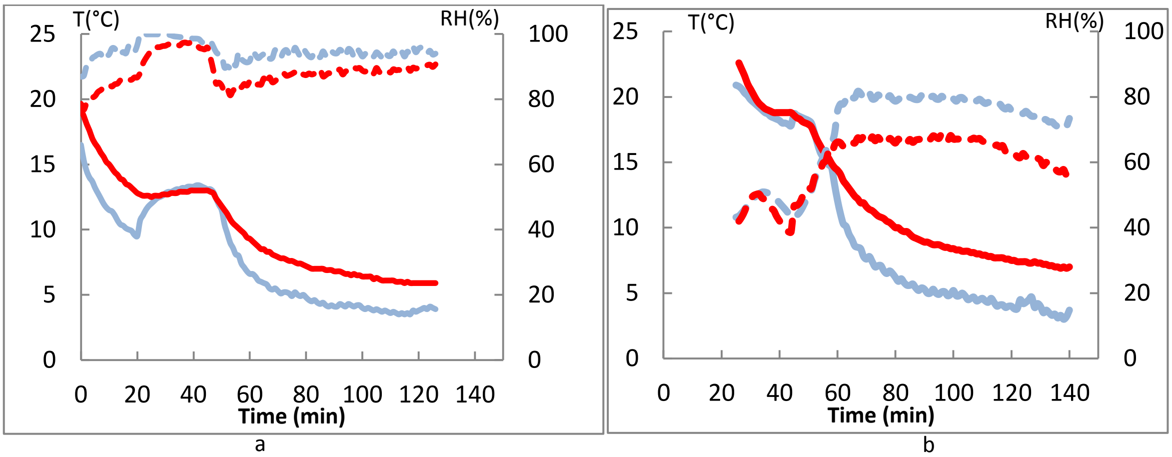
Relative humidity was recorded every minute using capacitive hygrometers (TESTO 174H, +/- 3%) during the entire drying process (as for the temperature, at some positions the relative humidity was only monitored 30 min after the beginning of drying). The sensors were also placed at the air inlet and outlet of the evaporator 1 (Figure 1).

Air velocity was measured at the air return grill of the second evaporator and the dehumidifier using a hot wire anemometer (Testo 435-2, range of measurement: 0-20 $m.s^{-1}$). It was assumed that the air flow rate of the two evaporators were similar. The air velocity at the air return of the second evaporator was measured in the experiment without dehumidifier and supposed to be the same for the experiment with dehumidifier. Using the measured air velocity and the cross section of air duct, the air flow rate of the second evaporator was estimated (around 12 000 m^3/h).

3. EXPERIMENTAL RESULTS – COMPARISON WITH AND WITHOUT DEHUMIDIFICATION

3.1. Air temperature and relative humidity evolutions

During the first 50 min, as explained in section 2.1, the evaporators were not operating exactly in a similar way in both experiments which explain a slight difference in the air temperature evolutions during this period. After that, they were both functioning, which induced a decrease in the air temperature at the outlet of the air inlet duct and thus also in the room (Figure 2).



— Ta blown (evaporator), — : Ta air return (evaporator), - - : RH blown (evaporator), - - : RH air return (evaporator)
Figure 2: Evolution of the air temperature and relative humidity for the air return of the evaporator and for air blown by it a- without dehumidifier b-with dehumidifier

Concerning the relative humidity, the difference with and without dehumidifier is crucial. It can be seen in Figure 2, that without dehumidifier it was always around 90%RH in the room during the whole process. In addition, when the working evaporator was defrosting between 20 to 45 min, the evaporated water contributed to increase the relative humidity of air (close to 100%) and the air temperature raised (from ~10°C to ~13°C). In comparison with a dehumidifier, the relative humidity was always below 70%RH at the air return of the evaporator which gives a good representation of the conditions in the room. Before the evaporators were switched on (<50 min) only the dehumidifier was working and temperature remained high, therefore the relative humidity was low (~50%). Then temperature decreased explaining that relative humidity increased.

Reducing the air relative humidity in the room from 90% to 60% makes the water evaporation faster and thus, decreases the bacterial survival (Likotrafiti et al. 2013).

3.2. Water content in the room

Knowing the water mass per square meter (shown figure 3) and the total surfaces of the wall (~182 m²), floor (~125 m²) and equipment (~80 m²), the water mass remaining on the surfaces at the beginning of the drying process can be estimated. The initial water mass on the floor was more significant without dehumidifier (~227 g/m² compared to ~130 g/m² with dehumidifier). The fact that the dehumidifier was also working during the cleaning process limits the water remaining during the drying period. In the case without dehumidifier the total water remaining at the beginning of the drying process was around 37kg while it was only about 24kg with dehumidifier.

During both experiments, the mass of water condensed on the second evaporator was measured: 6.4 kg (without dehumidifier) and 0 kg (with dehumidifier).

Using the relative humidity and temperature data at the first evaporator, the water content of inlet and return air at this evaporator can be calculated in both experiments. The time average of these values gives an order of magnitude of the condensed water mass on the evaporator, using the following equation:

$$m_{w,evap1} = \Delta x * \dot{m}_{evapo} * t \tag{1}$$

where Δx = time average value of the water content difference at the inlet and air return of the first evaporator

In the case without dehumidifier:

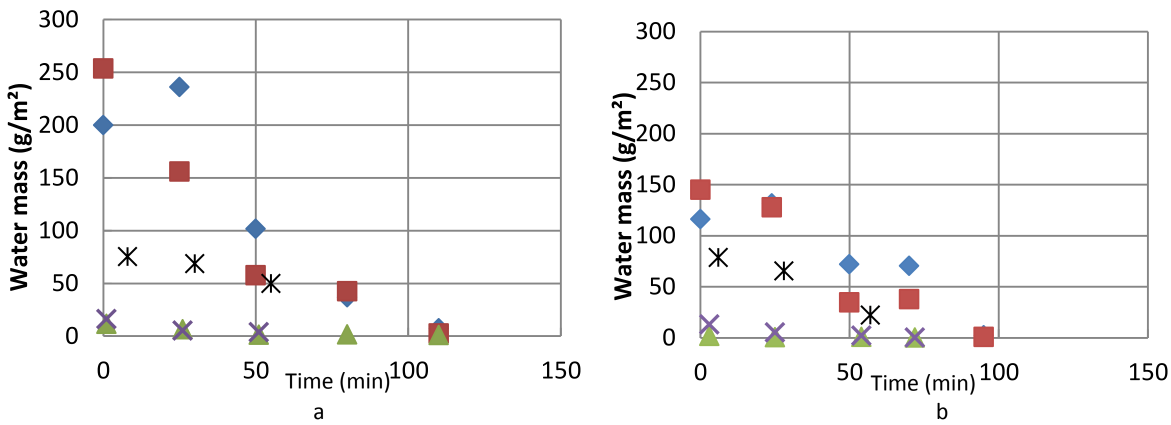
$\Delta x \sim 5.10^{-4}$ $kg_{water}.kg_{dry\ air}^{-1}$, $\dot{m}_{evapo} = 15\,000\ kg/h$ and t = 2 h (for the evaporator 1), t = 1h (for the evaporator 2)

For this case, the condensed water on the first evaporator is estimated at 15 kg and 7.5 kg on the second evaporator (because it worked only one hour working during two hours of drying period). This is close to the experimental value of 6.4 kg. When the estimated water condensed on both evaporators of 22.5 kg is compared with the initial water of the 37 kg in the plant, the water mass still remaining on the surfaces is about 14.5 kg at the end of drying period.

In the case with dehumidifier, $\Delta x \sim 0$ $kg_{water}.kg_{dry\ air}^{-1}$. This supposes that no water condensed on the evaporator, which was confirmed experimentally, and leads to suppose that the water evaporating on the surfaces of the plant was caught almost entirely by the dehumidifier. To have information of the water condensed on the dehumidifier, because we did not have the temperature and relative humidity at the air blown and air return of the dehumidifier, the calculation was made from the water difference on the surfaces between two interval times. It was considered that all of the water evaporated is caught by the dehumidifier. The water mass remaining on the surfaces after 70 min of the drying process was around 9kg, compared to 24kg initially. Thus, the condensation rate on the dehumidifier during the first 70 minutes of the drying process was around $13 kg.h^{-1}$, which is much lower than the dehumidifier capacity (~$19\ kg.h^{-1}$). This means that the evaporation rate is not limited by the dehumidifier capacity but by the lack of heat required to evaporate it. If additional heat would be provided in the room or directly to the surfaces for even a short period of time, the evaporated water could still be caught by the dehumidifier because of a more important maximal capacity, inducing a much lower drying time. The drying rate in the room is studied more accurately section 3.3.

3.3. Water mass evolution

The weights of water measured on the wall, floor and equipment (as described in section 2.2) during drying process are presented in both experiments; with and without dehumidifier (Figure 3).



◆ and ■: Measurements on the floor – ⚹ : equipment – ▲ and ✕: wall
Figure 3: Water mass evolutions on the wall, floor and equipment a- without dehumidifier b- with dehumidifier

In both cases, due to water stagnation on the floor, the initial water weight at this position is much higher than the one at the equipment and the wall. Water evaporation rate on the floor is however higher than at the other positions because of its high thermal inertia (~10cm thickness of concrete) which makes the floor temperature decreases slower than the wall and the equipment (~5cm thickness of concrete and ~100 kg of stainless steel for one equipment), Figure 4.

It was observed during the experiments that without dehumidifier, even after two hours of drying, water could remain on the surfaces, especially on the equipment. With dehumidifier, most of surfaces were dried after 100 min except at certain positions such as corners or complex equipment where water could

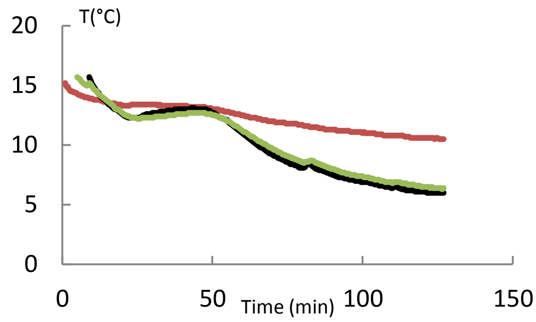


Figure 4: Surfaces temperature (▬: floor, ▬: wall, ▬: equipment). Case without dehumidifier (similar evolution in case with dehumidifier)

still remain because of low airflow. It is to be emphasized that the water mass evolutions presented in this study is an order of magnitude, there are heterogeneities of water distribution in reality.

The influence of the dehumidifier can be directly observed in the water mass evolution. Firstly, the amount of initial water to evaporate during the drying process is reduced; from around 37.0 kg without dehumidifier to 23.9 kg with dehumidifier. Secondly because of much lower relative humidity, the evaporation rate on all the surfaces is higher with dehumidifier. This induces a shorter time in the drying process and thus, less bacterial development. In addition, reducing the drying period would allow the production to be started earlier which could be important for manufacturer.

3.4. Analysis of exchange phenomena

The evaporation rate on surfaces is proportional to the mass transfer coefficient, k, and the difference of water concentration in the air in equilibrium with water (at the surface temperature) $C_{sat(T_{surface})}$, and the air circulating in the vicinity of the surface C_{wa} (eq. 2).

$$\dot{m}_{evap} \propto k \cdot \left(C_{sat(T_{surface})} - C_{wa}\right) \;\; with \;\; C_{wa} = C_{sat(T_{air})} * RH \qquad (2)$$

The mass transfer coefficient depends on the air velocity near the surfaces induced by ventilation, which was almost the same in the experiments with and without dehumidifier. The water concentration in the air in equilibrium with water increases with the surface temperature and the water concentration in the air decreases with the relative humidity.

Without dehumidifier, the relative humidity is rather high (~90%), the evaporation rate is mainly driven by the thermal inertia: higher for floor than for wall and equipment. With dehumidifier, the relative humidity decreases, thus, the increase of water content difference ($C_{sat(T_{surface})} - C_{wa}$) induces a higher evaporation rate. In this case, both low relative humidity and thermal inertia are driven forces for the evaporation.

In addition to dehumidifier, it is also possible to increase the air flow rate or to heat the surfaces. However, the air flow rate should not be higher than a critical value taking into account the well-being of workers. Supplying heat to the surfaces, especially to equipment where low evaporation rate was observed, could be a way to improve the drying process. Indeed, because equipment has a low thermal inertia, its temperature decreases fast. Heat and mass transfer models could help to forecast, for example, the impact of additional surface heating on the evaporation rate.

4. CONCLUSION

The importance of a dehumidifier has been underlined in this study to reduce the relative humidity in the room which induces a higher evaporation rate on the surfaces. Without dehumidifier, it requires more than 120 minutes to dry the surfaces, while with a dehumidifier it requires about 100 minutes except in places where ventilation is much lower (corners, complex equipment…). The possibility to supply heat on equipment can be a solution to reduce the drying time. However, if the evaporated water cannot be condensed on an evaporator or dehumidifier, the relative humidity in the room will keep increasing until fog apparition. The dehumidifier sizing is thus important to assure the dry air in the room (in this case, below 70% of relative humidity) and avoid that water still remains on certain surfaces after drying period. However, in some positions with low ventilation, even if the dehumidifier is oversized, the water won't evaporate much faster. Thus, some additional arrangement needs to be made in order to dry the room entirely. The supply of heat was discussed, but also some geometrical changes could be performed in the room to prevent water stagnation in corners. The heat can also be provided by installing an air renewal during the drying period, which would bring treated air at a higher temperature (~15-20°C) and with lower water content than the one blown by the evaporator.

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NOMENCLATURE

C	Water vapor concentration in air	$kg.m^{-3}$
k	Mass transfer coefficient	$m.s^{-1}$
m	Mass of water	kg
$m_{w,evap1}$	Mass of water condensed on one evaporator	kg
$\dot{m}$	Air mass flow rate	$kg.s^{-1}$
RH	Relative humidity	Dimensionless
T	Temperature	°C
x	Water content	$kg_{water}.kg_{dry\ air}^{-1}$

SUBSCRIPTS

a air *w* wall *e* equipment *0* initial time *f* floor

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