



PARTICLE GENERATION FROM HUMANS – A METHOD FOR EXPERIMENTAL STUDIES IN CLEANROOM TECHNOLOGY

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ABSTRACT

Particle generation from humans is a severe problem when working in cleanrooms and other controlled environments. Data regarding the number of particles generated by humans are few and there are no detailed references as to how these studies have been performed. An experimental method to determine the particle release from a human being in a cleanroom was developed and used to describe the variation of particle concentration with time, in regards to both physical activity as well as the protective garment used. The particle strength of source for a human being was studied during different activities and when wearing two different types of clothing. Results from this study could not be directly compared to data found in the literature, due to the lack of historical information. However, it was found that the cleanroom garment used is much more efficient, when greater movements were performed by the test subject.

INDEX TERMS

Cleanroom technology, Particle generation, Human, Cleanroom garment, Contamination control

INTRODUCTION

Cleanrooms are highly specialized working areas used to protect product, process, as well as personnel from being contaminated. A cleanroom is defined according to ISO 14644-1 (1999) as, “a room in which the number concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation and retention of particles inside the room and in which other relevant parameters, e.g. temperature, humidity and pressure are controlled if necessary.” The air cleanliness in a cleanroom is controlled by passing incoming ventilation air through highly efficient filters and by also dressing the operators in specialized cleanroom garments. Cleanrooms are used in many different industries, for instance, in the microelectronics, the pharmaceutical industry as well as the food and beverage industry. Cleanroom technology is also used when performing certain orthopaedic surgical operations (Ramstorp 2000).

Ever since the first cleanrooms were developed during the 1950s, it has been known that people are the major and also the most critical sources of contaminants (i.e. particles). The particles generated by humans are, to a very great extent, skin scales that are released when the outer layer of skin is replaced by new skin. Furthermore, since all outer surfaces of our bodies are more or less covered with microorganisms, these organisms are also released when the skin is renewed. The contaminants generated by humans can thus be divided into two major categories: dead particles and microorganisms. Both types of particles are of interest when protecting the work to be undertaken in cleanrooms.

To counteract the particles generated from personnel in a cleanroom, special textile fabrics as well as types of garments have been developed. These garments are used in order to act as a filter and thereby as a barrier between the wearer and the surrounding environment.

The number of particles emitted from a person during different activities and wearing different types of clothing can be found in the literature. But most of the information available originates from one source. In 1965 the Austin Contamination Index was published (Austin and Timmerman 1965). The article states that a person wearing a smock on top of private clothes generates 100,000 particles per minute ($\geq 0.3 \mu\text{m}$) when sitting or standing totally still. After 40 years, the Austin Contamination Index (see Table 1) is still being used as a guideline. The total area of cleanroom technology, including particle measuring methods, has developed immensely since then. Austin states that the data in the Austin Contamination Index are “estimations of collected data.” With this in mind, the

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natural question is: Does this still qualify as a standard that should be automatically followed?

Table 1. The Austin's Contamination Index. Number of particles generated by a person per minute, at different degrees of activity, wearing two different types of clothing ($\approx 0.3\mu\text{m}$) (Austin and Timmerman 1965). The present authors have inserted the ratio between snap smock and membrane coverall.

Activity	Snap smock (particles/min)	Membrane coverall (particles/min)	Ratio
Sitting or standing still	100,000	10	10,000
Light movement: head, leg, arm	500,000	50	10,000
Heavy movement: head, leg, arm, foot	1,000,000	100	10,000
Change position: sitting down, rising up	2,500,000	250	10,000
Walking 0.9 m/s	5,000,000	500	10,000
Walking 1.6 m/s	7,500,000	750	10,000
Walking 2.2 m/s	10,000,000	1,000	10,000

The purpose of the study presented in this paper was to develop an experimental method and establish a mathematical model to determine the particle strength of source of any particle-generating object. This method was used to determine the number of particles emitted from a person and to compare the data obtained with the data already existing in the literature. Different types of clothing and movement patterns were used.

RESEARCH METHODS

Experimental set-up

The particle release from a human being was experimentally determined using a test chamber (3 x 3 x 2.4 m) with floor, ceiling and walls made of stainless steel. The chamber was entered through an airlock equipped with airtight doors. The chamber was situated within a laboratory hall and equipped with a separate ventilation system. The ventilation air to the chamber was controlled for temperature as well as relative air humidity, and was filtered through a ULPA filter. The relationship between the incoming and outgoing airflow produced an overpressure of at least 5 Pa. The experimental chamber was designed in order to create a well-mixed system. Two air changes per hour were used during all experiments. The temperature was 20°C and the humidity 35% RH during all experiments. The particle size and concentration of the airborne particles was measured using an aerodynamic particle sizer (APS, model 3321, TSI Inc., USA). The APS determines the aerodynamic sizes of the particles, ranging between 0.3 and 20 μm .

Mathematical model

In order to calculate the strength of source, a model has to be established that describes how the concentration varies with time. The model also has to take into account various parameters that affect the concentration.

$$C = C_0 e^{-\frac{aQ+v_d A}{V_r} t} + \frac{QC_1 + c}{aQ + v_d A} \left(1 - e^{-\frac{aQ+v_d A}{V_r} t} \right) \quad (1)$$

t = Time [s]

C = Particle concentration at time = t [particles/ m^3]

C_0 = Particle concentration when $t = 0$ [particles/ m^3]

C_1 = Particle concentration in the air into the chamber [particles/ m^3]

Q = Ventilation flow rate [m^3/s]

v_d = Velocity of deposition [m/s]

A = Surface area of the chamber [m^2]

V_R = The volume of the chamber [m^3]

a = Mixing factor. For mixed ventilation the ideal value is 1, which means complete mixing.

c = Strength of source, number of produced particles per time unit [particles/s].

In order to determine the strength of source all parameters and constants in Equation (1) have to be established. This was done using the following procedure. Equation (1) can be simplified by measuring the decay of particle concentration subsequent to the introduction of a portion of aerosols to the chamber. The time is set to zero, at an arbitrary point immediately after stopping the production of aerosol. The concentration at this time is C_0 . Stopping the production of particles eliminates the strength of source. Since the incoming air is filtered through a ULPA filter the particle concentration, C_1 , is almost equal to zero and thus eliminated from the equation. This simplifies Equation (1) to:



$$C = C_0 e^{-\frac{aQ + v_d A}{V_R} \cdot t} \tag{2}$$

This expression can be brought to a linear form by taking the natural logarithm:

$$\ln C = \ln C_0 - \frac{aQ + v_d A}{V_R} \cdot t \tag{3}$$

By plotting $\ln C$ as a function of time, the intersection with the y-axis, $\ln C_0$, and the slope

$$\text{slope} = \frac{aQ + v_d A}{V_R} \tag{4}$$

could be determined. Since V_R is known, a value for $aQ + v_d A$ can be calculated. This means that the only unknown parameter in Equation (1) becomes the strength of the source, c . The values of the unknown parameters as a function of the aerodynamic particle diameter were experimentally determined using an aerosol generator (BEG 100, Palas GmbH, Germany) with glass particles as solid aerosol.

Determining the particle release from a person in a cleanroom

To determine the strength of source, the test person entered the almost particle free test chamber through the airtight airlock. The person performed specified movement patterns and the particle concentration was measured during a period of 30-45 minutes. The measured time-dependent particle concentration was fitted using a statistical software (Microcal Origin 5.0, Microcal Software Inc., USA) using Equation (1). The characteristic constants for the different particle size intervals, determined in earlier experiments, were inserted and the unknown strength of source was determined, using the least-square method.

Different people generate different amounts of particles at different times depending on a variety of parameters. This means that a reliable and exact investigation must be performed in a very controlled manner. The test person has to follow the same everyday procedures before and in between experiments and must not be exposed to any high-particulate environments. A reference method was used to assure the reliability of the experiments.

First, the strength of source was determined seven subsequent times in a series of experiments carried out on the same day in which the test person was only wearing underpants and not performing any movement (see Figure 1). The results showed that a stable particle release after showering was first obtained after about 6 hour. For that reason, the person followed a standardized procedure every day and all experiments were performed at least 6.5 hours after showering.

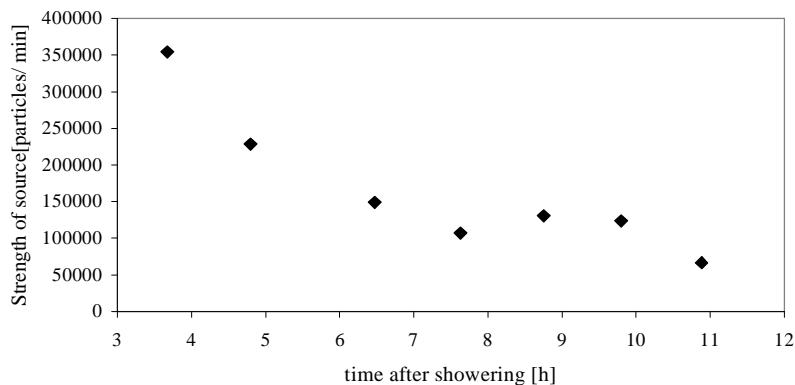


Figure 1. Particle strength of source as a function of time after showering for particles larger than 0.5 μm

Over several days a number of reference experiments were performed in which the test person wore the same clothes and performed the same activity. This was used to establish a reference level. All experimental days started with a reference test and a ratio to the reference level was calculated in order to directly compare different tests.

Characteristics of the test person and movement patterns

The test person: Male, 68 kg, 176 cm tall. No facial hair and moderate hair length.

Cleanroom garment: A coverall and hood (100 % polyester), single use facial protection and latex gloves. The coverall and hood were produced in a cleanroom environment, were new and had not been subjected to washing prior to use.

Movement

Sitting totally still – No movement at all.

Sitting while performing arm movements – One arm, at a time was moved at an angle of 90°, back and forth in a sweeping motion. The original position of the arm was directed straight ahead with a 90° bend at the elbow. The movement frequency was one second for one arm to be moved back and forth.

Standing with rotating torso – Both hands grabbing the waist and rotating the upper body from side to side, as far as possible in each direction. The time for turning from one side to the other was one second.

Walking on the spot – Walking on the spot with a frequency of two steps per second.

Figure 2 shows the particle concentration increasing after the test person enters the test chamber. After about 30-45 minutes the particle concentration stabilized. The mean particles size distribution at this steady state condition is shown in Figure 3

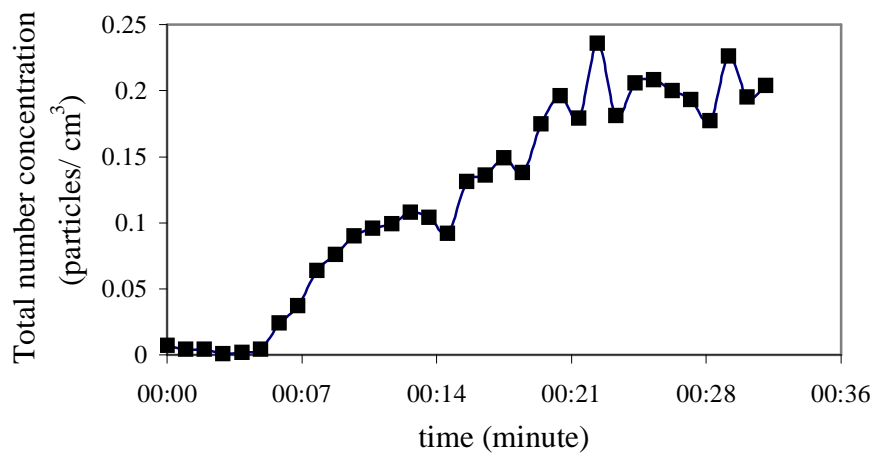


Figure 2. Variation of particle concentration versus time with a test person wearing underpants only and walking on the spot.

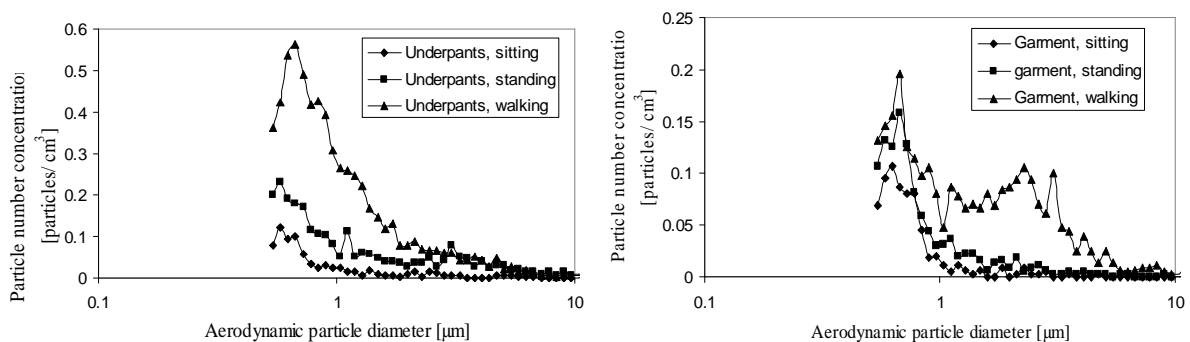


Figure 3. Particle concentration versus aerodynamic particle diameter for a test person wearing underpants only and cleanroom garment, performing different movements.

Table 2. Particle strength of source for the test person performing various physical activities and wearing underpants and cleanroom garment. ($D_a \approx 0.53 \mu\text{m}$). The ratio of underpants and cleanroom garment has been inserted.

Activity	Underpants (particles/min)	Cleanroom garment (particles/min)	Ratio
Sitting still	40,000	40,000	1.0



Sitting: arm movements	90,000	70,000	1.3
Standing: rotation torso	140,000	60,000	2.0
Walking on the spot	400,000	180,000	2.2

The estimated particle strength of source for different clothing and activity of the test person is summarized in Table 2.

CONCLUSIONS AND IMPLICATIONS

The number of particles generated by a human being presented in this paper cannot be directly compared to the data obtained from the Austin Contamination Index since these data only apply to particles $\geq 0.3 \mu\text{m}$ and the test method is unknown. The data obtained from the investigations presented in this paper are valid for particle sizes between 0.53 and 10 μm measured as equivalent aerodynamic particle diameter. Our results cannot be considered as general since only one person has been tested. However, a method that can be used to study the efficiency of protective garments in cleanrooms has been developed. Further studies are now in progress at our laboratory in Lund.

ACKNOWLEDGEMENTS

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