SIMULATION TOOL FOR INDOOR AIR QUALITY IMPROVEMENT IN A COVERED SWIMMING POOL

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ABSTRACT

The use of hypochlorite for water disinfection is source of chloramines production, which are transferred to the atmosphere.Nitrogen trichloride (NCl_3) is the main component, which is a major cause of respiratory and ocular problems for swimmers and lifeguards.
This first part comprised a sampling campaign concerning the measurement of NCl_3 in a swimming pool (Picardie-France) during 15 days (October 2001). This campaign concerned the air quality diagnostics and showed that the majority of detected levels were critical (P_{50} = 0,44 mg/m^3).
In a second part the simulation of the NCl_3 dispersion was conducted with two main simulation tools : TRNSYS (thermal simulation) and FLUENT (CFD simulation).
In order to generate a source term in the dispersion model, a pollutant mass transfer model has been developed to predict the NCl_3 concentration in the indoor atmosphere. The latter seemed satisfactory and values were injected into the 3D-dispersion model. The thermal simulation tool TRNSYS generated the following results : 1) the swimming pool thermal behaviour during one year, necessary to provide temperature and moisture values as CFD boundary conditions 2) the thermal building simulation versus the real energy consumptions 3) the possibility to make energy savings by inducing HVAC modifications. Fluent code enabled the visualisation of pollutant accumulation zones.

KEYWORDS

Pollution, Air, Trichloramine, Analysis, Transfer, Modelling

INTRODUCTION

Swimming pool water's disinfection is required to destroy organic matter usually related to swimmers. The oxidation of nitrogen precursors generates three main forms of chloramines : mono-, di- and trichloramine (NH_2Cl, $NHCl_2$, NCl_3). The French regulation proposed solely a recommendation concerning NCl_3 (comfort level) at 0,5 mg/m^3.

Usually, different solutions are tested to reduce NCl_3 levels in the swimming pool's atmosphere : shocking of the water (high levels of chlorine are added which enable the destruction of a big part of chloramines) : this objective is usually not reached. The other possibility is to ensure a correct ACH (air changes per hour) to extract them from the hall or to strip them from the water.
This global approach, from analysis to the extraction system, will lead to an increase of air quality in the swimming pool's atmosphere.

METHODOLOGY

Analysis campaign

The analysis campaign has been conducted during October 2001 (October 8 - 21).
The targeted swimming pool is located in the north of France and built as a “caneton” model (one main pool without any playing area).

Sampling methodology
The sampling of trichloramine is based on the absorption of the gas on a cartridge impregnated (*cf.* figure 1’) with a specific reagent able to reduce NCl_3 into chlorides Cl^-. After elution, these anions are analysed with ionic chromatography (Air Liquide in partnership with ATMO Picardie). The main reactions are shown below.

$$3\ OH^- + NCl_3 \xrightarrow{pH=12(Na_2CO_3)} NH_3 + 3\ ClO^-$$
$$2\ ClO^- + As_2O_3 \rightarrow 2\ Cl^- + As_2O_5$$

Figure 1 illustrates the NCl_3 sampling spots around the swimming pool.

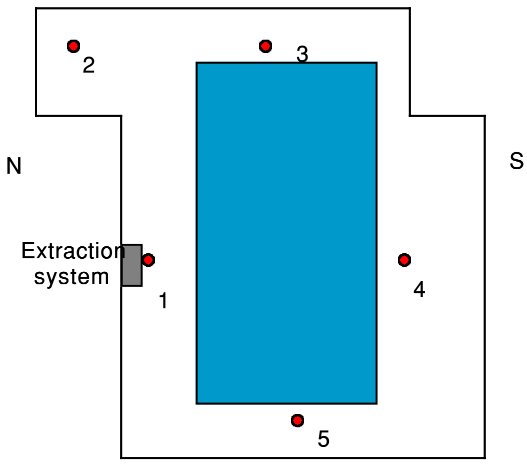

Figure 1 : sampling spots around the pool

Sampling strategy : 5 sampling spots as shown above (one located at the air extraction system / 4 spots surrounding the pool) - height = 50 cm - 3 sampling periods/day during 15 days (during different pool frequenting : students, public, training, ...)

$$[NCl3] = ([Cl^-] - [Cl^-]b) \times \frac{v}{V} \times \frac{1}{3} \times \frac{MNCl3}{MCl}$$

[Cl-] : chlorine concentration in sample (mg.L)
Cl-]b : chlorine concentration in blank (mg.L)
V :sample volume (mL)
V : air sampled volume (L)

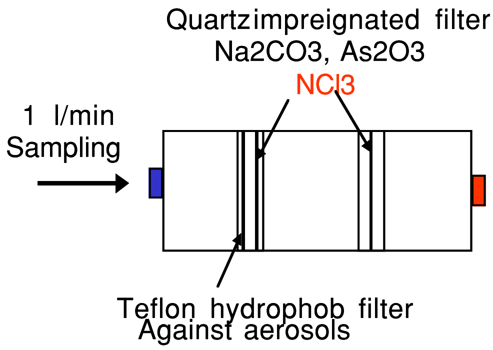

Figure 1' : Sample cartridge

Main results

The main results [NCl_3] (mg/m^3) obtained during the first two days are in Table 1 :

TABLE 1

Results of NCl3 concentrations during analysis campaign. AM : 8h30 – 11H30 (School) / PM1 : 13h30 – 16h30 (Public) / PM2 : 17h – 20h (training + public)

	Monday 8			Tuesday 9		
	AM	PM1	PM2	AM	PM1	PM2
Spot1	1,37	0,6	1,34	0,64	0,56	1,11
Spot2	0,55	0,71	0,68	0,99	0,35	0,86
Spot3	0,92	0,2		0,64	0,41	0,68
Spot4	0,94	0,38	1,08	0,33	0,44	0,95
Spot5	0,98	0,51	0,95	0,43	0,55	0,68

The major conclusions obtained during the analysis campaign are :

- 39% values > 0,5 mg/m^3
- NCl_3 concentration decreases a lot during window or roof opening
- No general behaviour rules were detected on NCl_3 concentrations measured on the same days
- No major behaviour related to pool frequenting mode (number of swimmers + swimmer's category : schools, training club, public, …)
- Spot 2 : may represent a potential accumulation zone : important levels measured
- Spot 1 : mainly represents average concentration and thus reflects good extraction

In conclusion, the high concentrations measured in this swimming pool confirm the need of a treatment system. Nevertheless, it seems that NCl_3 evaporation is related to several parameters, which make the prediction of NCl_3 concentration so difficult. This point will be discussed later with the attempt to define the evaporation model. A mass transfer model is created to enable the dispersion of a known amount of pollutant, which may represent a real evaporation case.

Simulation tool

The simulation tool is developed through three aspects : 1) a theoretical mass transfer model programmed with Matlab 6.1 2) a thermal simulation tool to generate boundary conditions (temperature and moisture) for the CFD tool and evaporation's influence on the mass transfer 3) CFD simulation to visualise NCl_3 dispersion into the hall.

Transfer model

a) Hydrodynamics of the pool : this part shows that the pool may be considered as a continuously stirred tank after 2h. A single reactor will be used to establish the mass transfer model even if a more complex model has also been developed.
b) Water-Air transfer model : gaseous phase transfer + liquid phase transfer are studied to assess the global mass transfer constants. The NCl_3 mass transfer limitation is globally located in the liquid phase and depends on several parameters : number of swimmers, pH, hall and water T°, area occupied by a swimmer, chloride requirement/swimmer, NH_3source/swimmer, energy dissipation/sw, …
c) Kinetic model : five chemical reactions are considered to predict the NCl_3 production from NH_3 source. No literature was found to consider urea contribution.

Results

An example of calculated NCl_3 concentrations is given in figure 2 concerning Tuesday 9 October. Figure 3 shows, for the same day, the concentration of all species in water.

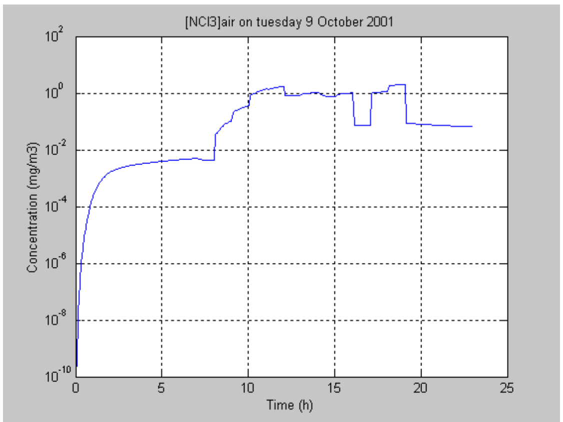

Figure 2 : $[NCl_3]$ evolution on Tuesday 9th October conditions are listed in Table 2.

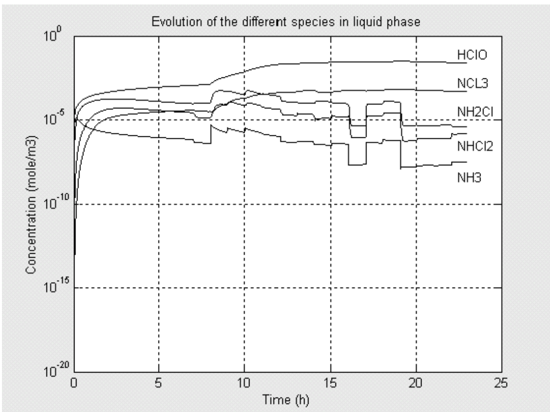

Figure 3 :All species evolution in liquid phase

Table 2 gives all the calculation parameters needed in the transfer model.

TABLE 2
Simulation conditions concerning 9 October

Day	NH_3	HClO	pH	Nb	Qv	Ab	T°hall	T°water
9/10	0,025	0,075	f(t)	f(t)	7500	4,7	f(t)	f(t)

*pH and Nb (number swimmers) : 8 values/day
T°hall and T°water : 23 values/day

The comparison with measurements are given in table 3.

TABLE 3
Comparison between $[NCl_3]$model and $[NCl_3]$ sampled

Sampling period	8h20 – 11h20	14h00 – 16H45	17h00 –20h00
$[NCl_3]$ air model (mg/m^3)	0,60	0,68	1,02
$[NCl_3]$air sampled at spot 1 (mg/m^3)	0,64	0,56	1,11

Discussion

The simulation values seem to match the real ones which were obtained on October 9. This was not always the case for the whole analysis campaign. The model needs to be validated by completing it with more frequent measurements of some parameters like the number of swimmers and pH.

CFD simulation

The CFD simulation is obtained with Fluent 5.

- Simulation domain : 500 000 Mesh grid
- Turbulence model : k-ε standard
- Steady calculation : October 9th - morning
- Boundary conditions : source term NCl_3 uniformly distributed on pool area
- Thermal boundary conditions on walls issued from TRNSYS software

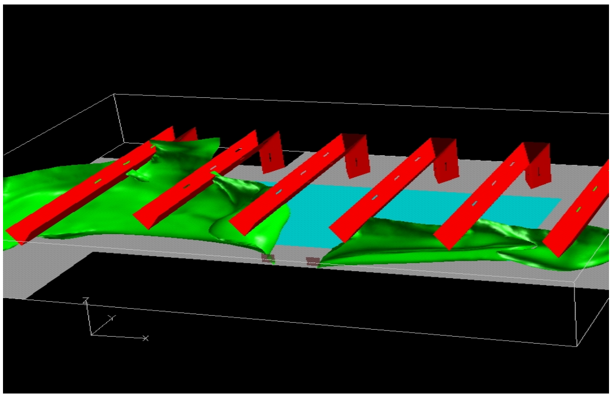

Figure 4 : CFD simulation on October 9

Results

Existence of 2 accumulation zones as shown on figure 4, in accordance with $[NCl_3]$ measured on spot 2 (0,99 mg/m^3) and spot 1 and 3 (0,64 mg/m^3).

Thermal simulation

The thermal simulation is achieved with TRNSYS. This tool is based on an evaporation model integrating pool frequenting and real meteorological data.

This information is obtained :

- ✓ boundary conditions are given over one year based on a the water evaporation model matching the real indoor temperatures measured during the analysis campaign

- ✓ energy savings reached by air flows and ventilation operation system : about 22% on air heating and 10% on water heating. Total annual savings are estimated at 14,4%.

CONCLUSION

The main objective of this study was to show the important levels of NCl_3 encountered in swimming pools. The mass transfer model seems useful to predict NCl_3 concentration which will improve the prediction of air quality when air treatment systems have been installed.
This first step showed also the benefit of a combined approach in a building (air quality + thermal comfort) which can be an interesting tool to predict human exposure to indoor pollutants. In addition, it demonstrates that the energy savings reached may be beneficial to focus on air quality improvement.

Next steps

A treatment system is expected, current 2002 to extract NCl_3, by stripping the chloramines of the pool. A second analysis campaign is planned after the treatment system has been installed in order to assess air quality improvement.

Acknowledgement

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