

Distribution of Airborne Microorganisms in Yellow Sands of Korea

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Distribution of airborne microorganisms was determined with two different types of air samplers, the Anderson cascade sampler and the Aerobioscope sampler, in the vicinity of Taejeon. The size distribution of particles carrying bacteria and fungi was concurrently measured. The concentration of detected viable airborne particles was greatly varied. It was observed that the number of microbial particles increased in April and October. The most size of particles carrying bacteria was larger than 4.7 μm in mean aerodiameter, which made up 69.8% of the total particle fraction. About 63.2% of fungi-carrying particles were smaller than 4.7 μm in aerodiameter. The distribution of particles on Yellow Sand Phenomena days was also analyzed. The number of fine particles having mass median aerodiameter from 1.0 to 10 μm increased on Yellow Sand Phenomena days to about 6 times that on normal days and the number of colony forming unit (CFU/m³) of airborne bacteria also increased by 4.3 times in April. The results from the Anderson sampler showed that the concentration of bacteria increased greatly on the fraction of fine particles ranging from 0.6 μm to 4.7 μm in diameter. Unlike the increase in bacterial flora on Yellow Sand Phenomena days, the fungal concentration slightly decreased and showed a normal size distribution pattern. This study suggests that a long-range transmission of bacteria results from bacteria adsorbing onto the fine particles during the Yellow Sand Phenomena.

Key words: airborne microorganisms, distribution of particles, concentration of microbial particles, Yellow Sand Phenomenon (YSP) days.

There has been the increasing concern about airborne microorganisms because many respiratory and other health disorders are associated with and spread by aerosols outdoor and indoor environments from natural, industrial, or artificial sources (14, 20, 31, 44). As naturally occurring airborne microorganisms consist mostly of bacteria, fungi, and viruses, knowledge of their sources, concentration, and biological activity are of great importance (23). Examples of infections that may result from the presence of microorganisms in the air include tuberculosis, measles, legionellosis, and histoplasmosis (44). With these concepts in mind, many studies have been conducted in office buildings, operating rooms, agricultural settings, animals feed and processing industries, sanitary landfills, waste water treatment, sewage treatment plants, and other facilities where biological air contaminants may pose health hazards (1, 6, 11, 15, 16, 18, 24, 28, 37, 42, 47).

Microorganisms were also discovered in the surface air far out at sea when Charles Lindbergh

found them at high altitude by holding open Petri dishes outside his airplane window over the Atlantic Ocean in 1933 and from commercial aircraft over the Caribbean Sea. More recently, with an airborne sampler, the spatial distribution of outdoor bacteria was positively related to air masses, fronts, urban activity, and altitude (30).

The measurements of seasonal or annual distributions of microorganisms in the atmosphere were conducted on a grass seed field in the Willamette River valley in Oregon, in Moscow, Russia, on the top of a 400 foot high building in Montreal, Canada (30), at four different localities during a period of 3 years, in Sweden (8), and in the urbanizing sites of Mexico city (40). A graph of Montreal data showed that the annual bacterial distribution had minor and major minima in summer and winter, with maxima in spring and fall, and that the fungi had a winter minimum and summer maximum (30). A report of Bovallius *et al.* (8) showed the influence of certain meteorological factors on the number of bacteria. Rain or high relative humidity caused a decrease in the bacterial counts, while high temperature or high wind velocities in-

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creased the counts. Long-range transmission of bacterial spores from a sandstorm area north of the Black Sea to Sweden by air was reported (7).

Selecting an air sampler to measure viable airborne microorganisms is important and difficult. As the overall efficacy of a bioaerosol measurement device depends on physical parameters like its inlet and collection efficiencies and its bioefficiency (46), the comparison of samplers for detection and enumeration of airborne microorganisms (22, 50) is still a hot issue. Available aerosol sampling techniques fall into several categories. The most important ones are gravitational sedimentation, inertial impaction, centrifugation, filtration, and electrical and thermal precipitation (23). Although, there are many questions concerning their efficiency and accuracy during assessment of concentration levels of viable microorganism, the most commonly used methods of airborne sampling techniques for microbial collection today are impaction into agar, impaction onto a glass slide, and impingement into a liquid (13, 14, 27).

A variety of methods is available for sample analysis: culturing, direct microscopy, bioassay, biochemical assay, and immunological assay (23). For direct microscopy, a staining method such as acridine orange direct counting (AODC) is usually utilized (48). Coulter count, immunofluorescence microscopy, scanning electron microscopy, or radioactive probes have also been utilized (10, 12, 21, 33, 36, 46). In addition, dynamic particle-size spectrometry has recently been used in laboratory experiments for measuring total and size-selective counts while microorganisms are still in the airborne state (46).

The most commonly used method for the assessment of viable airborne microorganisms is known as the cultural assay (23). The sample is collected onto an agar surface which can be cultivated directly to quantify the viable microorganism. In the presence of high microbial concentrations, a sample collected in to a liquid (impingement) has advantages over a sample collected onto agar (impaction) because it can be diluted to the required level and can also be analyzed by several different assays (23, 44). However, microbial clusters may break up during liquid impingement, potentially resulting in a high bioaerosol particle count during sampling, and it can cause the captured cells to become dehydrated, thus impairing their biological activities and making detection different (23). Other collecting methods are operated by impacting airborne microorganisms onto a nutrient surface by passage through slit or through several holes that are spaced in a uniform pattern.

The microorganisms are aspirated through the slit or holes to impact onto a stationary or moving agar surface (44). If the sample contains more than one impaction stage, this cascade impactor collects microorganisms of different size ranges. For example, the Anderson six-stage viable particle sizing sampler (2) (Graseby-the Anderson Inc., Atlanta, Ga.), well known as the best sampler for recovering aerosol of free microorganisms, collects microorganisms in six size ranges (22, 35). Each stage of this cascade impactor contains 400 impaction holes with diameters ranging from 1.81 mm in the first stage to 0.25 mm in the sixth stage. The corresponding cut-off sizes (i.e., the size of a microorganism at which 50% were collected) for the six stages are 7.0, 4.7, 3.3, 2.2, 1.1, and 0.65 μ m (22, 44). The Aerobioscope impactor sampler (Sibata co., Japan) has only one stage with a rectangular impaction slit. The latter impacts onto a moving agar surface, while the Anderson sampler impacts onto stationary surface. As the cutoff size of the Anderson sampler shows a collecting efficiency similar to the human respiratory system (3), it is useful for discriminating the distribution of respirable airborne microorganisms. Although the impinger sampler has an advantage in collection, its requirement for a harvesting solution seems to be the final disadvantage in field sampling. An impaction system was used in this study for these reasons.

When violent sandstorms happen in the district of Mongolia or North China it makes lots of fine particles float up to a high altitude. After floating at high altitude, these fine particles drift with a left sided western air flow and drop slowly over the whole Korean peninsula. It is called the Yellow Sand Phenomenon (YSP), which usually happens from March to May for several days (49). When the Yellow Sand Phenomenon happens, many people suffer with respiratory diseases or a sore eyes because Yellow Sand Dust includes minerals like quartz, feldspar, mica, and magnetite (45). The distribution characteristics of the airborne particles on days of Yellow Sand Phenomenon are not well documented (45, 49). Most scientific interest has been focused on short-range airborne transmission in medical or hygienic fields and more basic research has been done on the behavior of bacterial aerosols indoors (4, 14, 19, 26, 30). As the long-range airborne transmission of bacteria is little regarded as causing health or economic problems, there are few reports about the occurrence and mechanism on long-range transport of airborne microorganisms (7, 8, 9, 25). Comparing distributions of airborne microorganism between ordinary days and Yellow Sand Phenomena days will help us und-

erstand the mechanism of transmission of airborne microbes. This experiment suggests that there are indirect results of long-range transmission of microorganisms.

In this report, we present the distribution pattern of airborne microbes and dust particles during a year. The aim of this study was to determine the monthly variation in airborne microorganisms and to compare the distribution between normal days and Yellow Sand Phenomena days.

Materials and Methods

Apparatus

Samples were collected in the vicinity of Taejeon city. For field sampling, the Anderson cascade sampler (Graseby-Anderson Inc., USA) with a flow rate of 28.3 liters/min (2) was used from January to December 1988. The Aerobioscope impactor sampler (Sibata co., Japan) with a flow rate of 45 liters/min was used from May 1986 to December 1988. For monitoring airborne dust particle distribution, Royco Particle Counter (HIAC Royco Co. model M-218, U.S.A.), Aerosol Mass Monitor of Piezobalance (Kanomax Co. model 3511, Japan), and Digital Dust Indicator (Sibata Co. model P-512, Japan) were used. Methods applied in this study with the above instruments were of two types. One was a light scattering method using a Digital Dust Indicator and represented the relative mass. Another was a piezoelectric balancing method using a Respirable Aerosol Mass Monitor and represented the absolute mass. Values from monitors were converted as the value per minute in cubic meters. Samplers were located 1 m above the ground at the sampling site. Particles were usually collected between 10 a.m. and 3 p.m.. Sampling time was adjusted to 2 to 20 minutes depending on the efficiency of the sampling devices and the density of microbial populations. Each sample for particles and microbes was collected in triplicate or more.

Media

Because fungi grow faster than bacteria on nutrient media, it is still difficult to select the sole organisms in the process of air sampling. The precise evaluation of bacterial density is usually interrupted when filamentous fungi grow on agar plated Petri-dishes. For authentic culture of bacteria, four antifungal agents (griseofulvin, amphotericin B, nystatin, cycloheximide) were tested to inhibit the growth of twelve strains of fungi that frequently occurred in air. Influences on bacterial growth of these compounds were also evaluated with four strains of *Bacillus* sp. Among antifungal agents, nys-

tatin was the most effective Fungistatic and showed minimum inhibitory effect on tested bacterial growth (unpublished data). Selective culture media for fungi were also formulated through several tests for selection of optimal antibiotics in order to inhibit bacterial growth and show less influence on fungal growth. Supplement of surfactant was designed to retard the growth of fungi. Nine strains of fungi that frequently appear in nature were cultured on Potato Dextrose Agar for three days. *Rhizopus* sp. and *Mucor* sp. rapidly flourished with filamentous mycelia within 24 hours of inoculation. Petri-dish (inner diameter, 90 mm) was almost covered with mycelia and the growth diameter of *Rhizopus* sp. was about 329 mm after 72 hours culture. The addition of a nonionic detergent, Triton X-100 into basal media allowed for easy counting of fungal colony forming units collected on agar plated Petri-dishes from air. Bacterial samples were incubated on Tryptic Soy Agar with 50 µg/ml of nystatin. Fungal samples were incubated on Potato Dextrose Agar with 0.3% of Triton X-100 and 50 µg/ml of chloromycetin.

Enumeration

Air samples were directly impacted onto the surface of the pour-plated Petri-dish for the given time and incubated immediately. After consecutive incubations for 1 day at 37°C and 3 days at 30°C, the number of colony forming units on the surface of agar media was counted and reenumerated according to the positive hole methods (34, 41). After impaction of fungal samples onto agar, incubation and reenumeration steps were the same as that for the bacterial counts. An exception was that the incubation was carried out for 3 days at 20°C and for 2 days at 28°C consecutively.

After reenumeration, the colony number was treated as the real concentration of airborne bacteria in collected samples. There was no reenumeration step in the Aerobioscope sampler and the total number counted was regarded as the true concentration of airborne bacteria in collected samples (50).

Results and Discussion

Distribution of airborne bacteria

During the sampling period from 1986 to 1988, the concentration and distribution of airborne bacterial flora showed great variations depending on sampling period and sampling techniques used. For the comparison of diurnal fluctuations, the sampling was conducted at 10 a.m. and at 3 p.m. The ratio of bacterial concentration between morning and afternoon is shown in Table 1. Between

Table 1. Comparison of diurnal bacterial density collected by the Aerobioscope sampler at 10 a.m. and 3 p.m. in 1986

Month	Bacterial density (CFU/m ³)	
	10 a.m.	3 p.m.
May	99.0	114.0
June	73.1	74.0
July	56.7	57.2

*During this period, total sampling days was 57. Each sampling activity was conducted in triplicate or more.

May and July 1986, the total sampling period was 57 days and sampling activity was conducted with the Aerobioscope sampler only. During this period, the diurnal variation in bacterial concentration was surprisingly low. The maximum diurnal difference showed a 15% increase over of control in May 1986, but the difference in Jun and July 1986 was very slight. Considering the report of Lighthart and Schafer (30), the conditions of microclimate for sampling conducted during 10 a.m. to 3 p.m. might be similar. If samplings had been conducted at various time periods such as before the sunrise (i.e., 06 to 08 h), the midday (08 to 15 h), and the late-afternoon (15 to 18 h), diurnal differences of bacterial concentration would be clear.

Monthly variations in airborne bacterial concentrations in 1988 are presented in Fig. 1. The number of bacterial colony forming units (CFU/m³) increased in Spring and Autumn. The maximum value was recorded in October and CFU/m³ decreased sharply during winter season. It was thought that the lowest value in March was due to natural dryness and poor bacterial growth during cold winter season. The maximum peak of bacterial occurrence in October could be due to harvesting activities in rural districts and flushing of bacterial spores in air. This trend was very similar to the earlier report of Lighthart (28). The lower densities recorded between May and September was thought to be because heavy rain removed inorganic and organic particles from the air and the number of the particles carrying bacteria became scarce in the atmosphere. Among environmental factors for bacterial density, rain and high humidity can cause a decrease in the bacterial counts, while high temperature or high wind velocities are able to increase the counts (8).

During above sampling periods, the daily highest concentrations of airborne bacteria collected with the Aerobioscope sampler were 486 (1986. 8. 13.), 801 (1987. 10. 26.) and 1,579 CFU/m³ (1988. 10. 1.), respectively. The lowest concentration were 5 (1986. 2. 5.), 31 (1987. 8. 11.), and 32 CFU/m³ (1988. 4. 9.), respectively. During the sampling period in 1988,

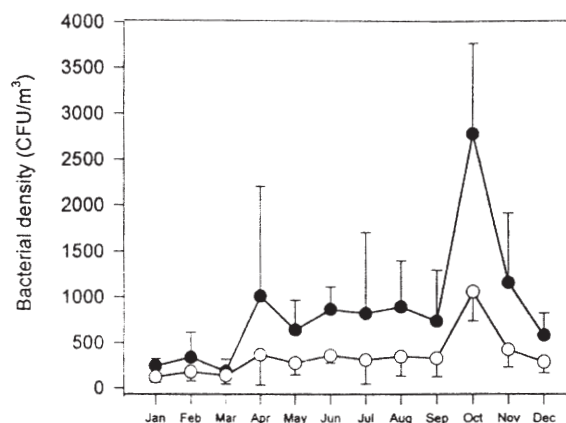


Fig. 1. Monthly mean distribution of bacteria in 1988. ●: analyzed with the Anderson sampler. ○: analyzed with the Aerobioscope sampler. Data represents the mean value with standard deviation.

the daily lowest concentration of bacteria collected with the Anderson sampler was 61 CFU/m³ on March 22 and the highest concentration was 4,178 CFU/m³ on October 20. The monthly variation was from 198 in March to 2,782 CFU/m³ in October. The annual mean of airborne bacteria collected with the Anderson cascade sampler was 805, whereas that with the Aerobioscope sampler was 356 CFU/m³. The average collection efficiency of the Anderson cascade sampler in 1988 was 2.4 times that of the Aerobioscope sampler. This result suggested that the Aerobioscope sampler has a poor collection efficiency for small particles.

It was thought that the density of airborne bacteria is greatly related to the number of particles in the air. A precise evaluation of microorganism concentration is a very difficult task, as has been reported earlier in many papers from the aerobiological field (13, 15, 22, 23, 26, 32, 35). Usually, the number of airborne microorganisms is very variable due to the several factors such as collection efficiency of sampler, microbial viability on nutrient media, relative humidity, temperature, microclimate, and ecological conditions of sampling site and time (8, 17, 29, 30, 38, 39, 44). In order to investigate the intact size of bacterial particle, the 6-stage cascade Andersen sampler was used and the results are shown in Table 2. About 69.8% of the natural airborne particles with the Anderson sampler had a diameter of larger than 4.7 μ m. Considering bacterial size itself, the result suggested that drifting bacteria attach to dust particles and become clusters rather than free cell forms.

Numerous authors investigating respiratory tract penetration by air particulate pollutants have recognized the relationship between particle size and lung penetration. It was concluded that the particle

size or aerosol of pathogenic organism determined the degree of infectivity by the respiratory route (3, 43). Nasal efficiency for screening out airborne particles entering the respiratory tract is practically 100 percent for particles above 5 μm and decrease with particle size to zero for 1 μm particles (3, 43). From these results of bacterial distribution (Table 2), particles having 1.2 to 4.7 μm of diameter were considered respirable airborne particles. Knowledge about distribution characters of these particles will provide basic information about airborne respiratory diseases.

When using a simple staining method such as acridine orange direct counts (AODC) for the detection of airborne microorganisms, the real concentration of collected airborne microbes would be higher than that of viable cell counts because the total bacterial counts included viable and dead cell numbers and the viability of airborne microbes on media reached at most about 30~70% of real number (46).

Concentration of fungi

Because of their growth and aero-persistence

characteristics, fungal spores are abundant on particles in the air and their densities often exceed 5,000 CFU/ m^3 (40). Monthly and seasonal variations in 1988 are shown in Fig. 2. Trends of these variations were not similar to those of bacteria. The overall density of fungal particles was much higher

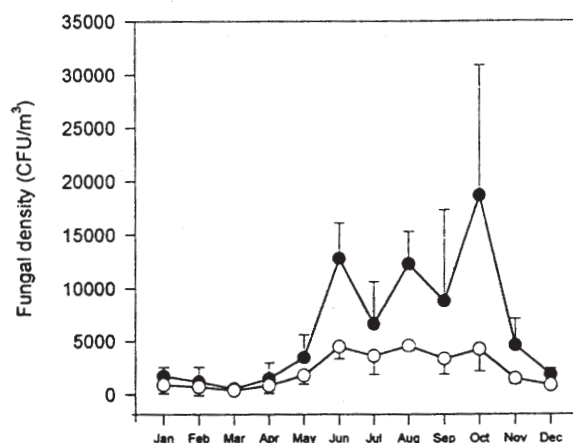


Fig. 2. Monthly mean distribution of fungi in 1988. ●—●: analyzed with the Anderson sampler. ○—○: analyzed with Aerobioscope sampler. Data represents the mean value with standard deviation.

Table 2. (a) Monthly mean size (μm , diameter) distributions of bacterial particles analyzed with the Anderson sampler in 1988 (b) Comparison of bacterial mean size distribution ratio (%) between normal days and Yellow Sand Phenomena (YSP) days in April, 1988

(a)						
Month	Distribution ratio (%) by particle size (μm , diameter)					
	>7.0	7.0~4.8	4.7~3.4	3.3~2.2	2.1~1.2	1.1~0.6
Jan	58.2	13.7	9.5	6.8	10.4	1.4
Feb	57.4	14.3	15.2	5.5	6.7	0.9
Mar	72.6	11.3	6.5	4.3	3.2	2.1
Apr	50.4	19.1	12.1	7.4	9.0	2.0
May	59.4	18.8	10.9	4.2	3.6	3.0
Jun	47.6	19.2	15.4	8.5	5.9	3.4
Jul	34.9	24.4	19.1	10.4	8.8	2.4
Aug	47.7	13.8	19.5	8.4	7.8	2.8
Sep	40.6	19.0	18.9	9.2	9.0	4.3
Oct	41.7	23.5	19.7	7.5	6.0	1.6
Nov	46.6	22.2	12.3	9.9	6.5	2.5
Dec	44.3	23.7	17.8	6.2	5.4	2.6
Annual mean	51.1	18.7	14.5	7.1	6.3	2.3

(b)						
Day	Distribution ratio (%) by particles size (μm , Diameter)					
	>7.0	7.0~4.8	4.7~3.4	3.3~2.2	2.1~1.2	1.1~0.6
Normal days	61.8	20.5	9.0	4.1	3.3	1.3
YSP days	47.8	18.8	12.8	8.1	10.3	2.2

Table 3. (a) Monthly mean size (μm , diameter) distributions of fungal particles analyzed with the Anderson sampler in 1988 (b) Comparison of fungal mean size distribution ratio (%) between normal days and Yellow Sand Phenomena (YSP) days in April, 1988

(a)						
Month	Distribution ratio (%) by particle size (μm , diameter)					
	>7.0	7.0~4.8	4.7~3.4	3.3~2.2	2.1~1.2	1.1~0.6
Jan	41.3	20.6	24.3	11.1	1.7	1.0
Feb	38.9	21.7	20.9	13.4	3.8	1.2
Mar	15.6	14.1	38.3	21.3	6.9	3.8
Apr	22.8	18.5	31.0	2.1.1	6.1	0.5
May	10.1	16.6	38.7	27.7	6.4	0.5
Jun	12.5	16.9	45.3	19.9	4.7	0.7
Jul	11.1	12.3	30.0	35.4	8.7	2.5
Aug	13.3	15.4	36.1	26.3	8.1	0.8
Sep	10.5	21.2	44.6	17.5	5.2	1.0
Oct	13.8	18.8	45.3	17.3	3.0	2.6
Nov	22.9	19.4	39.1	13.9	2.3	2.4
Dec	12.4	17.3	27.1	33.6	4.8	4.7
Annual mean	19.0	17.8	35.2	21.2	5.0	1.8

(b)						
Day	Distribution ratio (%) by particle size (μm , diameter)					
	>7.0	7.0~4.7	4.7~3.3	3.3~2.1	2.1~1.1	1.1~0.6
Normal days	25.5	19.7	32.5	17.5	4.3	0.5
YSP days	19.9	17.1	29.5	24.9	8.0	0.6

than that of bacteria. The annual mean concentrations of airborne fungi on collection media with the Aerobioscope sampler were 687 in 1986, 2,505 in 1987, and 2,293 CFU/m³ in 1988, respectively. The monthly distributions of airborne fungi in 1988 were from 525 in March to 81,701 CFU/m³ in October of 1988. The fungal concentration increased in June, August, and October. The airborne fungal particles with a diameter of 4.7 µm or less collected with the Anderson sampler occupied 63.2% (Table 3a) while bacterial ones made 30.2%. Contrary to the pattern of airborne bacteria, the portion of fungal particles larger than 7 µm of diameter occupied only a small fraction of about 19.0%. A large portion of respirable fungal particles in air may cause histoplasmosis. Like the airborne bacterial collection efficiency, the Anderson sampler had 2.7 times the efficiency of the Aerobioscope sampler in fungal collection. Because of discrete collection into a 6-stage cascade, the Anderson sampler had a high collection efficiency for small fungal particles. Owing to this point, The Anderson sampler is more applicable to identifying slow growing microorganisms such as *Basidiomycetes* sp. (unpublished data).

Distribution of fungal and bacterial concentrations on YSP days

Although there were many fluctuations in airborne microbial concentrations during this sampling period, fungi appeared more frequent than bacteria as shown in Table 4a. The relative minimum ratio between fungal and bacterial density analyzed with the Aerobioscope sampler was 2.2 in April and the maximum ratio was 12.5 in June 1988. But there was an exception in the ratio between fungal and bacterial density on Yellow Sand Phenomena (YSP) days in 1988 as shown in Table 4b. In April, there were five YSP days. The relative average ratio between fungal and bacterial density during YSP days above mentioned was 1.4 and 0.9 analyzed with the Aerobioscope sampler and the Anderson sampler, respectively. Analysis of normal days in April showed a relative ratio of 4.3 with the Aerobioscope sampler and 4.4 with the Anderson sampler. This result was due to an increase of bacterial density while fungal distribution showed a normal pattern (Table 4b) during YSP days. The greatest increase was seen in small particles (1.1–4.7 µm of diameter) carrying bacteria (Table 2b). The comparison of numbers of microorganisms ranging in size from 1.1 to 4.7 µm in diameter between the YSP days and the normal days is shown in Table 2b. In the case of bacterial distribution, the concentration of bacteria having

Table 4. (a) Monthly relative density ratio of airborne fungi and bacteria in 1988 (b) Comparison for density of airborne microorganisms on normal days and Yellow Sand Phenomena (YSP) days in April, 1988

(a)												
Sampler	Monthly density ratio of fungi to bacteria											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anderson sampler	6.9	3.4	2.8	1.5	5.4	14.7	8.0	13.7	11.9	6.5	4.0	3.2
Aerobioscope sampler	7.0	3.8	2.5	2.2	6.4	12.5	11.6	13.1	10.1	4.0	3.4	3.0
(b)												
Days	Date	Viable cell concentration (CFU/m ³)										
		Anderson sampler			Aerobioscope sampler							
		Fungi	Bacteria	Ratio (Fungi/Bacteria)	Fungi	Bacteria	Ratio (Fungi/Bacteria)					
Normal days	4th	1467	434	3.4	280	363	0.8					
	9th	100	105	9.5	267	32	8.3					
	15th	437	356	1.2	187	128	1.5					
	25th	577	621	0.9	1088	258	4.2					
	28th	5929	414	14.3	2570	244	10.5					
	Sum	8510	1930	4.4	4392	1025	4.3					
	Mean	1702	386	4.4	878	205	4.3					
YSP days	13th	2692	973	2.8	1522	267	5.0					
	18th	1107	3426	0.3	921	1041	0.9					
	19th	1944	225	8.6	561	164	3.4					
	21st	913	3019	0.3	607	895	0.7					
	23th	336	569	0.6	354	287	1.2					
	Sum	6992	8212	0.9	3965	2618	1.4					
	Mean	1398	1642	0.9	793	564	1.4					

respirable particles occupied 31.2% of total fraction on YSP days compared to 16.4% on the normal days. The actual bacterial number also increased to about 4.2 and 2.7 times that of normal days when analyzed with the Anderson sampler and the Aerobioscope sampler, respectively. These results were thought directly to coincide with the number of increments of fine particles on YSP days (Table 4b, Table 6).

The distribution ratio of fungal fraction collected in size having respirable particles when YSP days was slightly increased from 62.4% while normal days to 54.3% (Table 3b). But the total particle number of fungi on YSP days were very similar to that on normal days (Table 4b). As shown in Table 3b, the fungal fractions larger than 4.7 μm in diameter decreased somewhat. The number of fungi was less influenced by sand-blasting because they float as free forms or single spores in the air. As shown in Table 4b, the total fungal density on YSP days decreased slightly from that on normal days while bacterial density on YSP days increased to 4.3 or 2.6 times that of normal day when analyzed with the Andersen and the Aerobioscope sampler, respectively. It was concluded that the marked increase of respirable bacterial number in addition to the increase of fine particles was the prominent characteristic of Yellow Sand Phenomenon.

Distribution of dust particles

The calculated mean of annual mass was 20.4 $\mu\text{g}/\text{m}^3$. The lowest calculated value of mass was 4.2 $\mu\text{g}/\text{m}^3$ in July and the highest one was 118.5 $\mu\text{g}/\text{m}^3$ in April (Table 5a). The annual mean of absolute mass and relative mass were 50 and 20 $\mu\text{g}/\text{m}^3$, respectively (Table 5c). The mass value of particles on YSP days was 7.7 times that on normal days (Table 5b). The fraction showing the greatest increase was the density of the particles ranging in size from 1 μm to 5 μm in mass median aerodiameter. Appearance of particle with 10 μm diameter was rarely observed on normal days except in April. Maybe the strong sand-blasting on YSP days made it possible to carry particles overseas. The particle counter showed that density of airborne particles on the YSP days was 5.8 times that of the normal days (Table 6b).

In the literature, there are only few examples of long-range transmission of bacteria, and these have only been indirectly proved (7). However, the existence of airborne bacteria in various concentrations in different geographical localities and at high altitudes has been shown and studies of spores and particles have proved that long-distance transport is possible. In consideration of dis-

Table 5. (a) Monthly mean calculated mass distributions of particles in 1988 (b) Comparison of airborne particles of mean distribution on normal days and Yellow Sand Phenomena (YSP) days in April, 1988 (c) Distributions of the relative mass analyzed by the Digital Dust Indicator and of the absolute mass analyzed with the Respirable Aerosol Mass Monitor in 1988

(a)						
Month	Calculated mass ($\mu\text{g}/\text{m}^3$) by particle size (μm , diameter)					total
	>1.0	1.1~2.0	2.1~3.0	3.1~5.0	5.1~10.0	
Jan	4.6	13.9	10.5	1.1	0	30.1
Feb	1.7	4.2	2.1	1.4	0	9.4
Mar	1.8	4.7	3.2	0.4	0	10.1
Apr	12.7	50.3	54.2	1.0	0.3	118.5
May	2.1	7.0	3.2	1.2	0	13.5
Jun	2.4	2.0	0.1	0	0	4.5
Jul	1.8	2.3	0.1	0	0	4.2
Aug	2.9	2.3	0.1	0	0	5.3
Sep	2.2	4.9	2.0	0	0	9.1
Oct	5.8	3.6	0.5	0	0	9.9
Nov	1.4	6.6	1.6	0.2	0	9.8
Total	39.4	101.8	77.6	9.4	0.3	224.4
Annual average	3.6	9.3	7.1	0.5	0.03	20.4

(b)						
Days	Calculated mass ($\mu\text{g}/\text{m}^3$) by particle size (μm , diameter)					total
	>1.0	1.1~2.0	2.1~3.0	3.1~5.0	5.1~10.0	
Normal days	4.1	14.0	8.4	0.7	0.0	27.2
YSP days	21.2	86.5	99.9	1.2	0.5	209.3

(c)		
Month	Relative mass ($\mu\text{g}/\text{m}^3$)	Absolute mass ($\mu\text{g}/\text{m}^3$)
Jan	19	65
Feb	19	34
Mar	16	29
Apr	52	156
May	20	49
Jun	21	57
Jul	9	23
Aug	14	60
Sep	11	32
Oct	16	28
Nov	19	20
Dec	21	49
Annual mean	20	50

Calculated mass was analyzed with Royco Particle Counter and reenumerated on the assumption that every particle has a unit density.

tribution of airborne bacteria and the other climate characteristics of particles, fine particles aerosolized from the northern part of the China and Mongolia plateau, during YSP days (7, 9), and it suggested the possibility of long-range transmission of bacteria which was indirectly proved. To

Table 6. (a) Monthly mean number distributions of particles in 1988 (b) Comparison of airborne particle mean distribution on normal days and Yellow Sand Phenomena (YSP) days in April, 1988

(a)						
Month	Number ($\times 1000$) by particle size (μm , diameter)					
	>1.0	1.1-2.0	2.1-3.0	3.1-5.0	5.1-10.0	total
Jan	8810.7	3321.3	745.6	16.4	0	12894.0
Feb	3223.4	1002.9	146.0	20.9	0	4393.2
Mar	3378.8	1118.4	226.0	5.8	0	4729.0
Apr	24057.1	11998.6	3827.7	85.3	0.5	39969.2
May	4048.9	1663.1	228.8	2.7	0	5943.5
Jun	4577.2	481.2	419.1	0	0	5477.5
Jul	3384.4	556.6	6.4	0	0	3947.4
Aug	5449.9	549.4	4.4	0	0	6003.7
Sep	4159.8	1159.0	141.2	0	0	5460
Oct	11112.2	849.4	31.2	0	0	11992.8
Nov	7626.7	1563.6	117.2	0	0	9307.5
Total	79829.1	24263.5	5664.8	131.1	1.3	110117.8
Annual average	7257.2	2205.8	515.0	11.9	0.04	10010.7

(b)						
Days	Number ($\times 1000$) by particle size (μm , diameter)					
	>1.0	1.1-2.0	2.1-3.0	3.1-5.0	5.1-10.0	total
Normal days	7735.9	3341.0	591.2	10.2	0	11678.3
YSP days	40378.2	20656.2	7064.2	160.4	1.0	68260.0

understand YSP effects that could be of medical, ecological, and industrial interest, more systematic investigation and rapid monitoring seems to be necessary (5).

As previously described in this report, there must be a complicated relationship among the number of airborne microbes, dust particles, seasonal factors, and fungal distribution occurrences. However, it will be difficult to predict the correct pattern of airborne microorganisms. This study will suggest the basic direction of comprehensive views on the interaction among airborne particles and its understanding will help us understand the prospect scheme of natural or artificial release of microbes.

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