CHAPTER 4
Film Processing

KEY TERMS
agitation  flood replenishment  oxidation/reduction reaction
archival quality  hyporetenion  synergism
developer  latent image  volume replenishment
fixer  manifest image

OBJECTIVES
At the completion of this chapter the reader should be able to do the following:
• Describe the main differences between manual and automatic film processing
• List the main components of the developer and fixer solutions and state the function of each component
• Explain the proper mixing procedure for developer and fixer concentrate solutions
• State the chemical safety procedures for the safe handling of processing chemicals as described by the Occupational Safety and Health Administration (OSHA)
• Describe the basic tests for determining the archival quality of processed images
• List the six main systems of automatic film processors and state the function of each system
• Describe the methods of installing film processors in a darkroom

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After a film has been exposed to radiation, the image that it contains is still invisible to the human eye and is called a latent image. For the film to be converted into a visible image, or manifest image, the silver contained in the film must be changed from an ionized state (Ag⁺) into a neutral, or reduced, state (Ag⁰), in which the silver turns black. This requires the film to be processed by various solutions that convert the latent image into a visible one and also preserve the image for permanent storage. The two basic methods of film processing are manual and automatic.
MANUAL AND AUTOMATIC FILM PROCESSING

Manual Processing

In the manual processing method, film is moved from one solution to the next manually until processing is complete. This method requires more labor and time and is more prone to variations than automatic processing. For this reason, manual processing is seldom used in diagnostic imaging today. For film to be processed manually, several steps are required after the films are hung on special hangers.

Procedure

1. **Wetting agent.** The wetting agent is a chemical that loosens the emulsion so that subsequent solutions can reach all parts of the emulsion uniformly, which reduces development time. This step is optional because developer ingredients also soften the emulsion. If a wetting agent is used, the film should remain in the solution for about 15 seconds.
2. **Developer.** The developer solution converts the latent image into the visible image; therefore, this is the most important processing chemical. The film remains in the developer for 3 to 5 minutes depending on the temperature of the solution.
3. **Stop bath or water rinse.** The stop bath or water rinse step stops the development process and removes excess developer from the film. A stop bath is a 1% solution of acetic acid that chemically neutralizes the developer (because it is an alkaline solution) and requires only 5 to 10 seconds of film immersion time. A water rinse relies on water to remove the excess developer and requires about 30 seconds of film immersion.
4. **Fixer.** The fixer solution removes the unexposed and undeveloped silver halide crystals from the film emulsion and also hardens the emulsion so that the film can be permanently stored. The time of fixation varies with solution temperature, but the general rule for manual fixation is use of the following equation

   \[
   \text{Fixing time} = \text{Clearing time} + \text{Hardening time}
   \]

   The clearing time is the time necessary for the fixer to clear away the unexposed and undeveloped silver halide crystals, which should be accomplished within 5 minutes. The hardening time is the time it takes the emulsion to properly harden and is usually equal to the clearing time; therefore, a film that requires 5 minutes to clear requires another 5 minutes to harden, leaving a total fixing time of 10 minutes.
5. **Washing.** Excess fixer must be removed from film before it is allowed to dry, or the fixer components crystallize onto the film surface, a process known as hyporetention. This white, powdery residue can impair the diagnostic quality of the final image and must therefore be avoided. An example of an image with hyporetention can be found in Chapter 10. This step may take up to 20 minutes.
6. **Drying.** Drying prepares the film for viewing and storage and can be accomplished either by an electric dryer, which works in less than a minute, or by exposure to room air while the film is mounted on a special hanger, which may require an hour or more.

Automatic Processing

Automatic processing requires an electromechanical device called an automatic film processor, which transports the film from one solution to the next without any manual labor except for placing the film into the device. This shortens the overall processing time, increases the number of films that can be processed in a given period, and ensures less variability of overall film quality than manually processed films because the processing time, solution temperature, and chemical replenishment are automatically controlled. The disadvantages of automatic processing include higher capital and maintenance costs, increased chemical fog due to higher processing temperatures, and transport problems that can damage or destroy images during processing. In a diagnostic imaging department that has not converted to digital imaging, the advantages far outweigh the disadvantages and automatic film processing is virtually exclusive.

PROCESSING CHEMICALS

Developer

As previously mentioned, the developer is the most important processing solution; it converts the latent image into a manifest image. This is accomplished by the developer solution carrying out an oxidation/reduction reaction, or redox. When a chemical is oxidized (broken down), it releases electrons. These electrons are then available to convert another compound into a more simplified, or reduced, state (hence the term oxidation/reduction reaction). During film processing, the developer solution ingredients are oxidized and the silver halide crystal is reduced to black metallic silver. This chemical reaction can be summarized by the following equations:

- During exposure to radiation:
  \[
  \text{Ag}^+ \text{ Br}^- + \text{radiation} \rightarrow \text{Ag}^0 + \text{Br}^- + \text{Ag}^+ \\
  (5 \text{ atoms latent image})
  \]

- During immersion in developer:
  \[
  \text{Ag}^+ + \text{developer} + \text{Ag}^+ (5 \text{ atoms latent image}) \rightarrow \\
  \text{Ag}^+ (10^8 \text{ atoms visible image}) + \text{oxidized developer}
  \]

Developer Components. Developer is composed of developing or reducing agents, preservatives, accelerators or activators, restrainers, regulators, antifoggants or starters, hardeners, solvents, and sequestering agents; all act on the film.

Developing or Reducing Agents. Developing or reducing agents carry out the oxidation/reduction reaction
that converts the latent image into a manifest image. Two different reducing agents are used in standard developer solutions: phenidone and hydroquinone.

**Phenidone (Elon or Metol in Manual Developer).** Phenidone is fast acting and produces the image optical densities of up to about 1.2. It is responsible for the minimum diameter ($D_{min}$) and speed indicators used in sensitometric testing (described in Chapter 5).

**Hydroquinone.** Because hydroquinone acts more slowly than phenidone, the developmental process is completed so that the image optical densities that are greater than 1.2 are visualized. Hydroquinone is responsible for the maximum diameter ($D_{max}$) and contrast indicators used in sensitometric testing. These indicators are the first variables to show an indication of developer failure because hydroquinone is the processing chemical most sensitive to changes in temperature, concentration, and pH and to exposure to light and heavy metals. Hydroquinone levels should be maintained in the range of 20 to 25 g/L.

The overall optical density is created by the synergistic action of the two reducing agents. **Synergism** means that the action of the two agents working together is greater than the sum of each agent working independently. **Synergism** is also known as **superadditivity** (Fig. 4-1).

**Preservative.** The preservative, or antioxidant, protects the hydroquinone from both aerial oxidation (chemical reaction with air) and internal oxidation (chemical reaction with other developer ingredients). If the hydroquinone is oxidized, there is a decrease in the $D_{max}$ and contrast indicators during a sensitometric test, along with a loss of the shoulder on the H and D curve. Oxidized developer causes the developer solution to turn from a clear, brown liquid into one that is dark and muddy. If strongly oxidized, the solution also has the odor of ammonia because this is a byproduct of the oxidation chemical reaction. Most developer replenishment tanks have a floating lid inside the tank in addition to the main lid on the outside, to minimize contact with the outside air. The chemicals sodium sulfite, potassium sulfite, and cycon can be used as developer solution preservatives.

**Accelerator, Activator, or Buffering Agent.** The accelerator, activator, or buffering agent has two functions: to soften and swell the emulsion so that reducing agents can work on all of the emulsion and to provide an alkaline medium for the reducing agents. The developing agents must exist in an alkaline medium to have the free electrons available to reduce the silver to Ag⁺.

An indicator known as **pH** is used to measure the alkalinity of a solution. Potential hydrogen (pH) refers to the exponential ($p$) value of hydrogen ions ($H^+$) available for a reaction. Those chemicals having a high hydrogen potential ($H^+$) are called **acids**, and those having a high alkaline or hydroxide potential ($OH^-$) (and therefore, a low hydrogen potential) are called **bases**. The pH scale ranges from 0 to 7 (acids) and 7 to 14 (bases) (Fig. 4-2). This scale is based on the concentration of positively charged hydrogen ions ($H^+$) in moles per liter. For example, a pH of 4 would mean that a particular solution contains one ten-thousandth ($10^{-4}$) of a mole of hydrogen ions per liter. For this value to be converted to pH, the negative exponent ($−4$) is changed to a positive number (4). A solution with a $H^+$ concentration of one ten-millionth ($10^{-7}$) moles per liter would then have a pH of 7, and so on. Because the pH scale is logarithmic in nature, a change of one whole number on the pH scale can represent a tenfold change from the previous concentration. A pH of 1 denotes 10 times more $H^+$ ions than a pH of 2; a pH of 3 has 10 times fewer $H^+$ ions than a pH of 2, and so on. Pure water is neutral and has a pH of 7. Fixer is an acid solution; therefore, care must be taken not to introduce it into developer solutions because only 0.1% contamination deteriorates the developer activity enough to compromise image quality. Chemicals that can be used as accelerators include sodium carbonate, sodium hydroxide, potassium carbonate, and potassium hydroxide.

![FIGURE 4-1 Graph demonstrating superadditivity effect of phenidone and hydroquinone.](image1)

![FIGURE 4-2 Potential hydrogen (pH) scale.](image2)