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Test run for the evaluation of odour abatement efficiency of an ozone generation device in a domestic refrigerator

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Ozone has positive effects as micro organisms and micro pollutants abatement agent (Clamann et al. 1959; Elford et al. 1942; Achen et al., 2001; Carpentier et al, 1993; Kim et al. 1999); for this reason, ozone applications for odour, bacteria, germs and virus abatement are well estabilished, in particular in food industry (Ewel et al. 1938; Kim et al. 2000; Kim et al. 1999). Ozone can be delivered to food products to be treated as airborne agent or soluted in water.
Typical applications of ozone treatments (Kim et al. 2002; Sender et al. 2006; Xu 1999; Yousuful et al. 2001) are:

- Bacteria growth activation
- Fungus induced deterioration prevention
- Pest control chemical elimination
- Weed control

Main aim of the hereby presented experimental campaign is in particular to check the efficiency of an ozone generator in terms of odour abatement in a domestic refrigerator (Anselme et al, 1988; Bruchet et al 2004); food degradation occurring in refrigerator cabinet can in fact generate malodours, along with the ones produced by certain foodstuffs. Ozone generator inside the refrigerator is hence deemed to decompose odorous compounds within fridge cabinet, preventing the build-up of unpleasant odour concentrations in it.

1. Material and methods

1.1 Material

The two refrigerators used as test benches were full ventilated combi type (Ariston MBT 2012 IZS). Ion/ozone generation was achieved by a cold plasma discharge tube, designed for the purpose, installed within the fridge (cabinet ceiling) referred in the following as F1. The device has the following characteristics:

- Power line: 1,75 kV AC, 30 kHz
- Cold plasma ctivation duty cycle: 60%

A second refrigerator (F2), identical to F1 but for the absence of odour abatement systems, was used as a reference.

F1 and F2 fridge cabinet dimensions are:

- Height: 102 cm

- Width: 50 cm
- Depth: 45.5 cm
- Volume: 232 l

A mixed load was defined, common in type and quantity to both refrigerators, including meat, fish, fruit, vegetables, milk and dairies. To ensure complete evenness of foodstuff load, each food type batch was divided in two, weight wise, to obtain two identically composed refrigerator loads.

1.2 Methods

The whole experimental campaign was carried out considering only the refrigerator compartment, for the system has no reason to be used in the freezer.
Temperature set point was 5 °C, all over the experimental campaign. The foodstuff was introduced in the refrigerators and removed at the end of the experimental campaign (2 week of duration); no door openings were performed in between.
To allow air sampling within fridge cabinet without opening the door, a collection system was installed, to allow repeatable air sampling operations (4 liters) from 3 zones of internal fridge volume.
Air collection system was constituted by Teflon pipes (4 mm internal diam.; 6 mm external diam.)
Air sampling was performed on alternate days, in particular:

- After 4 hours from foodstuff insertion (baseline)
- After 2, 4, 7 9 and 11 days from foodstuff insertion

Freshly odourised samples were immediately submitted to olfactometric analysis at the Department of Chemistry, Materials and Chemical Engineering - Politecnico di Milano, where a facility is available for odour concentration testing, to be performed in compliance with EN 13725:2003 and UNI EN 13725:2004.
Test facility is equipped by a Mannebeck Mod. TO8 Olfactometer, PC controlled, with four odour essay stations. Tests were performed by a four people panel by olfaction sensitivity test as described by the above described regulations.
In particular, adopted methodology is based on identification by test panel of "odour threshold", defined as the odour level below wich 50% of panel components cannot perceive anything.
To obtain such an odour sample, an "olfactometer" is needed, to dilute polluted air with clean air, in known quantity, with dilution factors up to 1:65536.
The dilution factor neded to reach odour threshold is taken as a quantitative index of odour concentration, can be expressed in odorimetric units per cubic meter (ou_E/m^3).

2. Results

Table 1 summarises odour concentrations (ou_E/m^3) measured for each sample, comparing refrigetor F2 (reference) with F1 equipped with the odour abatement device. The results are organised by sampling point (H High, M Medium, L Low), and show the odour concetration progression over time.

Time	C_{od} (ou/m^3) – F1 Fridge (O_3)			C_{od} (ou/m^3) - F2 Fridge		
	H	M	L	H	M	L
4 h	910	680	540	970	810	720
23 h	260	220	170	460	430	360
97 h	230	270	360	910	910	1220
168 h	270	810	610	3900	5500	5200
214 h	720	610	480	3100	4300	4100
264 h	1000	970	810	5200	4600	5500

Tab. 1:Odour concentration within frifge F1 and F2 over time

Figure 1 shows in graphical form odour concentration data related to reference fridge F2:

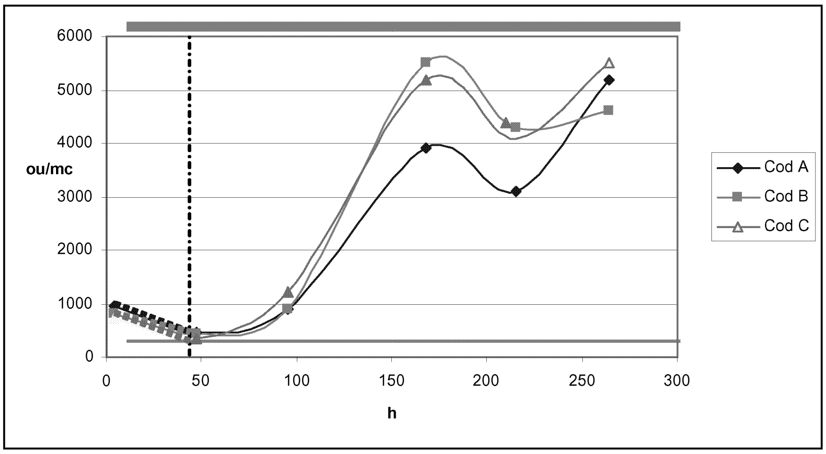

Fig. 1: Odour concentration in F2 over experiment timeframe

The graphic clearly evidences a first curve part (dashed), referable as transitory, where odour concentration inside the fridge cabinet is dominated by initial food stuff conditions: after just 4 hours since placing into the refrigerator, foodstuff ar not yet uniformly chilled and conditioned by the fridge environment. This explains the early decreasing trend of the curve, that reached a minimum when the food was presumably at target temperature. It is worth to remember that the bare odour concentration was measured, without considering the hedonic tone of the odour itself, probably pleasant in this phase.
A steep increase of odour concentration is then evident at increasing storage times, due to food degradation up to noticeable values of more than 5000 ou_E/m^3.
Figure 1 shows in graphical form odour concentration data related to reference fridge F2.

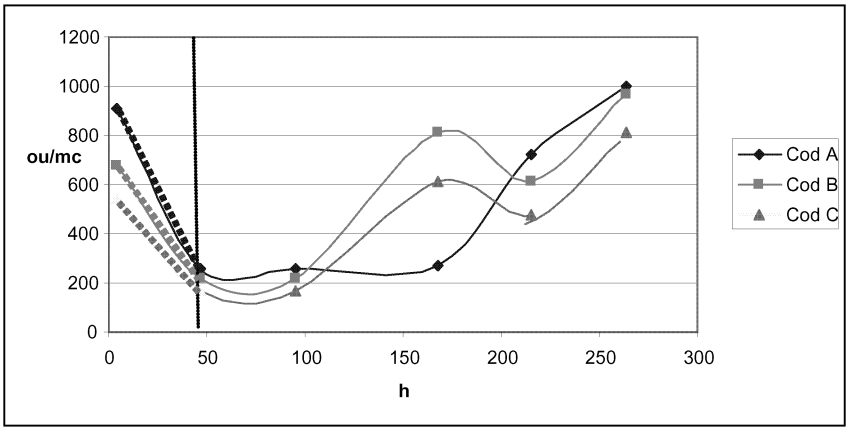

Fig. 1: Odour concentration in F1 over experiment timeframe

A similar behaviour in the early part of the experiment (dashed curve part) can be observed also for F1 refrigerator, presumably for the same reasons explained above. Again, a clear increase of odour concentration is then evident at increasing storage times, due to food degradation; in this case, however, absolute values are significantly lower than the ones obtained in the reference fridge, being kept below 1000 ou_E/m^3

A direct comparison of data is provided in figure 3, where the values obtained over the three sampling points of each fridge are averaged, providing a value presumably similar to the one a customer would perceive opening the door.

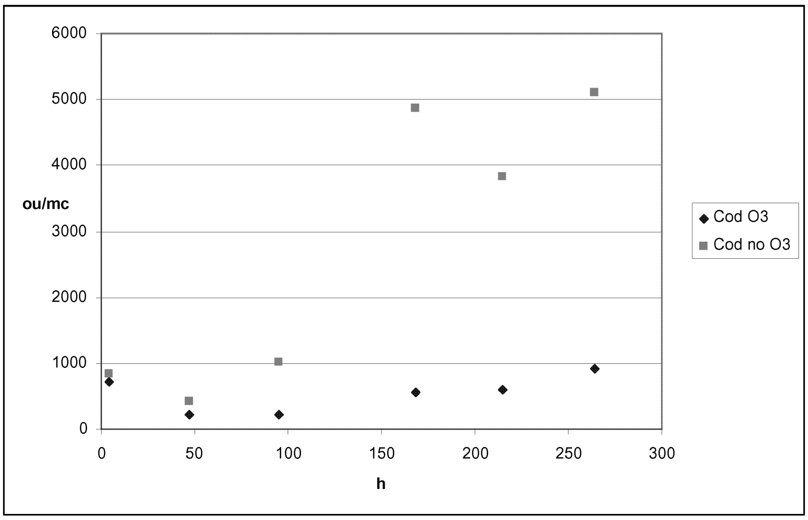

Fig. 3:averaged odour concentration trends comparison

The data were also elaborated to obtain an odour abatement efficiency index, calculated as (C_{od} F2- C_{od} F1)/ C_{od} F2; results are reported in Tab. 2

Time	Odour abatement efficiency index [%]		
	H	M	L
4h	6,2	16	25
23 h	43,5	48,8	52,8
97 h	74,7	70,3	70,5
168 h	93,1	85,3	88,3
214 h	76,8	85,8	88,3
264 h	80,8	78,9	85,3

Tab. 2: Odour abatement efficiency index relevant to fridge F2 with ozone generetor

The same data are reported in graphical form in figure 4:

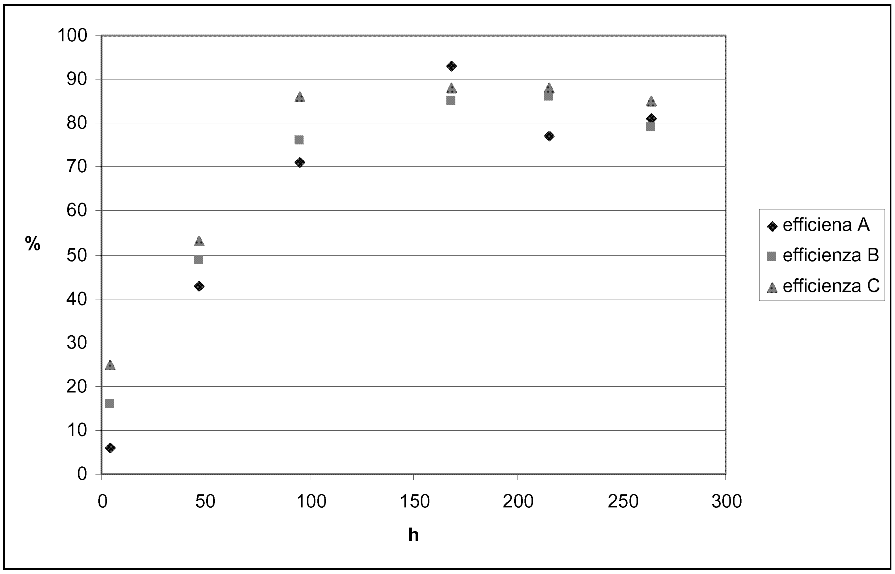

Fig. 4: Odour abatement efficiency index over time relevant to fridge F1

3. Conclusions

The analysis of the above described data allow the following consideration:

- Odour concentration measured during the early stages of foodstuff storage in the refrigerators were heavily influenced by the odour and conditions of the fresh food itself. In this phase, the efficiency of odour abatement by ozone and ions is limited, due to short residence time available to react with odorous compounds.
- Odour concentration within reference refrigerator F2 increases heavily with time growing from 1000 ou/m^3 up to 5000 ou/m^3 and more; this can be explained by the concentration of odour in the closed environment and the generation of odorous substances by foodstuff degradation.

- Odour concentration within F1 refrigerator, equipped with the odour abatement device, never exceeded 1000 ou/m^3 all over the experimental campaign.
- Odour abatement system is evident right for the early phases of the experiment, ranking variable values from 6% to 25% at the first air sampling. The average efficiency increases to 50% after 3 days, reaching 70% and then 85% after 5 and 7 days respectively. Odour abatement efficiency reaches then an asymptotic value around 80%.
- The three sampling points (low, medium, high) did not show appreciable differences in terms of odour concentration, indicating an uniform efficiency of the ozone action all over the refrigerator volume

4. Next steps

The planned follow-up of the presented work includes the hereby listed steps:

- An optimisation of the odour abatement system duty cycle, to ensure full performances without possibly affecting food aroma, in different load conditions ad with different food categories.
- A closed loop system, based upon the so defined logic, exploiting an ozone concentration sensor to ensure an optimal deodorisation activity for each situation.

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