The Determination of Humidity Limits to Prevent Colorant Bleed in Inkjet Prints

Eugene Salesin and Daniel Burge; Image Permanence Institute, Rochester Institute of Technology, Rochester, NY, USA

Abstract

The purpose of the project was to determine the absolute ceiling limits for temperature, humidity, and time combinations to prevent noticeable colorant bleed in photographs and documents printed with inkjet digital technologies. The research focused on a variety of dye printers and papers because it was known from previous work that these printer/paper combinations produced prints sensitive to humidity. The results of this work are intended to help cultural heritage institutions that collect these materials develop policies for use and care to prevent damage to their collections. The results may also benefit commercial services that offer prints made with these processes, as well as artists and photographers and the general public.

In this so called "humidity limits" study a series of nine different dye printer/paper sets were included along with one pigment printer/paper combination to serve as a control. Specimens were treated to twelve different time, temperature, and humidity regimes covering a span of time from one day to four weeks, temperatures from 15°C to 35°C and relative humidities (RH) from 60% to 90%. The tests included measuring Delta E with a spectrophotometer for a checkerboard target and line width changes with image analysis software for a CMYK line target. Analysis of the data from the humidity limits study indicated that the behavior of the inkjet dye printer/paper combinations to the various treatment conditions were quite variable.

Because institutions collections could contain prints similar to a very sensitive print in this study, a very conservative approach should be taken for their care. However, the results of this study indicate that that inkjet dye prints, even the most sensitive ones, are relatively safe from significant humidity bleed if kept at 65% RH or less.

Introduction

Examples from the field have shown that elevated humidity can result in bleeding of colorants in some digital prints [1] and several studies have identified the sensitivity of inkjet prints to high humidity [2,3]. The Image Permanence Institute (IPI) was able to replicate that effect in the Mellon-funded Digital Print Preservation Portal (DP3) Project and rank the various digital print processes according to their sensitivity to bleeding [4]. It is evident that the colorants of some printing systems are fugitive at high humidity. While high humidity levels are clearly associated with this problem, it is likely that temperature and time are also important variables that need to be integrated into the study of this effect. In this research, these additional factors were studied to determine the minimum conditions to initiate bleed. Having this information will be critical to institutions having permanent or temporary non-optimal storage conditions for their collections and as they move their materials into and out of controlled environments for the purpose of transport, patron use, or display. They need to know what absolute limits must not be crossed in order to prevent irreversible harm. In these tests, a set of samples already known to be sensitive to bleed were exposed to a series of temperature, humidity, and time variations to develop this set of new, strict environmental limits that must never be exceeded.

Sample Selection

For photographs, four different inkjet dye printers which included one hybrid printer (dye CMY, pigment K) were selected for printing seven different photo papers which represented four different paper technologies: microporous, polymer (swellable), fine art with image-receiving layers and a glossy paper formulated with a non-RC photo paper technology. For documents, one inkjet dye printer was selected for printing two different plain copy papers. There were nine different inkjet dye printer/paper combinations in total. In addition, an inkjet pigment printer was used for printing a microporous paper to serve as a control since inkjet pigment prints have been shown from previous work to be quite insensitive to humidity damage as compared to inkjet dye prints [4]. So there was a total of ten printer/paper combinations selected for this investigation. A summary of these printer/paper combinations including sample identifications (IDs) is provided in Table 1.

ID	Printer	Paper Type
1	Dye Photo 1	Microporous 1
2	Dye Photo 2	Microporous 2
3	Dye Photo 3	Polymer 1
4	Dye Photo 1	Polymer 2
5	Dye Photo 3	Plain 1
6	Dye Photo 3	Plain 2
7	Dye CMY Pigment K	Non-RC - Glossy
8	Dye Photo 1	Fine Art - Matte
9	Dye Photo 2	Fine Art - Glossy
P	Pigment Photo	Microporous 2

Table 1: Printer/paper combinations selected for the investigation.

Sample Preparation and Test Procedure

The nine different inkjet dye prints (both photographs and documents) and the inkjet pigment print were printed in duplicate with a combined checkerboard and a CMYK line target on a single sheet. The checkerboard target, which is designed to test the sensitivity of print systems to humidity exposure, is described in detail in ISO 18946 [5] but only the upper portion of the target described there was used. This target is illustrated in Figure 1.

The prints were conditioned at 21°C/50% RH for two weeks. It has been reported that changes can continue to occur after two weeks [6]. However, in this project measurements made of untreated samples kept at this condition for six months were measured again and no change was seen.

After the samples were conditioned, the checkerboard targets were measured with a spectrophotometer and the line targets were measured with image analysis software. (See below for the measurement methodology). The data from the duplicate samples were averaged. The targets were then treated in ovens to an initial series of humidities: 60%, 70%, 80% and 90%, each at three temperatures: 15°C, 25°C and 35°C, for 1, 2, 4, 7, 14, 21 and 28 days. After each of these treatments the checkerboard targets and line targets were measured again to determine color change and line width change.

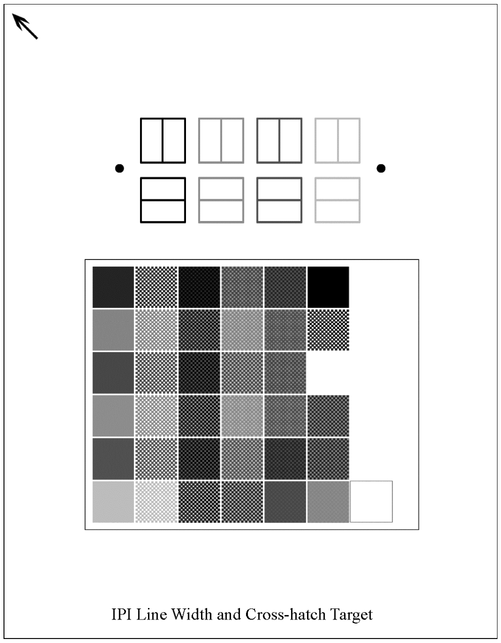

Figure 1: *The checkerboard and line target used for printing samples is shown in grayscale (actual target is in color).*

Measurements of Color and Line Width Change

CIELAB L*a*b* of each patch in the checkerboard target were measured with a Gretag Spectrolino/ Spectroscan® spectrophotometer (D50, 2° observer, with no UV cut-off filter). Delta E 2000 was calculated for each of the checkerboard patches but the patch that consistently produced the largest Delta E was used to provide the data published here. This patch is checkerboard test target patch E6 in Figure 1 of ISO 18946 and is made up of black and white squares. It is reproduced in Figure 2.

Average line widths for vertical and horizontal printed lines were measured utilizing ImageXpert® image quality measurement systems. The printed samples were scanned at 2400 dpi. The threshold for gray value was calculated as the 60% point between the dark mode (the mode of the histogram peak formed by the foreground such as the magenta line) and the light mode (calculated from the mode of the histogram peak for the paper in the same color channel). The threshold for each color is calculated in the color channel that provided the highest contrast, i.e. blue channel for yellow, green channel for magenta, red channel for cyan, and black.

Results and Discussion

The criterion for determining the condition for first noticeable bleed was selected to be a Delta E of three. This Delta E was based on previous experience obtained when artists and photographers viewed comparison prints at printmaking sessions [6]. They often chose a Delta E equal to two or three for observable differences in certain tones in these prints. Because there was a very good correlation between Delta E and line width change in this study, there was no need to use both measures to determine the condition that produced this change in the targets.

Analysis of the data from the initial set of twelve temperature and humidity conditions indicated that the behavior of the inkjet dye printer/paper combinations to these conditions were quite variable. A summary of these results is provided in Table 2. The detailed behavior of each of the printer/paper combinations is provided in Tables 3-7.

One print (Sample 7, Table 6) showed significant bleed even at one day at 80% RH/25°C. This was the printer/paper combination with non-RC photo paper technology printed with the hybrid printer. Also it was the only print that exceeded the Delta E criteria at all treatment times and at all three temperatures at 80% RH and at 21 and 28 day treatment times at 70% RH at 25°C.

It is also interesting to note that in general more prints exceeded the Delta E limit at 25°C than at 35°C, probably due to the higher moisture content at the lower temperature. Because the critical bleed point for some of the prints occurred between 70% RH and 80% RH, samples were tested at 75% RH. Only two prints (Samples 3 and 7) reached a Delta E of three at 75%RH. Also, the most sensitive print (Sample 7) was tested at 65% RH at 25°C because a Delta E of at least three was obtained at 70% RH at 25°C but not at 60% RH. This sample did not reach a Delta E of three at 65%RH/25°C.

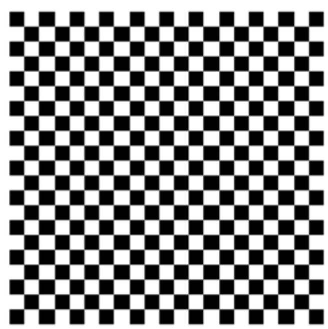

Figure 2*: An enlarged view of the checkerboard patch that consistently produced the largest Delta E.*

Table 2: The total number of inkjet dye prints (in bold print) producing a Delta E of at least three at each of these conditions. Note: Only the most sensitive inkjet dye print (Sample 7) was tested at 65%RH.

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	**1**	**1**	**2**	**2**	**3**	**4**	**4**
90%RH/25°C	**4**	**5**	**5**	**8**	**9**	**9**	**9**
90%RH/35°C	**4**	**6**	**6**	**6**	**7**	**7**	**8**
80%RH/15°C	**1**	**1**	**1**	**1**	**3**	**4**	**4**
80%RH/25°C	**1**	**1**	**1**	**2**	**3**	**3**	**3**
80%RH/35°C	**1**	**1**	**1**	**2**	**2**	**2**	**2**
75%RH/15°C	0	0	0	0	0	0	0
75%RH/25°C	0	0	0	**1**	**2**	**2**	**2**
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	0	0	0	0	0	**1**	**1**
70%RH/35°C	0	0	0	0	0	0	0
65%RH/25°C	0	0	0	0	0	0	0
60%RH/15°C	0	0	0	0	0	0	0
60%RH/25°C	0	0	0	0	0	0	0
60%RH/35°C	0	0	0	0	0	0	0

Table 3: Delta E of Samples 1 and 2 after the tested conditions. Delta E equal to or greater than 3 are in bold print.

Sample No. 1 - Dye Photo Printer 1/Microporous Paper 1

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	0	0	1	1	2	**3**	**3**
90%RH/25°C	1	2	**3**	**3**	**4**	**5**	**6**
90%RH/35°C	2	**3**	**3**	**4**	**5**	**6**	**7**
80%RH/15°C	0	1	1	1	2	2	2
80%RH/25°C	1	1	2	2	3	2	2
80%RH/35°C	0	1	0	1	1	1	1
75%RH/15°C	0	0	0	0	1	1	1
75%RH/25°C	1	1	1	0	0	1	0
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	0	0	1	1	0	0	1
70%RH/35°C	0	1	1	1	1	0	1
60%RH/15°C	0	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Sample No. 2 - Dye Photo Printer 2/Microporous Paper 2

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	0	1	1	2	**5**	**7**	**6**
90%RH/25°C	**4**	**5**	**6**	**7**	**8**	**9**	**10**
90%RH/35°C	**4**	**6**	**8**	**8**	**11**	**12**	**13**
80%RH/15°C	0	1	1	2	**5**	**7**	**6**
80%RH/25°C	1	1	2	2	**3**	**3**	**3**
80%RH/35°C	1	1	1	2	2	2	2
75%RH/15°C	1	0	1	0	1	1	0
75%RH/25°C	1	0	0	1	1	0	0
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	1	0	0	1	0	0
70%RH/35°C	1	1	1	0	0	1	1
60%RH/15°C	1	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Table 4: Delta E of Samples 3 and 4 after the tested conditions. Delta E equal to or greater than 3 are in bold print.

Sample No. 3 - Dye Photo Paper 3/Polymer Paper 1

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	1	2	**3**	**3**	**4**	**5**	**6**
90%RH/25°C	**6**	**8**	**11**	**14**	**18**	**19**	**21**
90%RH/35°C	**6**	**7**	**10**	**13**	**17**	**18**	**21**
80%RH/15°C	1	2	2	3	**5**	**6**	**7**
80%RH/25°C	2	2	3	**4**	**4**	**5**	**5**
80%RH/35°C	1	2	2	**3**	**4**	**5**	**6**
75%RH/15°C	0	0	1	1	1	1	2
75%RH/25°C	1	1	1	2	**3**	**3**	**4**
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	1	1	1	2	2	2
70%RH/35°C	1	2	1	1	2	2	2
60%RH/15°C	0	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Sample No. 4 - Dye Photo Printer 1/Polymer Paper 2

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	1	1	1	1	1	1	2
90%RH/25°C	**8**	**12**	**16**	**20**	**24**	**25**	**27**
90%RH/35°C	**9**	**13**	**19**	**22**	**24**	**26**	**27**
80%RH/15°C	1	1	1	1	2	**4**	**5**
80%RH/25°C	1	1	1	2	2	2	2
80%RH/35°C	1	1	1	1	1	2	1
75%RH/15°C	0	0	0	0	0	0	0
75%RH/25°C	0	1	0	1	1	1	1
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	0	1	1	0	1	1
70%RH/35°C	1	1	1	0	1	1	1
60%RH/15°C	0	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Table 5: Delta E of Samples 5 and 6 after the tested conditions. Delta E equal to or greater than 3 are in bold print.

Sample No. 5 - Dye Photo Paper 3/Plain Paper 1

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	0	1	1	1	1	1	1
90%RH/25°C	1	1	2	**3**	**3**	**3**	**3**
90%RH/35°C	1	1	1	2	**3**	2	**3**
80%RH/15°C	0	0	1	0	1	1	1
80%RH/25°C	1	1	1	1	1	1	1
80%RH/35°C	1	0	0	1	1	1	1
75%RH/15°C	0	0	0	0	1	0	1
75%RH/25°C	0	1	0	0	1	0	1
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	0	1	0	0	0	0	0
70%RH/35°C	1	1	0	0	0	1	0
60%RH/15°C	1	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Sample No. 6 - Dye Photo Paper 3/Plain Paper 2

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	0	1	1	1	1	1	1
90%RH/25°C	1	1	2	2	**3**	**3**	**3**
90%RH/35°C	1	1	1	2	2	**3**	**3**
80%RH/15°C	0	0	0	0	1	1	1
80%RH/25°C	1	1	1	1	1	1	1
80%RH/35°C	0	1	1	1	0	1	1
75%RH/15°C	1	0	0	0	0	0	1
75%RH/25°C	0	0	1	0	1	0	1
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	0	1	0	0	1	1
70%RH/35°C	0	1	0	0	0	0	1
60%RH/15°C	1	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Table 6: Delta E of Samples 7 and 8 after the tested conditions. Delta E equal to or greater than 3 are in bold print.

Sample No. 7 - Dye CMY, Pigment K Printer/Non-RC Photo Paper Technology

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	**9**	**12**	**17**	**21**	**28**	**29**	**28**
90%RH/25°C	**27**	**28**	**27**	**27**	**26**	**26**	**25**
90%RH/35°C	**22**	**25**	**27**	**28**	**28**	**28**	**28**
80%RH/15°C	**6**	**9**	**18**	**9**	**23**	**30**	**28**
80%RH/25°C	**9**	**9**	**12**	**14**	**16**	**17**	**18**
80%RH/35°C	**3**	**5**	**5**	**6**	**7**	**10**	**11**
75%RH/15°C	0	1	1	1	2	2	2
75%RH/25°C	0	0	1	**3**	**3**	**3**	**3**
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	2	1	2	2	**4**	**3**
70%RH/35°C	1	1	1	0	1	1	1
65%RH/25°C	0	1	1	0	1	1	1
60%RH/15°C	0	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Sample No. 8 - Dye Photo Printer 1/Fine Art - Matte Paper

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	0	1	1	1	1	2	1
90%RH/25°C	2	2	**3**	**3**	**4**	**6**	**8**
90%RH/35°C	2	**3**	**4**	**4**	**5**	**6**	**6**
80%RH/15°C	1	1	1	1	1	2	2
80%RH/25°C	1	1	1	2	1	2	2
80%RH/35°C	0	0	1	1	1	1	2
75%RH/15°C	0	1	1	1	0	0	1
75%RH/25°C	0	0	1	0	0	1	0
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	0	1	1	1	1	1	0
70%RH/35°C	1	1	1	1	1	0	1
60%RH/15°C	0	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Table 7: Delta E of Samples 9 and P after the tested conditions. Delta E equal to or greater than 3 are in bold print.

Sample No. 9 - Dye Photo Printer 2/Fine Art - Glossy Paper

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	1	1	1	1	1	1	1
90%RH/25°C	1	1	2	**3**	**4**	**4**	**5**
90%RH/35°C	1	1	1	1	1	1	1
80%RH/15°C	1	1	1	1	1	1	1
80%RH/25°C	1	1	1	1	1	1	1
80%RH/35°C	0	1	0	1	1	1	1
75%RH/15°C	1	1	1	1	0	1	2
75%RH/25°C	0	1	1	1	1	1	1
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	1	1	1	1	1	1
70%RH/35°C	0	0	1	0	0	1	0
60%RH/15°C	1	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Sample No. P - Pigment Photo Printer/Microporous Paper 2

	1 day	2 days	4 days	7 days	14 days	21 days	28 days
90%RH/15°C	0	0	1	0	0	0	1
90%RH/25°C	1	0	1	0	1	1	1
90%RH/35°C	1	1	1	1	1	1	0
80%RH/15°C	0	1	0	1	1	0	0
80%RH/25°C	1	0	0	1	1	1	0
80%RH/35°C	0	0	1	1	1	1	1
75%RH/15°C	0	0	0	0	0	0	0
75%RH/25°C	1	0	0	0	0	1	1
70%RH/15°C	0	0	0	0	0	0	0
70%RH/25°C	1	0	0	1	0	1	1
70%RH/35°C	0	0	1	1	0	1	1
60%RH/15°C	0	0	1	0	0	0	1
60%RH/25°C	1	0	0	1	0	1	1
60%RH/35°C	0	0	1	1	0	1	1

Conclusions and Recommendations

While the analysis of the data from the humidity limits study indicated that the behavior of the inkjet dye printer/paper combinations to the various treatment conditions were quite variable, it is possible to provide specific humidity damage prevention guidelines for the wide variety of inkjet print technologies that may be present in collections of these materials in cultural heritage institutions. It is safe to say that inkjet prints, even the most sensitive ones, are relatively safe from significant humidity bleed if kept at 65% RH or less for no longer than four weeks time at temperatures between 15°C and 35°C. However the safe period will dramatically shorten as the RH increases.

It is also interesting to note that for one print (Sample 7) the 80% RH condition at 15°C and 25°C produced greater changes than at 35°C, and in general, more prints produced a Delta E of at least three at 25°C than at 35°C indicating that a major driving force is probably the moisture content of the paper which would be greater at lower temperatures. But because there was so much variation in the behavior of the various inkjet dye prints to humidity it is clear that factors other than moisture content, such as paper formulation or physical structure, probably play a major role in the degree of bleed produced in these papers.

The most sensitive inkjet print in this study did not produce a Delta E of three even after four weeks at 25°C/65% RH. Because the longest period of treatment under the study conditions was four weeks, it is not known how these prints would behave if subjected to treatment for longer periods of time. Although the sample size was limited, it appears the inkjet dye prints on plain copy paper are relatively insensitive to humidity bleed and prints on fine art paper fare better than prints on photo paper. Results with the microporous and polymer (swellable) photo papers in this study indicated that microporous paper is somewhat better than polymer paper, but the sample size for this comparison was quite limited. As expected, the pigment print did not show a tendency to bleed at any of the conditions through four weeks.

Acknowledgments

The authors wish to acknowledge members of IPI staff for their advice and help in maintaining the environmental chambers and providing Delta E values from the Spectrolino data. In addition, students in the College of Imaging Arts and Sciences at the Rochester Institute of Technology provided substantial help with sample preparation and sample target measurements.

References

[1] Daniel Burge, Douglas Nishimura and Mirasol Estrada, "Summary of the DP3 Project Survey of Digital Print Experience within Libraries, Archives, and Museums," IS&T's Archiving 2009 Final Program and Proceedings, IS&T, Arlington, VA, May 4-7, 2009, pp133-136.

[2] Andrew Robb "The Effect of Relative Humidity on Inkjet Prints," Institute of Physics Conference Proceedings, "Preservation and Conservation Issues Related to Digital Printing," Rutherford Conference Center, London, England, October 26-27, 2000.

[3] Anna Fricker, Philip Green, Alan Hodgson "An Evaluation of the Humidity Test Method ISO 18946," NIP27 and Digital Fabrication 2011 Technical Program and Proceedings, IS&T, Minneapolis, MN, October 2-6, 2011, pp. 267-270.

[4] Eugene Salesin, Daniel Burge, Douglas Nishimura and Nino Gordeladze, "Short-Term High Humidity Bleed in Digital Reflection Prints" IS&T's NIP26: 2010 International Conference on Digital Printing Technologies, Austin, TX, Sept.19-23, 2010, pp. 386-389.

[5] ISO 18946 Imaging Materials – Reflection colour photographic prints – Method for testing humidity fastness.

[6] Mark McCormick and Henry Wilhelm, "The Influence of Relative Humidity on Short-Term Color Drift in Inkjet Prints," IS&T's NIP17: 2001 International Conference on Digital Printing Technologies, Fort Lauderdale, FL, Sept.30-Oct.5, 2001, pp. 179-185.

Author Biography

Dr. Gene Salesin, Research Assistant, received a B.S. in chemical engineering from the University of Michigan and an M.S. and Ph.D. in chemistry from Case Western Reserve University in 1960 and 1962, respectively. He retired in 1997 after 36 years of employment in the research laboratories and several manufacturing divisions at Kodak. He held a management position during his last few years there, leading the staff involved with providing the technical instructions and specifications for the manufacture of black-and-white films. Dr. Salesin joined IPI in 2004 and has been involved in the permanence properties of magnetic tape and digital prints at IPI since then.