A Continuous Process for the Development of Kodak Aerochrome Infrared Film 2443 as a Negative

Abstract

A process for the continuous dry-to-dry development of Kodak Aerochrome Infrared Film 2443 as a negative (CIR-neg) is described. The process is well suited for production processing of long film lengths. Chemicals from three commercial film processes are used with modifications. Sensitometric procedures are recommended for the monitoring of processing quality control. Sensitometric data and operational aerial exposures indicate that films developed in this process have approximately the same effective aerial film speed (EAFS) as films processed in the reversal process recommended by the manufacturer (Kodak EA-5). The CIR-neg process is useful when aerial photography is acquired for resources management applications which require print reproductions. Originals can be readily reproduced using conventional production equipment (electronic dodging) in black and white or color (color compensation).

False color infrared aerial films have unique spectral sensitivity characteristics which are particularly useful for resource management surveys of vegetation. These films are normally processed as a positive transparency for direct viewing. In natural resources applications, there is frequently a requirement for multiple reproductions of aerial films for which negative materials provide greatest flexibility.

Several investigators have reported on the development of color infrared film as negative. Pease (1969) described the use of a low temperature Kodak C-22 process with extended developer time for the processing of Kodak Aerochrome Infrared Film 8443 as a negative. Sensitometric results for this older emulsion were not satisfactory.

Zsilinszky *et al.* (1985) described two processes for the development of the current color infrared emulsion Kodak Aerochrome Infrared film 2443, for which satisfactory sensitometric performance was achieved in controlled tests. A low temperature C-22 process was evaluated using extended developer time without emulsion prehardening. This process provided negatives of good sensitometric characteristics (parallel sensitometric curves for all dye layers and low base + fog) and fine grain. Unfortunately, this process required exposure compensation up to one stop or one half of the effective aerial film speed of the film when processed as a positive. For an aerial film which is already slow, this process was only suitable for use with fast lenses (*f*/2.0 and *f*/2.8) while maintaining control of image motion with shutter speed. Further, the processing time of the process without emulsion prehardening is not considered appropriate for continuous dry-to-dry processing.

The second process described by Zsilinszky *et al.* (1985) involved the use of emulsion prehardening and high temperature development. This process provided the basis for subsequent investigations by the authors (Klimes *et al.*, 1987). Targeting this process for operational use required optimization of film processing to provide good quality sensitometric results with an effective aerial film speed (EAFS) similar to that of the reversal process EA-5. The process described herein has been used for the past three years in demonstration trials involving users in government and industry across Canada.

Material and Methods

To evaluate CIR-neg processing experiments and to develop quality control methods, quantitative sensitometric methods are used. The sensitometer is based on a design described by Carman (1969, 1982) and is calibrated by the National Research Council of Canada. Spectral output consists of simulated air photo daylight including near infrared light to 900 nanometres. All sensitometric exposures of CIR-neg materials are made in contact with a 21-step (0.15 density increments) calibrated step wedge. A Wratten 12 (minus blue) gelatin filter is used in all exposures.

To facilitate the capture of sensitometric data from films, a status M color transmission densitometer was interfaced to a personal computer. A computer program for evaluating sensitometric measurements with output in tabular and graphical form (Figure 1) was developed. In the absence of national or international standards for color aerial films, speed of the CIR-neg film is calculated in accordance with a standard for still color negative films (ANSI, 1981). Speed and average gradient are calculated for each color dye layer to evaluate consistency of contrast of all layers, using calculation methods derived from CSA specification (CSA, 1969). The calculation of infrared (IR) and red-green (RG) balance are made using the method described by Fleming (1980).

Processing Chemistry

Earlier tests (Zsilinszky et al., 1985; Klimes et al., 1987) used commercial photo chemicals from various Kodak processes (C-22, EA-5, E-4, and C-41), as well as user mixed chemicals. After extensive testing, the processing chemistry described in Table 1 was implemented.

Most of the described processing chemicals, once mixed, have a reasonably long shelf life. The exceptions are C-22 developer and EA-5 prehardener which age rapidly if left standing without utilization and replenishment. Our experience is that they are degraded within two weeks if unused.

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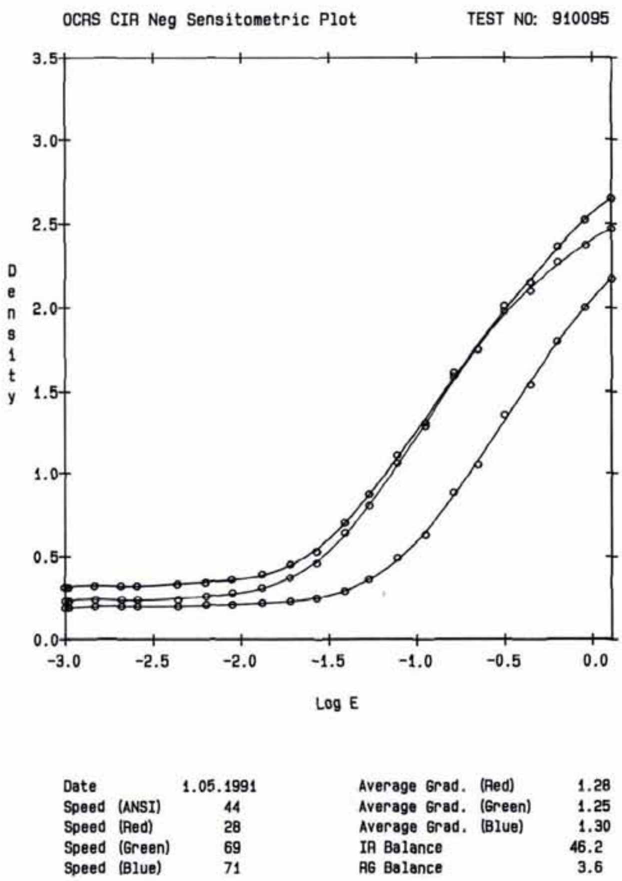

Fig. 1. Sensitometric report.

TABLE 2. PROCESSING SEQUENCE FOR CIR-NEG

Step No.	Solution	Time (min:sec)	Temperature ± Accuracy (°C)	Replenishment Rate (ml/m²)*
1	Prehardener	1:30	39.0 ± 0.2	645
2	Neutralizer	1:30	39.0 ± 1.0	645
3	Developer	5:30	39.0 ± 0.2	2152
4	Stop	1:30	39.0 ± 1.0	2152
5	Wash 1	1:30	39.0 ± 2.0	4 l/min
6	Bleach	3:00	39.0 ± 1.0	1076
7	Fixer	3:00	39.0 ± 1.0	1076
8	Wash 2	3:00	39.0 ± 2.0	4 l/min
9	Stabilizer	1:30	39.0 ± 2.0	645
10	Dry	5:00	50.0 ± 5.0	

* Note: replenishment rate based on surface area of film unless otherwise indicated.

The shelf life of mixed developer replenisher and prehardener replenisher is longer.

Processor

To facilitate the development and demonstration of this process, a film processor was designed and constructed to meet the authors' specifications. The processor is of the continuous leader type capable of processing films from 35mm to 241mm (9.5 inch) in width and in lengths of up to 122 metres (400 feet). It has racks with adjustable roller position which provide for ready modification of the processing time independently for each tank.

The processor has nine wet and two dry tanks. Solutions are thermostatically regulated individually, and transport speed is maintained by a digital controller. The processing sequence for each tank is shown in Table 2. An external replenishing system is used which consists of bellows pumps driven by a timer.

CIR-Neg Processing and Process Control

The CIR-neg process generally follows the roller transport processing sequences of Kodak Aerocolor Negative Film 2445

TABLE 1. DESCRIPTION OF PROCESSING CHEMISTRY

Solution	Chemical Used	Mixing Instructions
Prehardener	Kodak EA-5 Prehardener and Replenisher	Both working solution and replenisher are prepared by using 90% of the manufacturer's specified amount of water (i.e., 45 l instead of the specified 50 l)
Neutralizer	Kodak EA-5 Neutralizer and Replenisher	Both working solution and replenisher are prepared according to manufacturer's specification.
Developer	1. Kodak Liquid Developer, Process C-22 2. Kodak Liquid Developer, Replenisher, Process C-22 3. Benzotriazol 4. Citrazinic acid 5. 5N sulphuric acid	Both developer and developer replenisher are mixed according to manufacturer's specifications. After solutions are full mixed, 0.5g of citrazinic acid and 0.01g of benzotriazol are added to each litre of developer and developer replenisher. After mixing, solution pH is adjusted using 5N sulphuric acid. Working solution should have a pH of 9.80 and the replenisher solution a pH of 10.00. Experience has indicated that the developer working solution should stand for two days prior to use. Note: Benzotriazol is easier to use in the form of a water solution at 5g/l concentration.
Stop	Acetic acid	Acetic acid at a 2% concentration in water is used as both a working solution and replenisher.
Bleach	1. Kodak Flexicolor Bleach Replenisher II, part A 2. Kodak Flexicolor Bleach Replenisher II, part B 3. Kodak Flexicolor Bleach II Starter	Both working solution and replenisher are prepared according to manufacturer's specification.
Fixer	Kodak Flexicolor Fixer and Replenisher	Both working solution and replenisher are prepared according to manufacturer's specification.
Stabilizer	Kodak Photo-Flo	Both working solution and replenisher are prepared according to manufacturer's specification.

(Eastman Kodak, 1972). The processing sequence, contact times, temperatures, and replenishment rates are shown in Table 2.

Strict control tolerances must be established for most parameters regulating the process. Timing should be controlled to an accuracy of ±5 percent. The absolute tolerance of the temperature of the prehardener and the developer should not exceed ±0.2C°. Other solution temperatures can be controlled to the limits indicated in Table 2. Another critical parameter is the pH of the developer which should be controlled at pH 9.80 within a tolerance of ±0.02. Aeration of the bleach is implemented to minimize solution degradation, which might result in leuco-cyan development on the film (Eastman Kodak, 1977).

The CIR-neg process requires accurate sensitometric quality control. Because the processing method for CIR-neg is significantly different from that of the Kodak Aerocolor Negative process, it cannot use Kodak Control Strips. The authors have developed a quality control procedure for CIR-neg processing which involves the exposure of an ICAS/NRC sensitometric step wedge with Wratten 12 filter on a blank strip of 2443 film of known emulsion. After processing, the strip is read using a status M transmission densitometer interfaced to a personal computer. Sensitometric plot output from the computer (Figure 1) is then evaluated to determine the requirement for process adjustments.

Various emulsions of CIR film, when processed in the EA-5 (positive reversal) process, seldom provide sensitometric curves for all three color layers which would be parallel and without crossover. When optimizing the CIR-neg process, the same problem is apparent. In the absence of standard mathematical methods describing the quality of processed films other than "speed" and "contrast" (i.e., average gradient or contrast index), the authors rely on the traditional methods of visual examination. Figure 2 illustrates an idealized sensitometric plot suitable for obtaining high quality color prints. The influence of low or high developer pH is

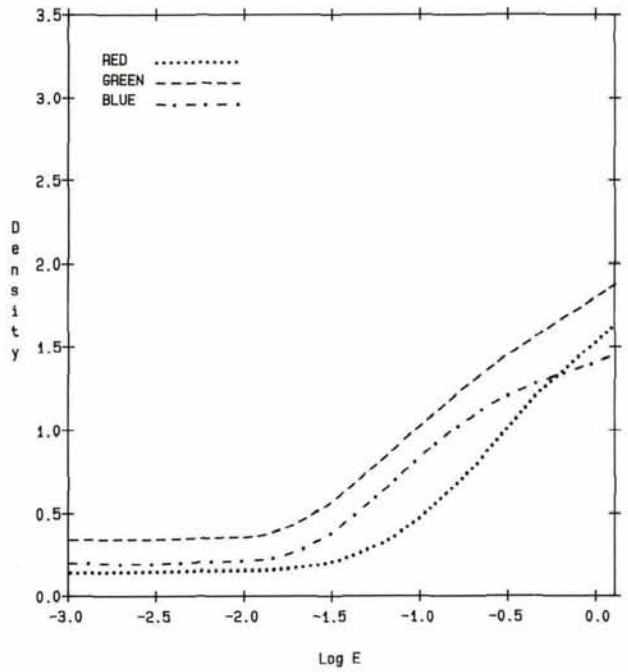

Fig. 3. Low pH effect on sensitometric curves.

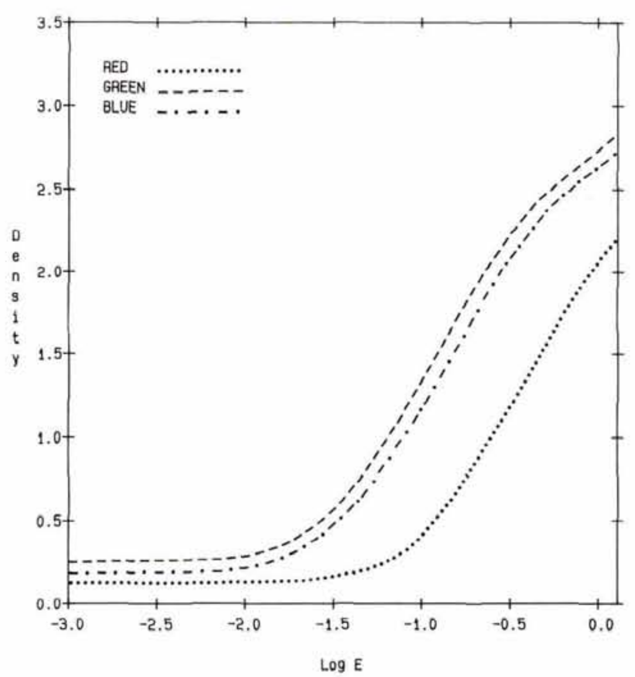

Fig. 2. Ideal sensitometric curves.

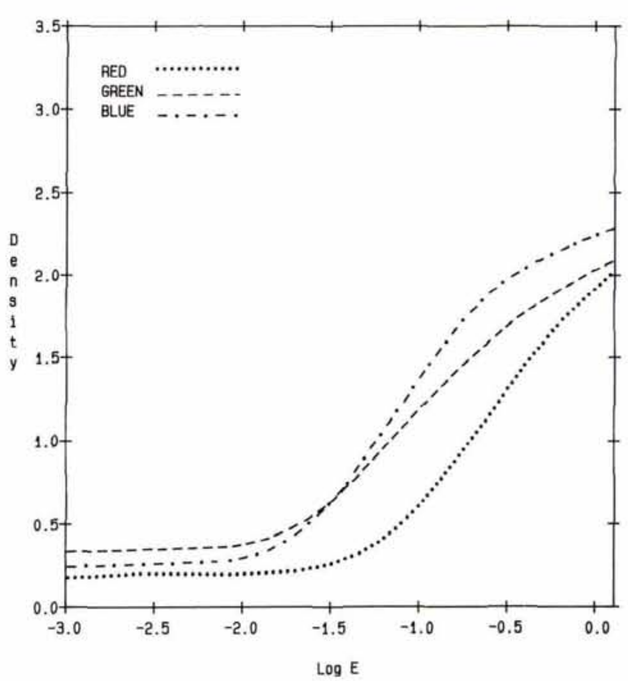

Fig. 4. High pH effect on sensitometric curves.

shown on Figures 3 and 4, respectively. Curves resulting from proper processing are shown on Figure 5. Our experience indicates that increasing developer temperature and processing time increases both the EAFS and the average gradient. Extended developer time has a greater influence on the average gradient while elevated developer temperature influences the EAFS. By careful selection and monitoring of the developer time, developer temperature, and pH, the operator can obtain properly developed negatives for color print reproduction.

Discussion of Results

The most significant feature of the CIR-neg is the ability to adjust color balance or to provide enhancements in photographic reproduction. Proper color balance is achieved through filtration in a darkroom rather than during data acquisition. Resulting prints generally have better color balance and, when printed on an autododging printer, are easily compensated for overall density changes due to lens vignetting, differential illumination, and bidirectional reflectance.

Several different types of imagery can be produced from the CIR-neg using conventional darkroom reproduction material and equipment. This includes black-and-white and color prints and color transparencies.

The most suitable material for production of black-and-white prints is Kodak Panalure Select RC paper due to its panchromatic sensitivity. With a color autododging contact printer and various color print filters, prints of high quality can be produced to suit the special needs of an interpreter. For example, a medium density cyan filter (CP50C) suppresses the excessive IR radiation reflected from vegetation, which otherwise might overwhelm the other spectral bands of the CIR-neg. This enhancement can facilitate better distinction between hardwood and conifer species for forest inventory applications.

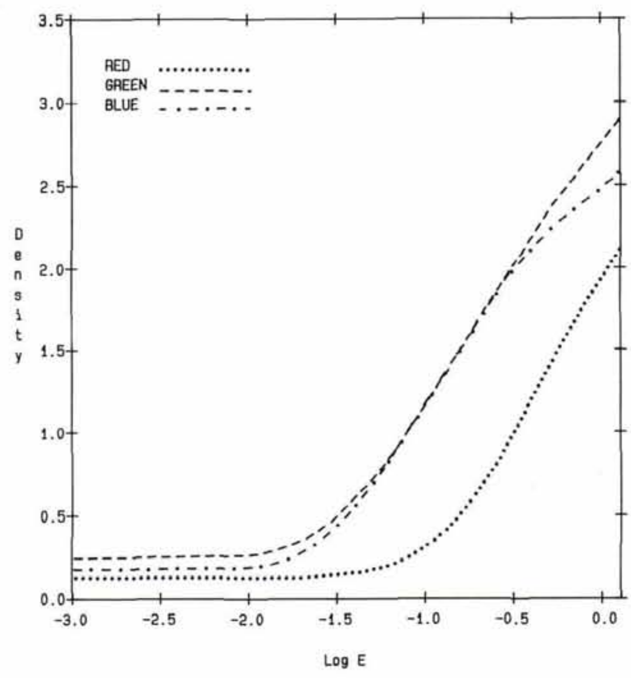

Fig. 5. Optimal sensitometric curves.

Color prints can be made in the same way prints are made from true color negative films using autododging contact printers or color enlargers. The color balance of the print can be adjusted to enhance details for special applications, such as geotechnical engineering studies of soil moisture. The particular advantage of color negative films is the convenience and higher production rates resulting from the use of autododging printers.

Positive transparencies can be made using clear-based display materials which can be processed in conventional EP-2 or RA-4 compatible processors with "Duratrans" mode. It is well known that second generation transparencies cannot match the resolution of first generation images produced by CIR-pos film. Nevertheless, transparencies from 35-mm and 70-mm negative films enlarged to 10- by 10-inch standard size are more readily made than from CIR-pos films.

To compensate for infrared balance due to altitude and emulsion differences when using CIR film, two techniques are used: selecting properly balanced emulsion from the stock of several different batches of film; or the use of color compensating filters during exposure (in addition to Wratten 12) (Fleming, 1980). When using CIR-neg, compensation for infrared balance is done during printing in the darkroom. There is no necessity of keeping large stocks of different emulsions or using color compensating filters which may result in a potential gain in exposure of up to two *f*-stops and eliminates geometric distortions from gelatin filters. Color balanced prints have been made to the satisfaction of photo interpreters from film emulsions with infrared balances of 0 to 45 (calculated based on Fleming (1980)).

Based on many years of experience in using CIR films, differences in EAFS have been noted between different emulsion numbers and between different formats of the same emulsion. It is recommended that the speed of CIR film should be determined by sensitometric test for every new emulsion and format combination in use.

A method for negative processing of long rolls of color infrared aerial film has been successfully demonstrated. To date, over 5000 metres (16,400 feet) of film involving different emulsion numbers have been processed. The process is suitable for production processing and uses commercial photochemistry with minor modifications.

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