Testing Film Speed and Development

Replace endless Trial-and-Error with a simple Test and Spreadsheet Evaluation

by Ralph W. Lambrecht *2011-Jan-16*

This paper is essentially an excerpt of a chapter called 'Customizing Film Speed and Development' in the book 'Way Beyond Monochrome, Ed2', published in 2011 by Elsevier, Focal Press, ISBN 978-0-240-81625-8. The film evaluation and its analytical method presented in this paper are based on a graphical evaluation methods described in that book. A basic understanding of the analog photographic process, including sensitometry and densitometry is assumed. This paper and the accompanying spreadsheet is provided as is, and the user agrees to accept all consequences that may result from their application, without holding the author responsible or liable in any way, shape or form.

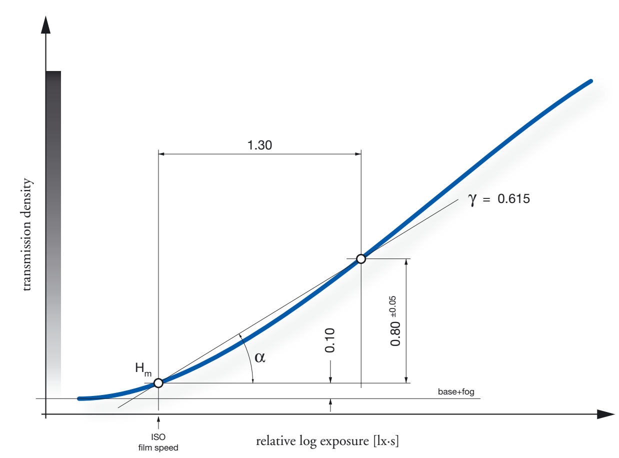
Film manufacturers have spent a lot of time and resources establishing the film speed and the development time suggestions for their products. Not knowing the exact combination of products we use for our photographic intent, they have had to make a few assumptions. These assumptions have led to an agreement among film manufacturers, which were published as a standard in ASA PH2.5-1960. It was the first standard to gain worldwide acceptance, but it went through several revisions and was eventually replaced by the current standard ISO 6:1993, which combines the old ASA geometric sequence (50, 100, 200, 400, 800, ...) with the old DIN log sequence (18, 21, 24, 27, 30, ...). As an example, an ISO speed is officially written as ISO 100/21°, but that is often abbreviated to 'ISO 100'.

Fig.1 shows a brief overview of the ISO standard, according to which, the film is exposed and processed so that a given log exposure of 1.30 has developed to a transmission density of 0.80, resulting in an average negative gradient of about 0.615. The film speed is determined by the exposure, which is developed to a shadow density of 0.10. This makes it an acceptable standard for general photography. However, the standard's assumptions may not be valid for every photographic subject matter, and advertised film speeds and development times can only be used as starting points.

A fine-art photographer appreciates fine shadow detail and often has to deal with subject brightness ranges that are significantly smaller or greater than the normal 7 stops from the beginning of Zone II to the end of Zone VIII. In addition, the use of certain equipment, like the type of enlarger or the amount of lens flare, influences the appropriate average gradient and final film speed. The nomograph in book provides an overview of these variables and their influence. The Zone System is designed to control all these variables through the proper exposure and development of the film. This requires adjustment of the manufacturer's film speed (or 'box speed') and development suggestions.

In general, advertised ISO film speeds are too optimistic and suggested development times are too long. It is more appropriate to establish an 'effective film speed' and a customized development time, which are personalized to the photographer's materials and technique. In most literature, the effective film speed is referred to as the exposure index (EI). Exposure index was a term used in older versions of the standard to describe a safety factor, but it was dropped with the standard update of 1960. Nevertheless, the term 'EI' is widely used when referring to the effective film speed, and we will accept the convention.

fig.1 Film exposure and development according to the current ISO standard.



Customized Film Testing

The following method of determining the effective film speed and development time requires the use of a densitometer, to measure negative densities, and a spreadsheet, called *FilmTestEvaluation.xls*, which can be obtained from my website at *www.darkroomagic.com*. The test summary provides enough information to determine the effective film speed and how it changes with different development times. It also provides a suggested development time for every possible subject brightness range. Negatives exposed and developed with this information will have a constant and predictable negative density range for any lighting situation. This method is ideally suited for use with the Zone System. The final results are well worth the time commitment to perform the test and to evaluate the data.

The use of a densitometer is essential for this test, but it is an expensive piece of equipment. A quality densitometer costs as much as a 35mm SLR, if purchased new, but they are often available for a fraction of that on the used market. This test only requires us to read transmission densities, but a densitometer which is able to read both transmission and reflection is a much more versatile piece of equipment. Some darkroom analyzers have a built-in densitometer function, and they can be used to read projected negative densities. Alternatively, you may ask a friend or the local photo lab to read the densities for you. Once you have a densitometer, you will find many uses for it around your darkroom.

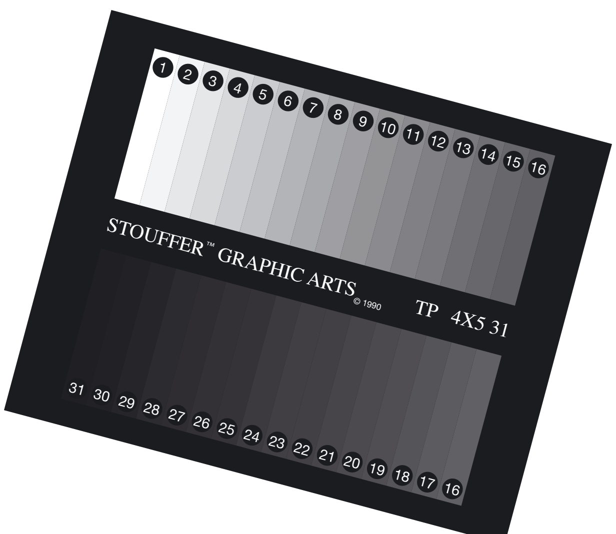


fig.2 This transmission step tablet, made by Stouffer, provides a 10-stop exposure range in 31 steps. *www.stouffer.net*

Exposure

Many different methods of generating the necessary negative test exposures have been published. Most require changes to lens aperture or camera shutter settings for exposure control. If conducted with care, using aperture and shutter control is a practical method providing acceptable accuracy. However, there are some equipment limitations, which we need to take into consideration to get reliable results.

Mechanical shutters are rarely within 1/3-stop accuracy, and their performance is very temperature sensitive, acting slower when cold. They also become sluggish after long periods of non-use. In these cases, it helps to work the shutter by triggering the mechanism a few times. In any event, they cannot be set in fine increments, and exposure deviations should be recorded down to 1/3 stop. This is not possible with mechanical shutters. Electronic shutters, on the other hand, are very precise, and sometimes provide 1/3-stop increments, although they are uncommon in large-format equipment. Lens aperture accuracy is usually very good, being within 1/10 stop, but apertures are notorious for being off at the largest and smallest setting. Medium aperture settings are far more trustworthy, but only if worked in one direction. Switching from f/8 to f/11 may not result in the same aperture as switching from f/16 to f/11, due to what is known as mechanical hysteresis. Consequently, we can use shutters and lens apertures to control test exposures, but must avoid mechanical shutters and change f/stops only in one direction.

As an alternative, consider the use of a transmission step tablet wherever possible. A step tablet is a very accurate and repeatable way to expose a piece of film. Fig.2 shows an example supplied by Stouffer in Indiana, *www.stouffer.net*, but they are available from different manufactures and in different sizes. The process is most simple if you purchase one in the same size as the negative format to be tested, and photograph it with the aid of a slide duplicator. If such a device is not available, then a similar setup can easily be rigged up. It can be as simple as placing the step tablet onto a light table, and taking a close-up copy.

I prefer the 31-step tablet to the 21-step version, due to the higher quantity of data points available. However, in the process of copying the step tablet, be certain that the steps on the final negative are wider than the measuring cell of the densitometer, otherwise you will not be able to read the density values properly. This may necessitate opting for the 21-step version with its wider bars or adjusting the scaling when you photograph the step tablet. This will be most likely the case only with 35mm negatives. You should be able to fit the 31-step version with most medium format and 4x5-inch film.

Film has a different sensitivity to different wavelengths of light. Therefore, select a light source with a color temperature representative of your typical subject matter and setup. In other words, use daylight or daylight bulbs if you are a landscape photographer, and use photofloods or flashlight if you mainly work in the studio. However, always keep exposure times between 1/500 s and 1/2 s to avoid inaccuracies due to reciprocity failure.

Assume the box speed to be correct and determine the right exposure with an average reading, or use a spotmeter for the medium gray bars. You can use the manufacturer's recommended film speed, since the actual exposure is not critical as long as it is within 1 stop. The worst that can happen is that a few bars are lost on either end. Once the step tablet is photographed and developed, you will have 21 or 31 accurately spaced exposures on every frame. They are accurate, because their relative exposure is fixed through the densities of the step tablet, and are not affected by any shutter speed or lens aperture inaccuracies. If you are testing sheet film, expose five sheets with the same exposure. If you are testing roll film, fill five rolls of film with the same exposure on every frame.

Development

Select the developer, its dilution and temperature you intend to use for this film. Develop the film in the same manner as you would normally, but for fixed and closely controlled development times. Develop the first roll or sheet for 4 minutes, the next for 5.5 minutes and the following for 8, 11 and 16 minutes, respectively. Start timing after the developer has been poured into the developing tank, and stop timing after it has been poured out again. Process and dry all film normally.

Make sure that all processing variables are constant and the only difference between these films is the development time. The temperature of the developer is critical, but it is more important to have a consistent temperature than an accurate one. Try to maintain an almost constant developer temperature throughout the process. Keeping the developing tank in a tempered water bath will help to do so. It does not matter if your thermometer is off by a degree or two as long as it reads the same temperature for the same amount of heat all the time. Do not switch thermometers. Pick one, and stick to it for all of your darkroom calibrations. For this test, all chemicals should be used as one-shot, but most importantly, do not reuse any developer solution. It does exhaust with use, and these five films must be developed consistently. The other chemicals are not as critical, but I still suggest using fresh chemicals for film development.

In addition, watch the film/developer ratio. The active ingredients of the developer are gradually exhausted during development. The rate of exhaustion during the test must be similar to your typical application. For example, do not develop one 4x5 test sheet in 1.5 liters of developer if you normally process six at a time in the same volume. Six sheets of film will exhaust the developer more quickly than just one, and consequently, negative densities of the test film will be higher than from normal development. In this case, prepare additional test sheets, also exposed with the step tablet, and develop them together with the actual test film.

Always conduct the test with film in your favored format. Emulsion thicknesses differ between film formats, and consequently, so does the development time. A test based on one film format may not be valid for another.

Collecting the Data

The 'Input Data' sheet of the spreadsheet is shown in fig.3 on the next page. The colors provides visual clues to cell functions. Yellow cells are reserved for entering data, green cells provide output, and blue cells contain default values that may be changed if necessary.

The first thing to look at is cell 'C48'. There you can switch between input for a 21-step or a 31 step tablet. The sheet will slightly change and adapt according to your selection. Then use cells 'G43:J49' to enter the basic parameters and variables of your film test, including the type of film,

Film Test Procedure Overview

1. **Exposure**
   Using the film's advertised speed, fill 5 sheets or rolls of film with identical exposures of a transmission step tablet.
2. **Development**
   Develop each film for 4, 5.5, 8, 11 and 16 min, respectively, and process normally.
3. **Collecting the Data**
   Measure the negative-density values for each test, and enter it into the 'Input Data' sheet.
4. **Charting the Data**
   Step through the individual worksheets for each curve, and adjust the average-gradient values if necessary.
5. **Creating a Summary**
   Smooth the development curves by fine-tuning the average-gradient values if necessary. Enter your normal average gradient. Estimate and enter your normal effective film speed (EI). Align target log-exposure value with target average gradient to estimate the effective film speed for any subject brightness range.

Film Test Evaluation								
Kodak TMax-100, Ilford ID-11, 1+1 @20°C, rotation processing								
©2010, 2011 Ralph W. Lambrecht (www.darkroomagic.com)								
version 1.1.0 (2011-Jan-13)								
		step tablet		negative density				
	theo	actual	actual	development time [min]				
step	density	density	log exp	4	5.5	8	11	16
1	0.00	0.00	3.00	0.69	0.98	1.33	1.66	2.23
2	0.10	0.10	2.90	0.63	0.94	1.27	1.57	2.14
3	0.20	0.20	2.80	0.60	0.91	1.22	1.52	2.06
4	0.30	0.30	2.70	0.58	0.87	1.17	1.46	1.99
5	0.40	0.40	2.60	0.54	0.83	1.13	1.41	1.92
6	0.50	0.50	2.50	0.49	0.79	1.08	1.37	1.84
7	0.60	0.60	2.40	0.45	0.74	1.04	1.32	1.78
8	0.70	0.70	2.30	0.42	0.68	0.98	1.26	1.70
9	0.80	0.80	2.20	0.39	0.64	0.93	1.21	1.63
10	0.90	0.90	2.10	0.35	0.59	0.88	1.14	1.56
11	1.00	1.00	2.00	0.34	0.55	0.84	1.08	1.48
12	1.10	1.10	1.90	0.30	0.50	0.79	1.01	1.41
13	1.20	1.20	1.80	0.27	0.46	0.72	0.94	1.33
14	1.30	1.30	1.70	0.23	0.42	0.67	0.88	1.24
15	1.40	1.40	1.60	0.20	0.37	0.62	0.82	1.14
16	1.50	1.50	1.50	0.18	0.34	0.57	0.77	1.03
17	1.60	1.60	1.40	0.16	0.30	0.51	0.69	0.92
18	1.70	1.70	1.30	0.13	0.25	0.46	0.60	0.81
19	1.80	1.80	1.20	0.11	0.22	0.40	0.54	0.72
20	1.90	1.90	1.10	0.09	0.18	0.35	0.47	0.61
21	2.00	2.00	1.00	0.07	0.16	0.30	0.42	0.53
22	2.10	2.10	0.90	0.06	0.12	0.24	0.34	0.42
23	2.20	2.20	0.80	0.04	0.10	0.19	0.27	0.34
24	2.30	2.30	0.70	0.03	0.07	0.14	0.21	0.26
25	2.40	2.40	0.60	0.03	0.05	0.10	0.14	0.18
26	2.50	2.50	0.50	0.03	0.04	0.07	0.10	0.13
27	2.60	2.60	0.40	0.03	0.04	0.06	0.08	0.10
28	2.70	2.70	0.30	0.02	0.03	0.05	0.06	0.07
29	2.80	2.80	0.20	0.02	0.03	0.04	0.05	0.06
30	2.90	2.90	0.10	0.02	0.03	0.04	0.04	0.05
31	3.00	3.00	0.00	0.02	0.03	0.03	0.04	0.04

		film:	Kodak TMax-100		
		format:	4x5 sheet film		
		developer:	Ilford ID-11		
Stouffer Step Tablet		dilution:	1+1		
max density:	3.00	temperature:	20°C	relative	
# steps:	31	agitation:	rotation processing	Dmin	Dmax
increments:	0.10	date:	2006-Dec-06	0.17	1.37

fig.3 The 'Input Data' sheet provides visual clues to cell functions. Yellow cells are reserved for entering data, green cells provide output, and blue cells contain default values that may be changed if necessary.

developer, dilution, temperature, agitation method and the date when the test was conducted.

Ideally, the 21-step tablet should have 0.15 step-to-step density increments, and the 31-step tablet should have 0.1-density increments. Be aware that your step tablet will most likely deviate slightly from these anticipated values. This is also true for calibrated step tablets. Therefore, measure the densities of the step tablet itself, and list them in cells 'E11-E41'. The test results will be more precise when charting the test data against these actual values.

Now, measure the densities of the five development test times, and fill them into cells 'G11:K41'. Note that the timing sequence 4, 5.5, 8, 11 and 16 is highly recommended, but the spreadsheet will accept other values.

My densitometer has a calibration button to 'zero' out the measurements, because it does not have an internal light source of known intensity for transmission density readings. In other words, it can be used with different light sources and allows for relative and absolute density measurements. If your equipment has a similar feature, then take the first reading with nothing in the light path, push the 'zero' button, and then, continue to take all the measurements. This will enable you to measure the 'base+fog' density of the test negatives. If you 'zero' the measurements to a blank piece of the film before taking any readings, then all base+fog densities are equalized, and you would be unaware of any fog increase due to development time. If your densitometer does not have a 'zero' button, which is most likely the case if it has its own light source, then you can be assured that your readings are absolute values and no correction is required.

The typical measurement accuracy of a standard densitometer is ±0.02 density, with a reading repeatability of ±0.01 at best. This is a more than adequate measurement performance for a film development test. In addition, be aware that the Stouffer step tablet repeats step 11 or 16, and so we only need one reading for this density. Feel free to average the two readings if you find them to be slightly different.

In fig.1, we saw how the ISO standard defines normal development as a log exposure range of 1.30 and a density range of 0.80, measured at a 0.10 shadow density. We will now replace these values with our Zone System target values as explained in *Way Beyond Monochrome*. Fig.4 illustrates the change, which will better suit the Zone System and fine-art photography. First, we use our minimum shadow and speed-point density of 0.17. This ensures proper shadow exposure, even when development time is reduced to support high-contrast scenes. Second, we use our standard fixed negative density range of 1.20 (pictorial range). This covers the entire

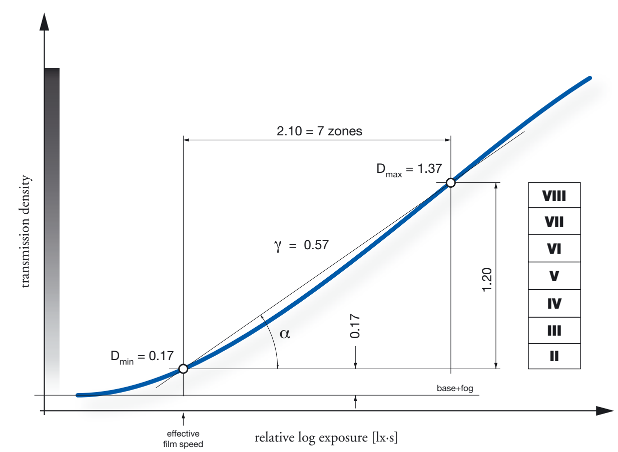


fig.4 Film exposure and development have been adjusted to work in harmony with the Zone System. The speed point has been raised to a density of 0.17, and the development has been adjusted to fit a normal subject brightness range onto a grade-2 paper.

paper exposure range, from the beginning of Zone II to the end of Zone VIII, for normal graded papers printed with a diffusion enlarger. This, combined with a minimum shadow density of Dmin = 0.17, fixes the maximum highlight density at Dmax = 1.37. Both values are the default values in cells 'K49' and 'L49'. In addition, we also sets the normal log exposure range to 2.10, since we need 7 subject brightness zones to expose the 7 paper zones above, and each zone is equivalent to 0.3 log exposure. The normal average gradient can be calculated as 1.20 / 2.10 = 0.57.

Charting the Data

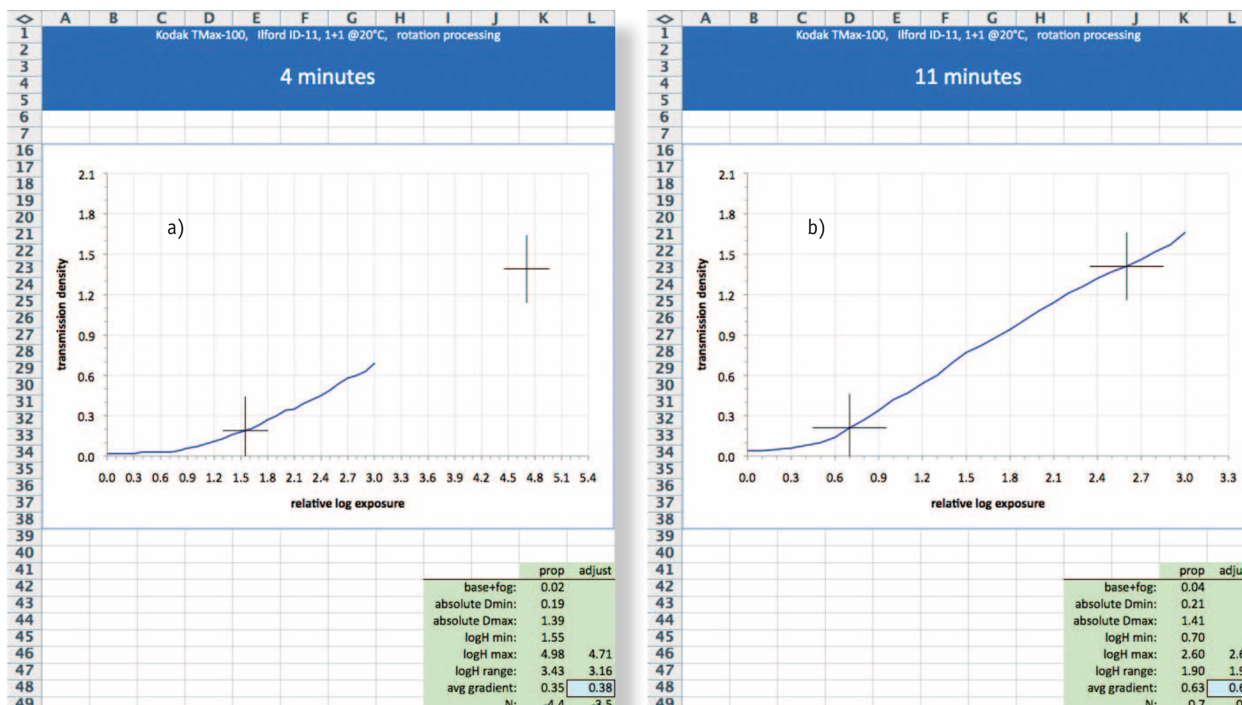
A spreadsheet is a good way to collect and view a large amount of numerical data, but you need to graph individual tests in order to evaluate the results more closely. Five additional sheets are included to chart transmission densities against relative log exposure for each of the five development test. Their tabs are labeled 'Curve 1' to 'Curve 5', and two examples are shown in fig.5 to take a closer look at the 4 and 11-minutes test data, (fig.5a&b, respectively). Major tick marks are in increments of 0.3 units, which correlate conveniently with 1 stop of exposure for both axis.

All five sheets are automatically filled by using the values on the 'Input Data' sheet. The data is plotted, and relevant parameters are first calculated and then listed in the 'proposed' column. In addition, two cross hair are calculated and shown in the graph. The one on the left marks the point on the curve at which minimum density (Dmin) is achieved. That is our speed point! The other marks Dmax, and together, they define the log exposure range and the achieved contrast, which is listed in terms of average gradient and as an N-development factor for Zone System worker.

If, for any individual test, a sufficient amount of data points are available, as illustrated in the 11-minute graph (fig.5b), Dmax calculations are relative reliable and require no further correction. If however, only a limited amount of data was obtainable, as shown in the 4-minute example (fig.5a), then, a manual adjustment may be necessary. This is very common with shorter development times and no reason for concern, because it is easily corrected.

Start by visualizing a smooth curve through the existing data points in fig.5a. Then, imagine an extension of that smooth curve all the way up to the right cross hair (Dmax). Now, adjust the average gradient value in cell 'L48' slightly, trying to improve its current position until it intersects with your visualization of that smooth extension. This may need a little practice, but as you will see, it does not have to be perfect to significant improve the following calculations.

fig.5a&b For each development-time test, transmission density is plotted against relative log exposure. Major tick marks are in increments of 0.3 units, which correlates conveniently with 1 stop of exposure. In the left graph, a proposed average-gradient value of 0.35 was adjusted to 0.38 to better reflect actual conditions.

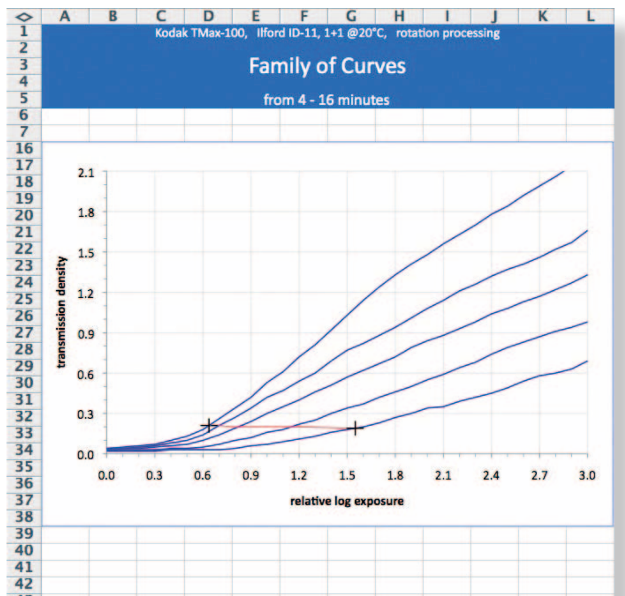


A Family of Curves

The next tab in the workbook is called 'Family of Curves', and it simply is a data collection from curve 1-5, including the adjustments made to their average gradient values. Looking at these superimposed graphs (fig.6) illustrates how film development changes negative transmission density with time, and it also shows how the effective film speed is affected at the same time.

Creating a Summary

We are beginning to close the loop and are finally getting to see some of the results, which will guide us to use our film effectively and without trial and error. The ability to precisely predict development times, in order to cope with many lighting scenarios, is a major advantage. Select the final tab in the workbook, called 'Summary', and you will be presented with the final sheet, presenting a summary of the film test in four graphs. Do not be alarmed if these graphs do not look as smooth as you may have expected it. We will correct that in the next step.



time	logH	avgG	N
4	1.55	0.38	-3.5
5.5	1.15	0.43	-2.3
8	0.82	0.52	-0.7
11	0.70	0.63	0.7
16	0.64	0.96	2.8

fig.6 A 'family of curves' illustrates how the development time changes the negative transmission density.

Estimating Development Time

In the upper left-hand graph (fig.7a), the average gradient is plotted against development time. We conducted five development tests, and therefore, we have five data points connected by a smooth line. Data points for development times creating an average gradient below 0.4 and above 1.0 are not shown, but of course, you can include them by changing the default scaling values of the graph.

The lower left-hand graph (fig.7b), plots development compensation (N) against development time. There is little difference to the previous graph, but the five average-gradient values from the test were first converted to their correlating 'N' values. If you are comfortable thinking of development compensations in terms of N- or N+, you may find this graph more useful than the previous. The relationship between development compensations in Zone System 'N' terms and the average gradient is explained at length in *Way Beyond Monochrome*.

It is quite possible that these graphs are not as smooth as you would like them to be. There are several reasons for this to happen, including lack of data, test inaccuracies, measurement errors and computational shortcomings of the spreadsheet. Cells 'D10-H10' offer the flexibility to make minor changes to the data in order to improve overall data smoothness. The most common problem is the lack of data for short development times. Just take another look at fig.5a, this example's data for a 4-minute development, to appreciate the mathematical challenges this spreadsheet is facing. In addition to the adjustments you already made in the individual sheets, you can continue to that here.

With these graphs at hand, predicting accurate development times has become simple. However, care must be taken not to alter any of the other significant variables. Be sure to keep temperature, chemical dilution, film/developer ratio and agitation as constant as possible.

Predicting Effective Film Speeds

The final task is to determine the effective film speeds for all developments. Of course, we would like to have these effective film speeds in ISO units, but doing this directly is a complex task and involves laboratory equipment not available to a fine-art photographer. The only data obtainable at this point are the relative log exposures required to develop the speed point densities of our five curves.

There are two ways to convert relative log exposures to effective film speeds: the long way to get precise results, and the quick way, based on years of film-testing experience, which will get us reasonably close. Both methods are based on identifying the normal effective film speed, or personal exposure index (EI), in terms of ISO units.

A long but precise way to determine the normal EI requires one more roll of film and an additional test. However, years of experience, testing numerous film/developer combinations, have shown that in 90% of all cases the normal EI is about 2/3 stop below the film speed indicated by the manufacturer (box speed). In other words, a film advertised as ISO 100/21°, will most likely have an EI of 64 ASA. We will use this shortcut for now, but I recommend a sixth test, as explained in *Way Beyond Monochrome*, for people who are after more reliable results. In either case, enter your normal EI into cell 'L9'.

In the upper right-hand graph (fig.7c), the average gradient is plotted against relative log exposure. A black horizontal line marks the chosen normal average gradient. A red vertical line marks the corresponding relative log exposure. Its position is unfortunately not automatic. Estimate the relative log exposure required for the red and black line to intersect the curve, and enter that value into cell 'L10'.

The lower right-hand graph (fig.7d), plots development compensation (N) against effective film speed, showing the appropriate film speed for any development compensations this particular film/developer combination is capable of. We can see how the film sensitivity decreases with development contraction. In other words, the film requires significantly more exposure to maintain constant shadow densities, when development time is reduced.

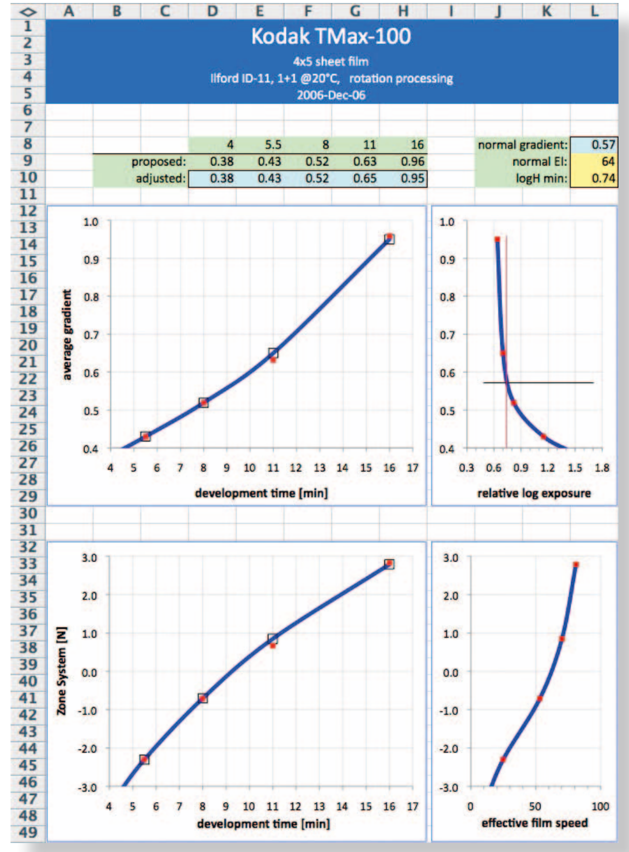


fig.7 The 'Summary' sheet contains all information required to properly expose a given film under any lighting condition and then develop it in a given developer with the confidence to get quality negatives.

Depending on your equipment, you may want to adjust the normal average gradient in cell 'L8'. The optics of your enlarger and camera or lens flare, make a negative seem to be needing a different grade of paper but print with the same quality once the negative density range is adjusted.

The 'Summary' sheet contains all information required to properly expose a given film under any lighting condition and then develop it in a given developer with the confidence to get quality negatives. No longer is there a need for uncontrolled trial and error adjustments. These negatives will always print well on a standard ISO grade-2 paper.