5.4 Visibility degradation

5.4.1 Introduction

When visibility is degraded, the surrounding scenery becomes difficult to see clearly compared with normal conditions. People's first experience of air pollution is normally visibility degradation. Visibility degradation can also be caused by meteorological conditions such as fog, but this paper addresses the problem of visibility degradation due to air pollution.

5.4.2 Causes of visibility degradation

The light from the sun deteriorates through its being absorbed and scattered due to aerosols, absorption by air pollutants and water vapor, scattering by airborne particles, and so forth. The main cause of visibility degradation due to air pollution are aerosol and gasses in the atmosphere, but the visibility conditions can differ greatly due to atmospheric conditions such as humidity, the optical characteristics of the target matter, and the strength and distribution of the light at the time in question. When air pollution is severe, the atmosphere appears to be colored, but the color can vary depending on the type of pollution. Air pollution appears black when it is due to soot from the burning of fossil fuels, but has a whitish hue when it is due to photochemical air pollution.

(1) Extinction coefficient (b_{ext})

If (I) is the strength of the light when it reaches the eyes of a person at distance (x) from the light (I_0) of the visibility target, then Eq. (1) is established according to Lambert's rule:

$$I = I_0 \, [\, Exp\,(-b_{ext})\,]^x \qquad \cdots\cdots \qquad (1)$$

This is called b_{ext} extinction coefficient, and Eq. (2) can be obtained. The unit is m^{-1}.

$$b_{ext} = \frac{\dfrac{\ln I_0}{I}}{x} \qquad \cdots\cdots \qquad (2)$$

Because the primary cause of visibility degradation due to air pollution is the absorption and scattering of light, the extinction coefficient b_{ext} can be analyzed in four parts, as per Eq. (3) below. Namely, scattering coefficient of light due to gases: b_{sg} (this is normally called the Raleigh scattering coefficient), scattering coefficient of light due to particles: b_{sp} (scattering coefficient of light due to menute particles is normally called the Mie scattering coefficient), absorption coefficient of light due to gases; b_{ap}, and absorption coefficient of light due to particles: b_{ap}.

$$b_{ext} = b_{sg} + b_{sp} + b_{ag} + b_{ap} \qquad \cdots\cdots \qquad (3)$$

Of these four, scattering coefficient of light due to particles: b_{sp} is vital for visibility degradation. The optical features of airborne particulate matter vary greatly depending on the diameter of the particles concerned. Light is refracted when the diameter of the particles is 10 or more times greater than the wavelength of the light. Rainbows caused by water droplets in the air are a phenomenon representative of this. In contrast, when both the wavelength of the light and the diameter of the particles are approximately the same size, scattering becomes the main effect. Because the mean wavelength of solar light is approximately 0.52 μ m, Mie scattering due to minute particles with an approximate diameter of between 0.1 and 10 μ m has the greatest effect on visibility deterioration.

(2) Threshold contrast value: According to results obtained in the laboratory under daytime conditions, the threshold contrast value which can be detected by humans is I/I_0= 0.018 to 0.03. X is substituted by 0.02, the mean value, in Eq. (2), Eq. (4) is obtained. This is called the Koschmeider formula.

$$b_{ext} = \frac{3.912}{x} \quad \cdots\cdots\cdots \quad (4)$$

When the visibility (x) is 10 km, the extinction coefficient b_{ext} becomes 3.91×10^{-4} (m^{-1}), and when visibility is 1 km, the extinction coefficient bext becomes 3.91×10^{-3} (m^{-1}). On the other hand, an atmosphere with no atmospheric pollutants is called ideal atmospheric conditions, and only the Raleigh scattering due to air molecules has any effect. The extinction coefficient when the elevation above sea-level is 0 m is approximately 13.2×10^{-6} (m^{-1}), and the threshold contrast distance becomes 296 km. It becomes approximately 403 km when the evaluation is 3 km aloft.

There has been little recent research into the relationship between visibility and the concentration of air pollution, but as an approximate measure, when the concentration of floating particulate matter in the atmosphere exceeds approximately 0.12 mg per 1 m^3, visibility is reduced to 10 km or less, when the concentration exceeds approximately 0.24 mg, visibility is reduced to 5 km or less, and when the concentration exceeds approximately 1.2 mg, visibility is reduced to 1 km or less. However, these values differ according to the composition of the particles and meteorological conditions.

(3) Visibility degradation and atmospheric pollutants

Air pollutants that affect visibility degradation differ greatly depending on both the season and the characteristics of their sources in the particular region in question. Visibility is also very closely connected to meteorological conditions. When ground inversion occurs and the winds are weak, such as during the early morning of winter, the air pollutant concentration rises due to a reduction in atmospheric diffusion capability, and visibility consequently worsens. During the day, there are many occasions when visibility is restored alongside the eradication of the inversion layer. On the other hand, in the case of photochemical air pollution during the summer, visibility degrades from noon onwards and throughout the afternoon due to generation of secondary generation particulate matter alongside the escalating reaction. This polluted air mass is carried inland by the local sea-land breezes, and the phenomenon that regions where visibility is poor shift in response to the movement of the air mass is often observed. According to results measured in Los Angeles, when a degradation in visibility can be seen during the summer, a striking increase in particulate matter with a diameter of 0.1 to 1.0 μ m can clearly be seen when compared with days on which there is no visibility degradation.

Seinfeld (1986) collated the results of various measurements taken in America that relate to visibility, and has expressed the following opinions in their regard.

1. Visibility degradation of 60 to 95% is caused by the scattering of light due to particles.
2. Sulfate is always the matter most responsible for the scattering of light. The next most important are organic carbon particles. Nitrate, is important in some regions.
3. Light absorption due to particles of soot are the cause of a visibility degradation of 5.40%.
4. Except for smoke emissions from thermal power stations, carbon dioxide does not cause very much visibility degradation.
5. Of all the airborne particulate matter, the ability of soot particles in units of cubic content to degrade visibility is three times that of sulfate, nitrate, and organic carbon particles.

5.4.3 Measuring visibility

Visibility measurement is generally conducted by eye. Specifically, one decides in advance on a marker such as a building or a mountain for which the distance from the measuring site is known in each direction, and this is then viewed by eye and the visibility is measured. When setting the marker, it is hoped for that the background is as whitish a sky as possible, and the marker itself is not white in color, and is of an appropriate size. The distance at which these markers can be barely differentiated is the level of visibility. Visibility measurement at night is difficult, but light that has not been condensed and whose intensity is known at a site whose distance is also already known is taken to be the index. Further, the outline of a mountain or the like against the background of the night sky can also be used as a marker. Depending on the direction of the measurement from the same terrestrial point, values such as maximum visibility, minimum visibility, mean visibility, and prevailing visibility will differ. The value of the maximum horizontal visibility from the measuring point for a total range of 180 degrees or more from all the horizontal directions is called the prevailing visibility. At this time, the ranges do not necessarily need to be contiguous. Specifically, the angles for each segment are totaled in sequence from the segment with high visibility, and when the total angle exceeds 180 degrees, the visibility value for the last segment is applied as the prevailing visibility. Given above is the method used for measuring by sight, but in airports, where visibility is an especially important safety factor, a transmissometer is used. This is a device that projects light towards the horizon from a height of 3 m above ground level, and then collects the light at a remote distance of approximately 150 m, by means of which, it can determine the visibility between both points. At present, devices are being constructed that can also measure within ranges of from 10 m to 100 km.

5.4.4 Effects of visibility degradation

Visibility degradation not only worsens the quality of the living environment through the deterioration of the scenery, but also reduces the number of tourists in tourist locations because the beautiful scenery has been damaged, thereby inflicting harm upon the local economy. Further, when visibility is degraded, because no visual flights can either take off or land, greater economic damage is incurred. This has become a major problem particularly in the U.S, where there are many privately-owned airliners. Airline flight rules are comprised of both the IFR (Instrument Flight Rule) and the VFR (Visual Flight Rule). Generally, if ground visibility is 5 km or better, and the clouds are a minimum of 300 m high, this is known as VMC (VFR Meteorological Conditions), and the VFR is considered possible. However, any other circumstances are known as IMC (IFR Meteorological Conditions), and the VFR is not permitted. In regions where visibility is poor, special instruments and special proof from the pilot are required for the VFR to be applicable, and this cannot help but add to the social costs. In addition, when visibility is extremely poor, the number of traffic accidents also increases. It is said that on land, when visibility is less than approximately 100 m, both traffic accidents and airplane accidents occur very easily, and when visibility at sea is less than approximately 1 km, ships very easily meet with disaster.