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Risk assessment in a damaged clean room by using the entropic Lattice Boltzmann method

Piroz Zamankhan

School of Engineering, University of Kwazulu-Natal, Durban, South Africa

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ABSTRACT

Contamination risk factor (CRF) measures the effectiveness of clean room particle containment in preventing the airborne particles migration into a clean room from a corridor. This study describes the use of computer experiments to assess decontamination effectiveness of a barrier device such as a door to minimize particle migration rate. To this end, the air flow, which leaks out of the clean room through the gap of the door that is out of alignment, is simulated using the Lattice-Boltzmann method with the Bhatnagar–Gross–Krook (BGK) operator for collisions. The Knudsen number of the airborne particles is Kn ~ 1, and they are in the transition regime. The blowing of airborne spherical particle in the corridor is simulated assuming that the forces experienced by a particle are a complex combination of interactions with individual gas molecules, and macroscopic interactions. It is shown that the misaligned door and uneven gaps along the edges induce an unstable pressure field. The unstable pressure results in an undesired air direction and increases the CRF level. This observation indicates that improper maintenance of a cleanroom can lead to contamination and a severe loss in end user product quality.

1. Introduction

A cleanroom is an environment with a low level of environmental pollutants including dust, aerosol particles, chemical vapors and bacteria (Whyte, 2001). Cleanrooms are used for manufacturing or scientific research. Clean conditions are necessary to prevent products from getting contaminated and either to malfunction or become hazardous to people.

Figure 1(a) illustrates the clean room floor plan in Iceland. This clean room is used for scientific research and it has a controlled level of contamination which is characterized by the number of very small particles such as airborne particles per cubic meter. A cleanroom as defined in the International Organization for Standardization (ISO) standard 14644-1:2010 is a room in which the concentration of airborne particles is highly controlled. Table 1 lists selected airborne particulate cleanliness classes for cleanrooms and clean zones. The table indicates that an ISO 1 cleanroom allows only 12 particles per cubic meter of 300 nm and smaller (Whyte, 2001). Note that the air outside of the cleanroom may contain 35,000,000 particles/m^3 of air in the size range 500 nm and larger in diameter.

In light of the above, cleanrooms should be constructed and used in such manner as to minimize the introduction, generation, and retention of particles inside them. For example, the ISO 7 cleanroom standard recommends the use of tightly sealed doors to limit leak flow at a pressure difference of up to 50 Pa (Whyte, 2001). For a perspective, the ISO 7 cleanroom standard allows 350,000 particles/m^3 of 500 nm and larger and only 2500 particles/m^3 of 5 μm and larger.

E-mail address: qpz002000@yahoo.com

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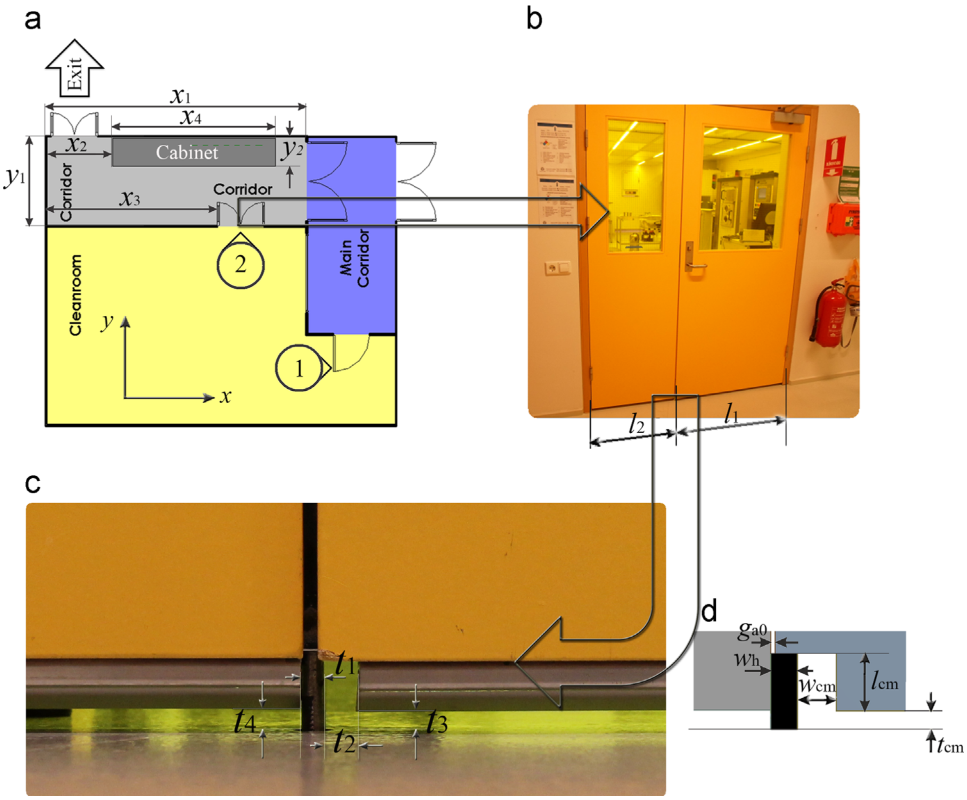

Fig. 1. (a) The clean room floor plan in Iceland. (1) The clean room front door. (2) The damaged emergency door. (b) An image of the damaged door from outside. Here, $l_1 = 0.9$ m and $l_2 = 0.6$ m. (c) The undesignated openings around doorframes and compression seal door sets. Here, $t_1 = 0.012$ m, $t_2 = 0.03$ m, $t_3 = t_4 = 0.005$ m. (d) A simplified model for the undesignated opening around doorframes. The following are door opening sizes; $t_{cm} = 0.005$ m, $l_{cm} = 0.045$ m, $w_{cm} = 0.03$ m, $w_h = 0.012$ m and $g_{a0} = 0.001$ m.

Table 1
The basic classification table for cleanrooms and clean zones proposed in ISO DIS 14644-1 (2010).

ISO classification number (N)	Maximum particle number density limits (particles/m^3 of air) for particles equal to and larger than the considered sizes shown below					
	0.1 μm	0.2 μm	0.3 μm	0.5 μm	1 μm	10 μm
Class I	10					
Class II	10^2	24	10	10		
Class III	10^3	237	102	35		
Class IV	10^4	2370	1020	352	83	
Class V	10^5	237×10^2	102×10^2	3520	832	
Class VI	10^6	237×10^3	102×10^3	352×10^2	8320	293
Class VII				352×10^3	832×10^2	2930
Class VIII				352×10^4	832×10^3	293×10^2

The cleanroom in Fig. 1(a) is a positive air pressure cleanroom Heating, Ventilating and Air Conditioning (HVAC) system. This cleanroom with an area of approximately 50 m^2 is normally used for the manufacture of electronics and optics items and for high quality research. An inner workspace appears to be certified to an ISO 5 cleanroom classification.

The air conditioning system is dependent of a supply air for keeping a room at a pressure differential with the ambient areas. The concentration of particles per cubic meter of this air may be estimated as 352×10^5 in the size range 500 nm and larger in diameter.

The facilities (such as walls, floors, ceilings, air conditioning derbies, spills, *leaks*, room air and vapors), skin flakes, spittle, fibers, hair, friction and wear particles, particulates floating in air, Bacteria, organics and moisture, floor finishes or coatings, cleaning chemicals and the product being manufactured can all contribute to contamination.

Figure 1(b) shows an image of the door between the clean room and the corridor. The yellow light shines through windows is used to prevent unwanted exposure of photoresist to light of shorter wavelengths (Jaeger, 2002). The door is misaligned and uneven gaps along the edges and the compression seal sets are illustrated in Fig. 1(c).