THE TRANSMISSION OF VISIBLE LIGHT THROUGH FOG

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Abstract

Measurements were made on the transmission of visible light through artificial fog which was produced by condensing low pressure steam in a chamber 300 cm long and about 25 cm square. Curves for several fog densities were obtained and they all indicated a definite maximum transmission at about 0.490μ. The relation between the transmission of light through fog and the fog density was found to be practically linear. The maxima obtained are not in agreement with the results of other investigators but a comparison of the particle sizes of the fogs used in this work with those of the fogs used by others leads to the conclusion that the shape of the transmission curve is dependent on the particular particle size or sizes of the fog on which the measurements are made.

Due to the increasing importance of commercial aviation considerable experimental work has been done on the transmission of light through fog and it is now generally realized that no type of visible radiation possesses any marked fog penetrating powers. However, since complete lighting equipment is required in any event for night flying, it seems that advantage should be taken of even the small increase in visibility to be expected from the use of the proper type of light. Much of the existing experimental data on this problem are purely qualitative and depend to a large extent on individual judgment under special conditions. Such quantitative data as are available are somewhat difficult of analysis and of comparison because of the different conditions under which the measurements were made. The work described in this paper was undertaken with the hope of clarifying the problem and indicating the type of light most effective for fog penetration.

Due to the uncertainty of the occurrence of natural fogs and the desirability of controlling the density, all measurements were made on artificial fog. This also simplified the measurement of the density of the fog and the size of the fog particles. The fog was produced by condensing low pressure steam in a zinc-lined wooden chamber 300 cm long and about 25 cm square. At one end of this chamber were located the incandescent lamp light sources, the necessary optical systems and filters for obtaining various bands of wavelengths in the visible spectrum. At the far end of the chamber was located the detecting apparatus which consisted of a photoelectric cell, a two-stage direct current vacuum tube amplifier and a sensitive milliammeter.

In order to duplicate more closely natural fogs, no condensation nuclei were added, the steam condensing on the nuclei normally present in the air. The only apparent difference between artificial fog produced in this manner and natural fog is the size of the fog droplets, the artificial fog being composed of somewhat smaller particles of more uniform size.

In a chamber of such small dimensions as the one described above, the density of the fog changes quite rapidly due to settling and condensation and it was found desirable to produce a new fog for each reading. It was, therefore, necessary to have a means for duplicating a given fog a number of times. Due to variations in humidity, temperature and the number and size of the condensation nuclei, it is not feasible to duplicate fogs by admitting a given amount of steam at a specified pressure. After some experimentation, it was decided that for the purposes of this work, a fog could be satisfactorily specified by the transmission of a standard light which is assumed to have a constant candle power and spectral distribution. In this paper fog density is defined as the ratio of the intensity of the standard light after passing through the fog to its initial intensity and is expressed as a decimal fraction. This method permits of a continuous reading of density. This is desirable since a dense fog may be formed and allowed to settle to the desired value thereby obtaining a more uniform and less turbulent fog.

Although a spectroscope or a source with conspicuous line spectra would probably have proved advantageous, an incandescent lamp source together with suitable gelatine filters was chosen because of their greater convenience, a choice justified by the small changes of transmission with wave-lengths. The pass bands of the filters used ranged in width from about 0.030 to 0.050 μ and the visible spectrum was fairly well covered with eight filter combinations. Certain of these filters had additional pass bands in the infrared which, however, did not affect the results because of the selective action of the photoelectric cell. The attenuation of the filters in the pass bands was so high that a 200 watt concentrated-filament lamp was required to obtain sufficient illumination. Some difficulty was experienced in obtaining a parallel beam from this source but this was finally accomplished by first focussing the light on a small iris which was in turn at the focus of a second collimating lens. This system exhibited some chromatic aberration but in view of the relatively narrow bands of wave-lengths used this was not considered detrimental.

A second light source was used to specify the fog density as described above. No filters were employed so it was possible to use a lamp of lower candle power which had a very small filament. To insure constant candle power this lamp was operated at somewhat under rated voltage from a storage battery. A simple, long focus lens system sufficed to produce a parallel beam with no appreciable chromatic aberration. Both lamps remained lighted at all times during the measurements in order to maintain a constant illumination. The beams were controlled by shutters which, for convenience, were arranged to be operated from the far end of the chamber where the measuring apparatus was located.

Some difficulty was experienced in finding a photoelectric cell which would be sensitive over the entire visible spectrum, many of them being useless above 0.500μ. One was finally obtained which was quite satisfactory throughout the desired range and in addition cut off in the near infrared where some of the filters had extraneous pass bands. The cell was mounted behind a glass window at one end of the fog chamber and the light sources were adjusted so that each beam completely covered the cathode of the cell. In order to prevent condensation on the glass window a shutter was placed before it and so arranged that it was only opened while a reading was actually being taken. The filters were similarly protected by the shutters used for controlling the light beams.

The photoelectric currents were amplified to readable values by means of a two-stage direct current vacuum tube amplifier. In order to obtain sufficient stability and to prevent excessive extraneous pick-up the amplifier was constructed of the most stable circuit elements available and the circuit was so arranged that all batteries could be grounded as shown in Fig. 1. It

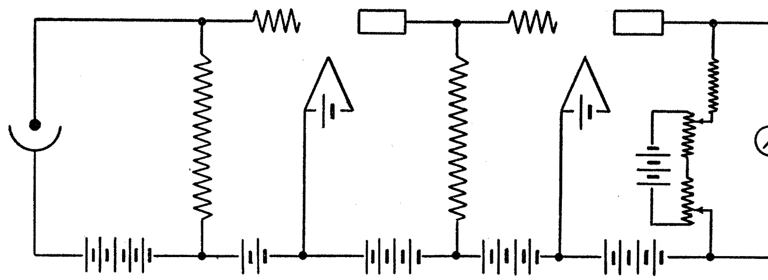

Fig. 1. Amplifier for photoelectric cell.

was also found desirable to ground the metal lining of the fog chamber and to shield the photoelectric cell and the first amplifier stage. The overall characteristic of light intensity on the photoelectric cell versus amplifier output current proved to be substantially linear but this curve was used as a calibration curve in all of the measurements.

The transmission of the light was expressed as the ratio of the intensity of the light transmitted through the fog to the initial intensity. In this way it was not necessary to measure absolute values of intensity. Runs were taken over the visible spectrum at a constant fog density. A curve may be obtained from these data by plotting the transmission ratio against an average wave-length for the filter combination used. Several such curves for different fog densities are given in Figs. 2, 3 and 4. It will be noted that each of these curves has a definite maximum at about 0.490μ. Sufficient data were taken in each case to eliminate any experimental errors. The possible effect of the previously mentioned infrared pass bands of some of the filters was tested by including additional filters which definitely excluded this region and no differences were noted in any case. There were no known pass bands in the ultraviolet but this region was effectively eliminated by the large amount of glass in the optical system.

Because of the finite width of the pass bands of the filters, the curves as given do not represent the true spectral transmission. The true curve would have a somewhat sharper maximum but it happens that the filter used to obtain the point at 0.490μ has a very narrow pass band so that the error is not very great.

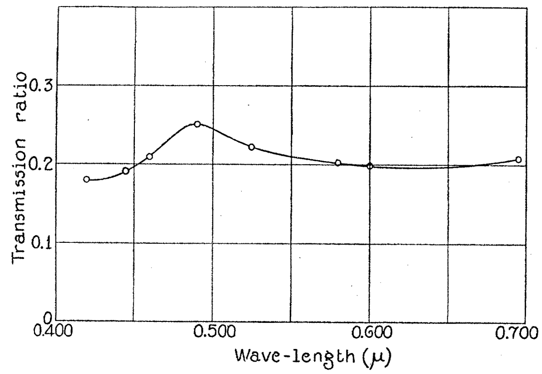

Fig. 2. Transmission of light through a fog of 0.20 density.

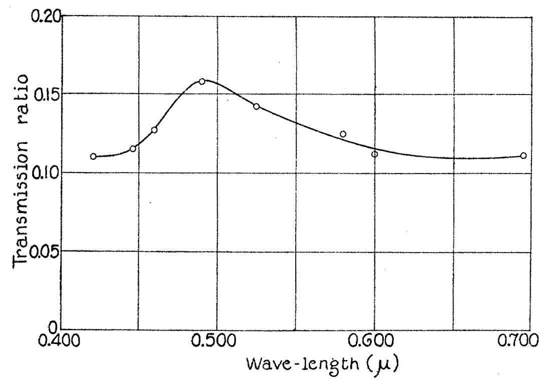

Fig. 3. Transmission of light through a fog of 0.125 density.

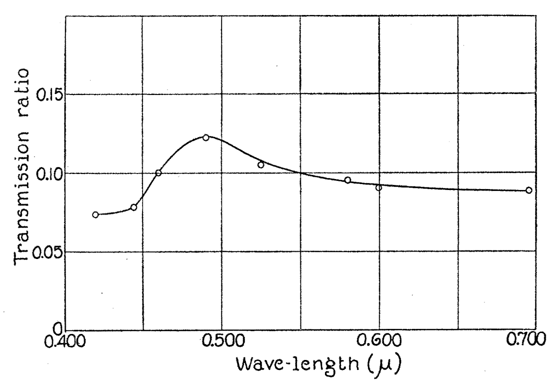

Fig. 4. Transmission of light through a fog of 0.10 density.

A second set of curves can be obtained from the same data by plotting transmission ratio against fog density for a given wave-length. Several such curves are given in Fig. 5. It will be noted that they are all practically linear as is to be expected if the particles scatter independently although they must obviously pass through the point (1, 1). They are at least sufficiently linear to permit of reasonable extrapolation to fogs of less density than those used in this investigation.

Comparable measurements on the transmission of light through fog have been made by Utterback,[1] Granath and Hulburt,[2] and Anderson.[3] Utterback used artificial fog produced by the sudden expansion of moist air, but his measurements were made by means of a Macbeth illuminometer and so apparently include the sensitivity curve of the eye. This curve is so markedly peaked that it would effectively mask the transmission curve for the fog alone. This is borne out by the location of Utterback's maximum at 0.560μ which

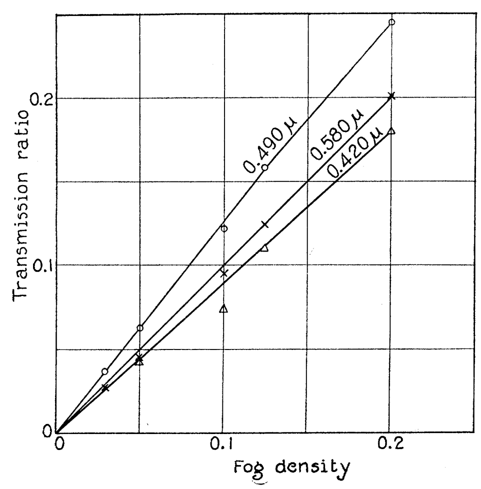

Fig. 5. The transmission of light of a single wave-length through fog as a function of fog density.

corresponds almost exactly to the accepted average value for the peak of the eye sensitivity curve. Granath and Hulburt made all of their measurements on natural fogs using a quartz spectrograph and a recording densitometer in the visible spectrum. The measurements were also extended into the infrared using relatively wide bands of radiation. Their results show no peaks, merely a gradual increase in transmission for the longer wave-lengths.

Anderson used artificial fog made with artificially introduced hygroscopic nuclei. His measurements were made with filters and a photoelectric cell much as described in this paper and in common with Granath and Hulburt he found no maximum transmission but merely a rise towards the red end. Anderson also gives curves similar to those of Fig. 5, which are also practically linear.

The attenuation of light by fog is probably due principally to scattering rather than absorption. The classical solution of this problem, when the

[1] C. L. Utterback, Trans. I. E. S. **14,** 133–140, No. 3 (1919).
[2] L. P. Granath and E. O. Hulburt, Phys. Rev. **34,** 140 (1929).
[3] S. H. Anderson, Aviation **28,** No. 19, May 10 (1930).

particles are small compared to the wave-length, was given by Lord Rayleigh[4] who found that the intensity of the scattered light varied inversely as the fourth power of the wave-length. This serves to explain the red sunsets and the red appearance of the sun when viewed through so-called "smoke fogs," but hardly applies to true fogs where the particles are larger than the wave-lengths of visible light.

The definite maxima of the curves obtained in this work and the total absence of any such peaks in the results of other investigators suggests a difference in the fogs used. The curves of Fig. 5 together with Anderson's similar results indicate quite definitely that it is not a question of the density of the fog. It appears reasonable to suppose that the size of the particles is a controlling factor in the location of the wave-length of maximum transmission and it was, therefore, decided to determine the size of the particles of the fogs used.

The method of corona measurements as employed by Kohler[5] and others for measuring the droplet size of natural fogs appeared to be a convenient means and an attempt was made to apply it to this problem. Either due to space limitations in the fog chamber, the small size of the particles or to imperfections of the apparatus, results from the corona measurements were entirely unsatisfactory. Furthermore, corona measurements give no indication of the distribution of particle size but merely an average value.

Recourse was next had to the microscope. Due to the transparency of the droplets and their rapid motion it is rather difficult to view them microscopically. It was found desirable to employ very intense transverse or dark field illumination. This type of illumination gives rise to various diffraction disks which make it possible to detect ultramicroscopic particles but which are somewhat confusing in the case of larger particles. With a little care it was found possible to identify definitely the fog droplets. Even with the lowest power objective which could be used the motion of the particles across the relatively limited field of view was so rapid that no size comparisons could be attempted. To reduce this motion a small glass chamber with sliding doors was fitted over the end of the objective. In this way, it was possible to trap a number of fog particles and hold them relatively still although there was still considerable motion due to eddies, settling, and possibly Brownian motion. Size comparisons were made by placing objects of known size in the eyepiece of the microscope. It was found that the droplets were quite uniform and ranged from about two to three microns in diameter. Attempts to photograph the particles were entirely unsuccessful due to the low illumination and the rapid motion of the particles.

Although no definite information is available, it seems that the particles of the natural fogs used by Granath and Hulburt and of Anderson's artificial fogs were larger than two or three microns. This leads to the conclusion that the shape of the transmission curve is largely dependent on the particle size

[4] Lord Rayleigh, Phil. Mag. **41,** 107–274 (1871).

[5] Hilding Kohler, Meddelanden Fran Stratens Meteorologist—Hydrografiska Anstalt **2,** No. 5 (1925).

of the fog used and, therefore, that any transmission curve is applicable only to the particular fog on which the measurements were made. Thus the results obtained in this work might well apply to a particular small particle natural fog or haze but would have no application whatsoever to larger particle fogs.

In view of the above it was decided to undertake a theoretical investigation of the problem which could be verified by these particular experimental results and then extended to other types of fog. The definite maxima of the experimental curves make them particularly suitable for this purpose. This theoretical work has been completed and is presented in another paper.

Apart from the transmission of the radiant energy through the fog there are other extremely important factors which affect the visibility of lights in fog. As previously noted, the sensitivity curve of the eye is so markedly peaked that a maximum of the magnitude obtained in this work would be completely masked. This would, of course, not apply to infrared or other radiations beyond the visible spectrum where other than visual means of detection are employed. In the case of visible light, the nature of the background against which the light is viewed is of the utmost importance. Thus, it appears certain that against the white background commonly produced by general illumination in fog, a red light would be much more effective than a white one. Apparently very little work has been done on this question of contrast and it seems that a study of the problem together with a proper consideration of the eye sensitivity curve would produce valuable results.