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Method of Reducing Temperature in High-Speed Photography

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METHOD OF REDUCING TEMPERATURE IN HIGH-SPEED PHOTOGRAPHY

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INTRODUCTION

A continuing problem in high-speed motion picture photography is adequate lighting and the associated temperature rise. Large temperature rises can damage subject matter and make recording of the desired images impossible. The problem is more severe in macrophotography because of bellows extension and the necessary increase in light. This report covers one approach to reducing the initial temperature rise: the use of filters and heat-absorbing materials. The accompanying figures provide the starting point for selecting distance as a function of light intensity and determining the associated temperature rise. Using these figures will allow the photographer greater freedom in meeting different photographic situations.

In most high-speed photography the film is exhausted in less than 10 seconds, with most work requiring only 1 to 5 seconds (approx 100 ft at a frame rate of 4000 fps is equal to 1 sec). The major temperature rise occurs in the first 10 seconds; the temperature continues to rise at a reduced rate to 30 seconds, where it stabilizes. Therefore, it is critical to control or delay the rate of temperature rise in the first 5 to 10 seconds. Many methods have been employed to achieve the desired temperature reduction - water-cooled filters, vortex generators, etc. This report deals only with filtration using uncoated glass and infrared (IR) absorbing (cutoff) filters.

FILTRATION METHOD

In a laboratory environment, a high-intensity GE EHL tungsten bulb (300 W at 120 V) was mounted on a long aluminum filter holder that was secured to a chamber to reduce heat convection, as shown in figure 1. The chamber contained an iron-constantan thermocouple that displayed temperature through a digital display. A Minolta Auto III F light meter was used to record incident light.

To establish a constant, temperature data were taken at a given distance with no filters in place. Then additional data were taken for various filters. In the first 5 seconds the temperature increased 33° F above ambient for the light source without any filters (fig. 2). Since a coated 0.125-inch-thick filter was to be tested, it was necessary to determine the effect that 0.125-inch-thick uncoated glass has on temperature. The curve in figure 2 for thick glass shows this temperature rise. Using a standard of 5 seconds, the curve shows a temperature rise of 28° F above ambient as compared with the 33° F

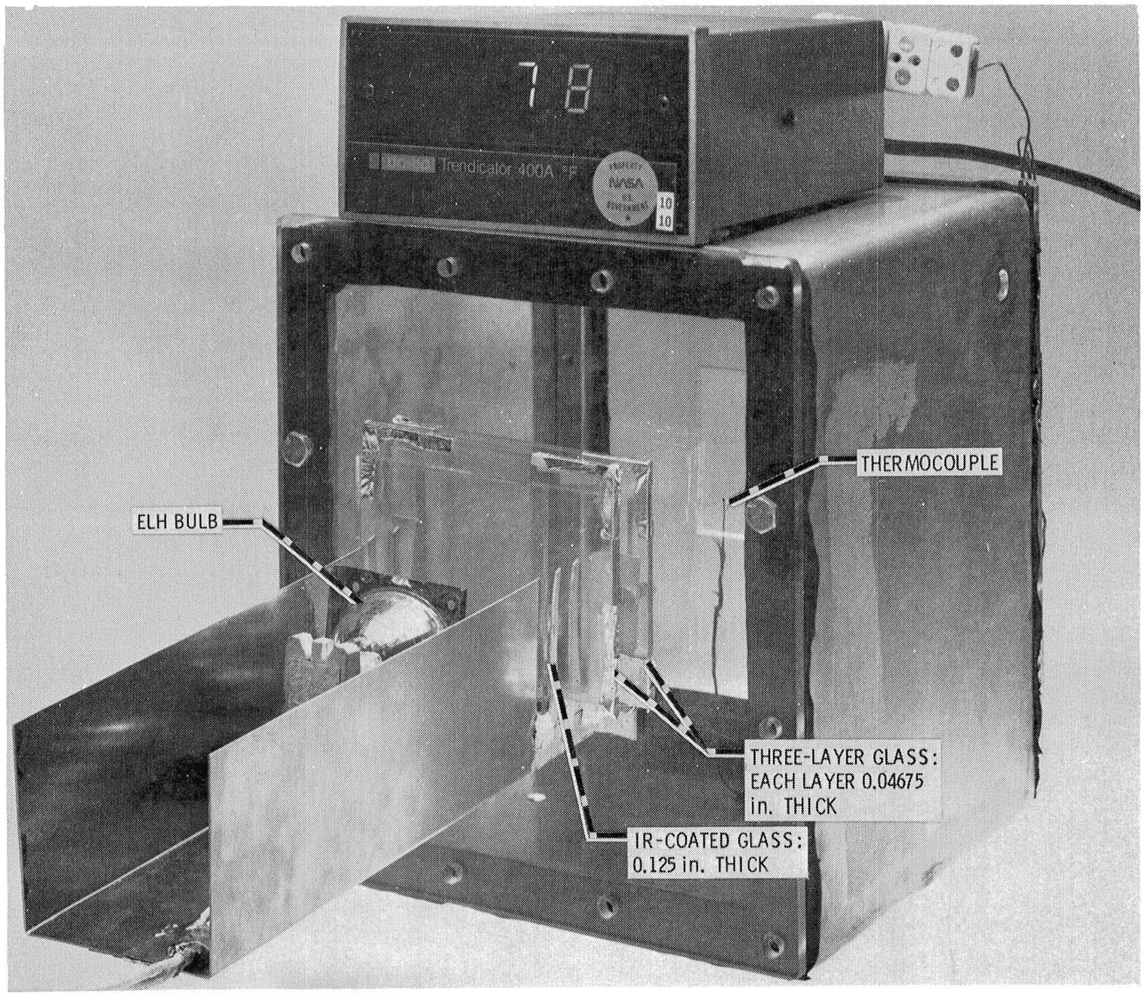

Figure 1. - Test setup with recommended filtration.

constant. This represents a 15 percent reduction in temperature rise. Replacing 0.125-inch-thick glass with an equal amount of thinner glass (three sheets, each 0.04675 in. thick) secured together produced a 24 percent reduction in temperature rise. This extra reduction in temperature rise with an equal amount of glass can be attributed to contact resistance between the surfaces of the filters.

Figure 3 represents the spectral "performance" or response of the coated IR cutoff filter. The visible spectrum is from 350 to 700 nanometers, with the infrared region falling beyond 700 nanometers. The high-intensity tungsten bulbs generate extreme heat and almost one-third of it is caused by the longer IR wavelengths. A single 0.125-inch-thick IR cutoff filter produced the greatest reduction in temperature rise, 27 percent (fig. 2).

Combining two or more IR cutoff filters did not significantly reduce the temperature rise. Conversely, the first IR filter absorbed all IR radiation while transmitting the visible wavelengths. Adding further IR cutoff filters did not reduce the temperature rise significantly as the full transmittance of visible wavelengths continued. Combinations of other filters were then tested to obtain greater temperature rise reduction with a minimum of light loss.

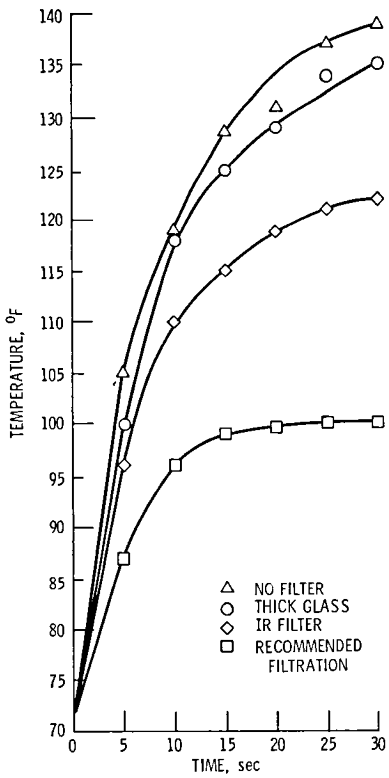

Figure 2. - Temperature rise as a function of time at light-to-subject distance of 6 inches under a variety of conditions.

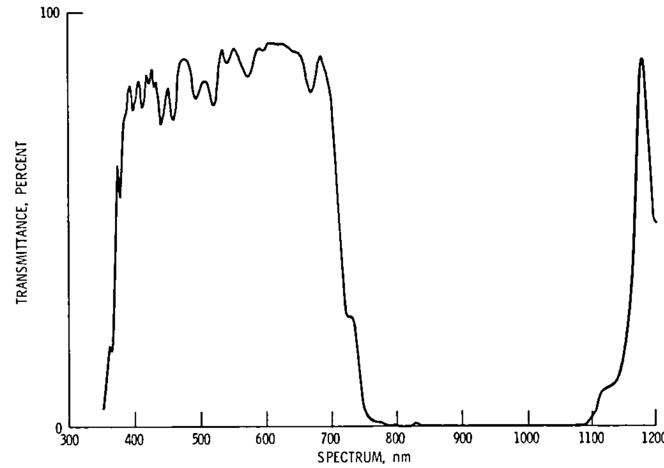

Figure 3. - Spectral response of IR cutoff filter.

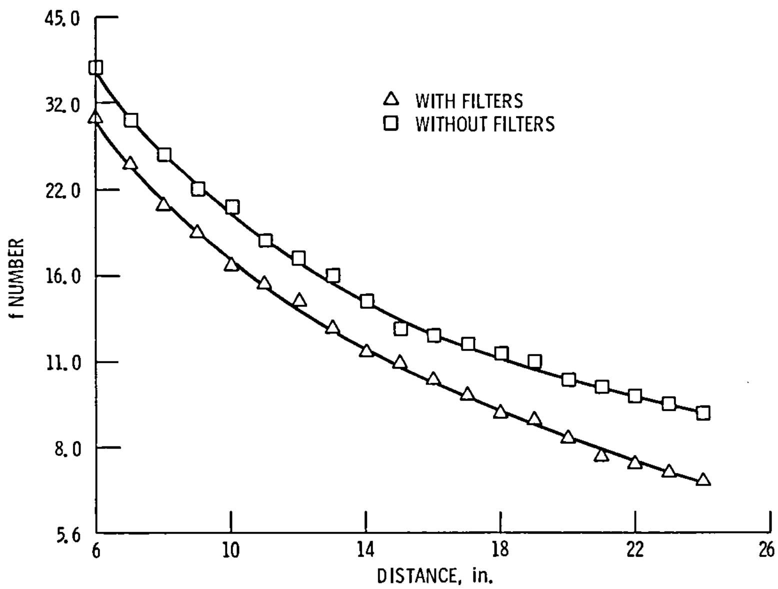

Figure 4. - f numbers as a function of distance without filters and with recommended filtration. (f numbers are based on 1/60th of a second and ASA 25 film.)

A single IR filter and two 0.125-inch-thick glass filters each composed of three thin layers of 0.04675-inch-thick glass produced the best overall temperature rise reduction with minimum loss of light. After 5 seconds, the set of filters produced a 45.4 percent temperature rise reduction (fig. 2) and a light reduction of only 2/3 stop (fig. 4).

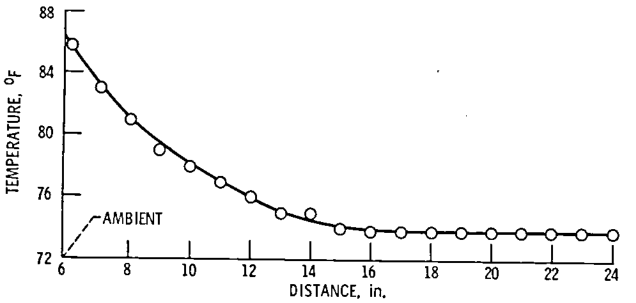

Figure 5. - Temperature rise in 5 seconds as a function of distance for recommended filtration.

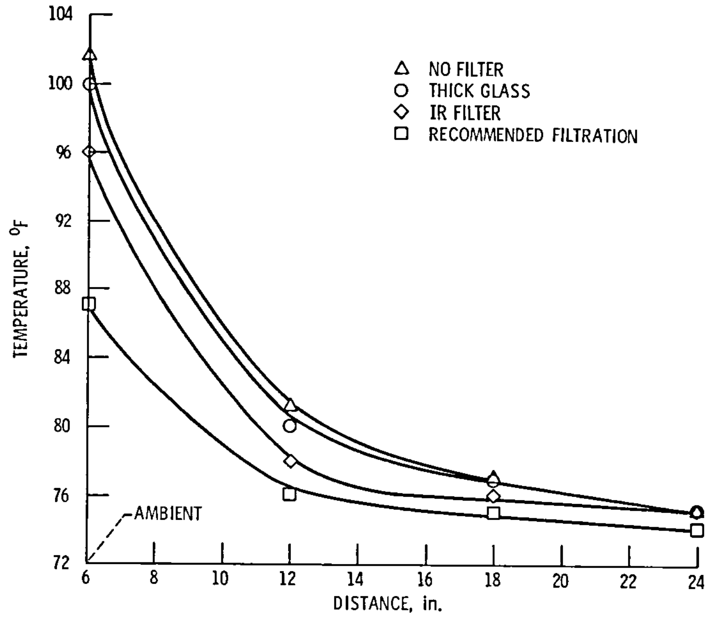

Figure 6. - Temperature rise in 5 seconds as a function of distance under a variety of conditions.

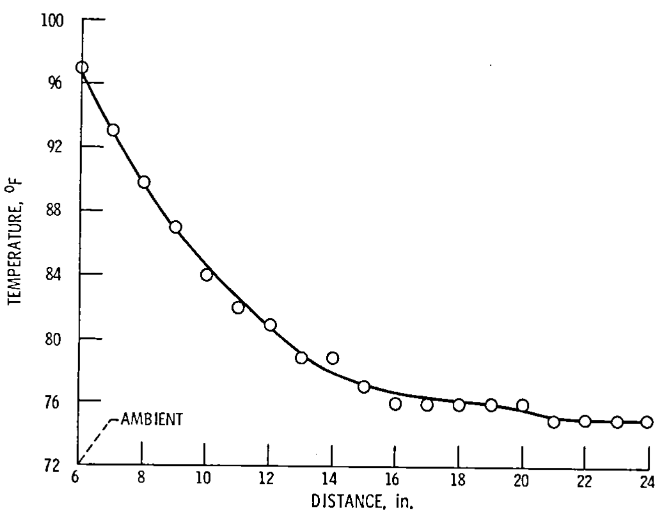

Figure 7. - Temperature in 15 seconds as a function of distance for recommended filtration.

The success of the three-filter combination became more evident after 15 seconds. With no filters in place, a temperature of 130° F was reached (fig. 2), 58° F above ambient. The single thick glass reduced the temperature to 125° F, or a poor 8.6 percent reduction in temperature rise. The single IR cutoff filter produced a 24.1 percent reduction. Finally, the combination of three filters (IR, three thin glass, and three thin glass) produced a 53.4 percent reduction: a temperature of only 99° F was obtained, as displayed in figures 2 and 5, and again with only a 2/3-stop loss of light.

By varying the light-to-subject distance, a greater temperature rise reduction can be obtained (figs. 6 and 7). For example, doubling the distance to 12 inches and using the three-filter combination resulted in a minimal 4° F rise above ambient, as compared with a 10° F rise without filters (fig. 6). Therefore, depending on the photographer's needs and requirements, a vast array of combinations can be obtained by using the accompanying graphs.

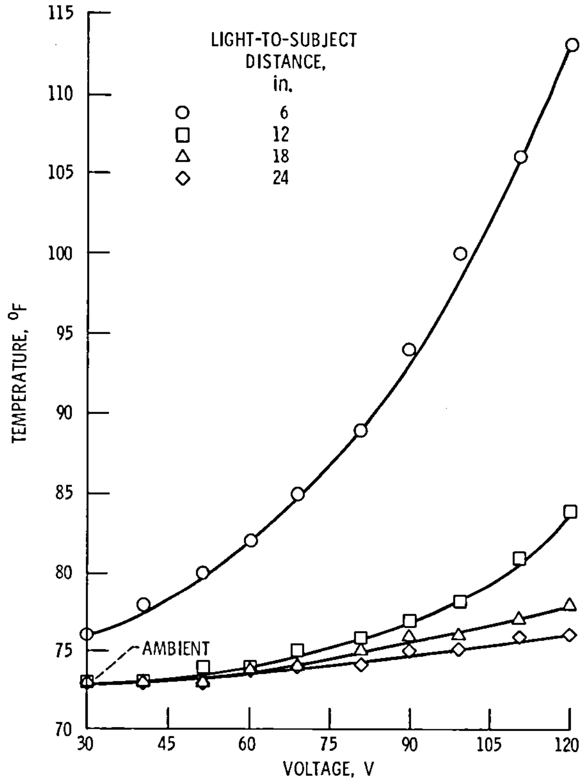

Figure 8. - Temperature after 30 seconds as a function of voltage at various distances for recommended filtration.

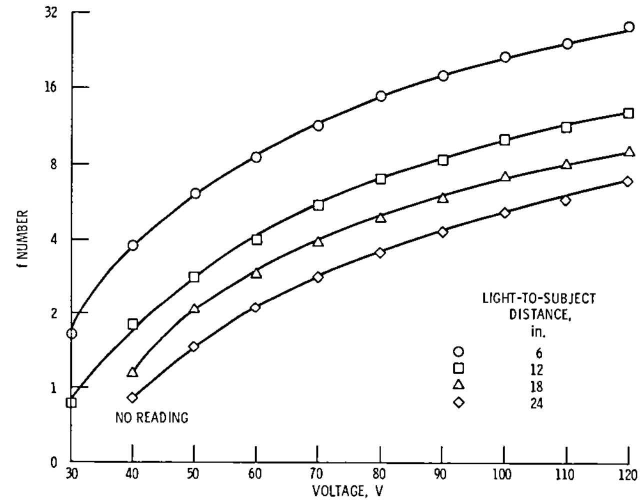

Figure 9. - f number as a function of voltage at various distances for recommended filtration. (f numbers are based on 1/60th of a second and ASA 25 film.)

Another method of controlling temperature rise in conjunction with the filters is to use a voltage regulator. If distance from the light source cannot vary and only a limited temperature rise can be tolerated, a voltage regulator in combination with the three-filter set will reduce temperature rise greatly (fig. 8). There will be significant light loss at lower voltages and greater distances (fig. 9).

More light may be needed (to fill shadows, etc.). Figure 10 shows the greater heat produced by two lights (with filters) at a given distance. Temperature increased approximately 5° to 7° F above the single-light (with filters) temperature after 5 seconds and increased 10° to 13° F after 15 seconds. One stop was gained when a second light with filters was added at a 45° angle.

For example, to obtain high-speed data of ice forming on an airfoil, the temperature rise could not exceed 3° F above ambient in the first 5 seconds, and an aperture of f/5.6 would be needed at a frame rate of 200 fps. The film used was Tri-X reversal 7278 with an ASA of 160. At this frame rate, a pin register camera with a 120° shutter could be used with a factor of 3 times the frame rate. This would make the corresponding shutter speed equivalent to 1/600th of a second. Figure 6 shows that a distance of 16 inches with ASA 25 film at 1/60th of a second will give an appropriate low temperature rise. Figure 5 shows that an f number of 8.5 at 16 inches can be used with one light and the filter combinations of IR, three thin glass, and three thin glass. Converting ASA 25, which was used in all of the graphs, to ASA 160 requires approximately a 2-1/2-stop exposure decrease. Going from 1/60th of a second to 1/600th requires a 3-1/3-stop exposure increase to f/6.0. A final example of using the graphs is given next.

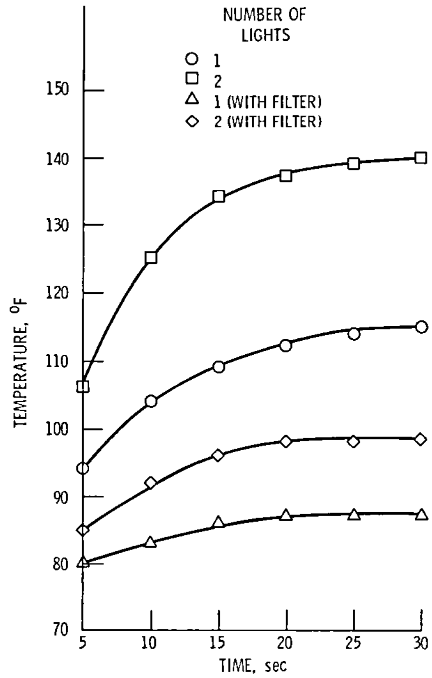

Figure 10. - Temperature as a function of time for a variety of conditions.

The high-speed filming of pesticide being sprayed on cabbage leaves is required. A leaf temperature exceeding 110° F changes the waxy composition of the leaf and the way the spray interacts with it. The depth of field requires f/8.0 with a frame rate of 4000 fps for good speed resolution. Figure 6 shows that using a distance of 6 inches with the recommended combination of filters produces a leaf temperature of only 87° F - far below the limit of 110° F. Figure 4 shows that at 6 inches an f number of just under 32 is possible. Now, this information must be converted to the actual ASA and shutter speed. Again, data were collected at ASA 25 with a shutter speed of 1/60th of a second. ASA 25 to 400 (7250 High Speed Video News Tungsten film) require a 4-stop decrease in exposure to f/128. Using a Fastex camera with a factor of 3 times the frame rate produces an equivalent shutter speed of 1/12 000th of a second. Going from 1/60th to 1/12 000th of a second requires an increase of 7-3/4 stops to f/11. This gives the photographer freedom to have a longer film running time, change the distance of the light or add another light, open up another stop, etc.

SUMMARY

Clearly, filtration is an effective method of reducing the temperature rise associated with high-intensity tungsten lights. By using an infrared cutoff filter to eliminate infrared wavelengths, which produce approximately 27 percent of the rise in temperature, and combining it with sheets of thin, uncoated glass, a reduction of over 50 percent in temperature rise is possible at close distances. Light loss is kept to a minimum - only a 2/3 increase in exposure is necessary with the filters in place at most distances. By varying the light-to-subject distance in conjunction with the filters, temperature can be controlled even further. The figures accompanying this paper represent a starting point. Figure 2 can be used to approximate the temperature rise in a

given time under a variety of conditions. By using figure 4, a photographer can approximate the f/number and distance combination necessary for the photographic situation. Figure 8 shows how temperature is affected by voltage at various distances if a voltage regulator is added. Figure 9 illustrates how a photographer will have to compensate for exposure as voltage varies. Finally, figures 5 to 7 will enable the photographer to predict temperature rise at various times and distances. The figures offer a wide selection of possibilities that will give the photographer more flexibility in meeting different photographic situations.

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15. Supplementary Notes

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16. Abstract

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