12-1988

"Supercalendering: The Blackening Reaction and Its Effect on Strength and Optical Properties of Rotogravure Paper"

Valerie Bland
Western Michigan University

"Supercalendering: The Blackening Reaction and Its Effect on on Strength and Optical Properties of Rotogravure Paper"

Submitted by: Valerie Bland

Submitted to: Dr. Ellsworth Shriver

Date Submitted: December 8, 1988

Course: Papr 473

Table of Contents

ABSTRACT

This senior engineering problem is the study of the mechanism of blackening and methods of measurement for blackening. The effect of blackening is the loss of color and opacity in the sheet. The loss of opacity can result in transparent spots in the sheet. The loss of color results as a darker sheet. There are 3 major variables which cause blackening: moisture content, nip pressures, and roll temperatures. The increase in any of these variables results in blackening. In this experiment, the increase of moisture content produced the most significant blackening. The increase of pressure and increase of temperature produced slight blackening effects. The most blackened sheet occurred at 10% moisture, 200°F, and 900 psi. An unblackened sheet resulted at 6% moisture, 200°F, all pressures. Blackening became evident at 8% moisture, 200°F. Safe nip loadings would be between 300-600 psi to prevent blackening. A safe moisture level would be 6%. A safe temperature range would be 150-175°F. The most valid method of blackening measurement is with a color meter. The opacity measurement can also be used, but in this experiment, blackening was not severe enough to produce widely variable opacity values.

INTRODUCTION

Supercalendering is the last process machine which can affect the quality of the paper. The objective of supercalendering is to reduce the caliper of the sheet and to improve the smoothness and gloss of the sheet with the least possible reduction in bulk (1). Many variables can cause blackening, such as moisture of the sheet, temperature of the sheet, and pressure of the nips of the supercalender (2). Supercalendering is usually used to improve gloss and smoothness in uncoated and coated high quality printing grades (3). This senior engineering problem involves the analysis of the blackening reaction and its effect on the strength and optical properties of supercalendered groundwood rotogravure paper. The analysis of different methods of measuring blackening will also be presented.

PROCEDURE

My original laboratory plan was to produce rotogravure newsprint. using 75% groundwood and 25% kraft pulps as my stock. The groundwood that I was going to use was repulped stub rolls from the Kalamazoo Gazette. Then I decided to use groundwood pulp that was the same as used in the Wall Street Journal. This pulp had been run previously on the WMU pilot plant paper machine and was full of shives and dirt, causing the sheet to break several times during the run. Therefore, the groundwood pulp that I used was 100% groundwood broke from a previous pilot plant machine run. The source of the original groundwood in this broke is unknown. I then added 25% kraft

pulp to the furnish to create a typical newsprint blend. I prepared 800 lb. of stock for my machine run. To this stock, I added 10% calcined clay, 1% rosin, and 2% alum. The clay was added to produce a smooth printing surface. The rosin and alum were added for sizability for ink holdout and to provide good runability on the machine and supercalender. I determined a constant basis weight to run from the literature of 30 lb/ream.

I varied the moisture of the sheet on the machine to help induce blackening in the supercalender. The moistures that I determined from the literature were 6, 8, 10, 12, and 14%. The machine tenders at the pilot plant strongly advised against the 12 and 14% moistures, predicting extremely poor runability on the paper machine and especially in the supercalender. Therefore, the moistures that I ran were 6, 8, and 10% moistures.

For each of these moistures, I planned to run various temperatures and nip loadings in the supercalender. Originally, I planned to run temperatures ranging from 150 to 200^{o}F at 10^{o}F intervals to induce blackening. These temperatures I determined from the literature. In the interest of time, I was advised to run only 3 temperatures on each moisture content, these temperatures being 150, 175, and 200^{o}F. After discussing the plan with pilot plant machine tenders, it was decided to run these different temperatures on only one moisture content trial. This was due to the fact that the supercalender rolls could not be cooled down after the supercalender was running. Therefore, in the interest of time, the different

temperatures were only run on the 10% moisture content trial, as I thought this trial would produce the most serious blackening results. The nip pressures that I was going to use originally were 35, 140, 280, and 350 kg/cm^2, which I determined from the literature. The supercalender that I was planning on using, the WMU pilot plant supercalender, was not able to produce pressures this high. Mr. Schuster, the pilot plant director, informed me that blackening usually occurred on this supercalender at about 700-900 psig. The supercalender could range pressures from 100-900 psig. Therefore, I chose 3 pressures that I ran on each moisture trial and on each temperature trial for the 10% moisture of 300, 600, and 900 psig.

After I ran these trials, I tested the supercalendered and unsupercalendered paper for strength and optical properties. The tests that I performed were grammage, caliper, density, moisture, tear (MD and CD), Burst, Tensile (MD and CD), Brightness, Opacity, Color, Gardner Gloss, and Parker Smoothness. The results from these tests and graphical representations of the results are presented in the "RESULTS" section.

RESULTS

Run	Basis Wt (lb/ream)	Grammage (g/m2)	Caliper (mil)	Density (lb/ft3)	Density (g/cm3)	Moisture (%)
6% un	49.5	30.4	3.88	31.3	0.502	6.56
8% un	49.9	30.6	4.03	30.4	0.487	6.79
10% un	48.4	29.7	3.19	37.2	0.597	8.13
1	46.5	28.6	2.22	51.5	0.825	7.39
2	47.1	28.9	2.14	54.0	0.865	7.30
3	47.4	29.1	2.14	54.4	0.872	7.10
4	48.4	29.7	2.23	53.3	0.854	7.06
5	47.6	29.2	2.14	54.6	0.876	6.72
6	47.7	29.3	2.03	57.7	0.925	6.60
7	46.5	28.5	2.14	53.3	0.855	7.59
8	46.7	28.7	2.10	54.7	0.876	6.63
9	47.5	29.2	2.11	55.4	0.886	7.99
10	50.2	30.8	2.68	46.0	0.737	8.65
11	48.1	29.5	2.65	44.5	0.715	7.15
12	49.6	30.4	2.56	47.5	0.763	7.16
13	50.8	31.2	2.90	43.0	0.690	7.05
14	50.4	30.9	2.70	45.8	0.735	7.02
15	51.2	31.4	2.74	45.8	0.736	7.08

Table 1 -- Trial Data

Run	Opacity (%)	Color	Gard. Gloss (GGU)	Smoothness (microns)	Run	Pressure (psi)
6% un	84.5	81.85	5.5	5.36	6% un	0
8% un	87.2	80.14	5.1	5.04	8% un	0
10% un	86.5	79.65	7.4	4.17	10% un	0
1	84.4	79.71	17.4	2.54	1	300
2	85.1	79.03	23.3	1.93	2	600
3	85.7	79.58	28.4	1.60	3	900
4	86.2	79.59	19.0	2.31	4	300
5	86.0	79.25	23.6	1.96	5	600
6	84.0	78.94	26.0	1.83	6	900
7	85.4	79.96	17.4	2.65	7	300
8	85.2	79.64	19.2	2.17	8	600
9	83.2	79.32	24.3	1.92	9	900
10	84.8	81.51	13.4	2.87	10	300
11	84.4	81.20	14.7	2.77	11	600
12	85.6	80.68	16.5	2.51	12	900
13	85.6	82.33	13.1	3.08	13	300
14	84.3	82.31	14.3	2.90	14	600
15	85.3	82.18	15.0	2.71	15	900

Table 1 - cont'd

Run	Tear MD (mN)	Tear CD (mN)	Burst (psi)	Tensile MD (kg/15mm)	Tensile CD (kg/15mm)	Brightness (%)
6%un	325	455	9.99	3.07	1.57	58.1
8%un	333	491	8.93	3.11	1.49	55.5
10%un	314	439	8.03	3.15	1.29	54.5
1	209	353	6.51	2.46	1.32	52.6
2	196	322	5.90	2.35	1.22	53.3
3	220	290	5.31	2.68	1.23	51.4
4	275	342	7.10	2.82	1.34	52.5
5	217	294	5.69	2.43	1.77	52.1
6	217	298	5.44	2.28	1.23	51.7
7	209	306	7.61	2.63	1.27	53.3
8	251	254	6.23	2.55	1.27	52.6
9	193	278	6.38	2.54	1.19	51.9
10	254	348	6.48	2.84	2.63	58.5
11	254	301	5.66	2.27	1.24	55.4
12	240	309	5.19	2.39	1.10	55.2
13	303	405	6.75	2.76	1.53	58.0
14	314	341	6.48	2.68	1.32	57.3
15	239	341	5.41	2.34	1.27	56.9

Table 1-cont'd

Run	Temp. (oF)	%Mois. (%)
6%un		
8%un	0	6
10%un	0	8
	0	10
1	150	10
2	150	10
3	150	10
4	175	10
5	175	10
6	175	10
7	200	10
8	200	10
9	200	10
10	200	8
11	200	8
12	200	8
13	200	6
14	200	6
15	200	6

Table 1 - cont'd

Trial	Opacity 6% (%)	Brightness 6% (%)	Color 6%	Density 6% (lb/ft3)
6% un	84.5	58.1	81.85	31.3
13	85.6	58.0	82.33	43.0
14	84.3	57.3	82.31	45.8
15	85.3	56.9	82.18	45.8

Table 2 -- 6% Moisture Trial Data

Trial	Opacity 8% (%)	Brightness 8% (%)	Color 8%	Density 8% (lb/ft3)
8% un	87.2	55.5	80.14	30.4
10	84.8	58.5	81.51	46.0
11	84.4	55.4	81.20	44.5
12	85.6	55.2	80.68	47.5

Table 3 -- 8% Moisture Trial Data

Trial 300 psi	Opacity 10% (%)	Brightness 10% (%)	Color 10%	Density 10%(lb/ft3)
10% un	86.5	54.5	79.65	37.2
1	84.4	52.6	79.71	51.5
4	86.2	52.5	79.59	53.3
7	85.4	53.3	79.96	53.3

Table 4 -- 10% Moisture Trial Data (300psi)

Trial 600 psi	Opacity 10% (%)	Brightness 10% (%)	Color 10%	Density 10%(lb/ft3)
10% un	86.5	54.5	79.65	37.2
2	85.1	53.3	79.03	54.0
5	86.0	52.1	79.25	54.6
8	85.2	52.6	79.64	54.7

Table 5 -- 10% Moisture Trial Data (600psi)

Trial 900 psi	Opacity 10% (%)	Brightness 10% (%)	Color 10%	Density 10% (lb/ft3)
10% un	86.5	54.5	79.65	37.2
3	85.7	51.4	79.58	54.4
6	84.0	51.7	78.94	57.7
9	83.2	51.9	79.32	55.4

Table 6 -- 10% Moisture Trial Data (900 psi)

Trial 150oF	Opacity 10% (%)	Brightness 10% (%)	Color 10%	Density 10% (lb/ft3)
10% un	86.5	54.5	79.65	37.2
1	84.4	52.6	79.71	51.5
2	85.1	53.3	79.03	54.0
3	85.7	51.4	79.58	54.4

Table 7 -- 10% Moisture Trial Data (150°F)

Trial 175oF	Opacity 10% (%)	Brightness 10% (%)	Color 10%	Density 10% (lb/ft3)
10% un	86.5	54.5	79.65	37.2
4	86.2	52.5	79.59	53.3
5	86.0	52.1	79.25	54.6
6	84.0	51.7	78.94	57.7

Table 8 -- 10% Moisture Trial Data (175°F)

Trial 200oF	Opacity 10% (%)	Brightness 10% (%)	Color 10%	Density 10% (lb/ft3)
10% un	86.5	54.5	79.65	37.2
7	85.4	53.3	79.96	53.3
8	85.2	52.6	79.64	54.7
9	83.2	51.9	79.32	55.4

Table 9 -- 10% Moisture Trial Data (200°F)

Trial	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
6% un	3.07	3.15	325
13	2.76	2.46	303
14	2.68	2.82	314
15	2.34	2.63	239

Table 10 -- 6% Moisture Trial Strength Data

Trial	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
8% un	3.11	8.93	491
10	2.84	6.48	348
11	2.27	5.66	301
12	2.39	5.19	309

Table 11 -- 8% Moisture Trial Strength Data

Trial (300psi)	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
10% un	3.15	8.03	314
1	2.46	6.51	209
4	2.82	7.10	275
7	2.63	7.61	209

Table 12 -- 10% Moisture Trial Strength Data (300psi)

Trial 600 psi	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
10% un	3.15	8.03	314
2	2.35	5.90	196
5	2.43	5.69	217
8	2.55	6.23	251

Table 13 -- 10% Moisture Trial Strength Data (600psi)

Trial 900 psi	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
10% un	3.15	8.03	314
3	2.68	5.31	220
6	2.28	5.44	217
9	2.54	6.38	193

Table 14 -- 10% Moisture Trial Strength Data (900psi)

Trial (150oF)	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
10% un	3.15	8.03	314
1	2.46	6.51	209
2	2.35	5.90	196
3	2.68	5.31	220

Table 15 -- 10% Moisture Trial Strength Data (150°F)

Trial (175oF)	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
10% un	3.15	8.03	314
4	2.82	7.10	275
5	2.43	5.69	217
6	2.28	5.44	217

Table 16 -- 10% Moisture Trial Strength Data (175°F)

Trial (200oF)	Tensile MD (kg/15mm)	Burst (psi)	Tear MD (mN)
10% un	3.15	8.03	314
7	2.63	7.61	209
8	2.55	6.23	251
9	2.54	6.38	193

Table 17-- 10% Moisture Trial Strength Data (200°F)

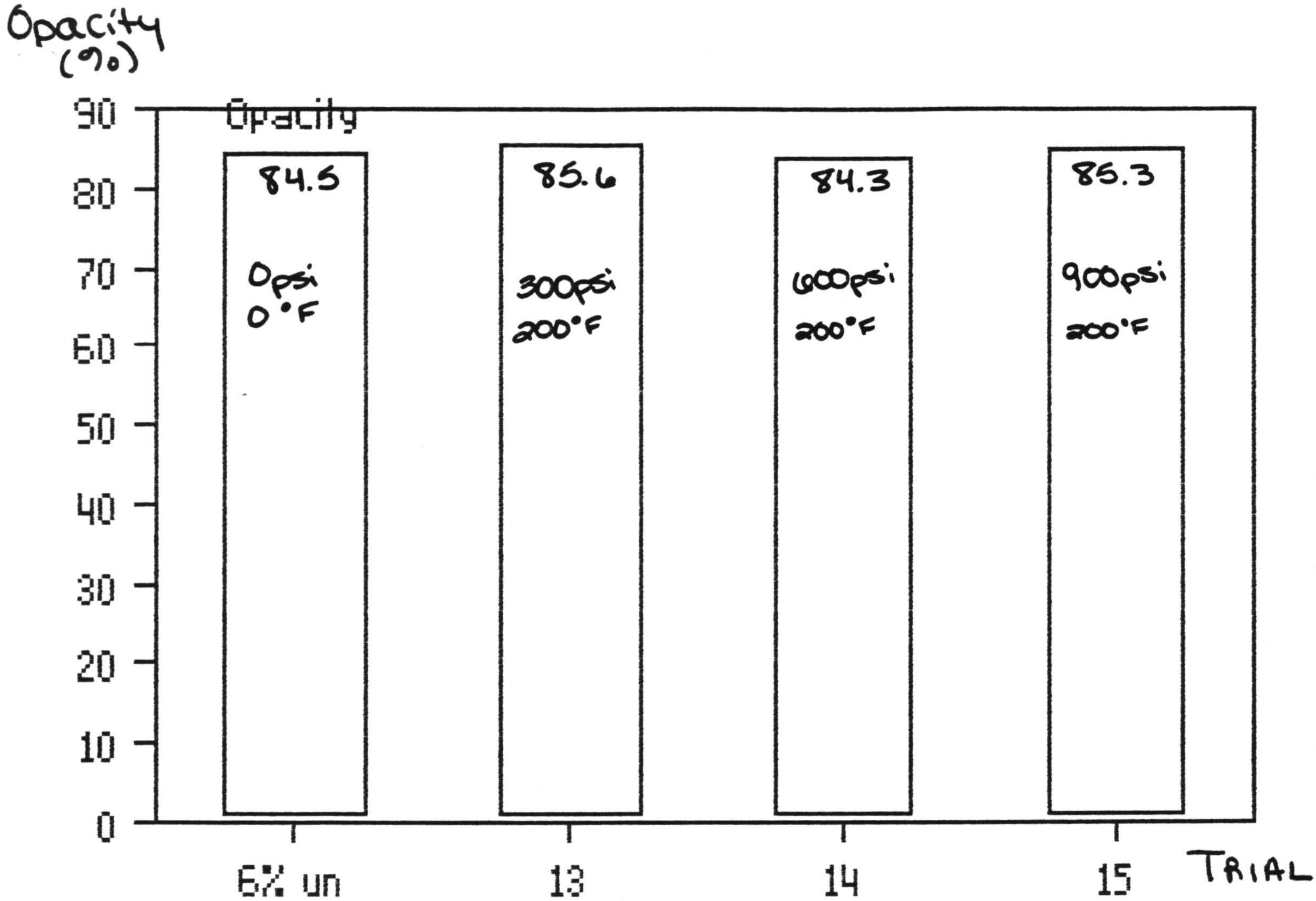

Fig.1 -- Opacity for 6% Moisture Trial

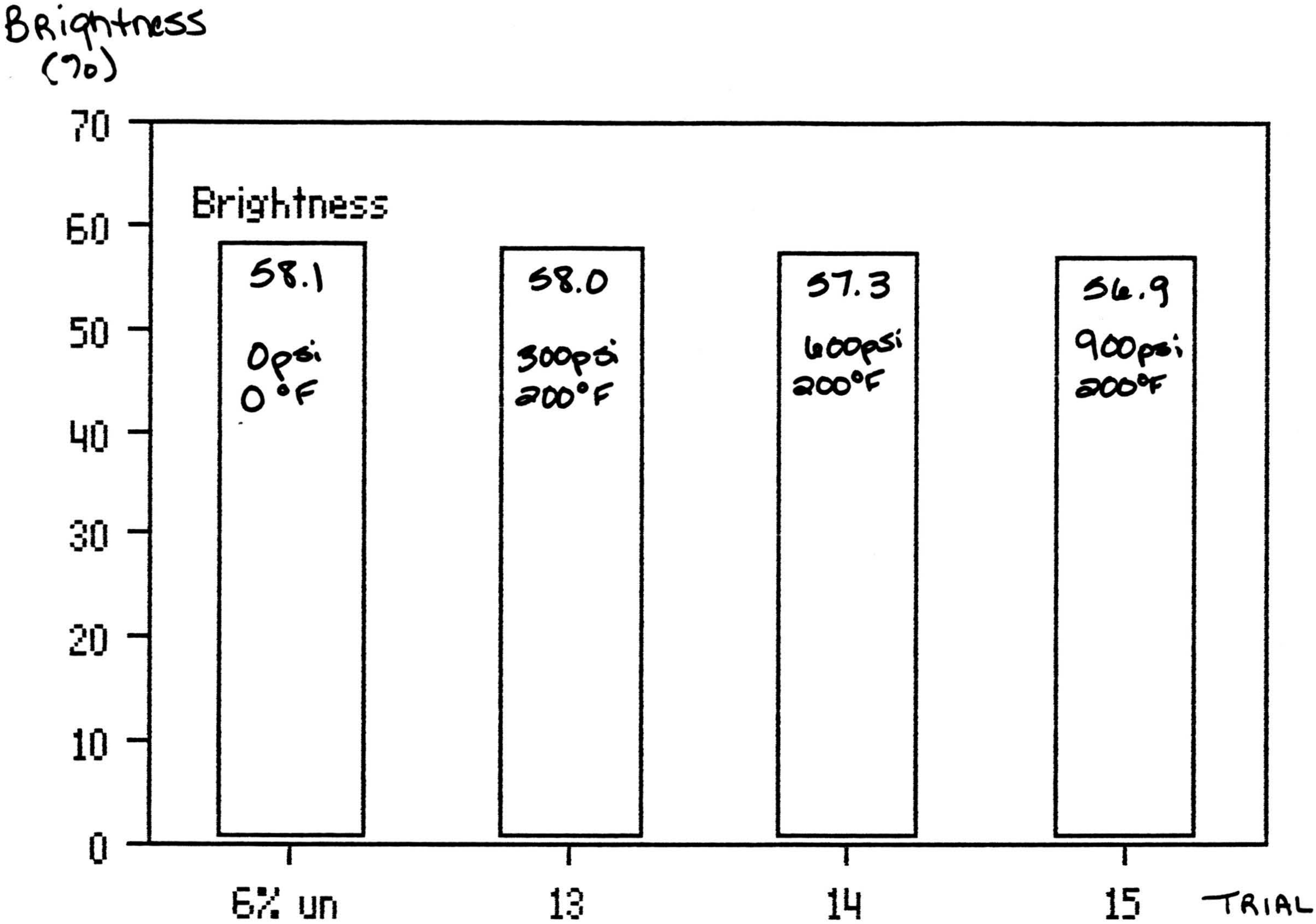

Fig 2 -- Brightness for 6% Moisture Trial

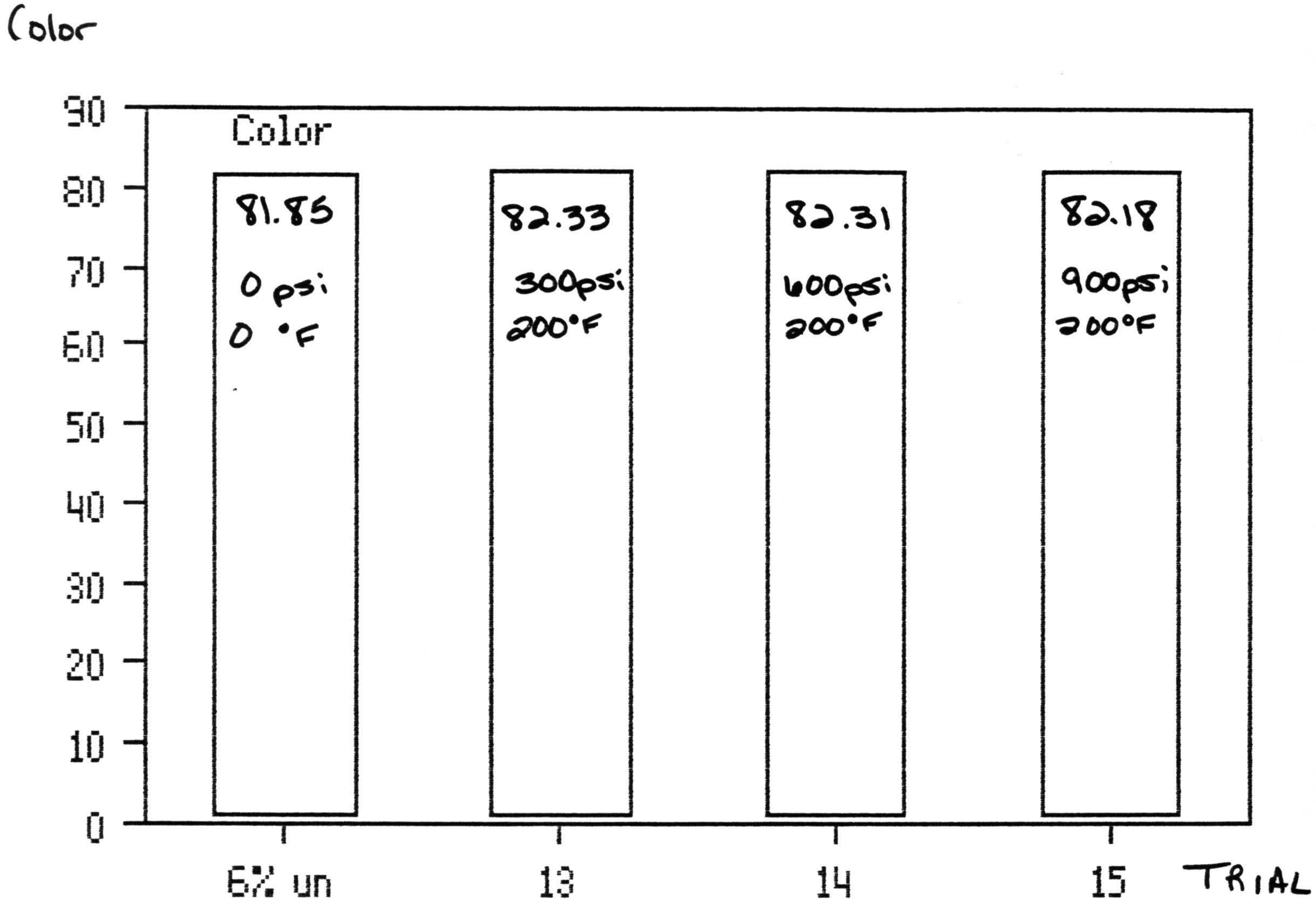

Fig. 3-- Color for 6% Moisture Trial

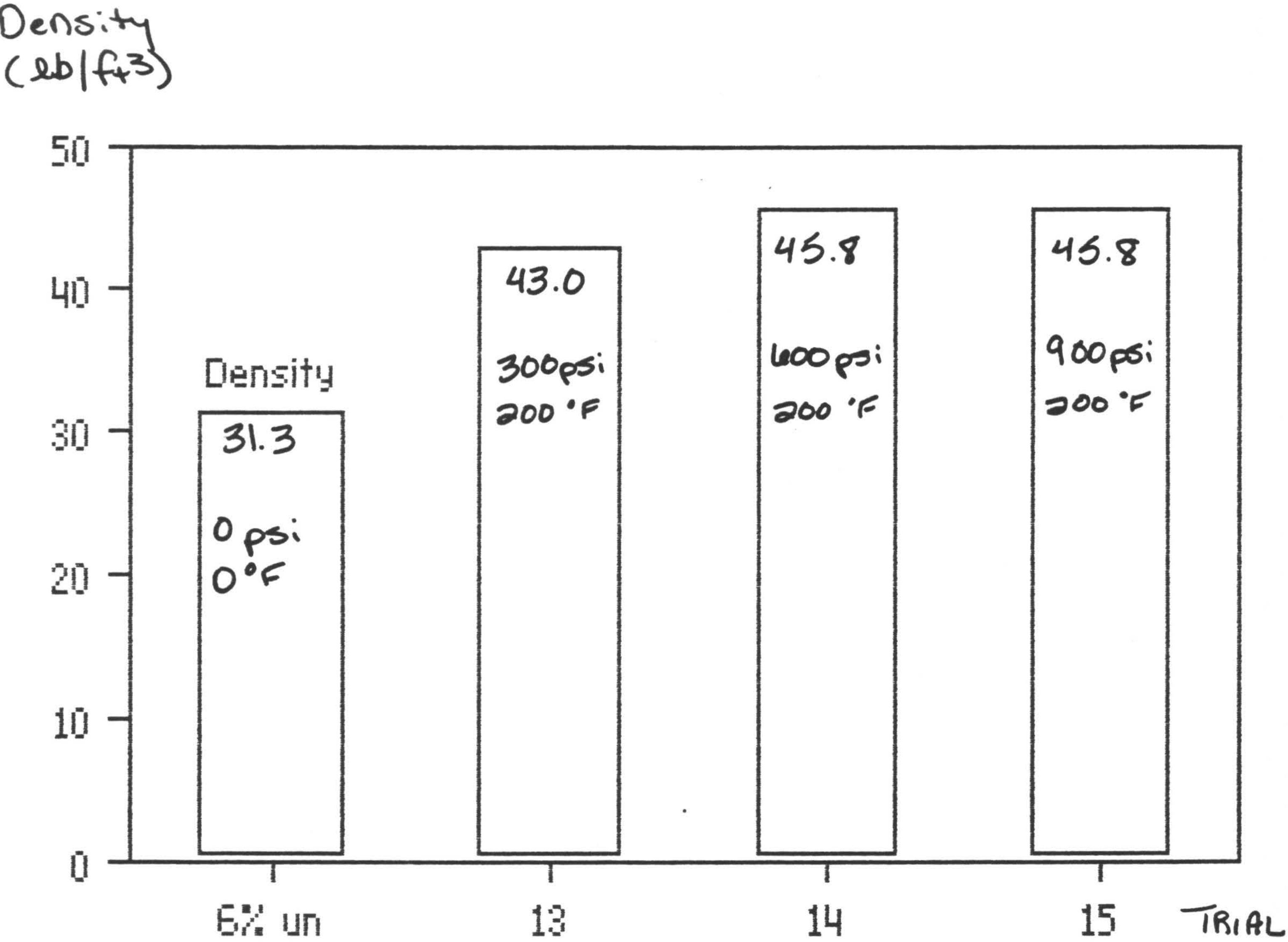

Fig 4 -- Density for 6% Moisture Trial

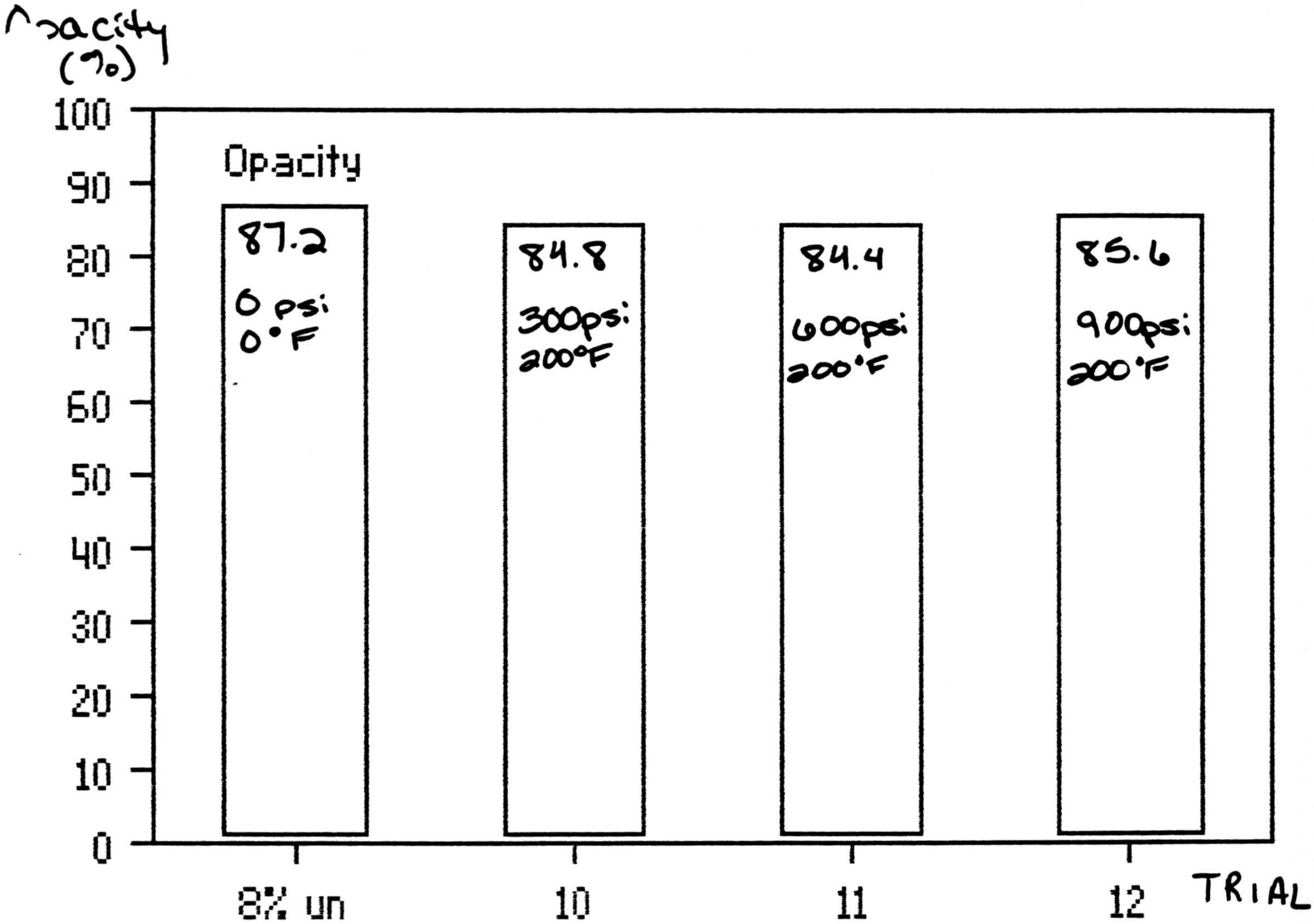

Fig. 5-- Opacity for 8% Moisture Trial

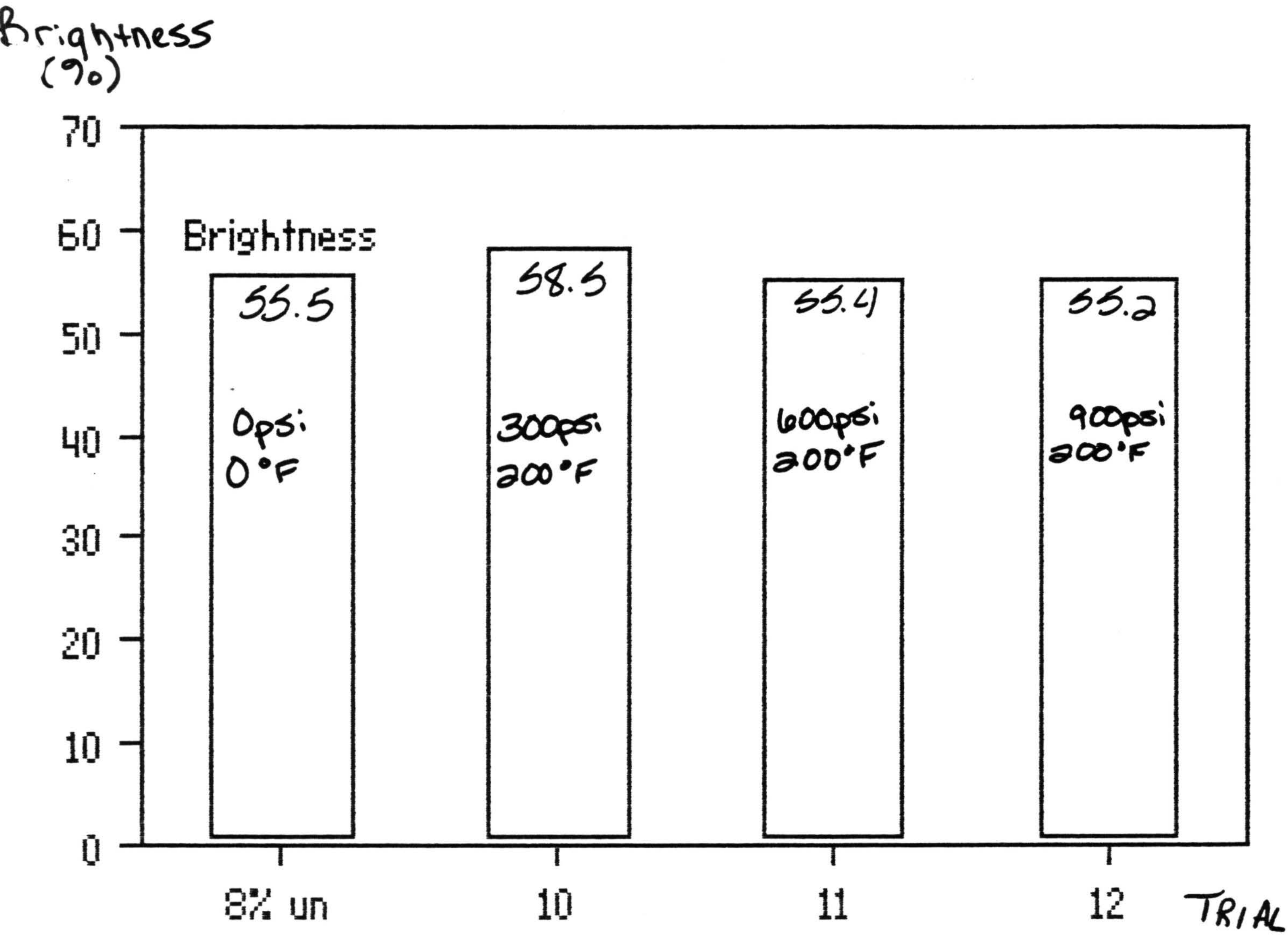

Fig 6 -- Brightness for 8% Moisture Trial

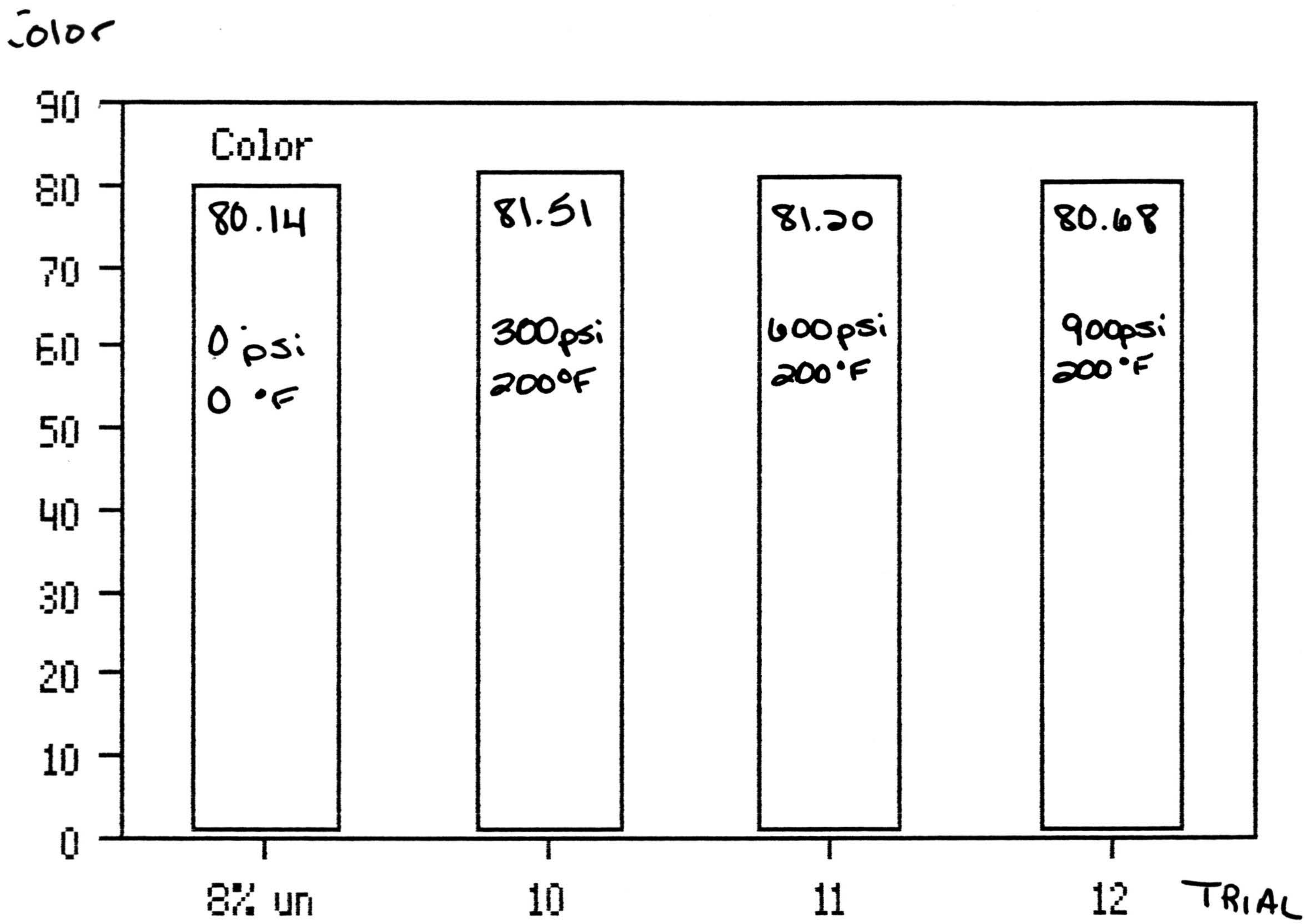

Fig 7-- Color for 8% Moisture Trial

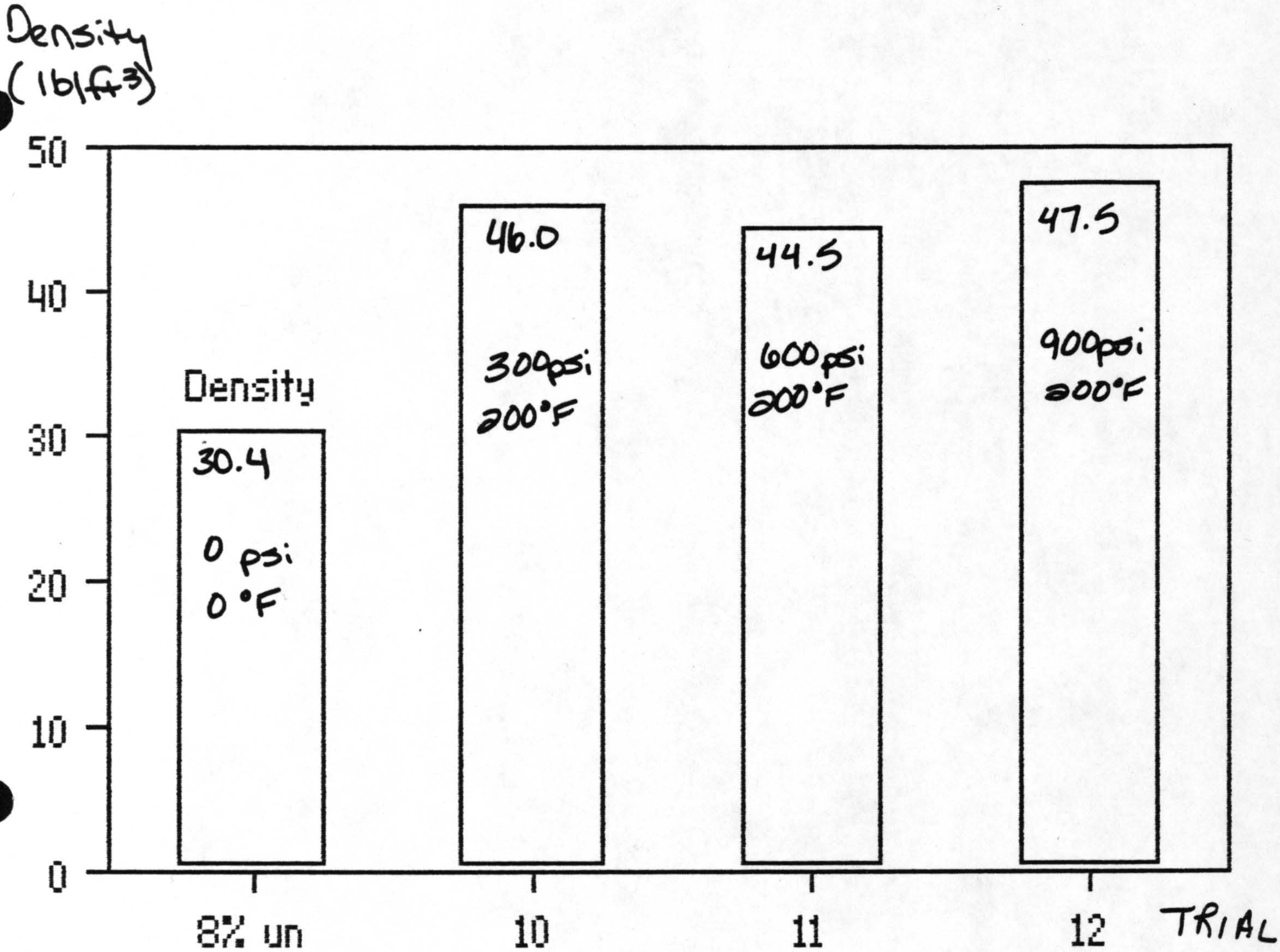

Fig. 8--Density for 8% Moisture Trial

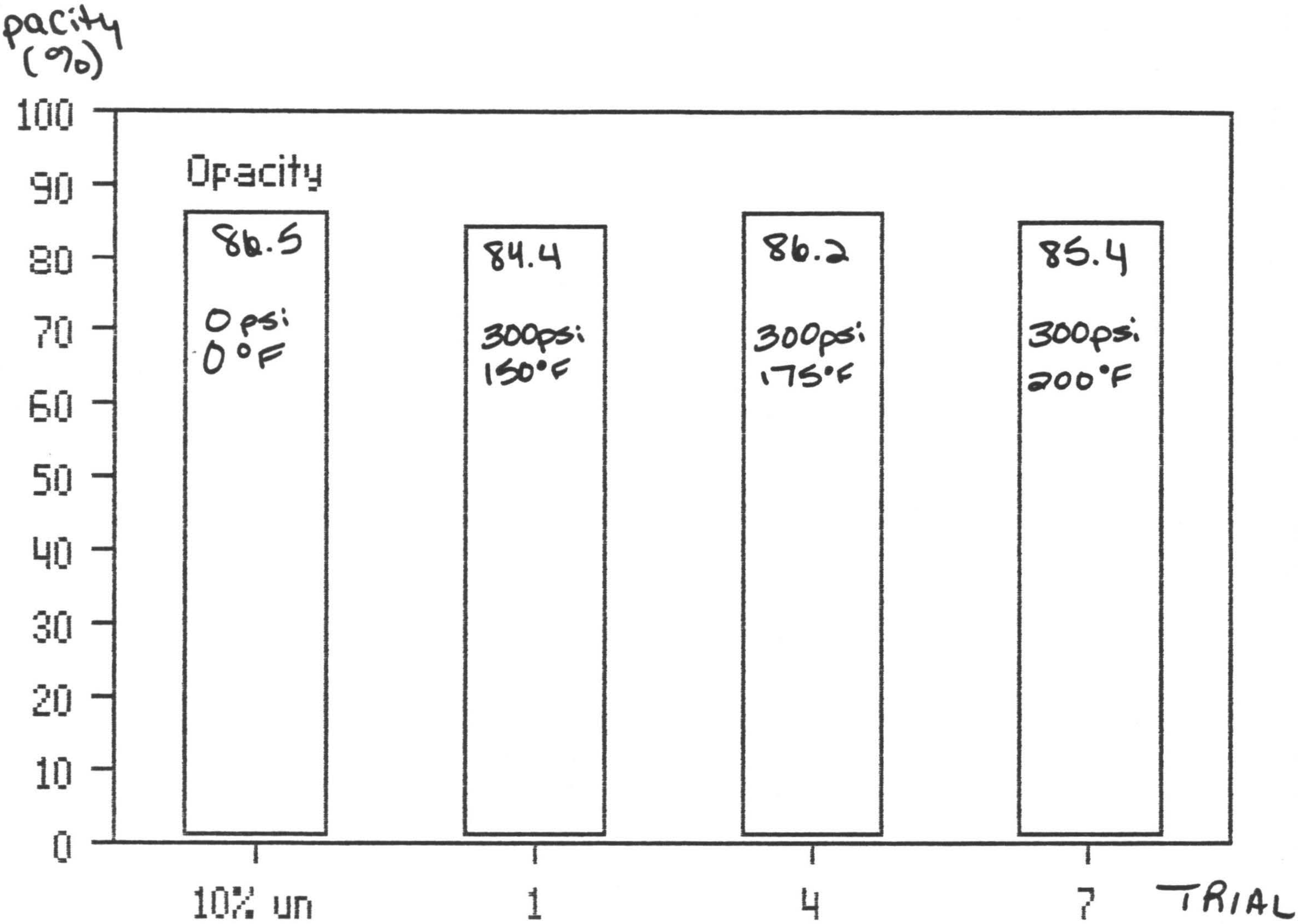

Fig 9-- Opacity for 10% Moisture Trial (300psi)

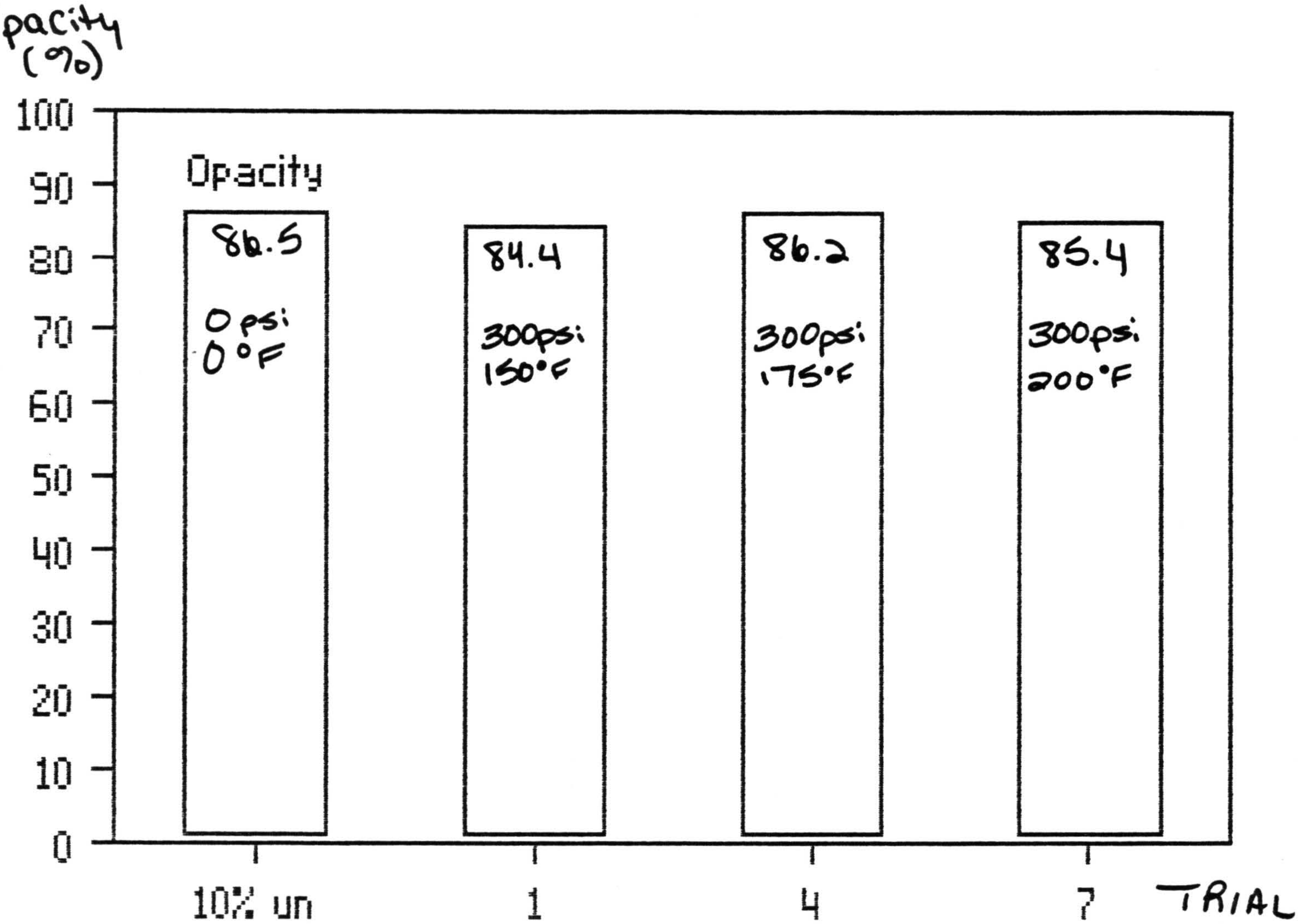

Fig 9-- Opacity for 10% Moisture Trial (300psi)

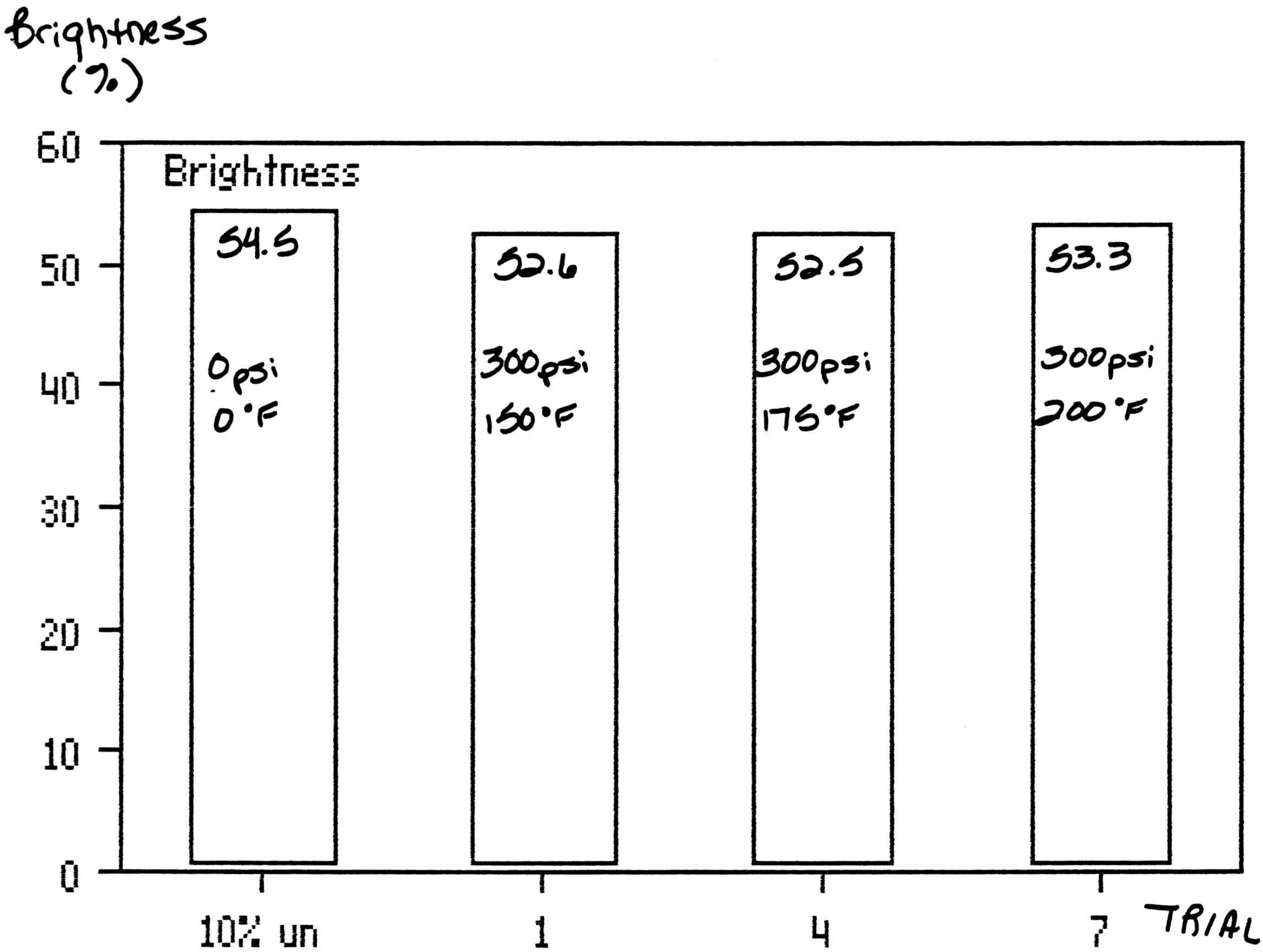

Fig. 10 -- Brightness for 10% Moisture Trial (300psi)

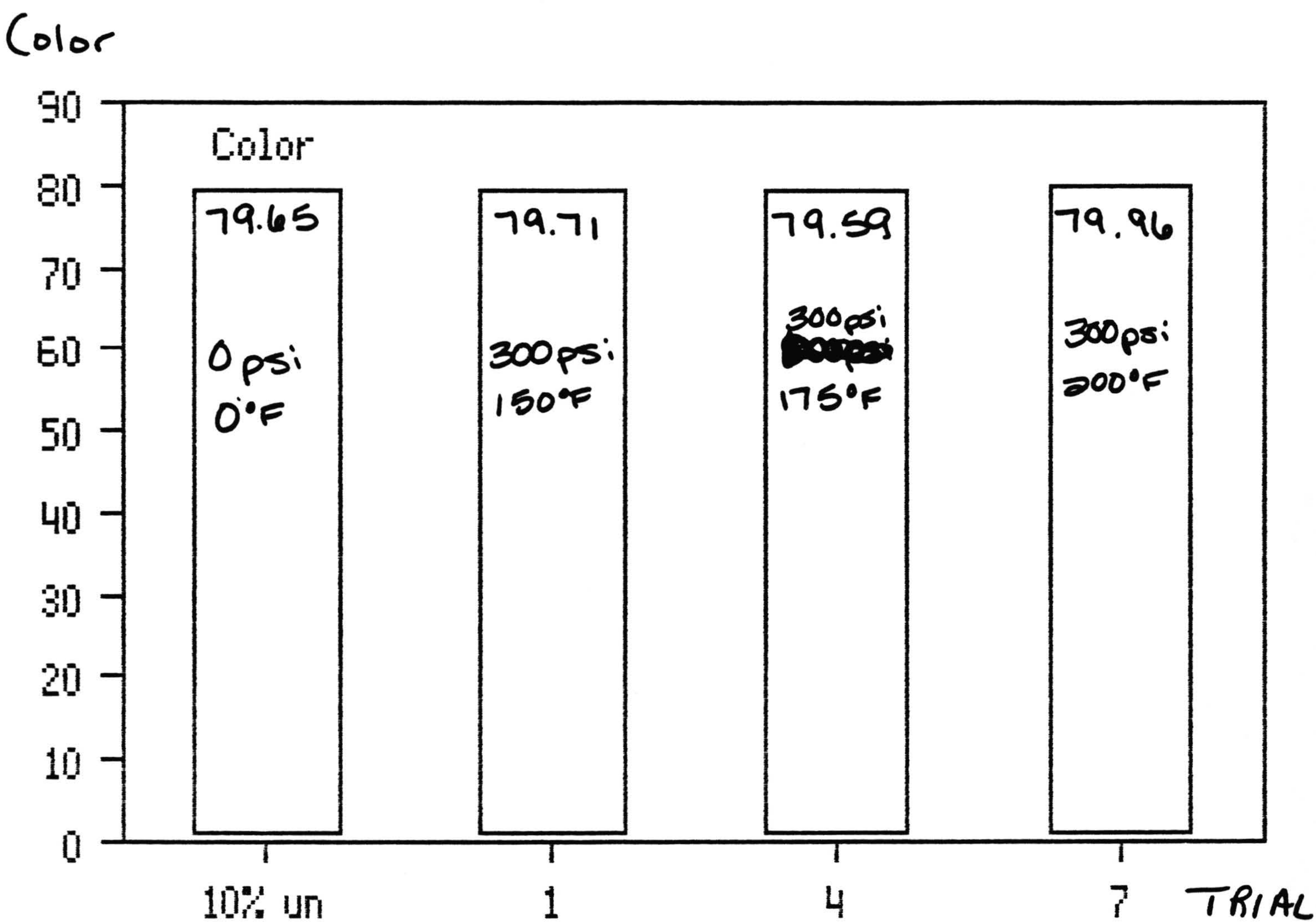

Fig. 11 - Color for 10% Moisture Trial (300psi)

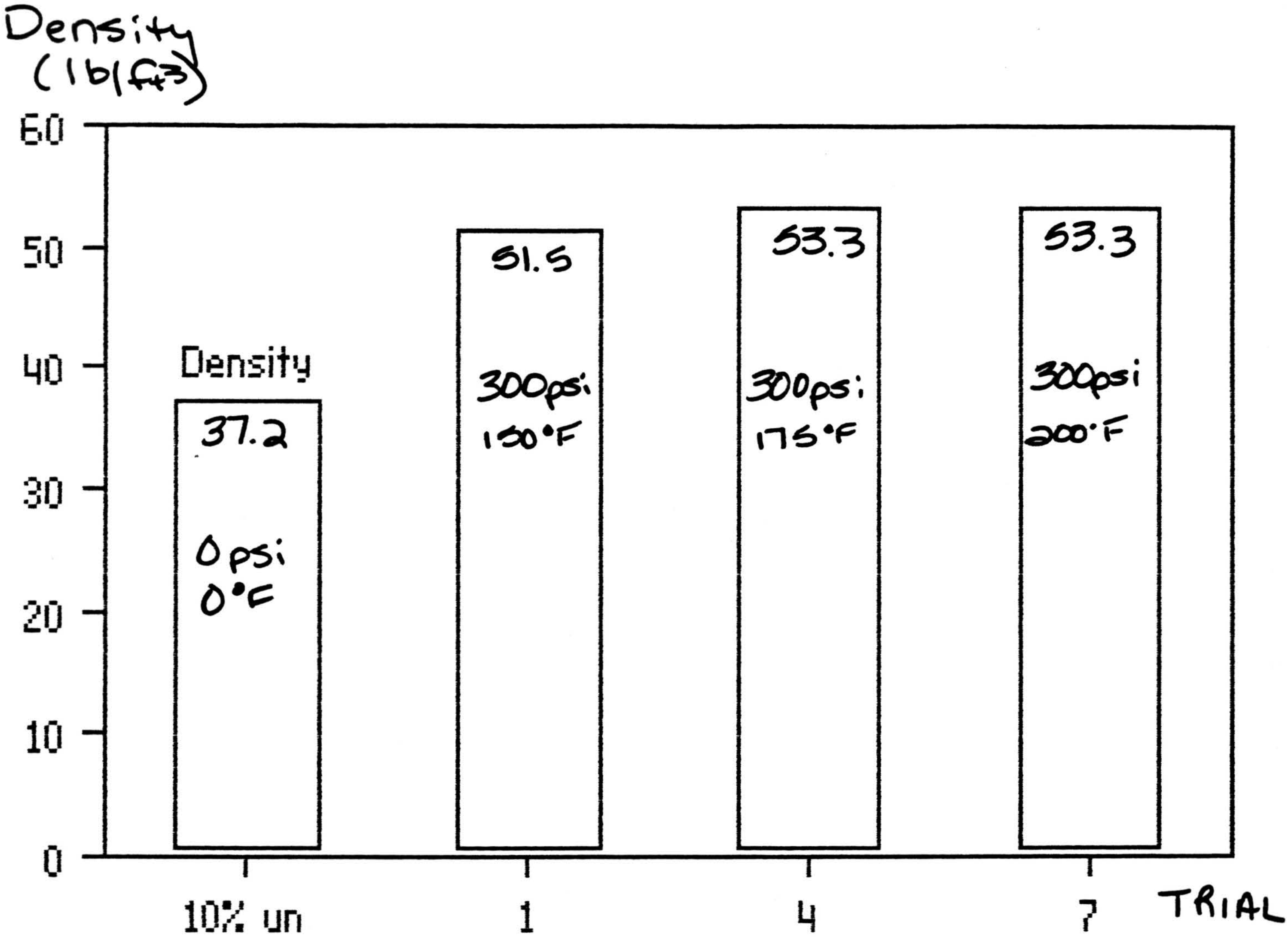

Fig.12 - Density for 10% Moisture Trial (300psi)

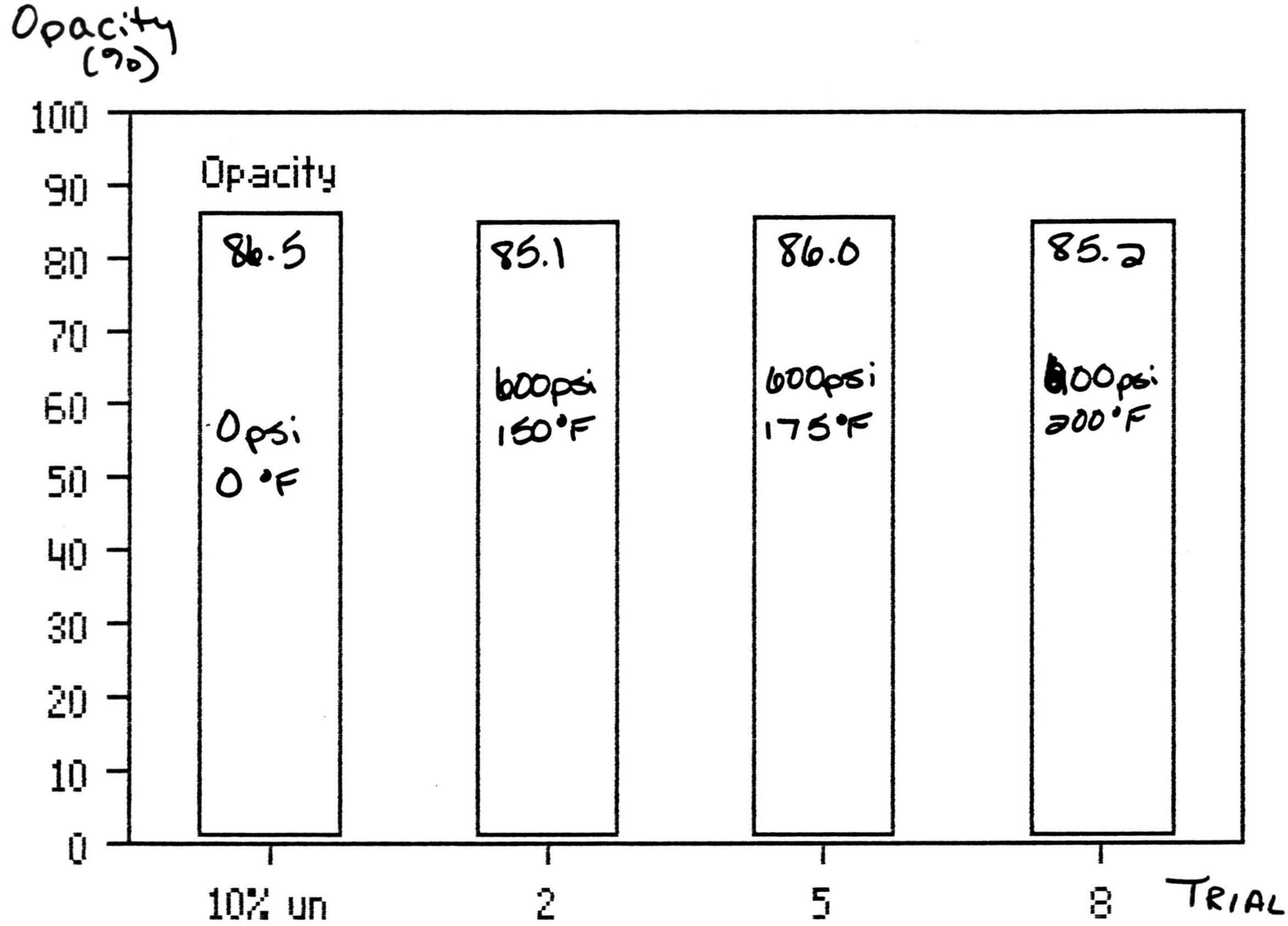

Fig 13 -- Opacity for 10% Moisture Trial (600psi)

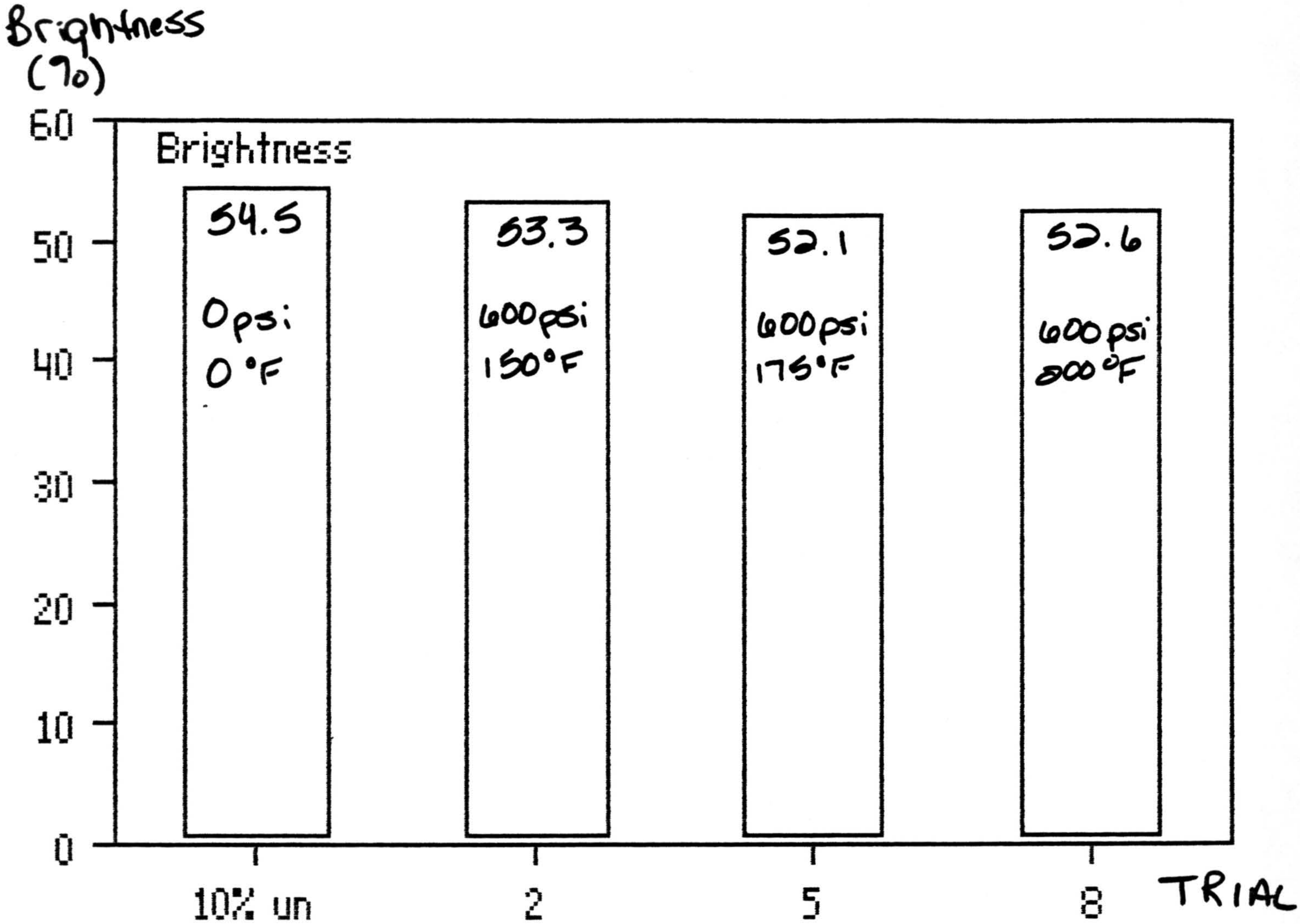

Fig. 14--Brightness for 10% Moisture Trial (600psi)

Color

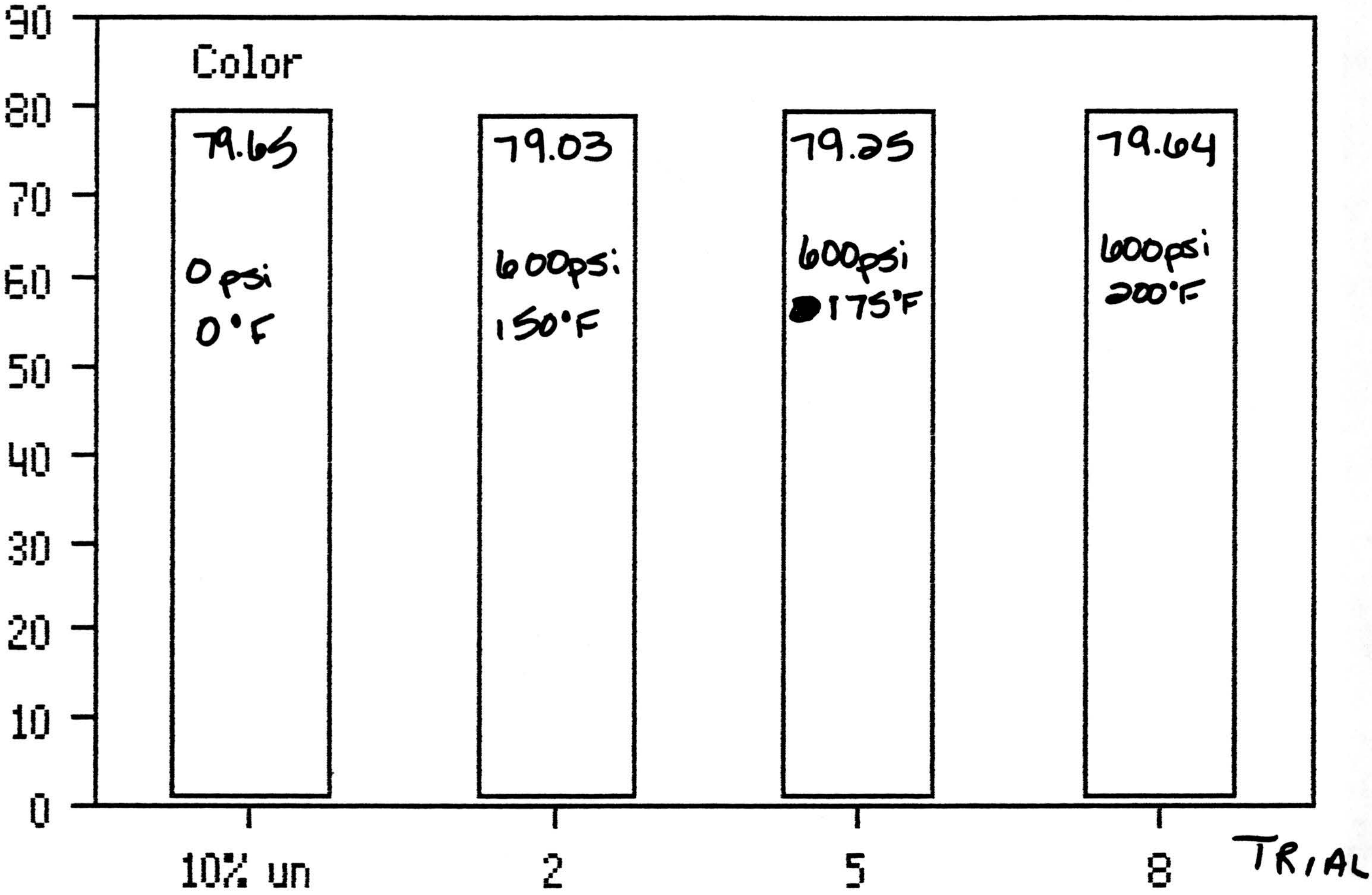

Fig. 15--Color for 10% Moisture Trial (600psi)

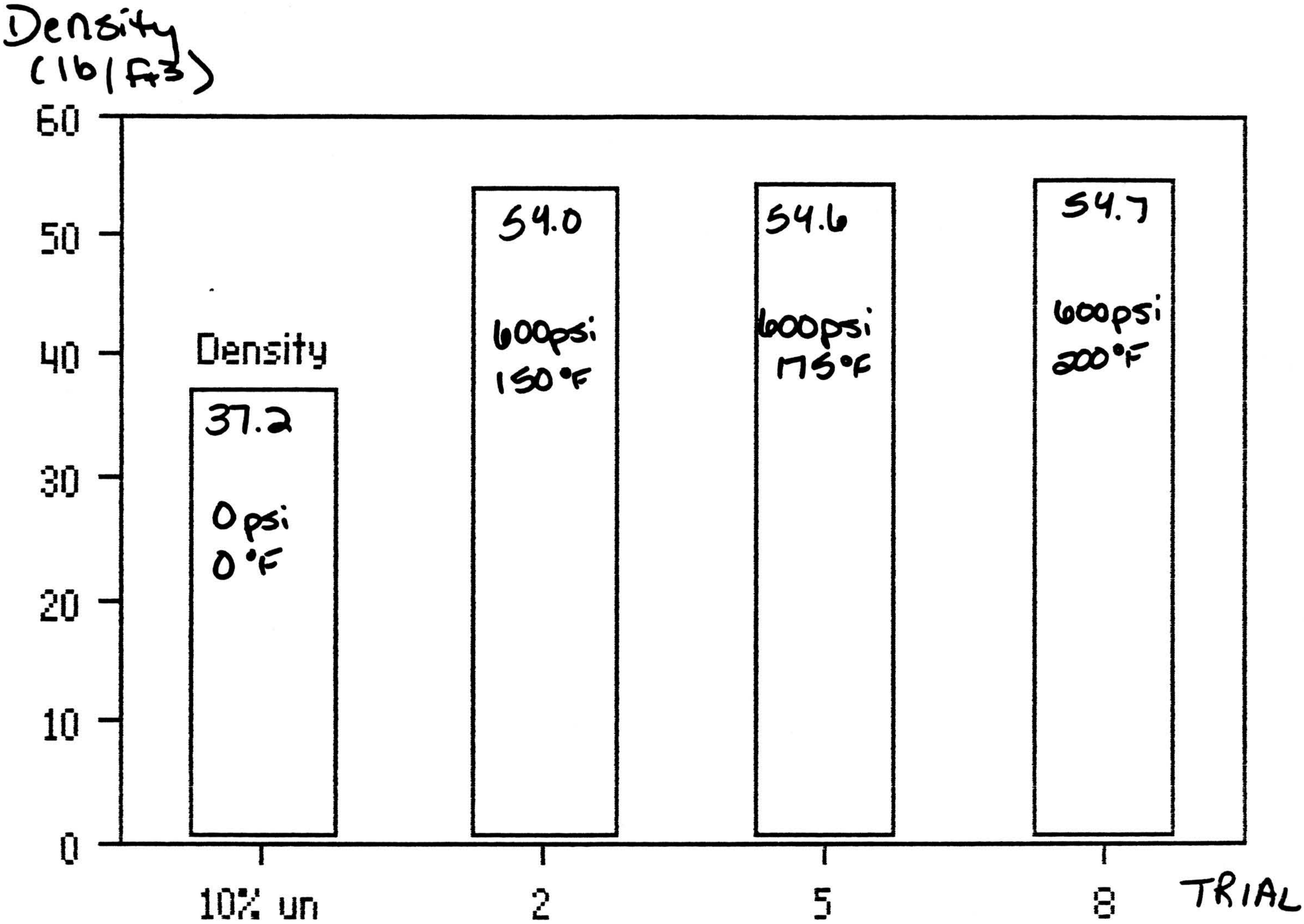

Fig.16-- Density for 10% Moisture Trial (600psi)

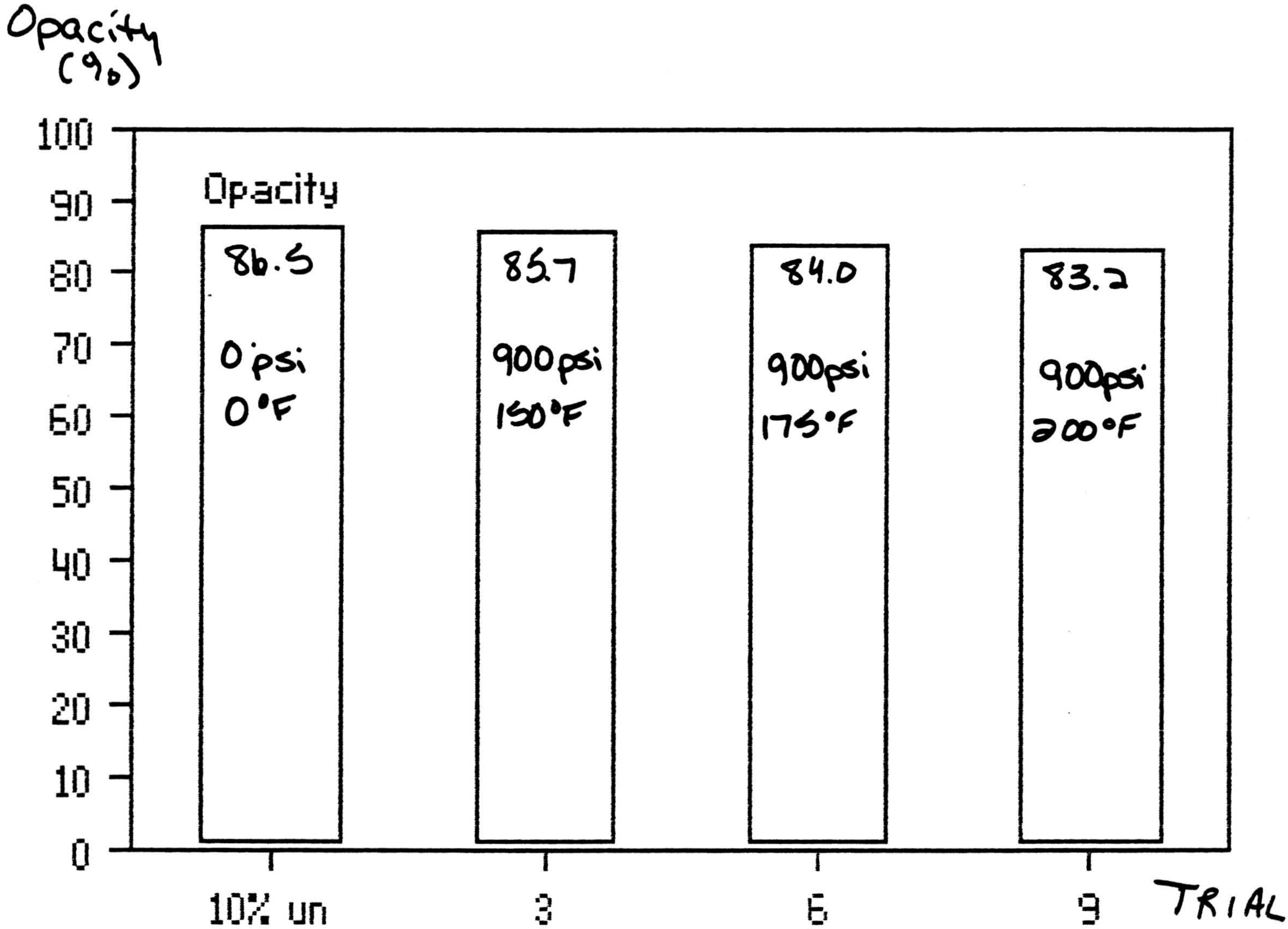

Fig.17-- Opacity for 10% Moisture Trial (900psi)

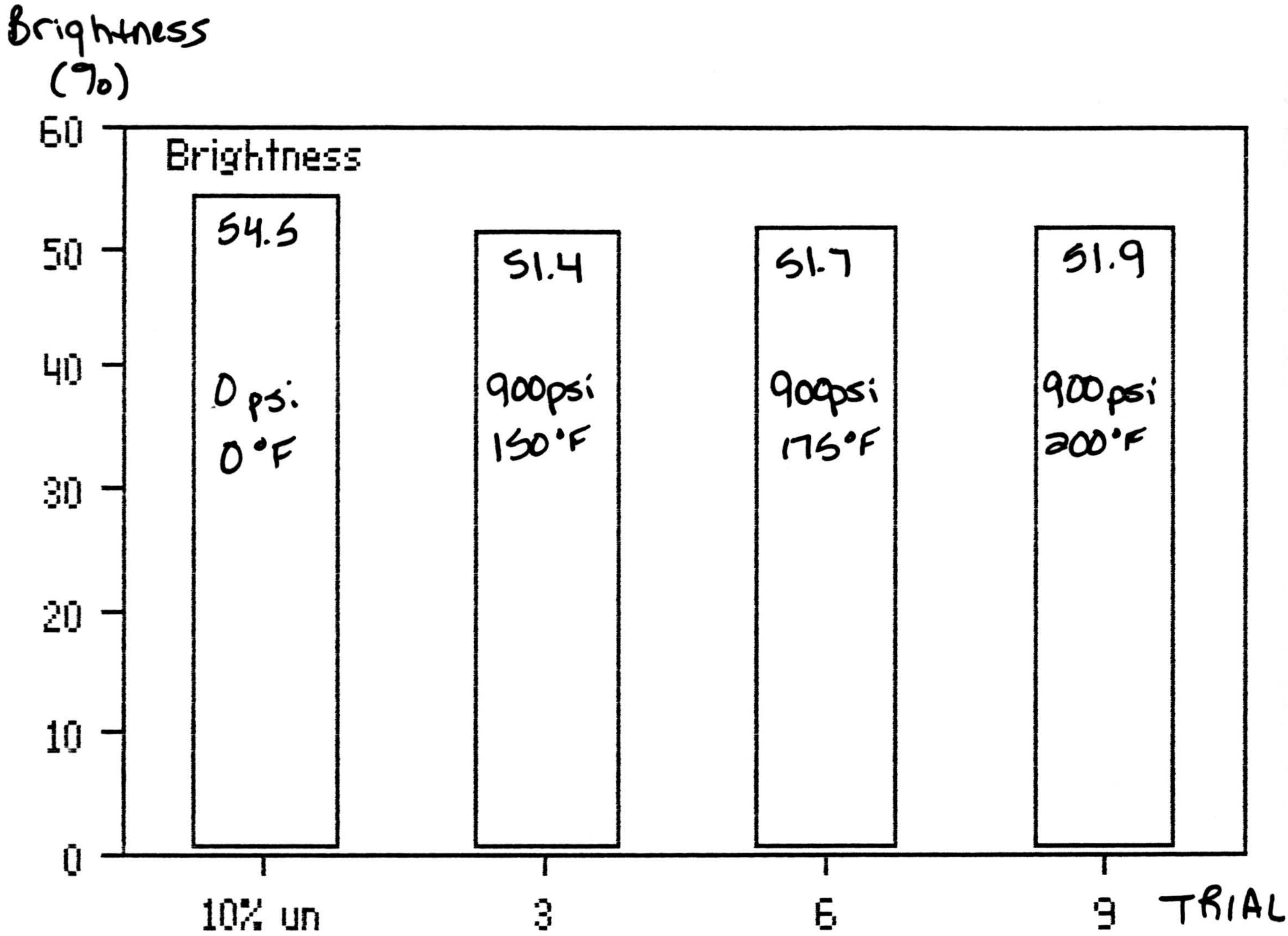

Fig.18-- Brightness for 10% Moisture Trial (900psi)

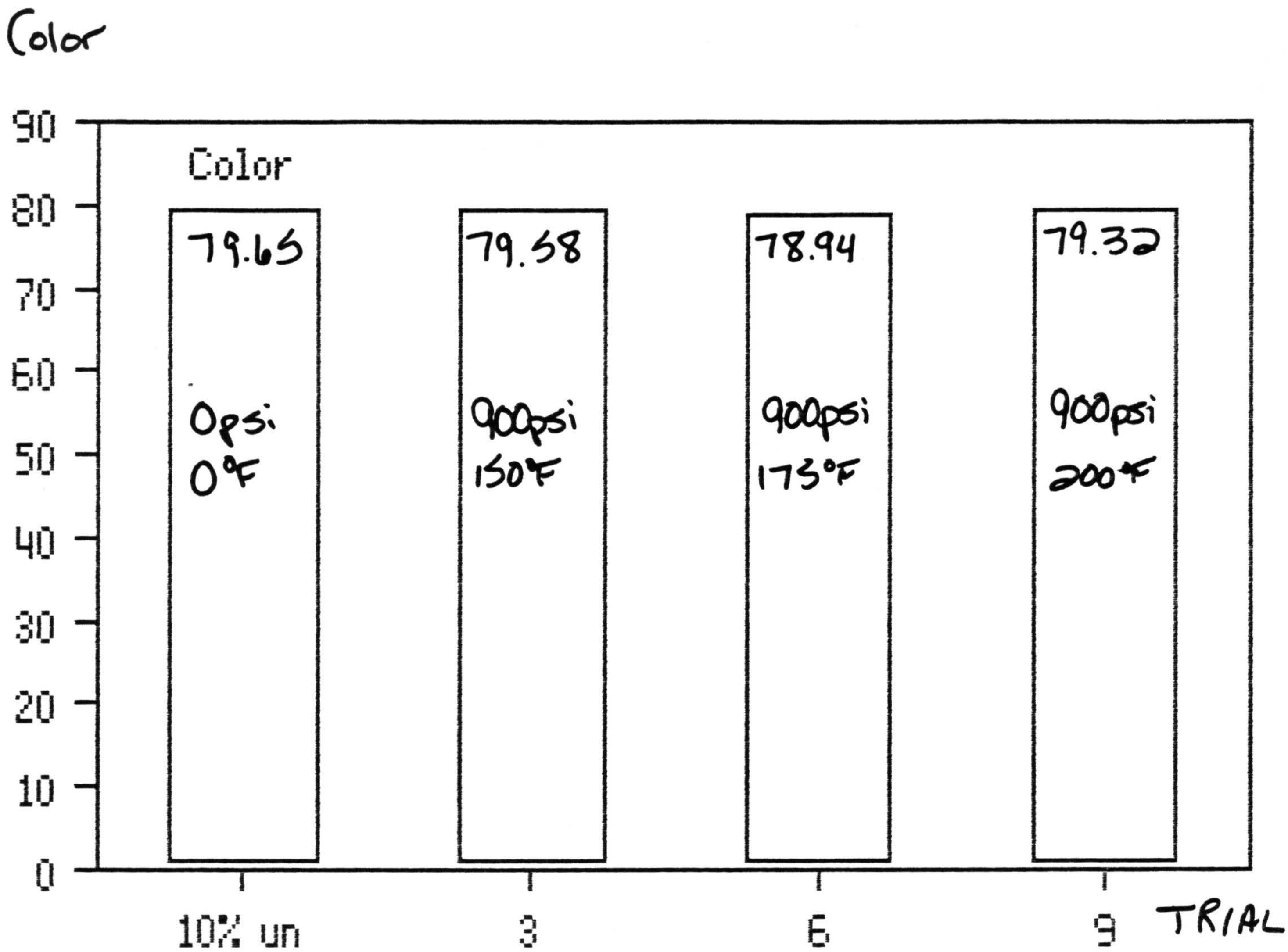

Fig. 19 -- Color for 10% Moisture Trial (900psi)

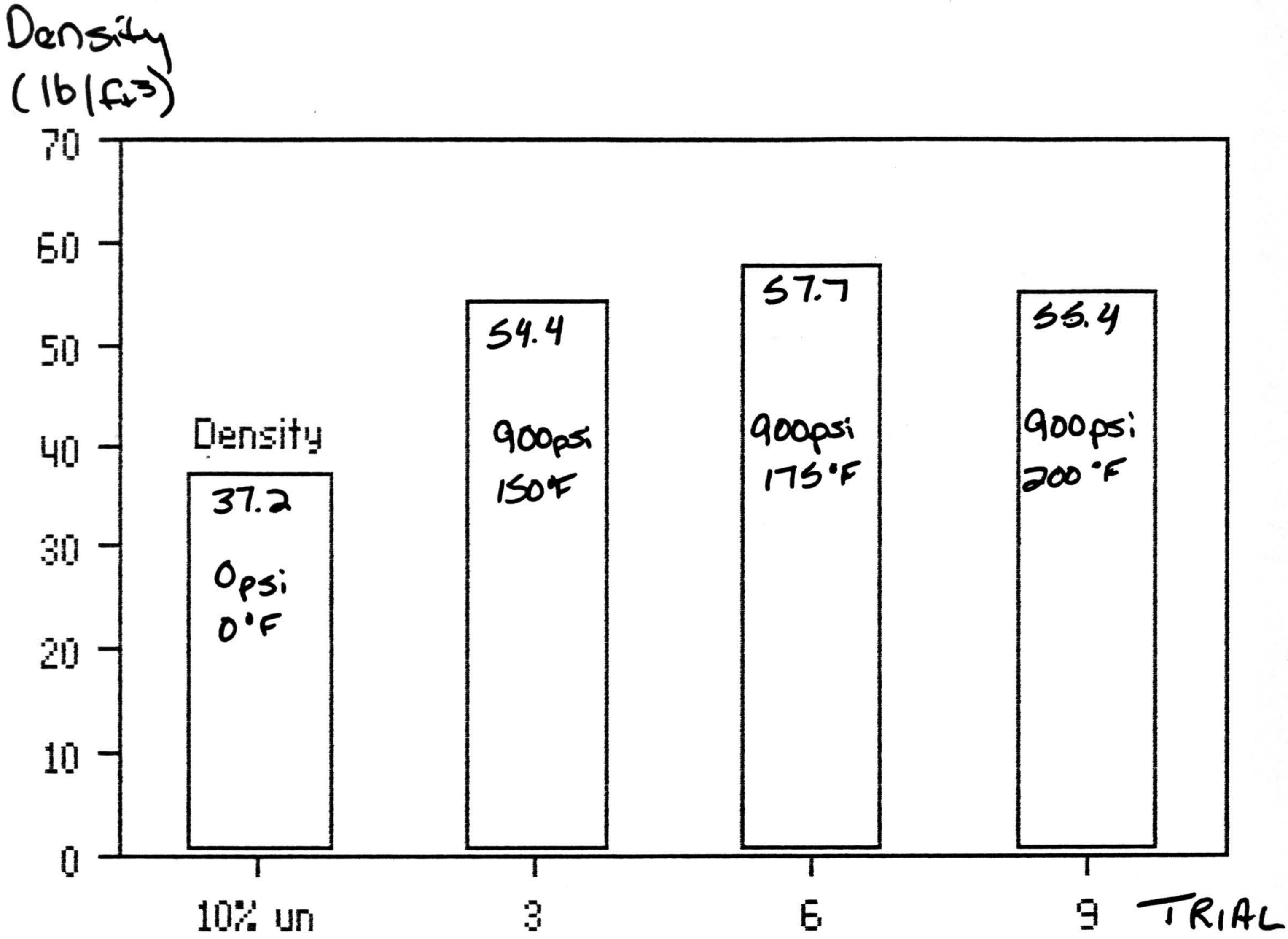

Fig.20-- Density for 10% Moisture Trial (900psi)

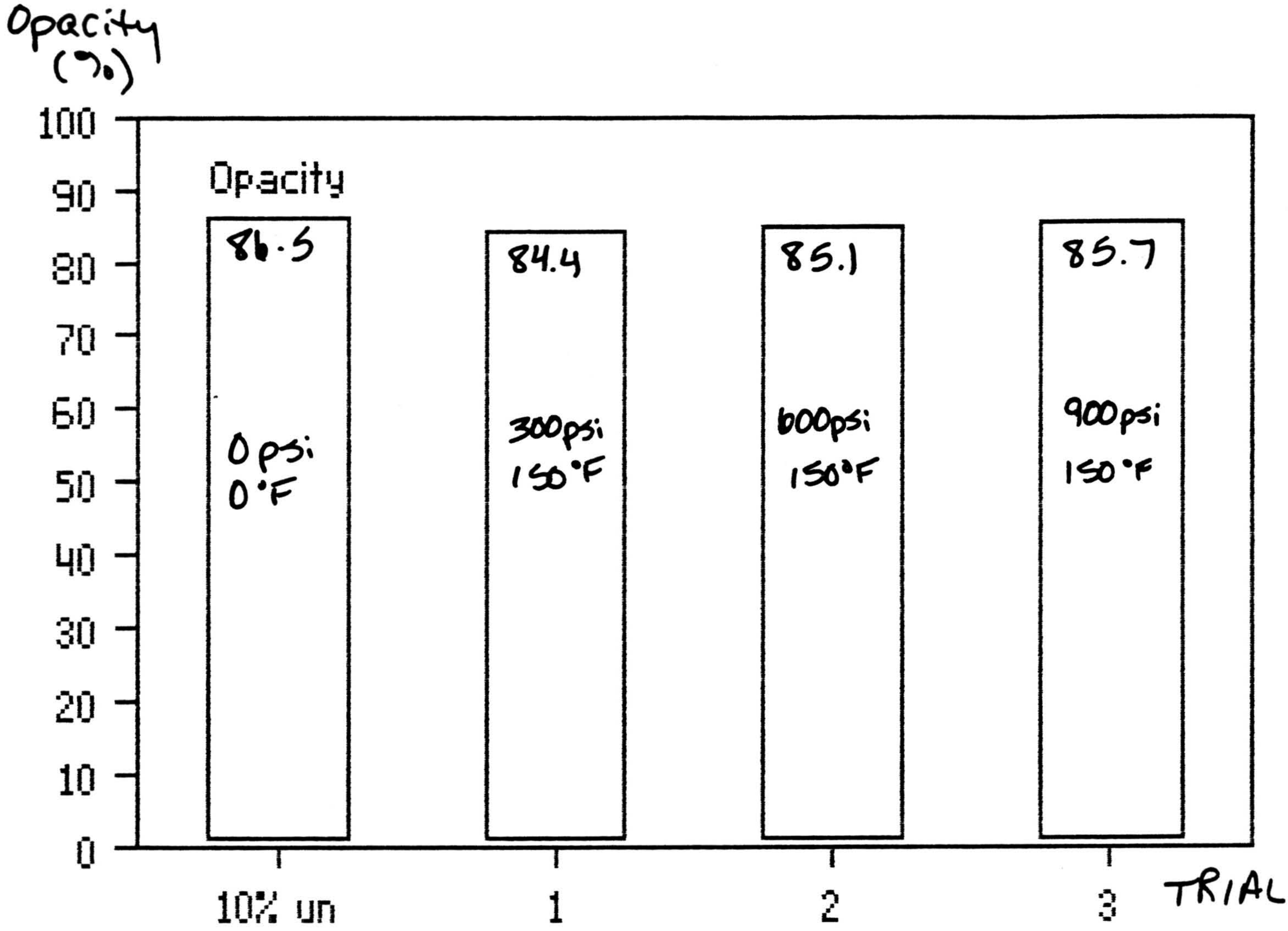

Fig. 21--Opacity for 10% Moisture Trial (150°F)

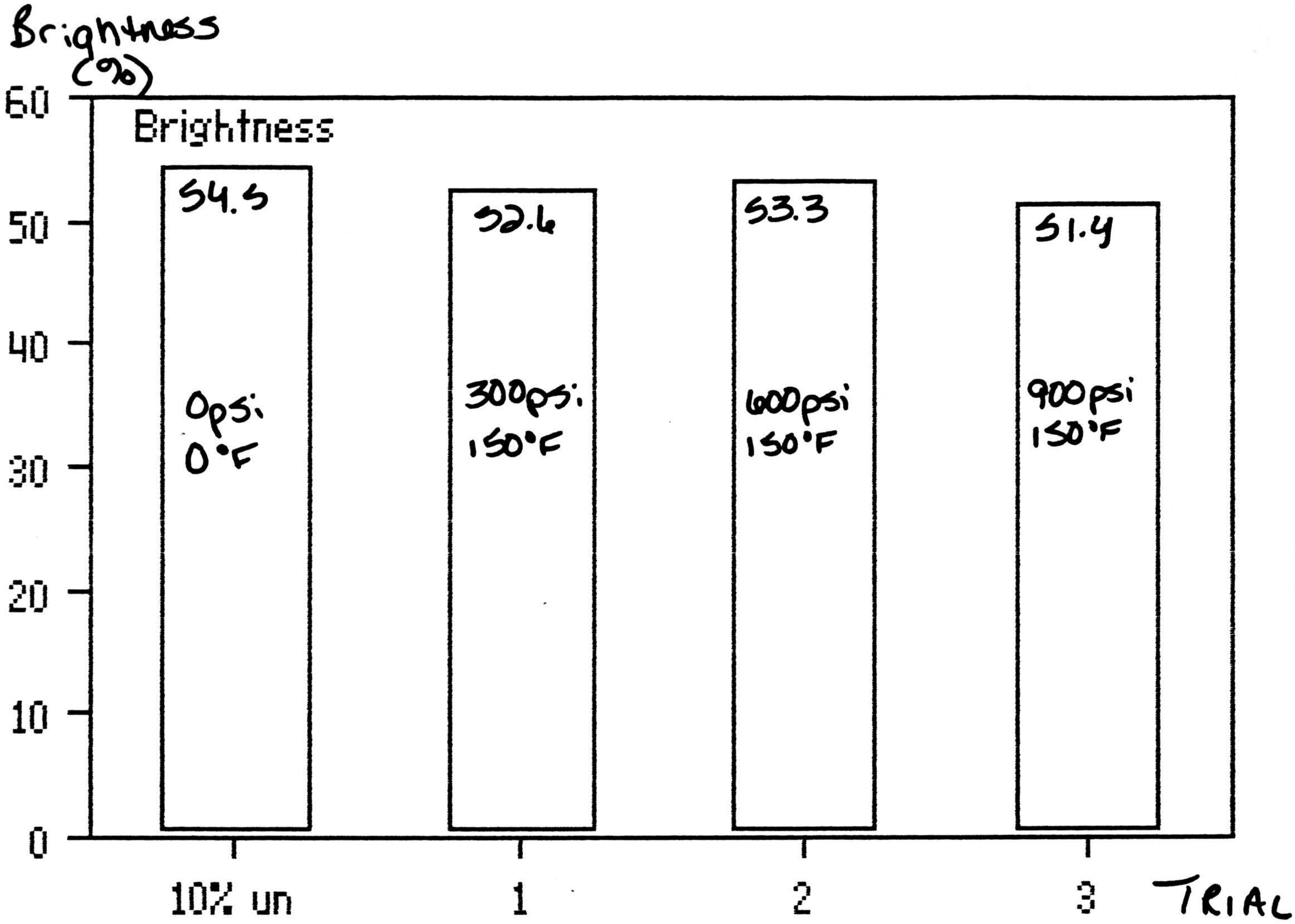

Fig. 22 -- Brightness for 10% Moisture Trial (150°F)

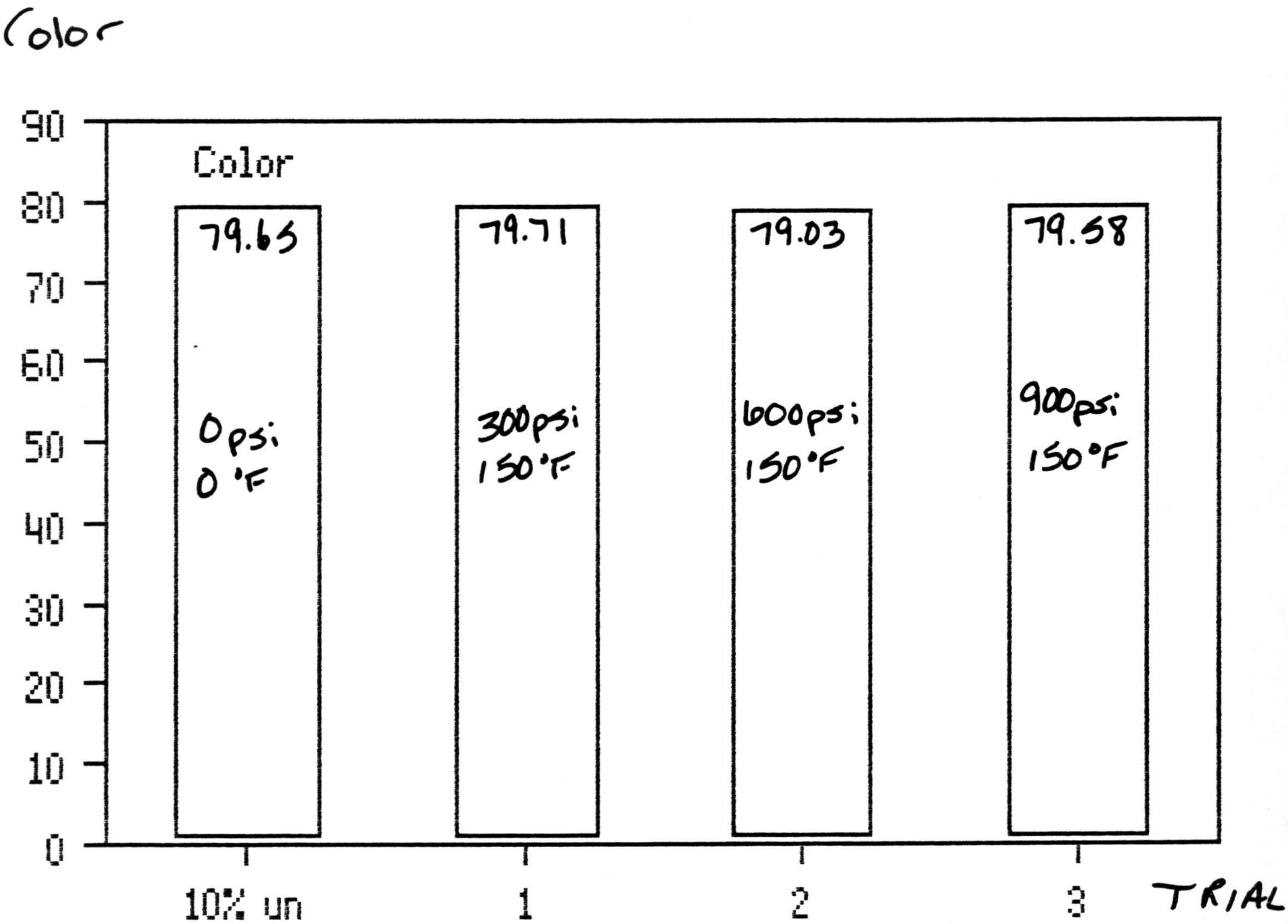

Fig.23-- Color for 10% Moisture Trial (150°F)

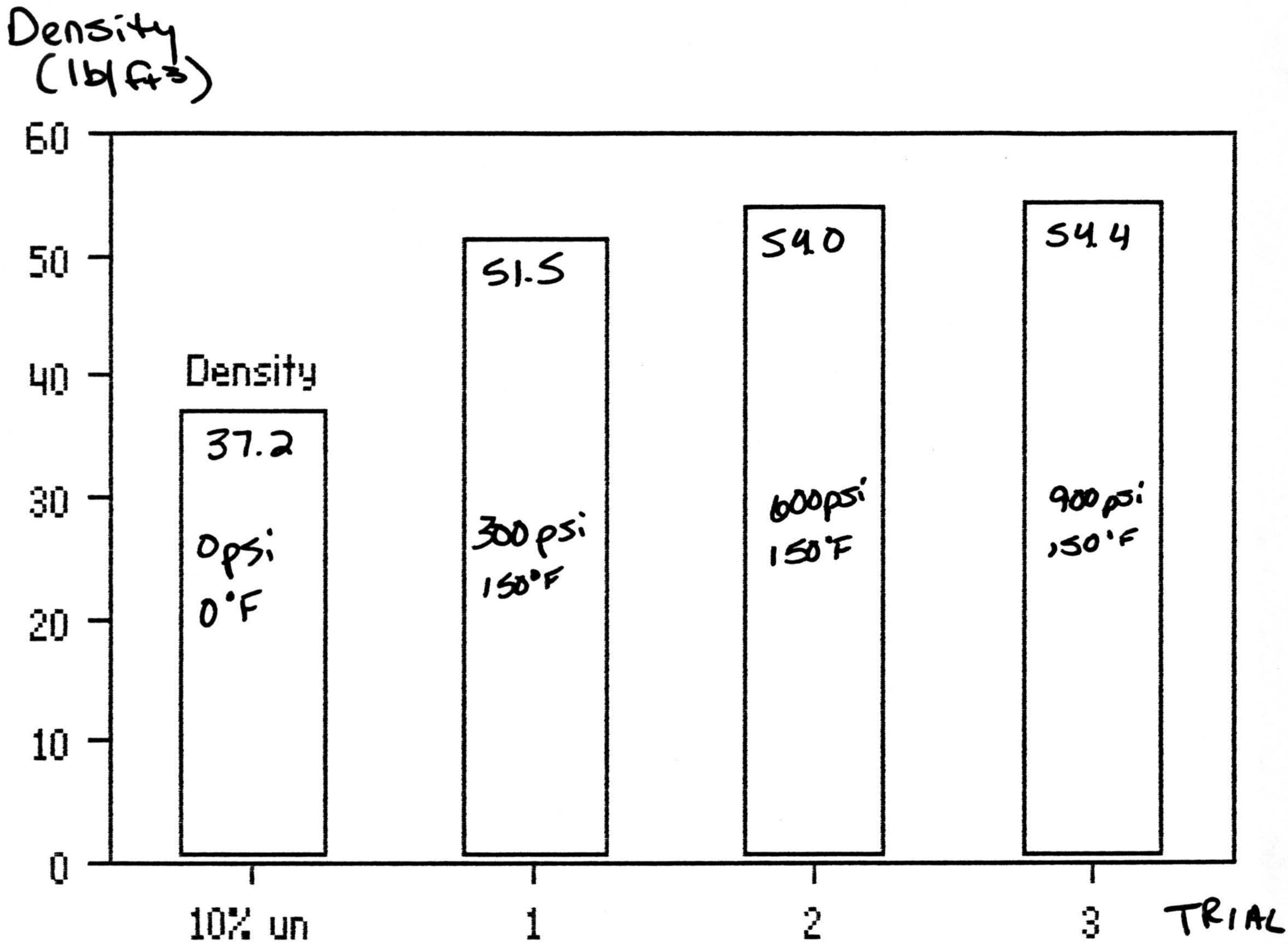

Fig. 24--Density for 10% Moisture Trial (150°F)

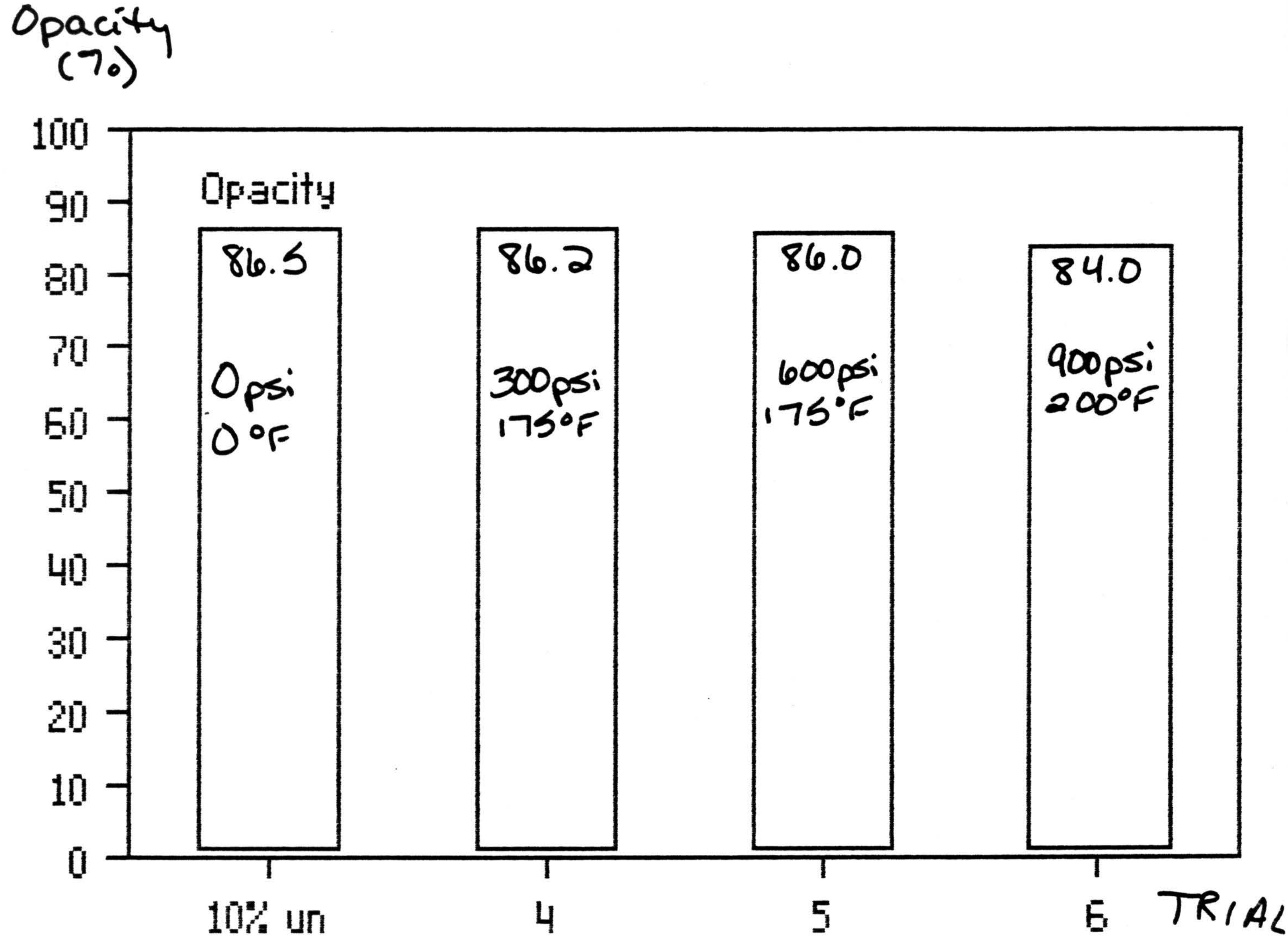

Fig.25--Opacity for 10% Moisture Trial (175°F)

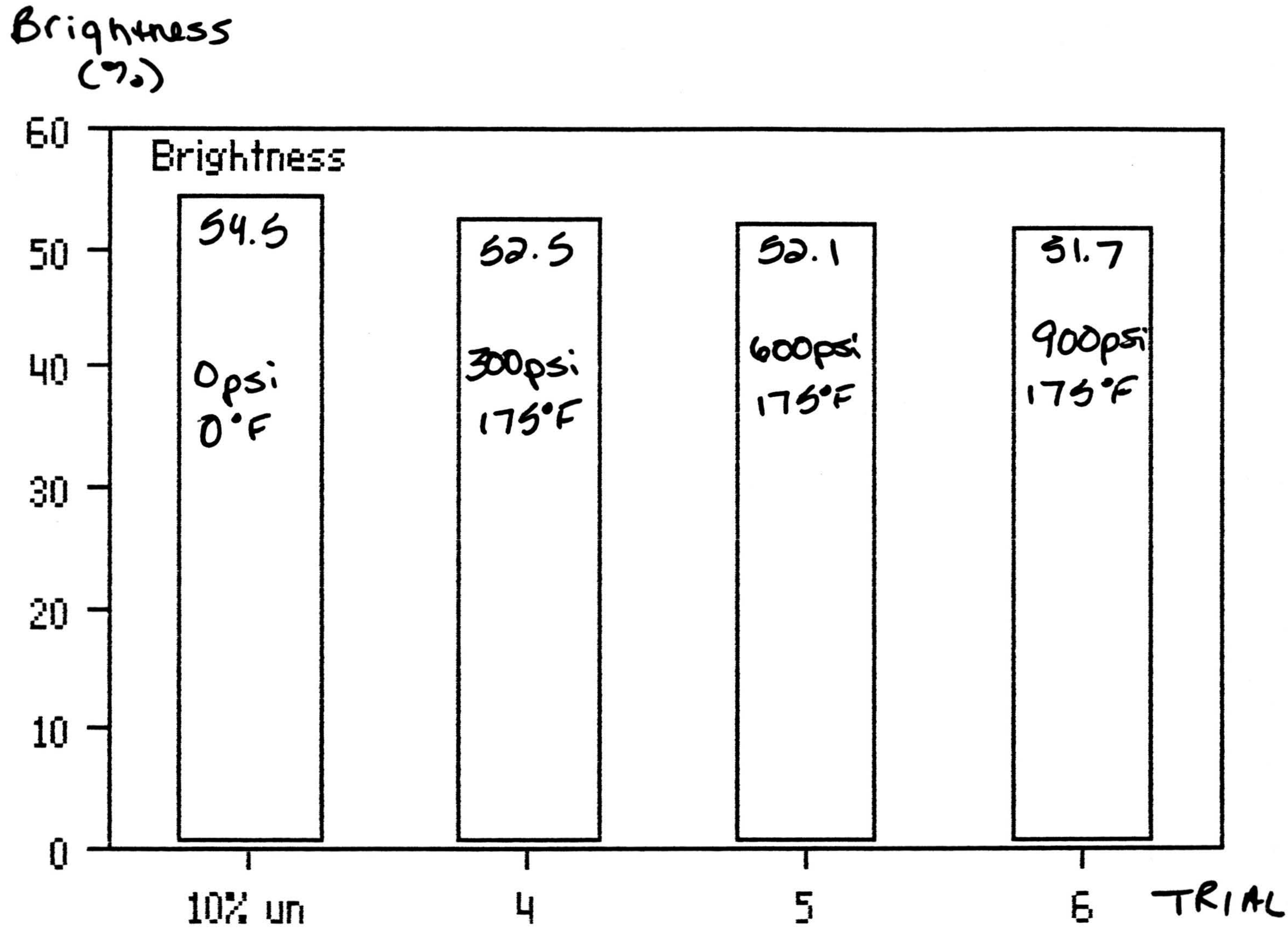

Fig. 26 -- Brightness for 10% Moisture Trial (175°F)

Color

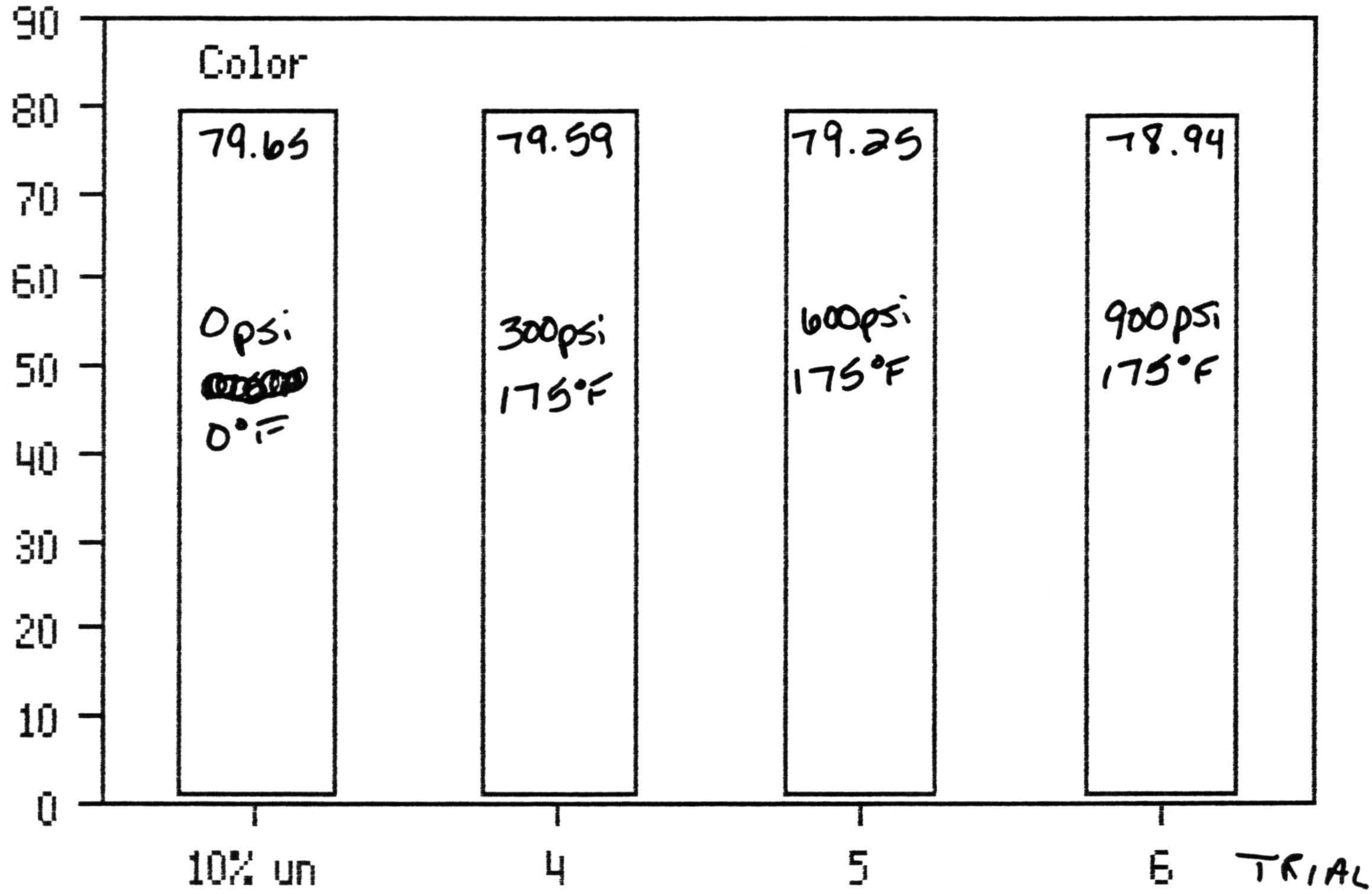

Fig. 27.-- Color for 10% Moisture Trial (175°F)

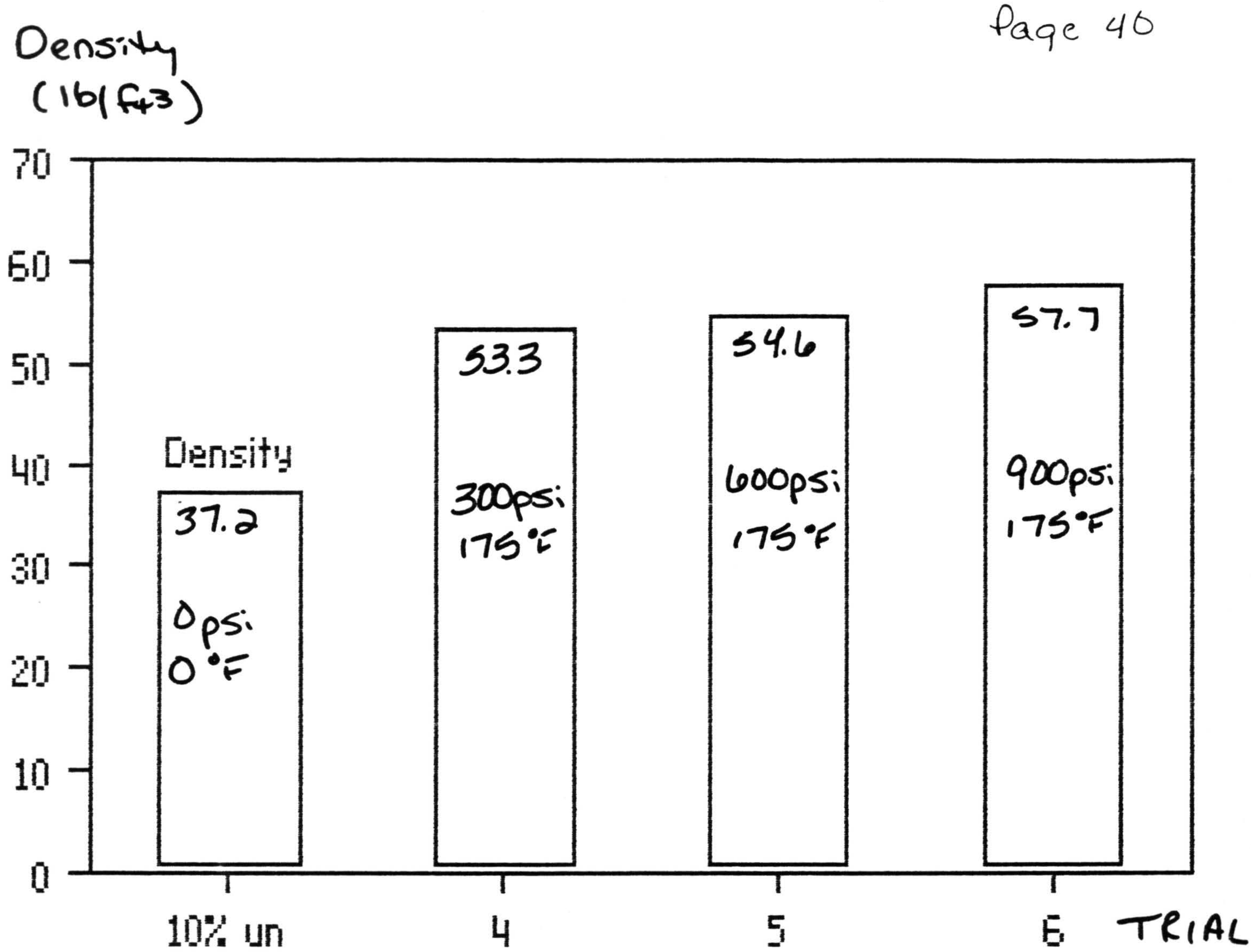

Fig. 28.. Density for 10% Moisture Trial (175°F)

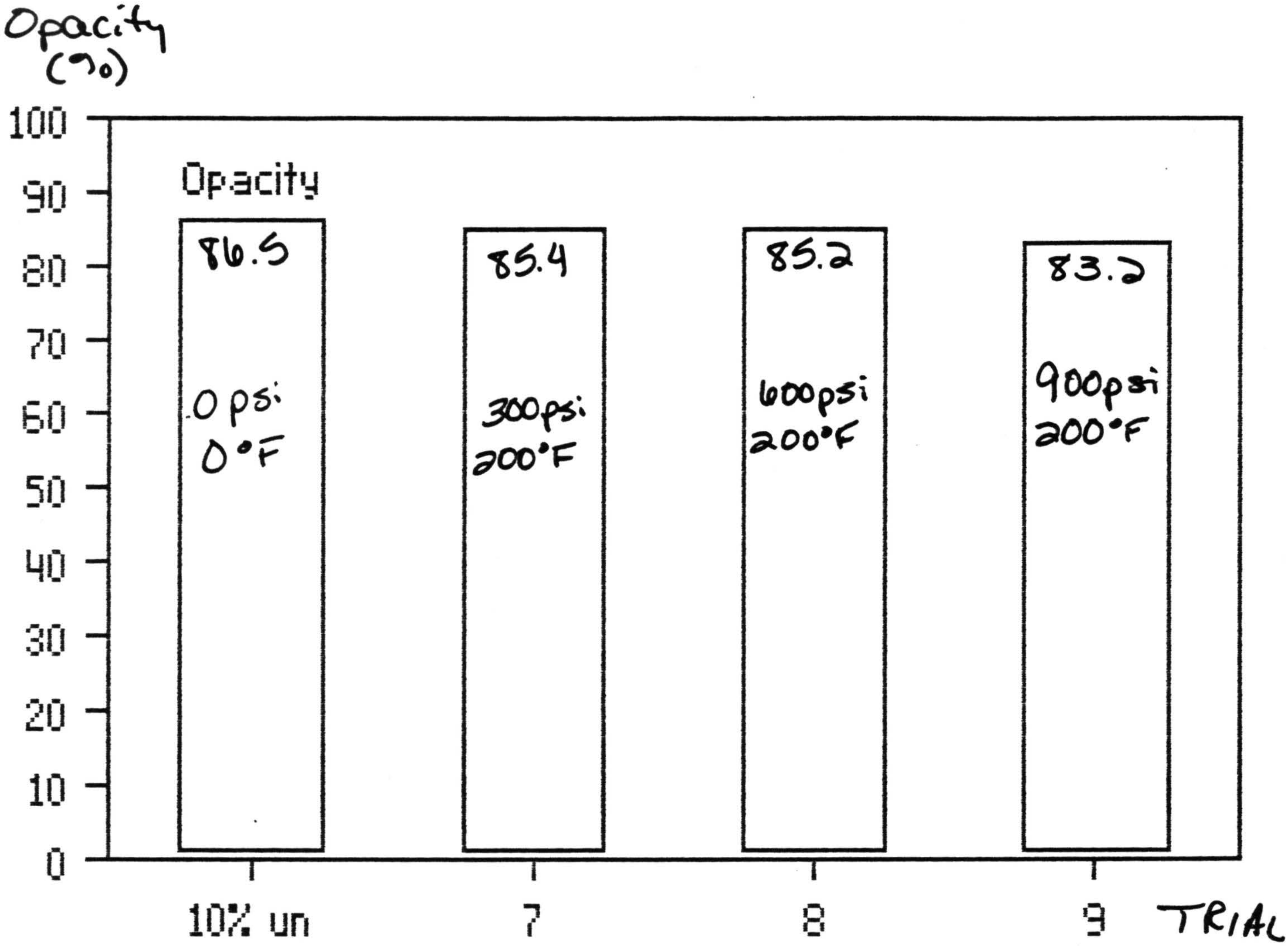

Fig. 29.-- Opacity for 10% Moisture Trial (200°F)

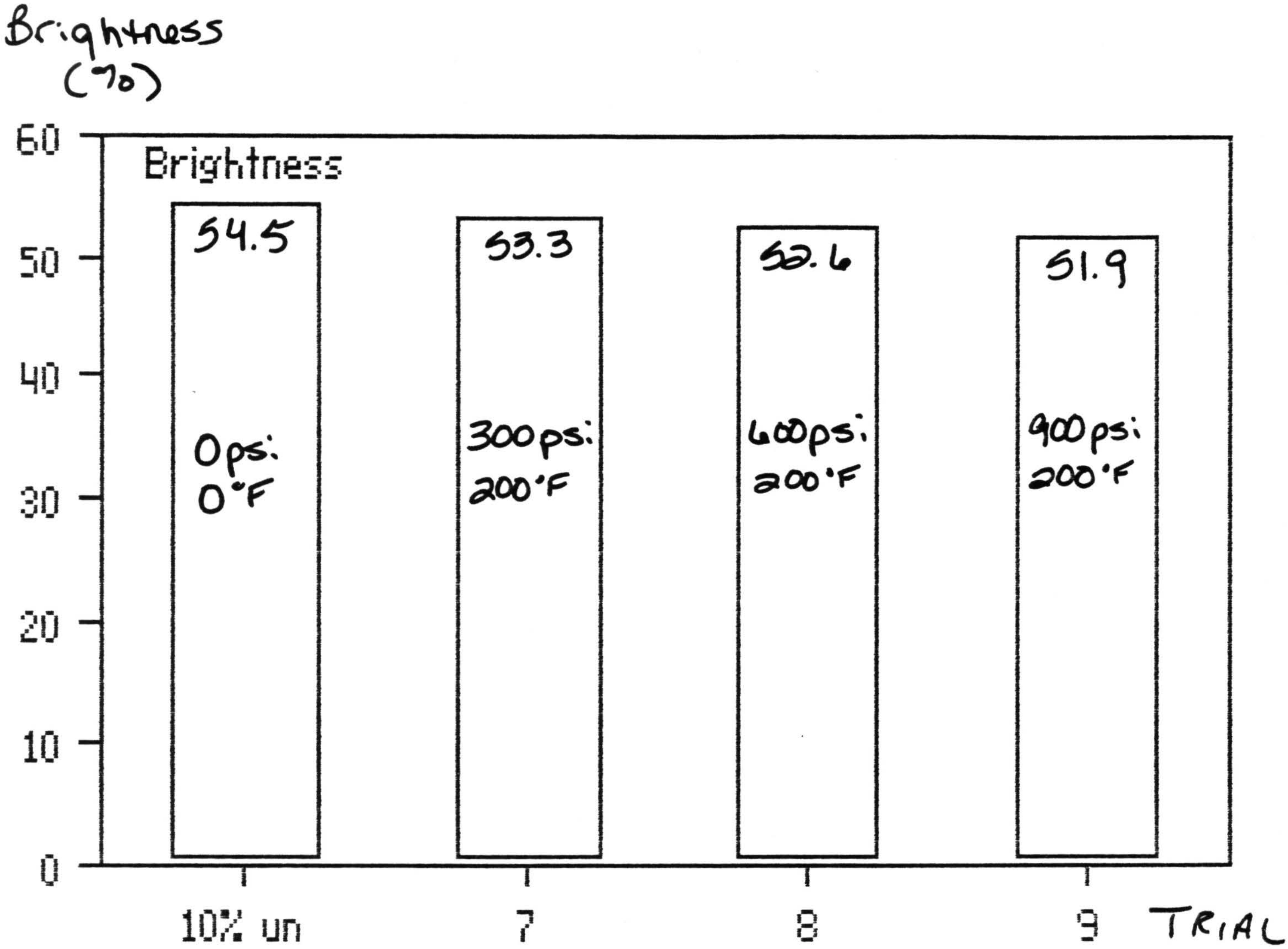

Fig. 30--Brightness for 10% Moisture Trial (200°F)

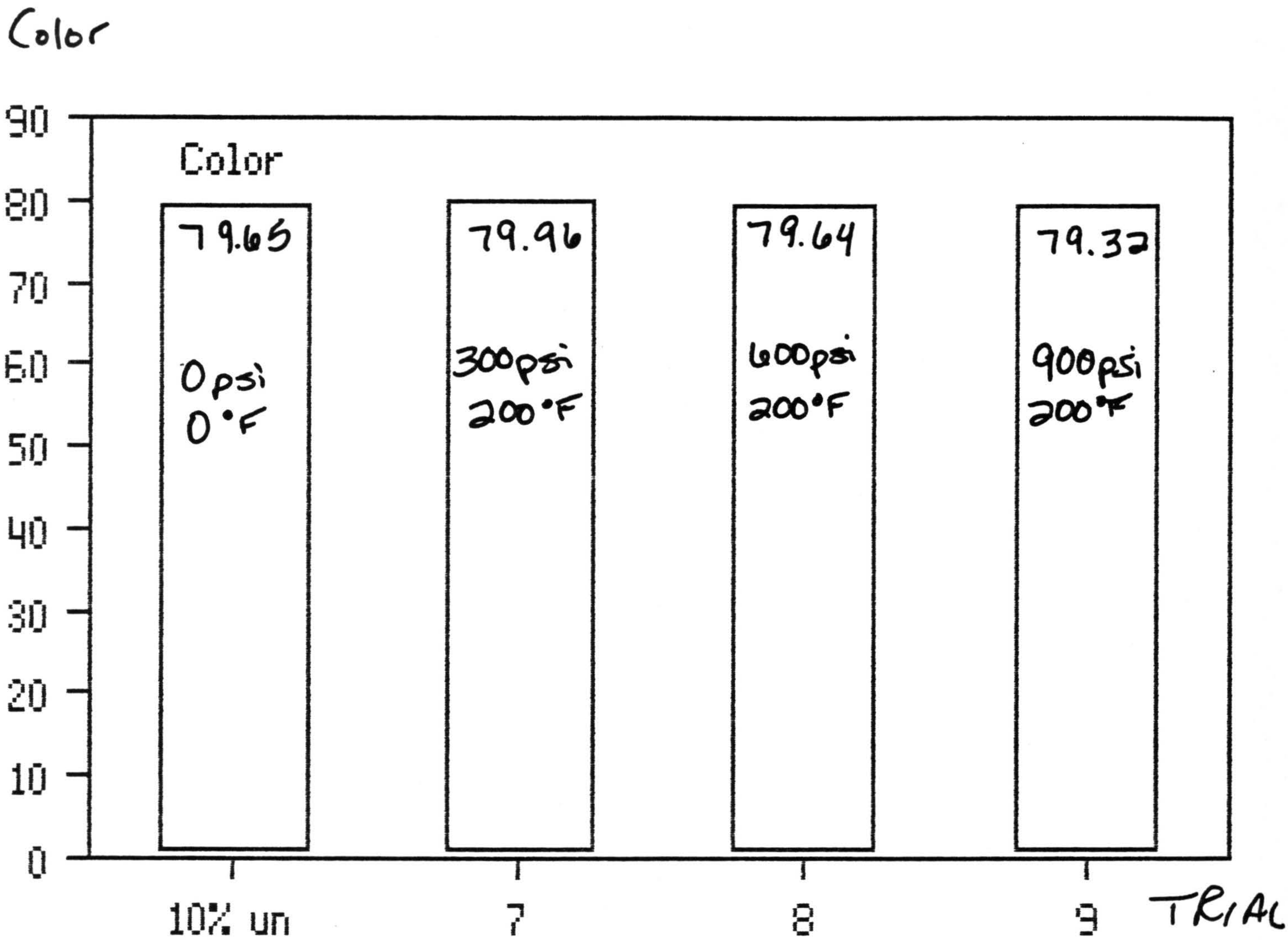

Fig. 31 -- Color for 10% Moisture Trial (200°F)

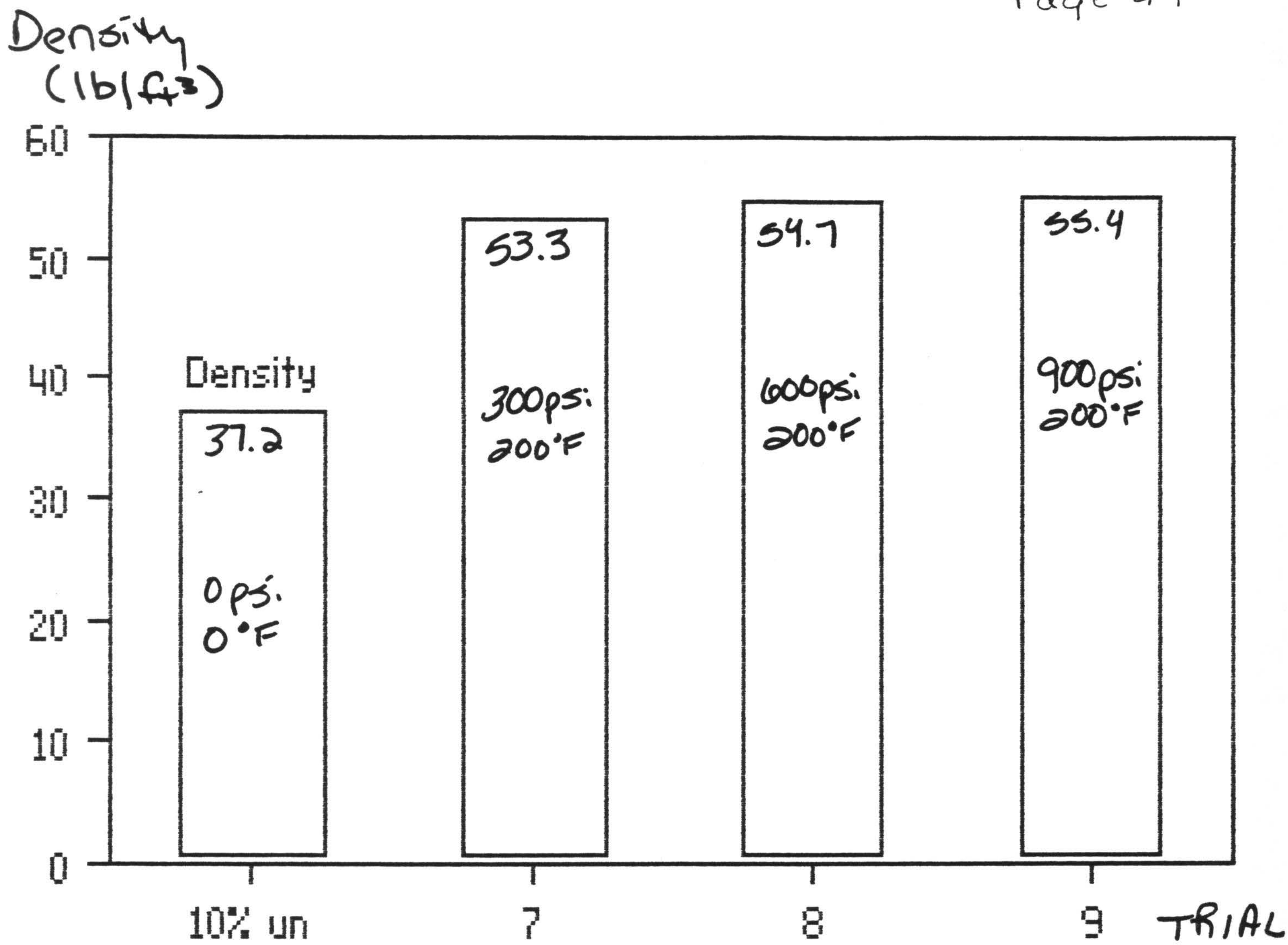

Fig.32.-Density for 10% Moisture Trial (200°F)

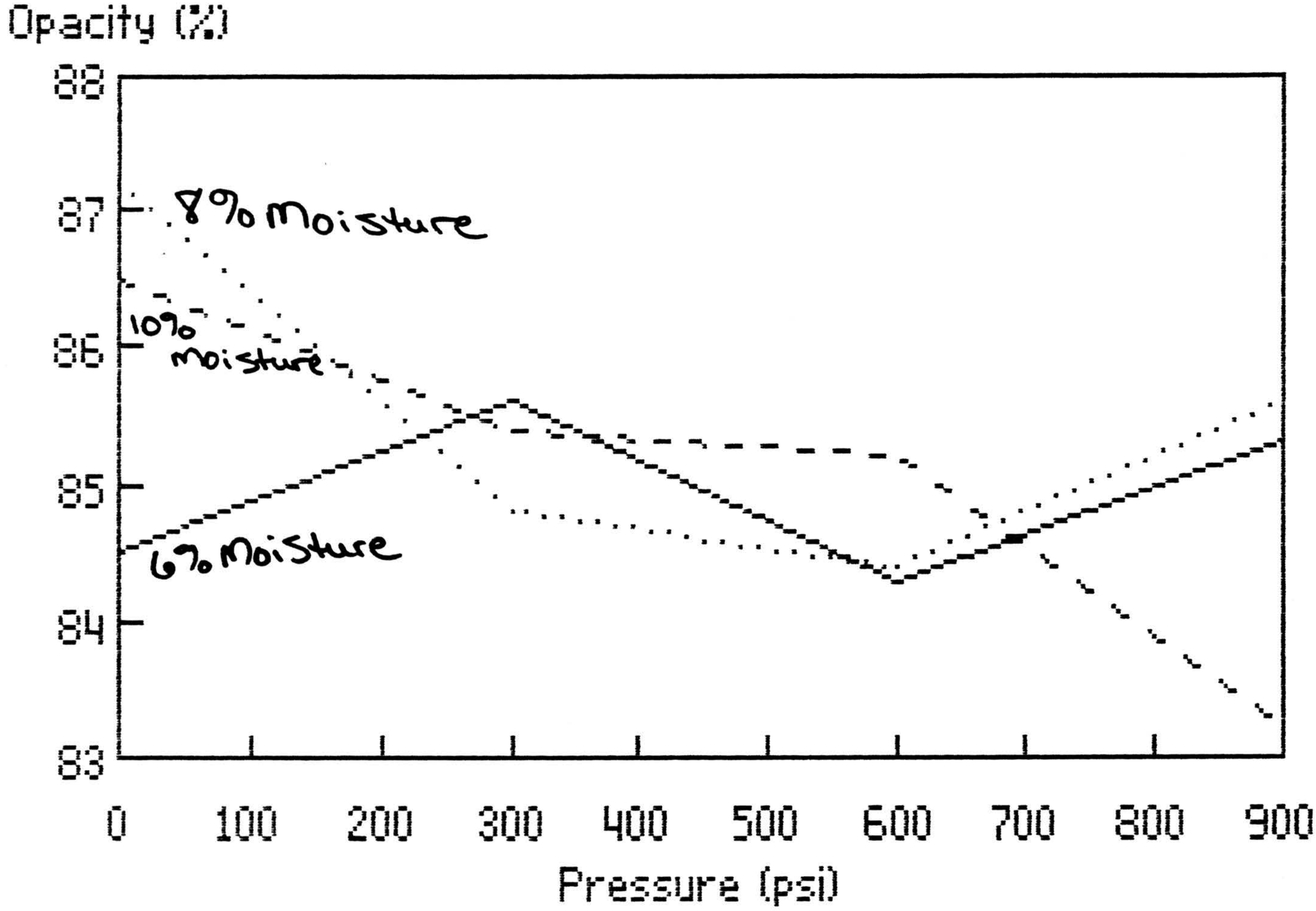

Fig. 33... Opacity vs. Pressure (200°F)

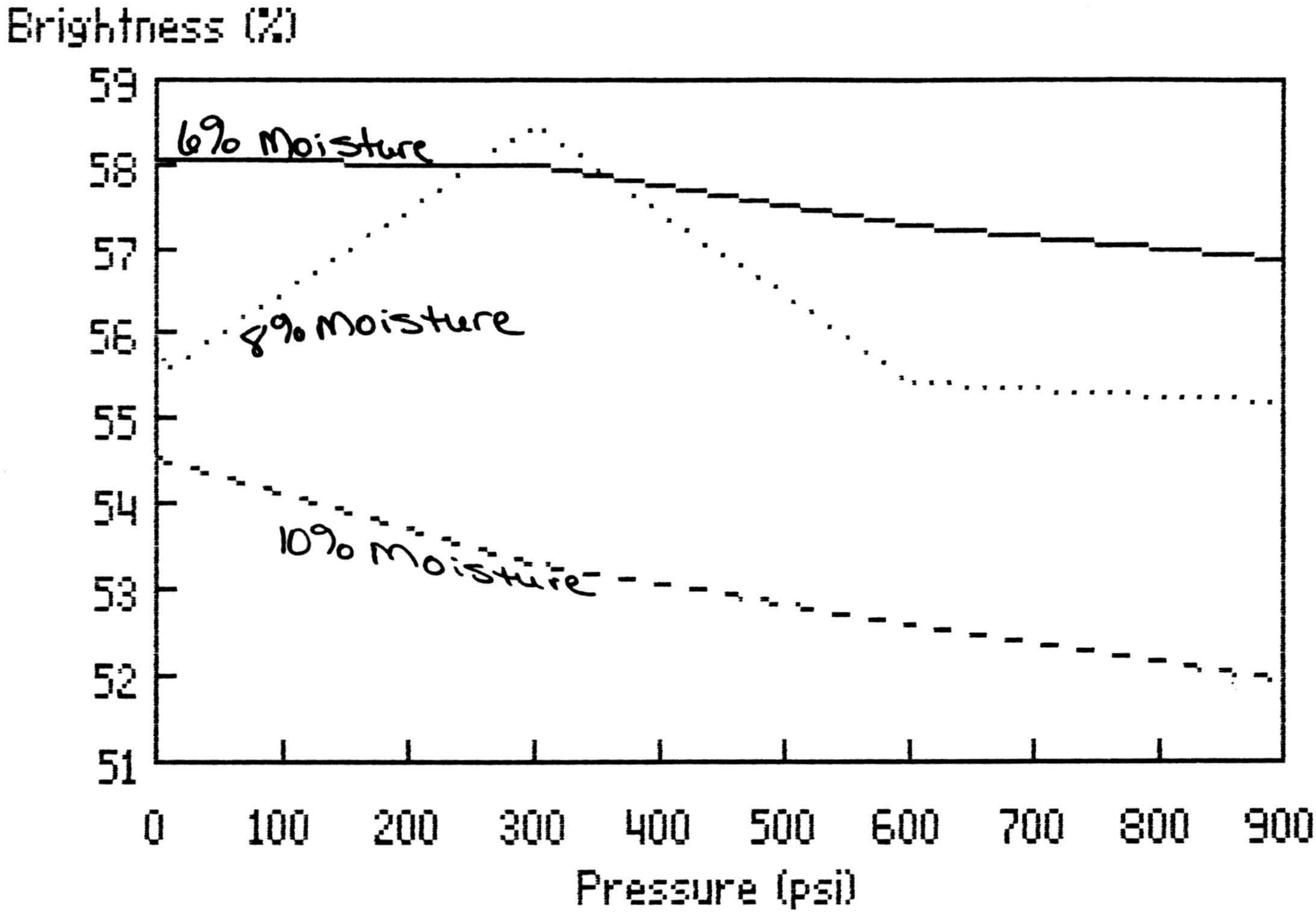

Fig. 34 - Brightness vs. Pressure (200°F)

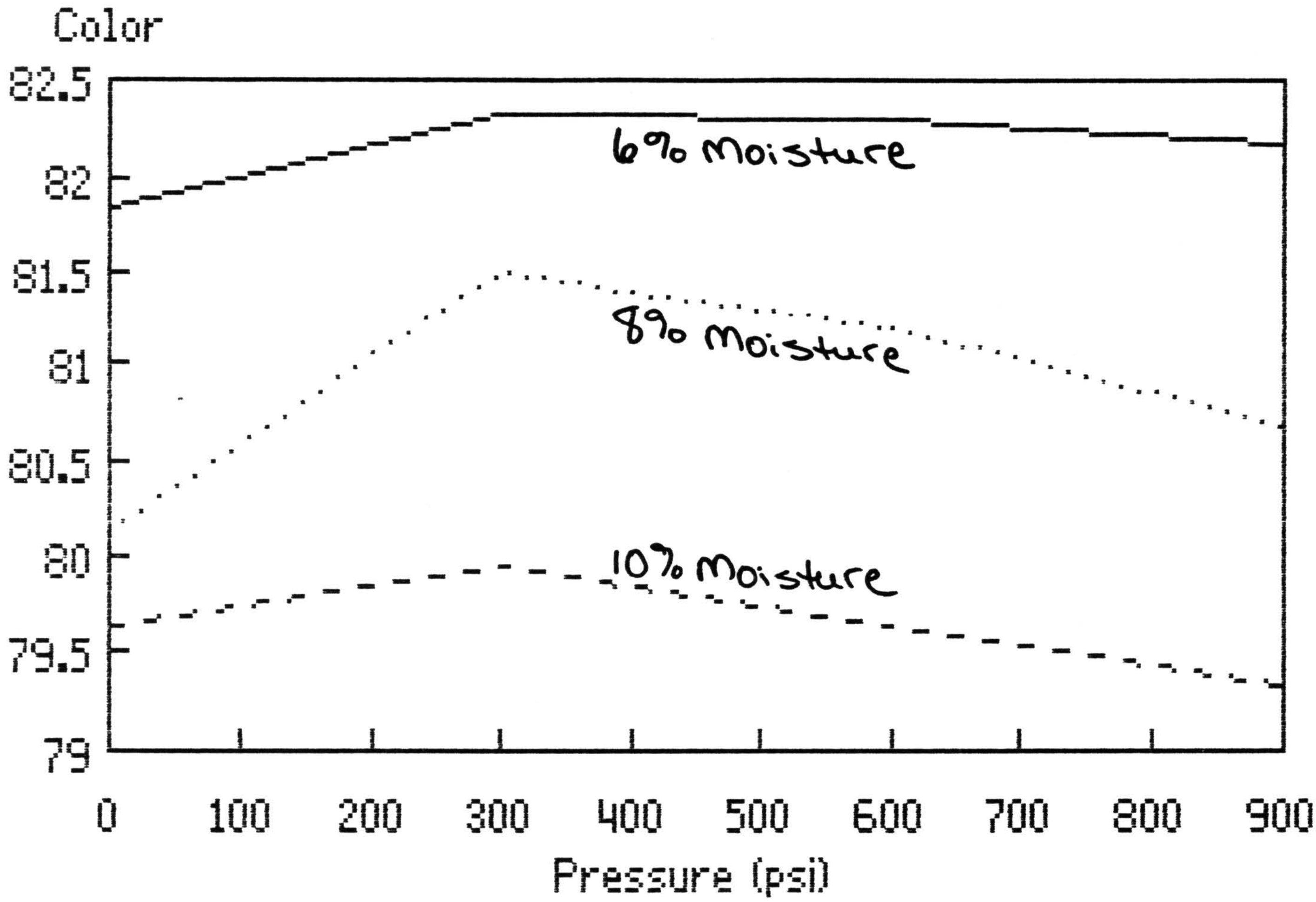

Fig. 35 -- Color vs. Pressure (200°F)

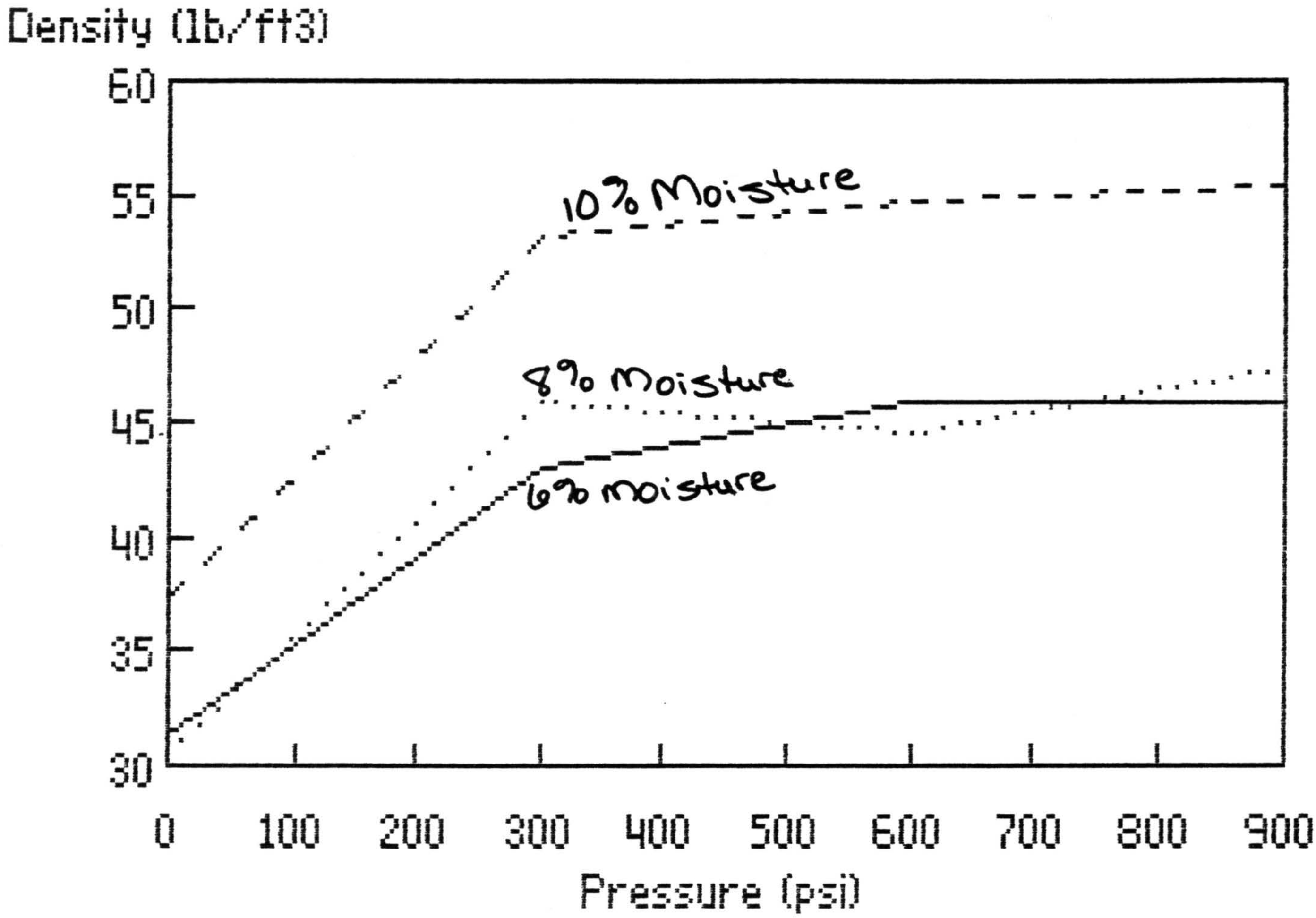

Fig. 36-- Density vs. Pressure (200°F)

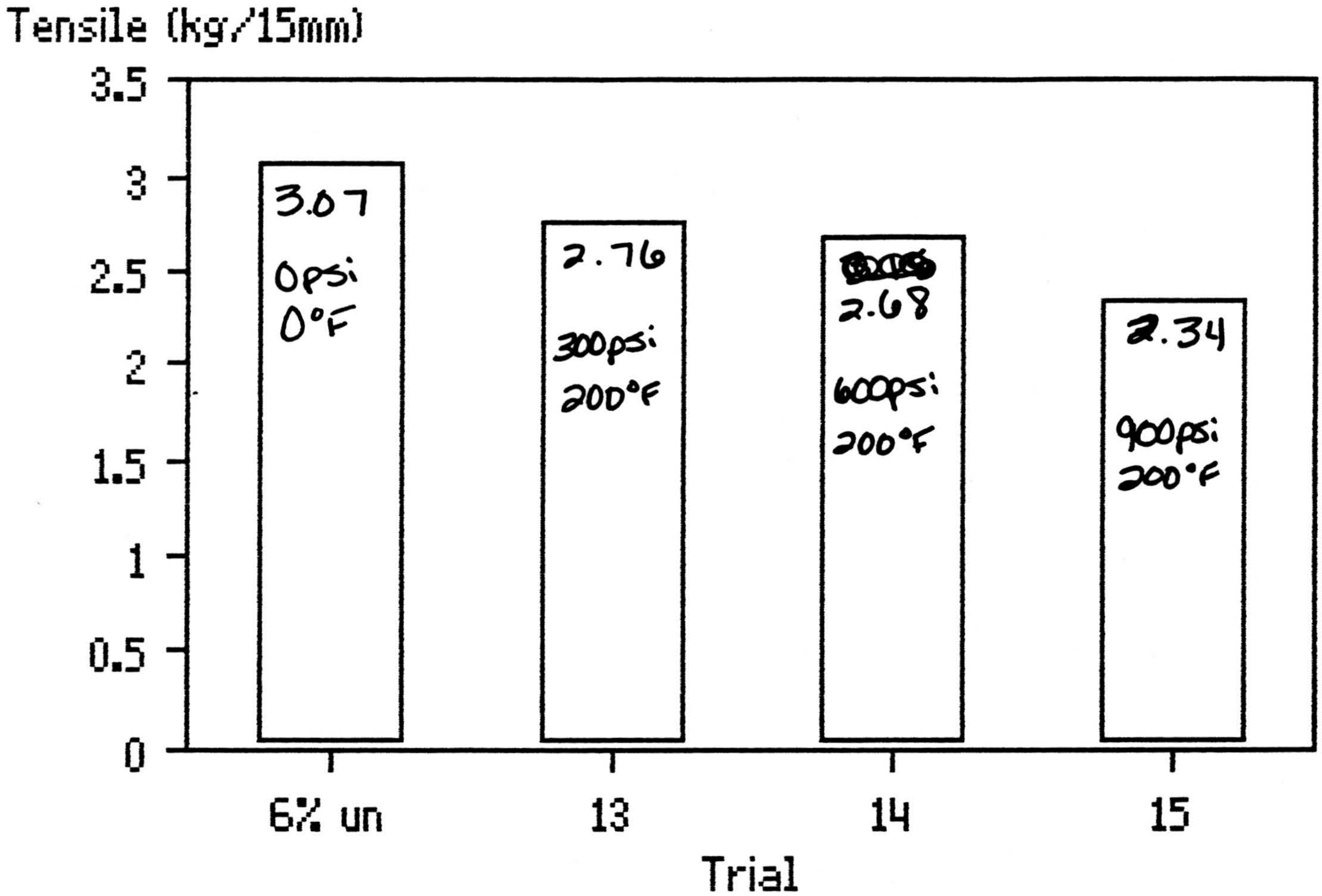

Fig. 37-- Tensile MD for 6% Moisture Trial

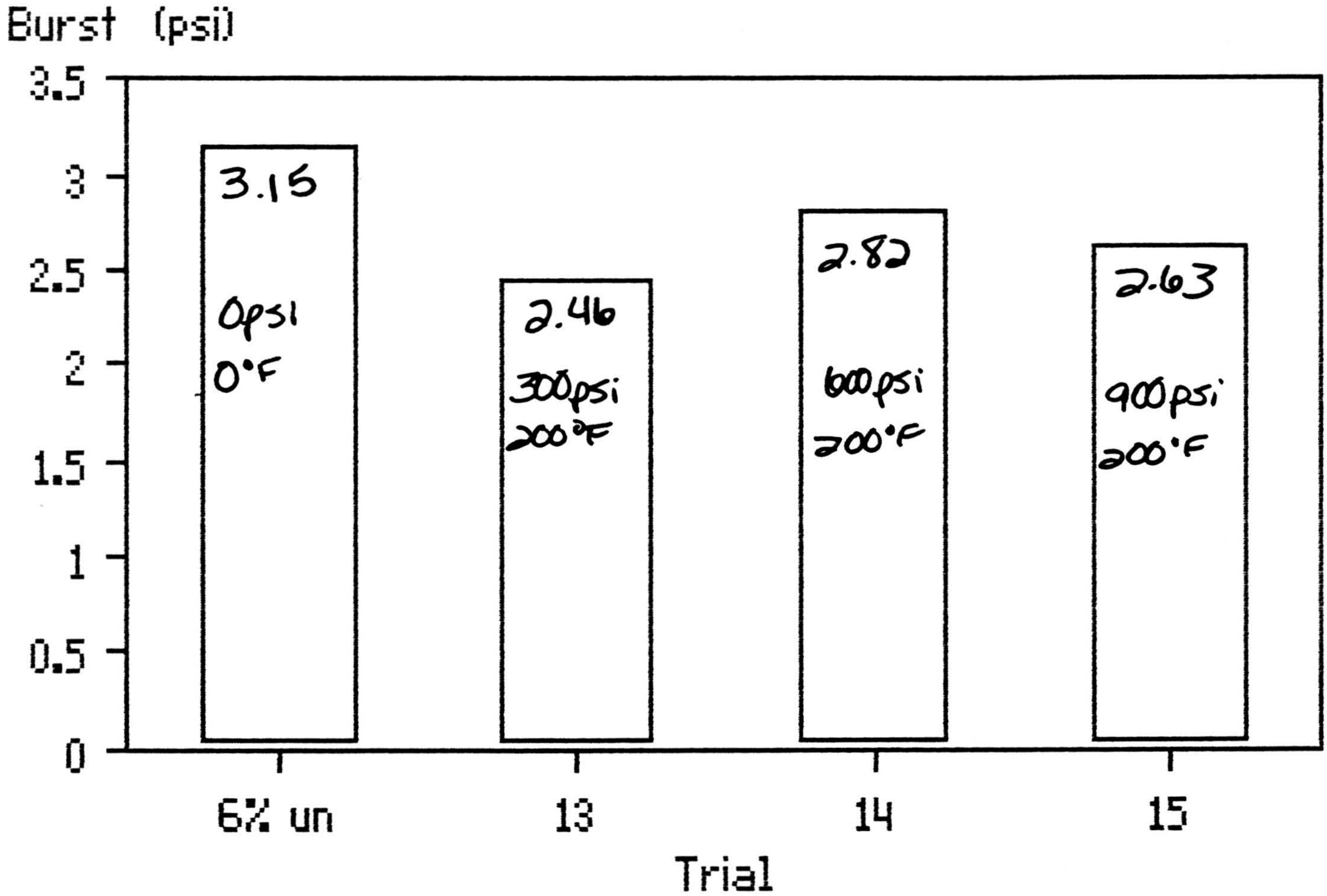

Fig. 38-- Burst for 6% Moisture Trial

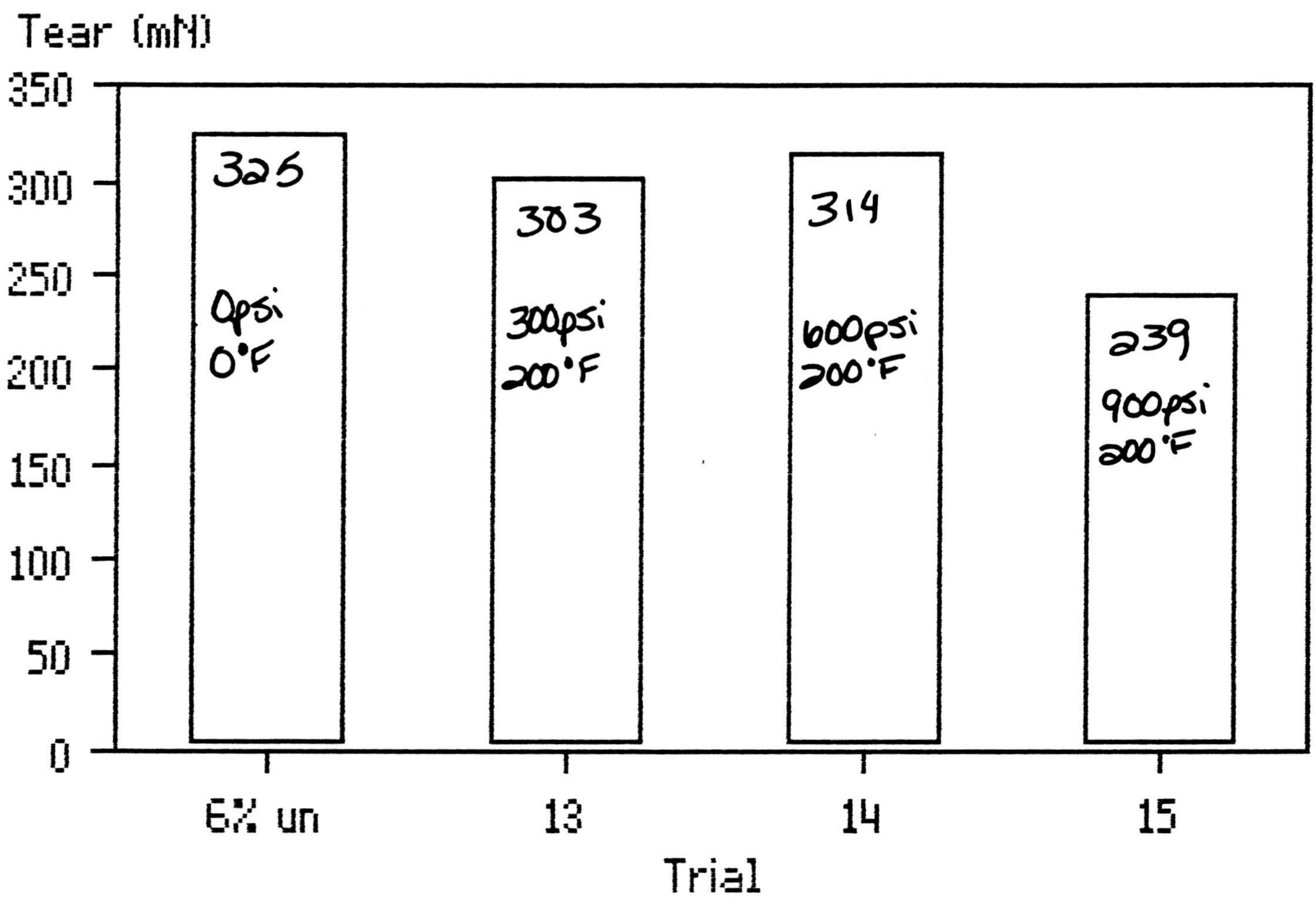

Fig. 39 -- Tear MD for 6% Moisture Trial

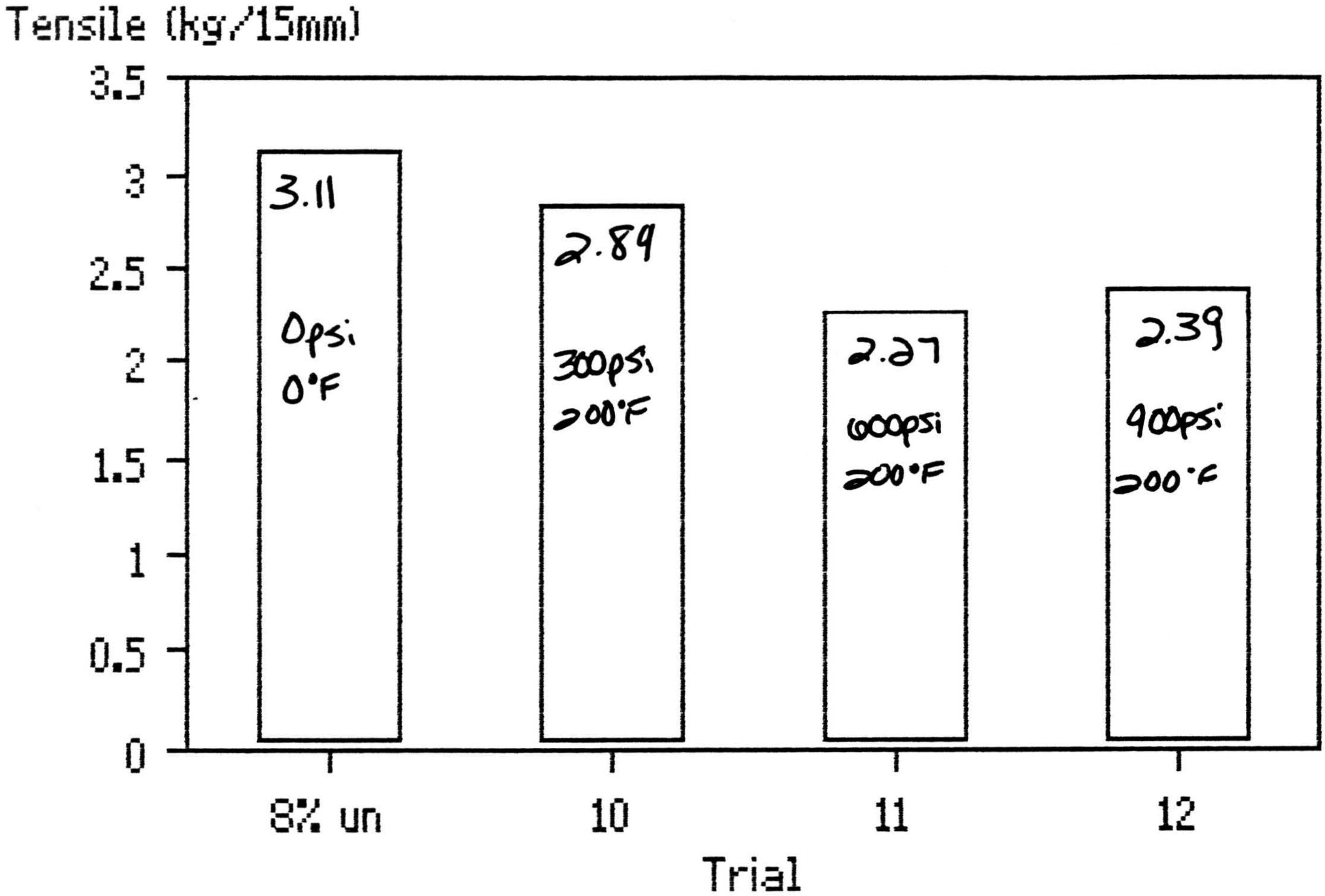

Fig. 40 -- Tensile MD for 8% Moisture Trial

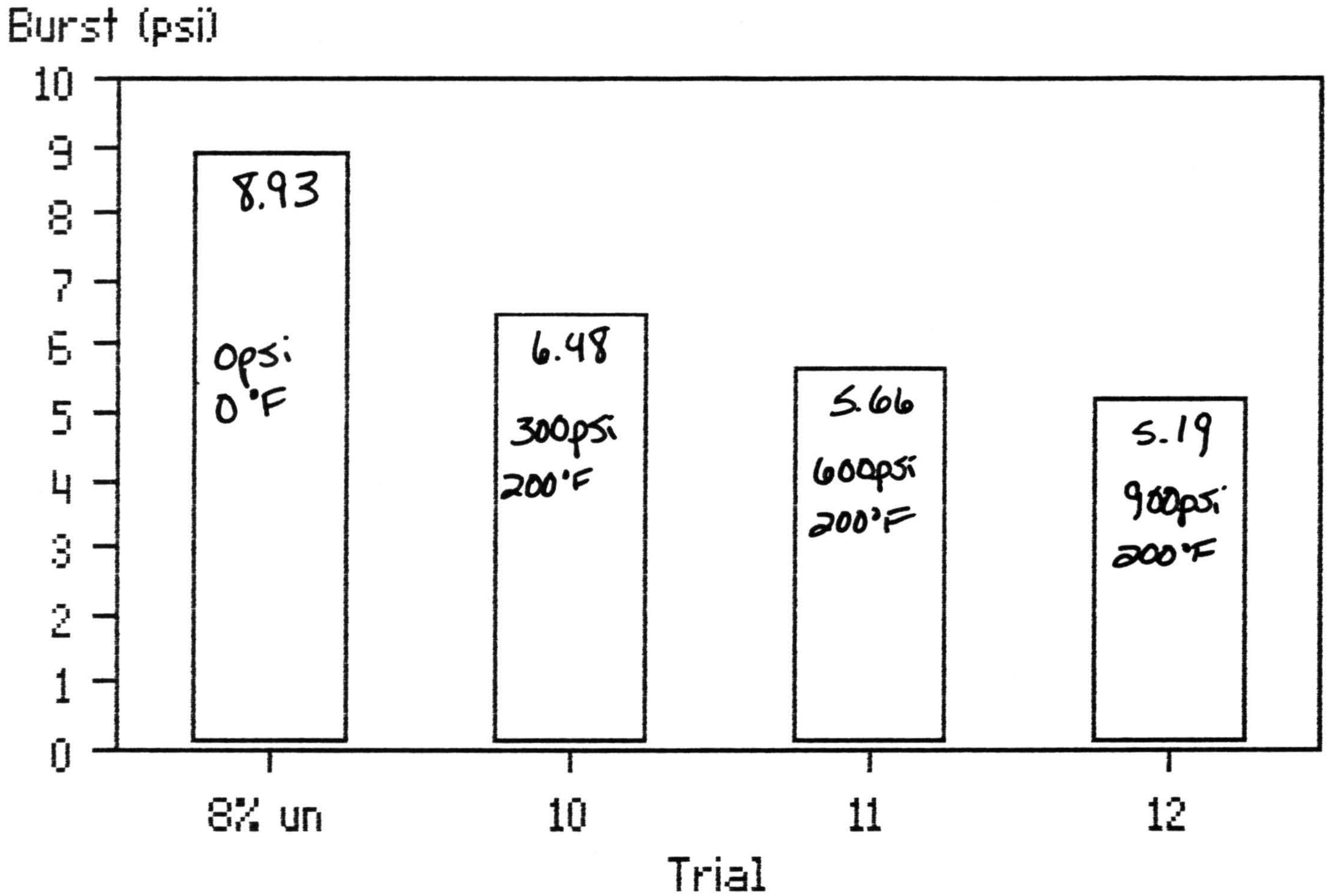

Fig. 41-- Burst for 8% Moisture Trial

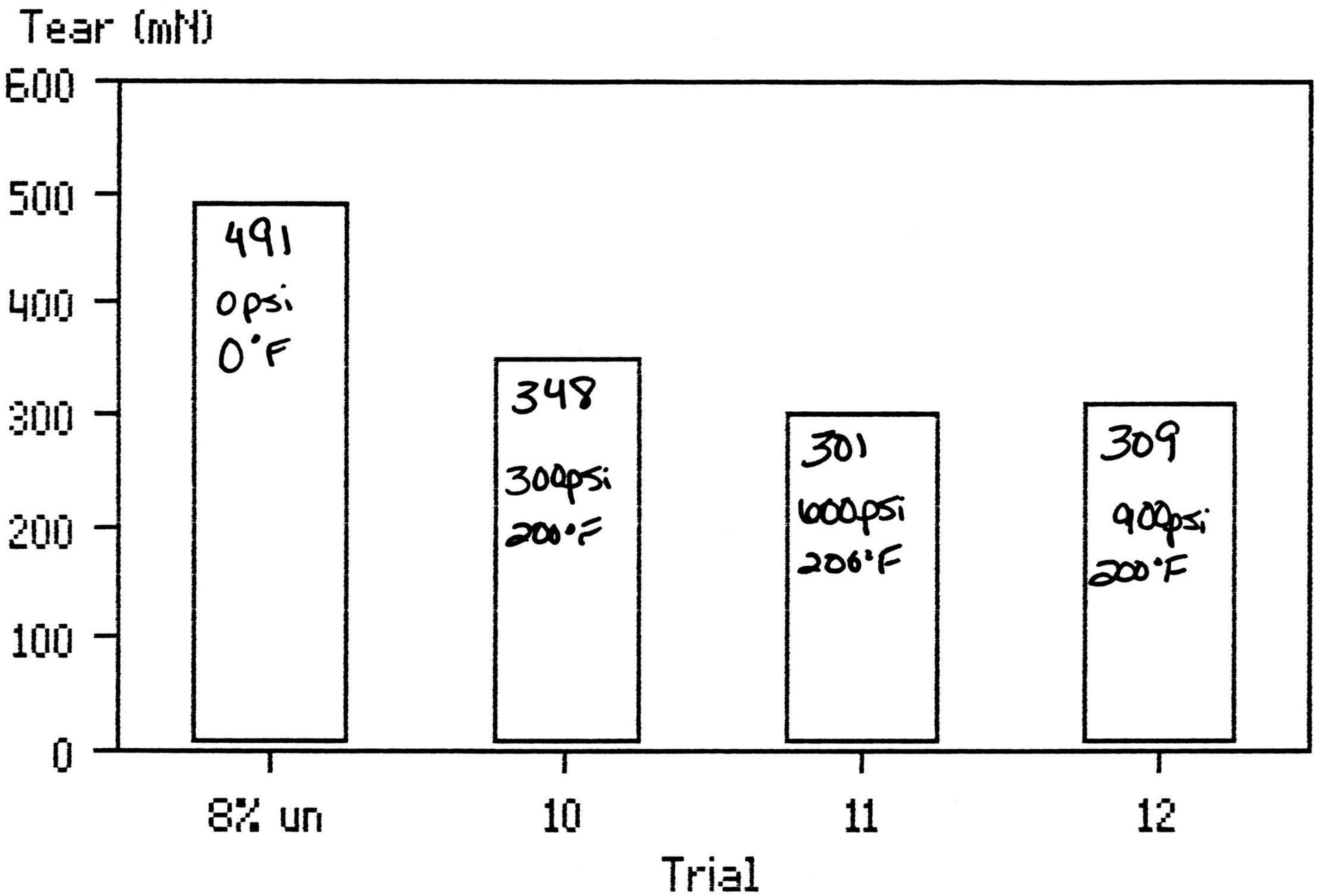

Fig. 42 -- Tear MD for 8% Moisture Trial

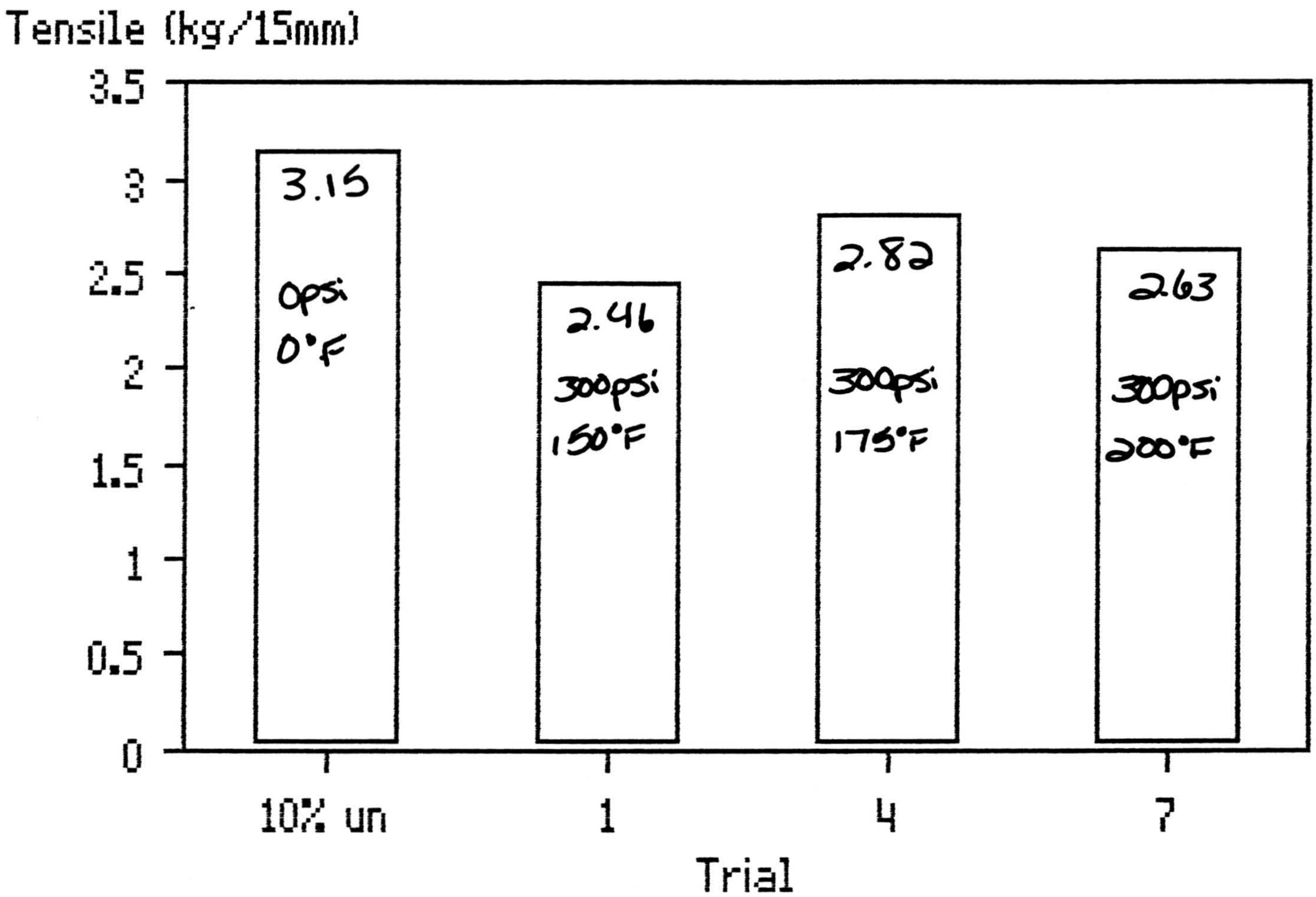

Fig. 43 -- Tensile MD for 10% Moisture Trial (300psi)

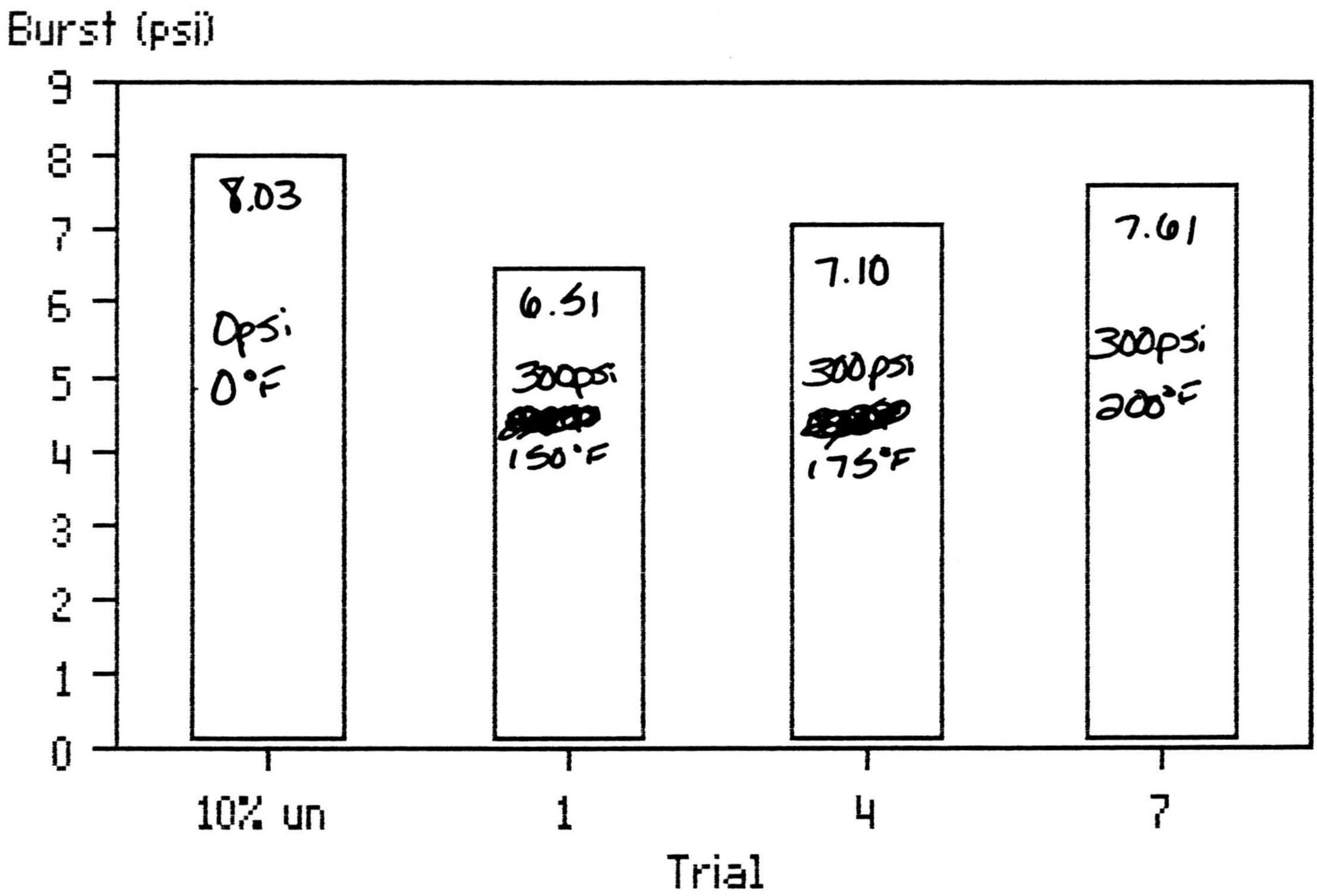

Fig. 44.. Burst for 10% Moisture Trial (300psi)

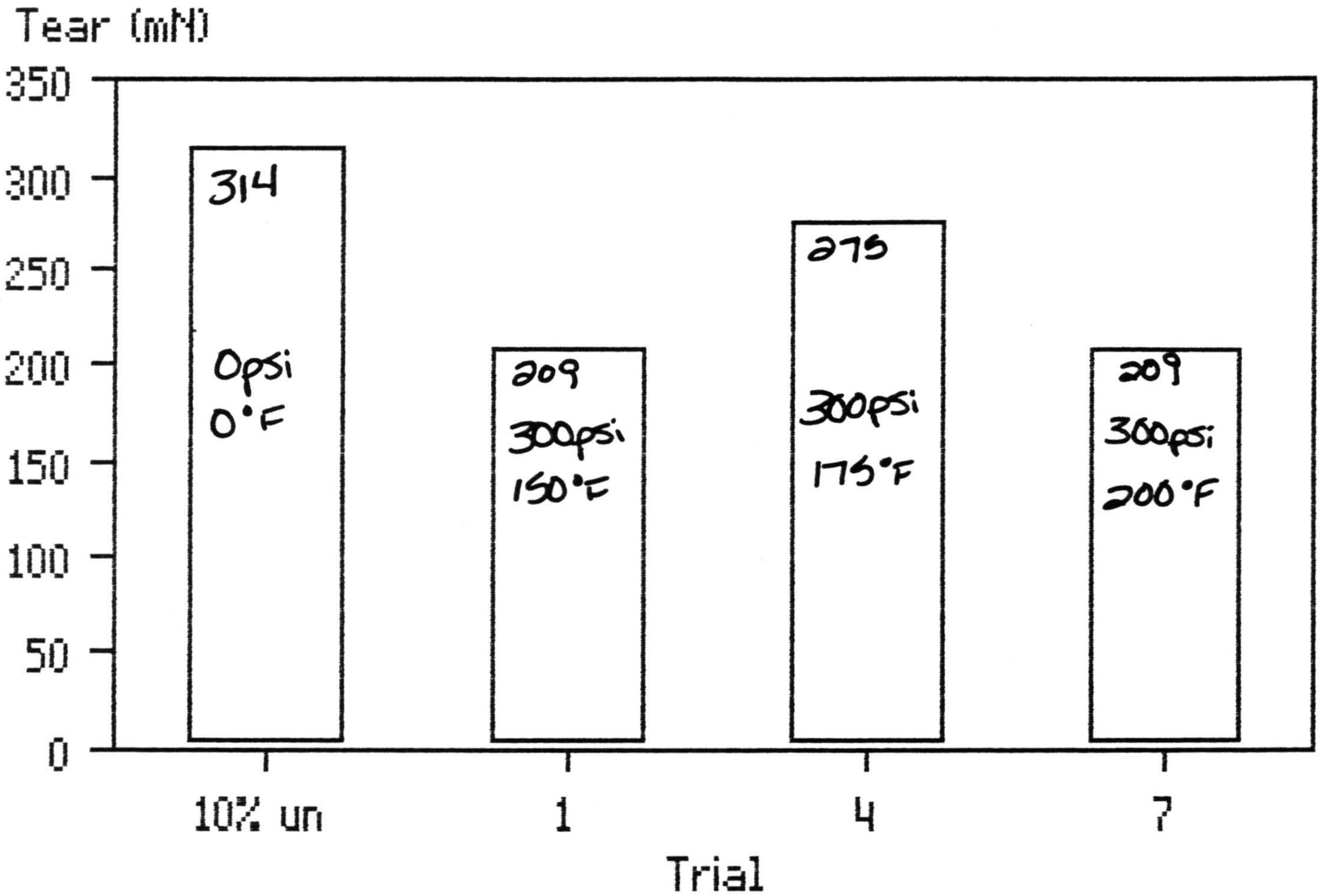

Fig. 45 -- Tear MD for 10% Moisture Trial (300psi)

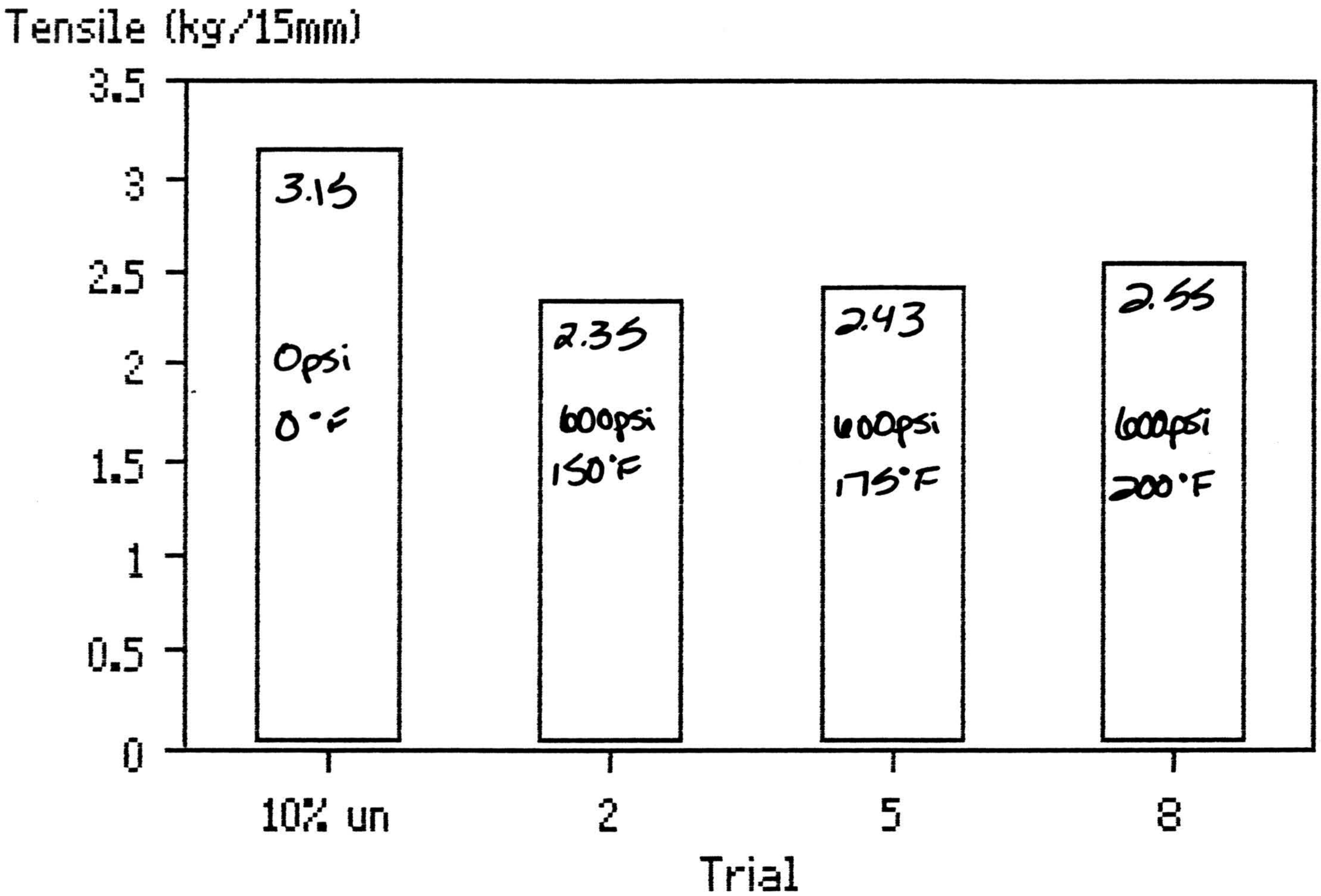

Fig. 46 -- Tensile MD for 10% Moisture Trial (600 psi)

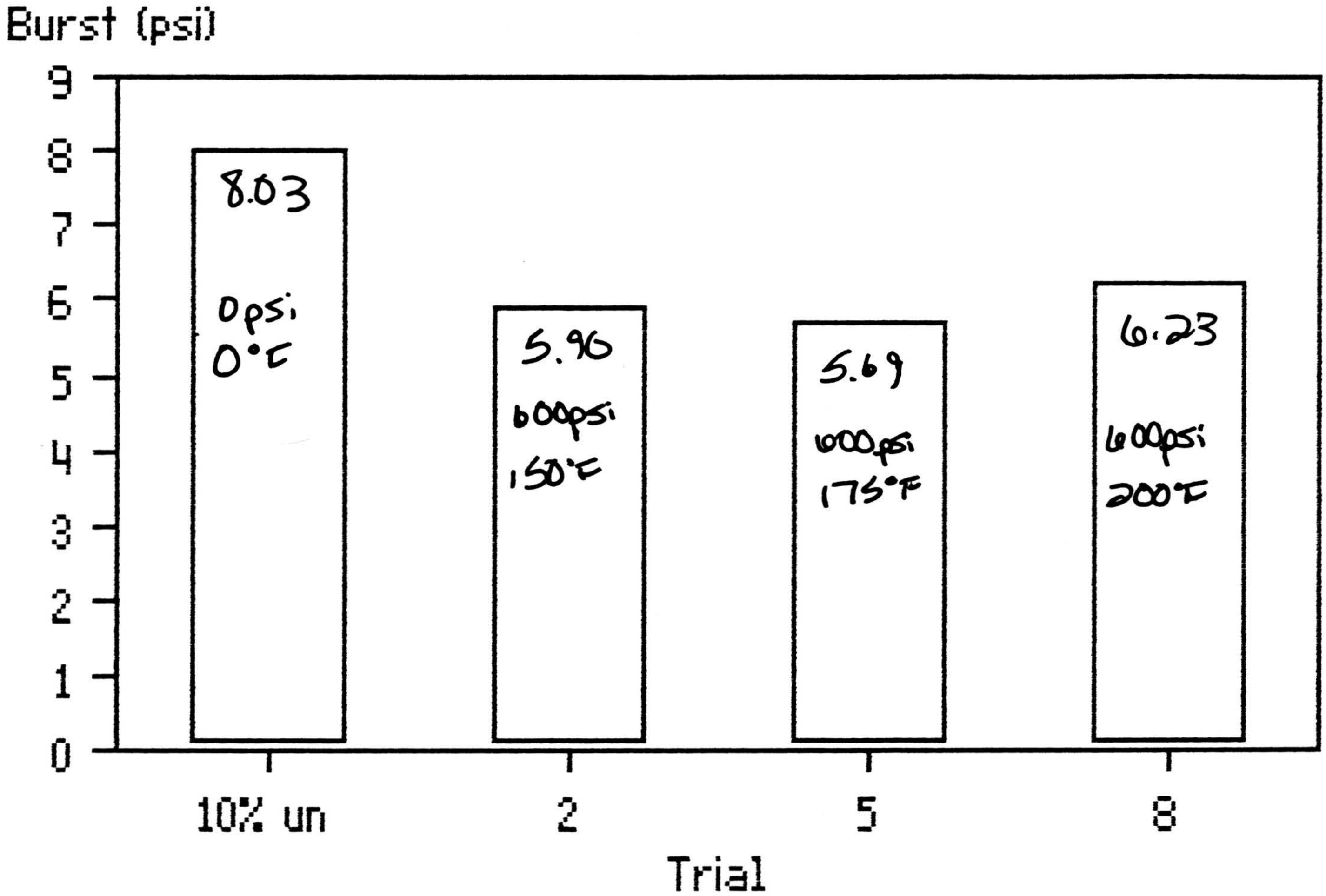

Fig. 47-- Burst for 10% Moisture Trial (600psi)

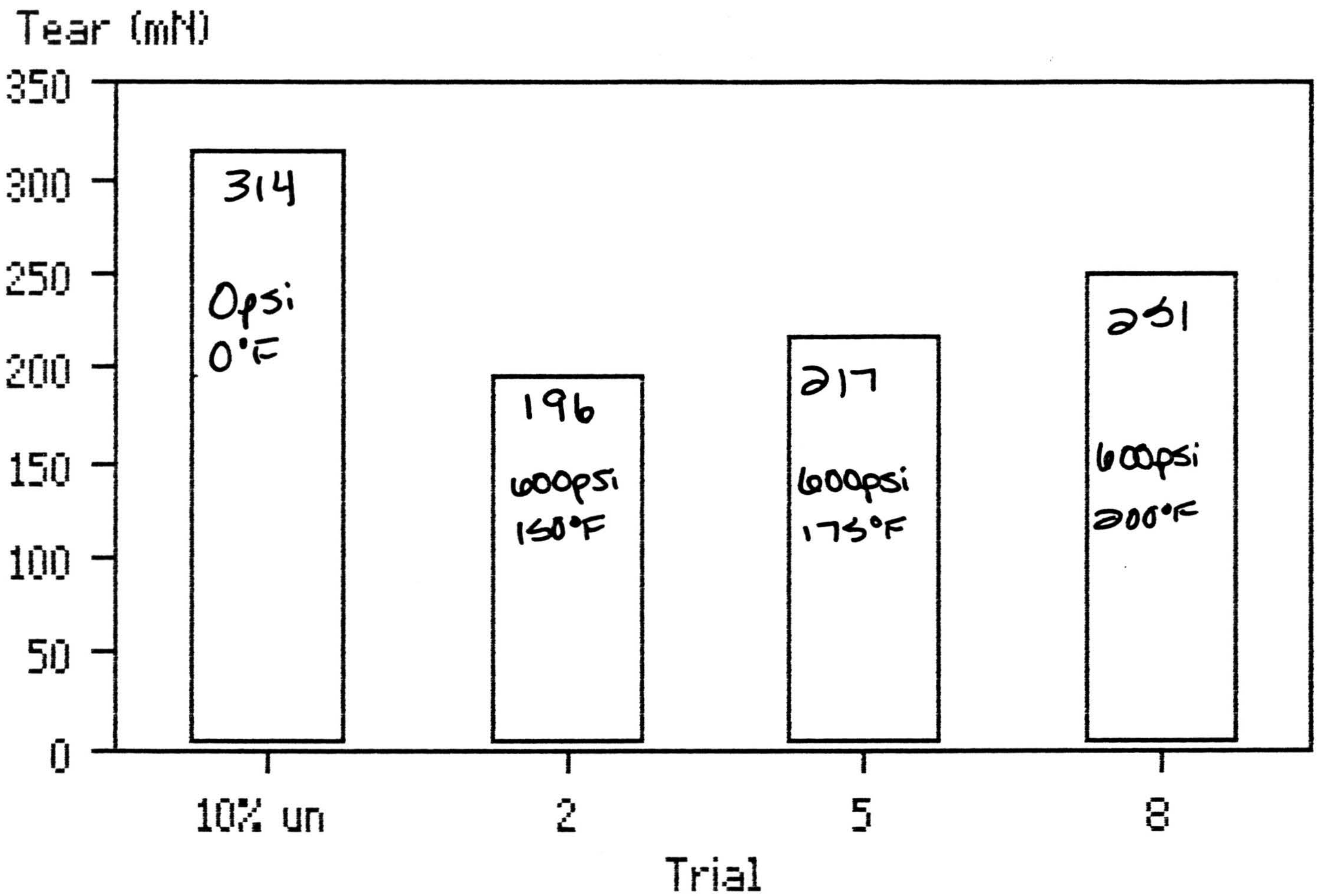

Fig 48 -- Tear MD for 10% Moisture Trial (@600 psi)

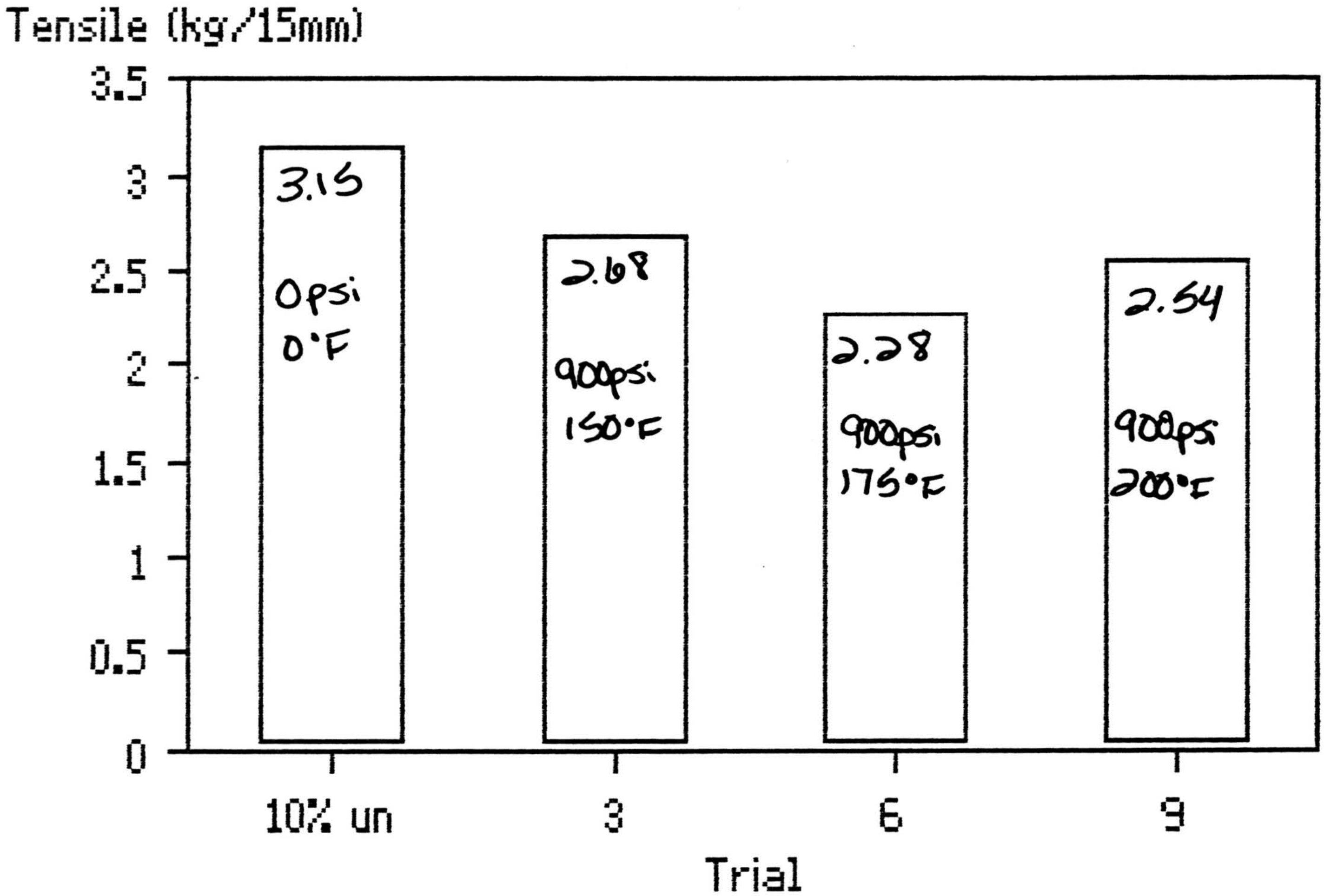

Fig. 48-- Tensile for 10% Moisture Trial (900psi) MD

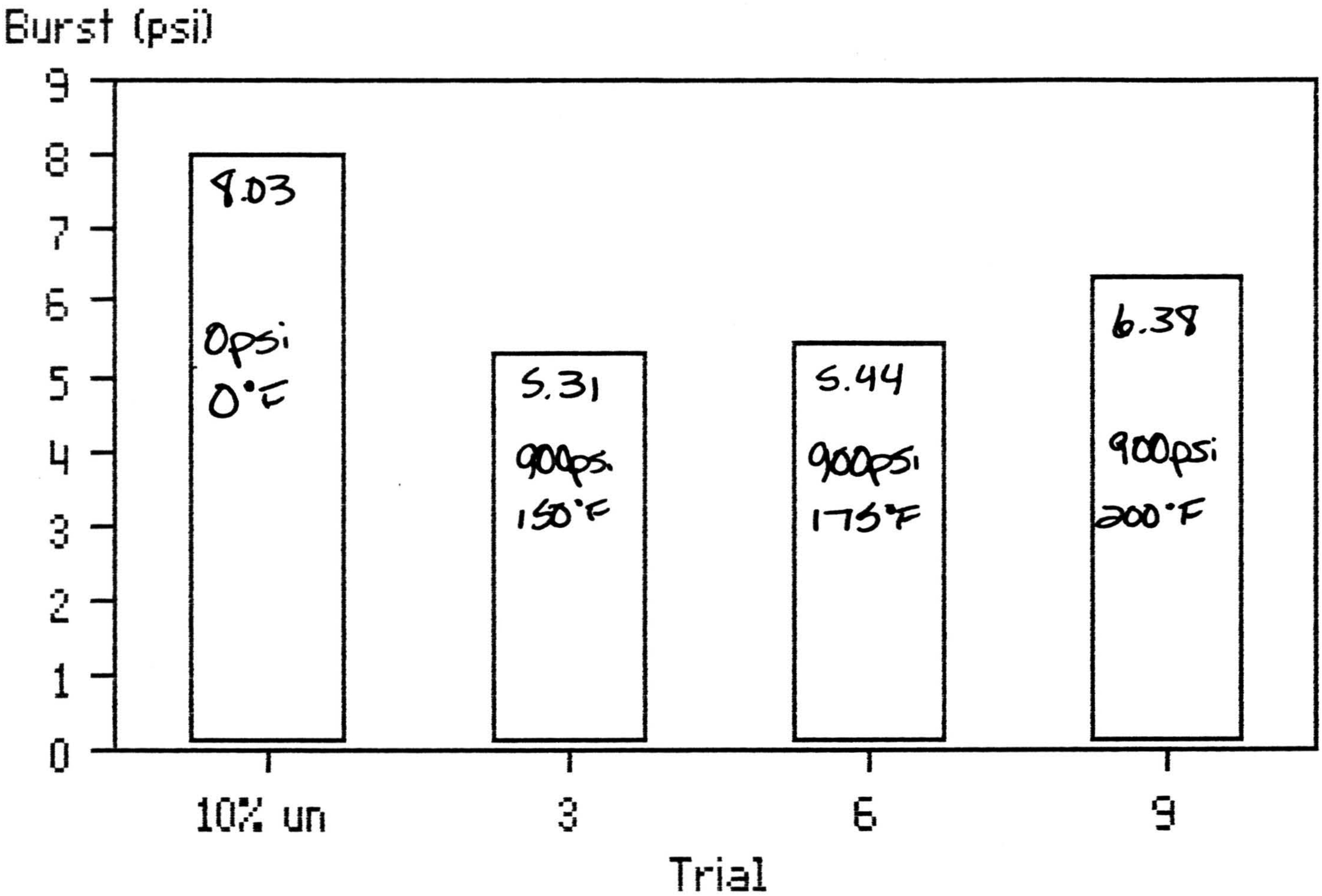

Fig. 50 -- Burst for 10% Moisture Trial (900psi)

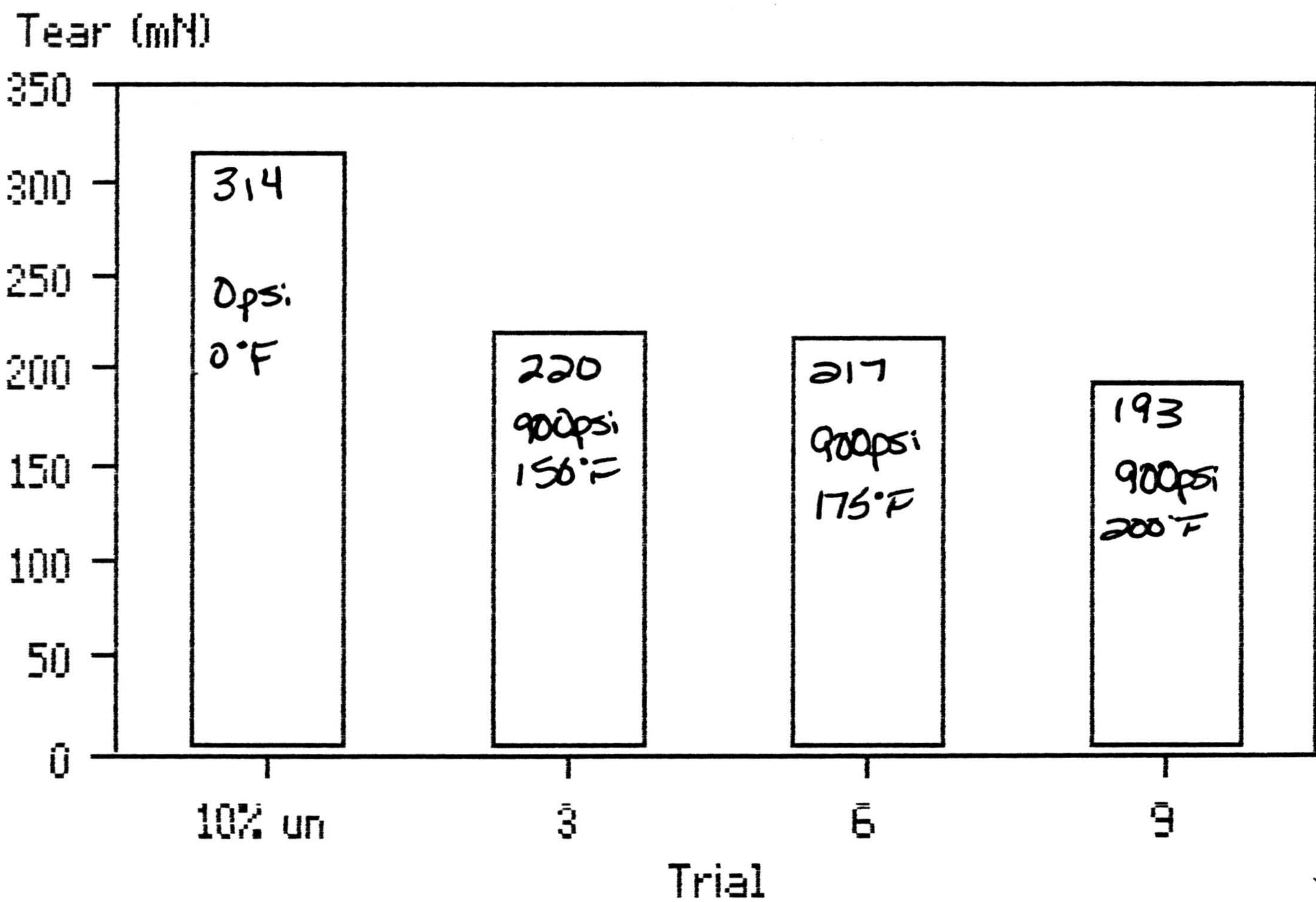

Fig 51 – Tear MD For 10% Moisture Trial (900psi)

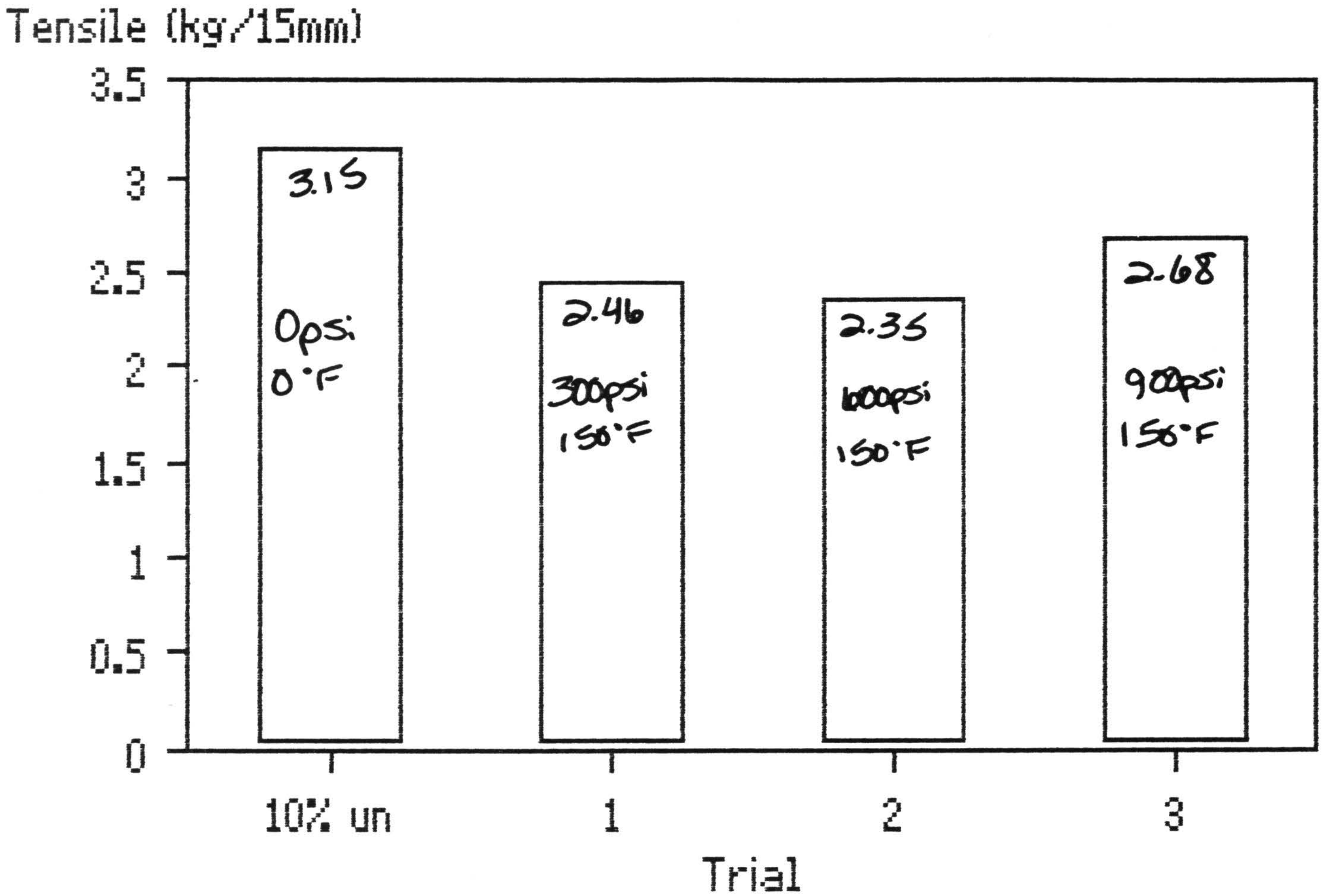

Fig. 52 -- Tensile MD for 10% Moisture Trial (150°F)

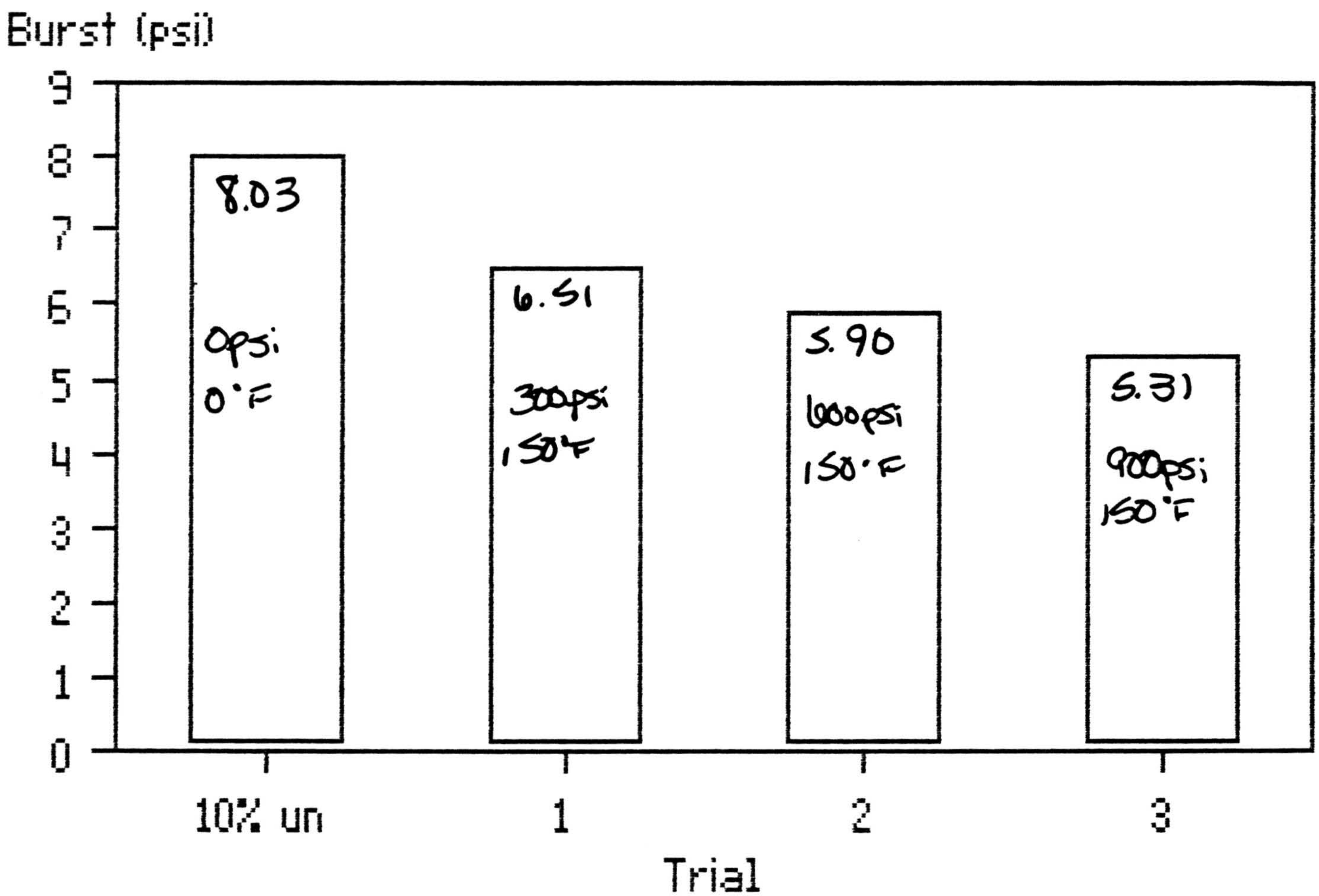

Fig. 53.. Burst for 10% Moisture Trial (150°F)

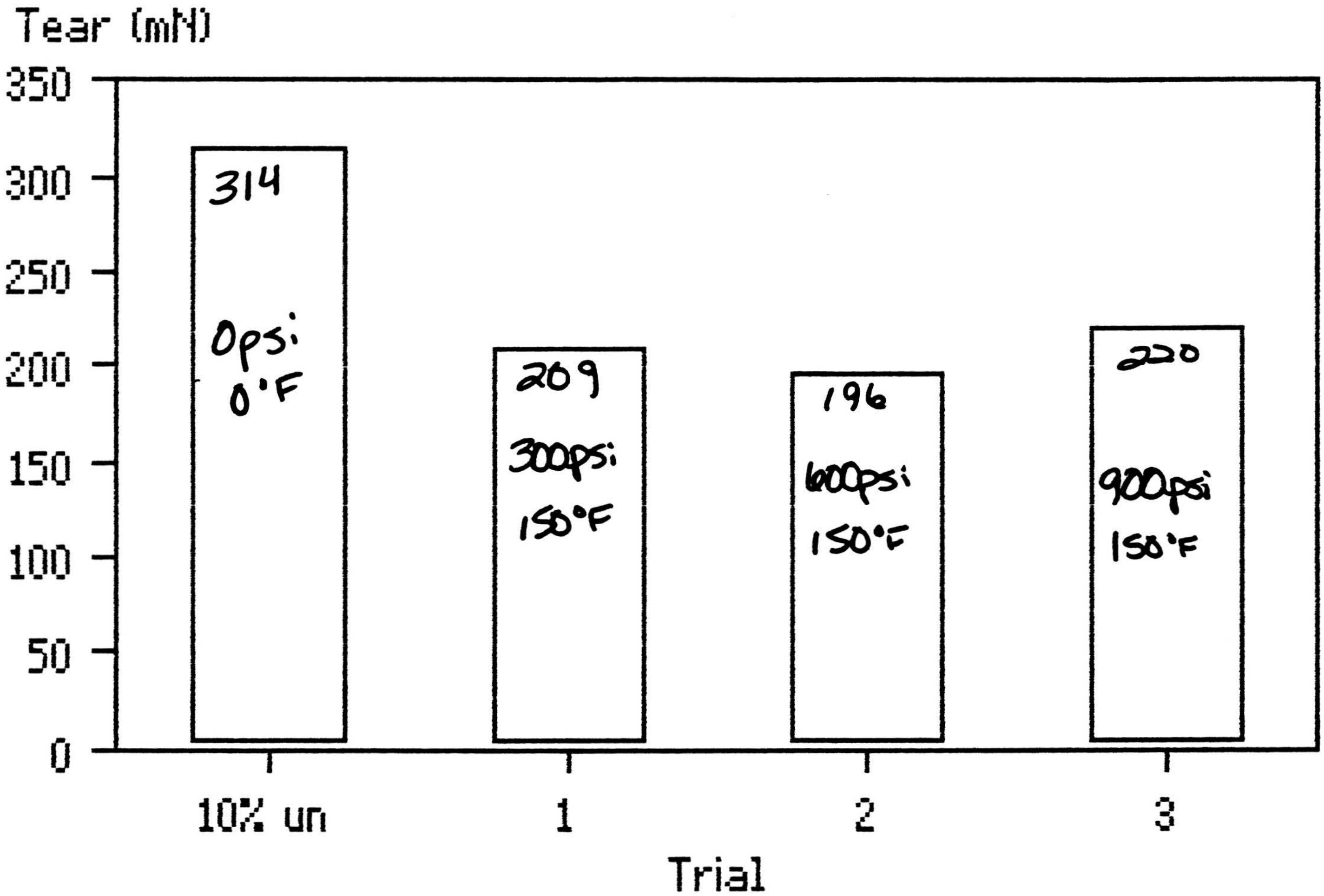

Fig. 54 -- Tear MD for 10% Moisture Trial (150°F)

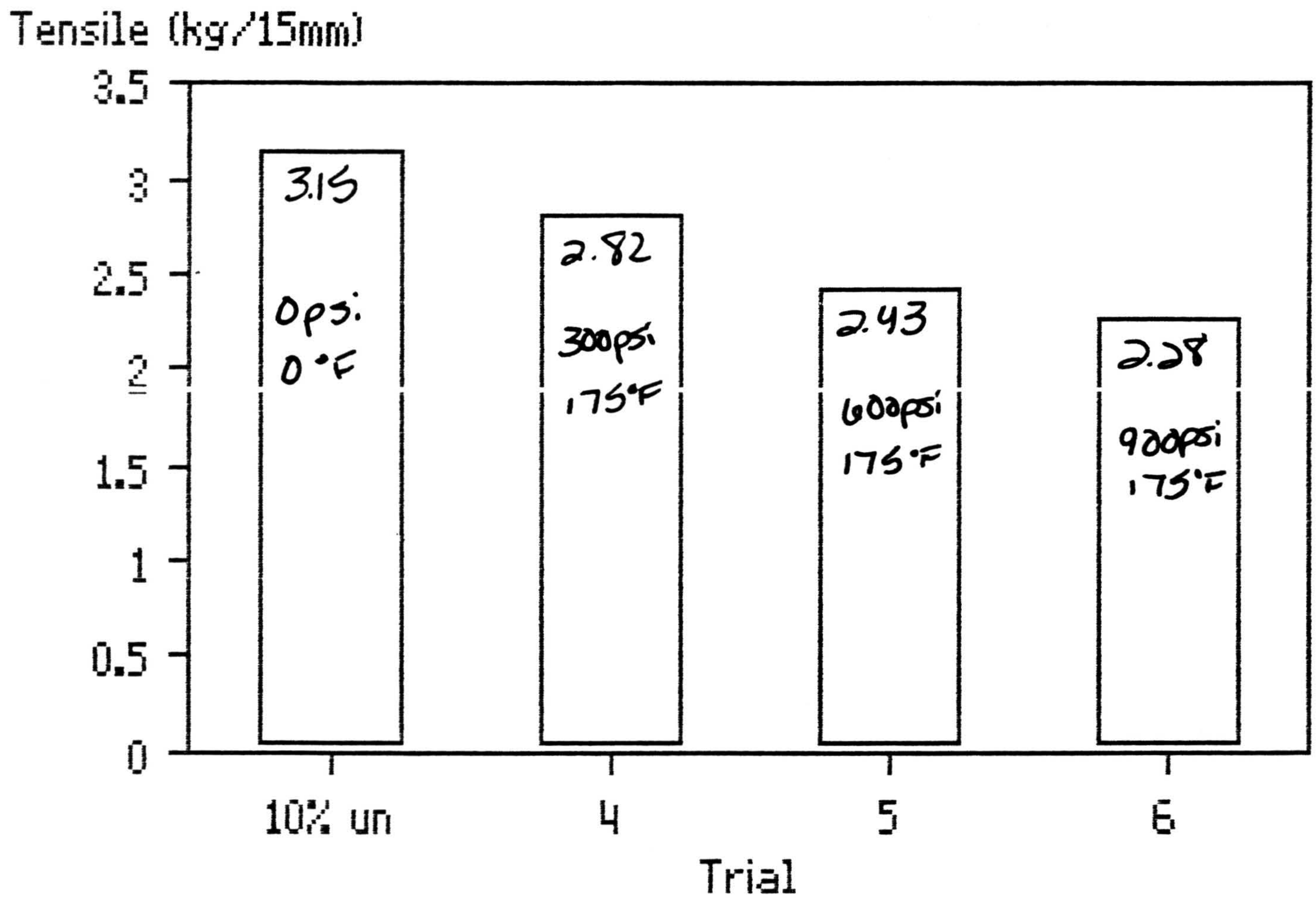

Fig. 55 -- Tensile MD for 10% Moisture Trial (175°F)

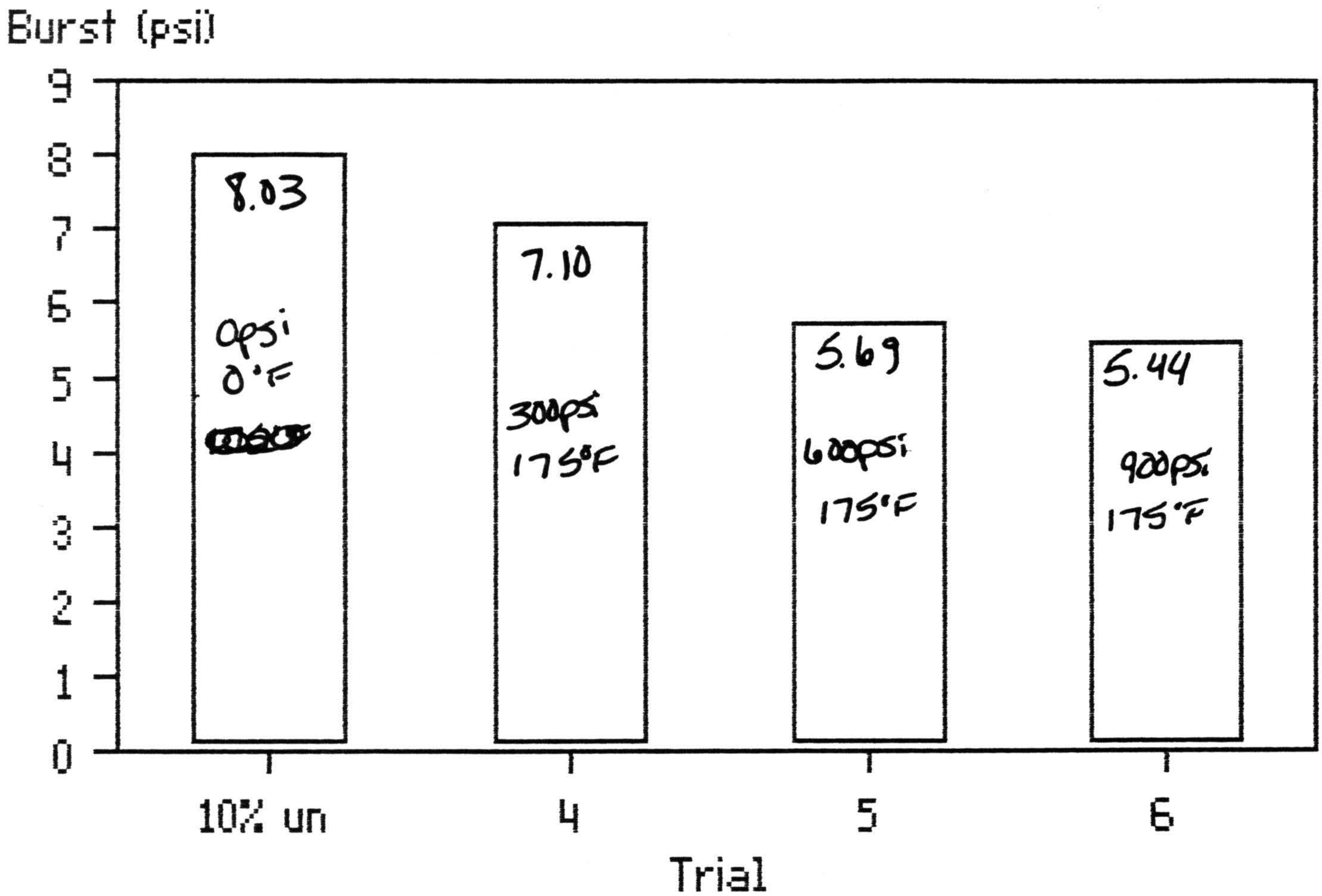

Fig. 56 -- Burst for 10% Moisture Trial (175°F)

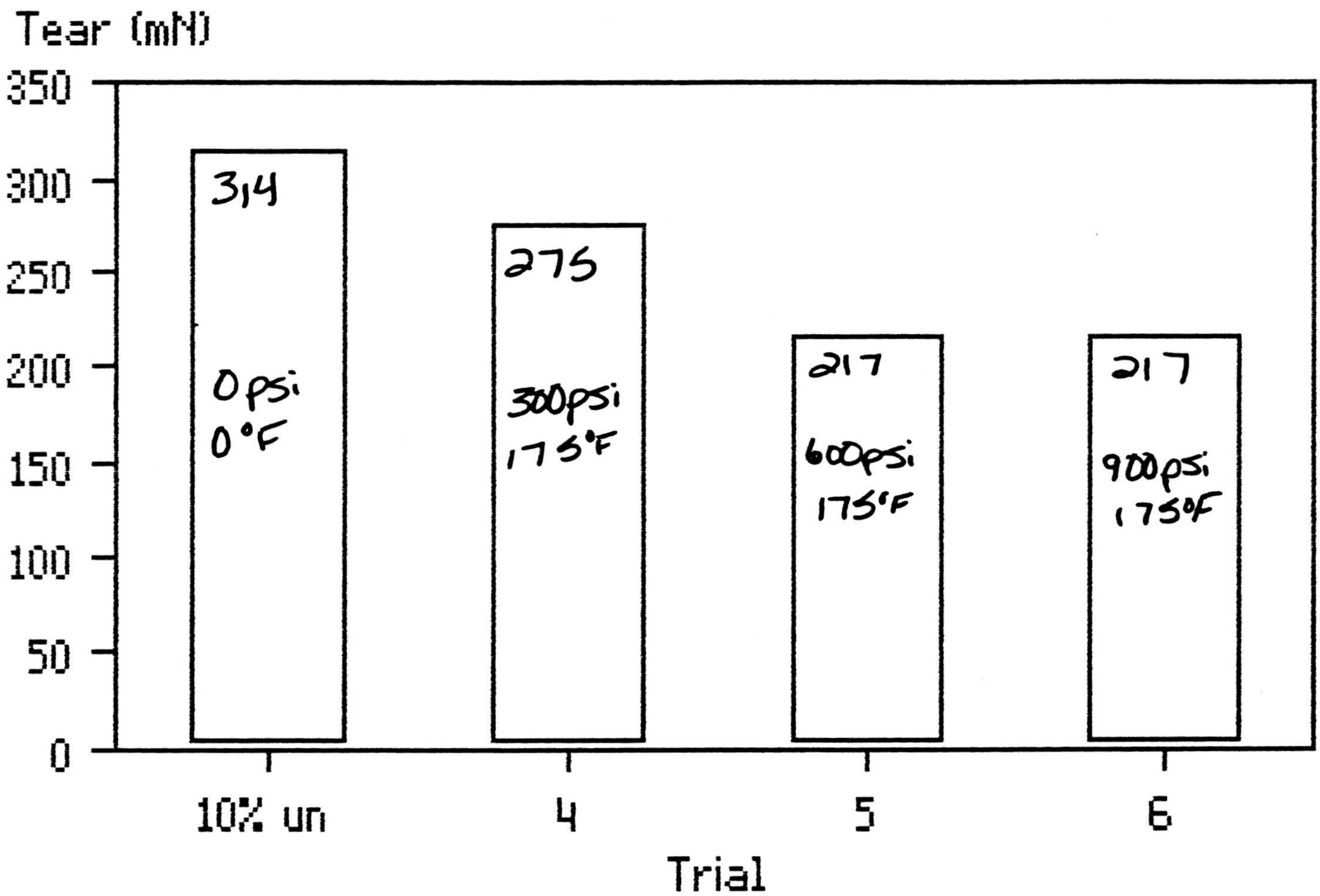

Fig. 57.. Tear MD for 10% Moisture Trial (175°F)

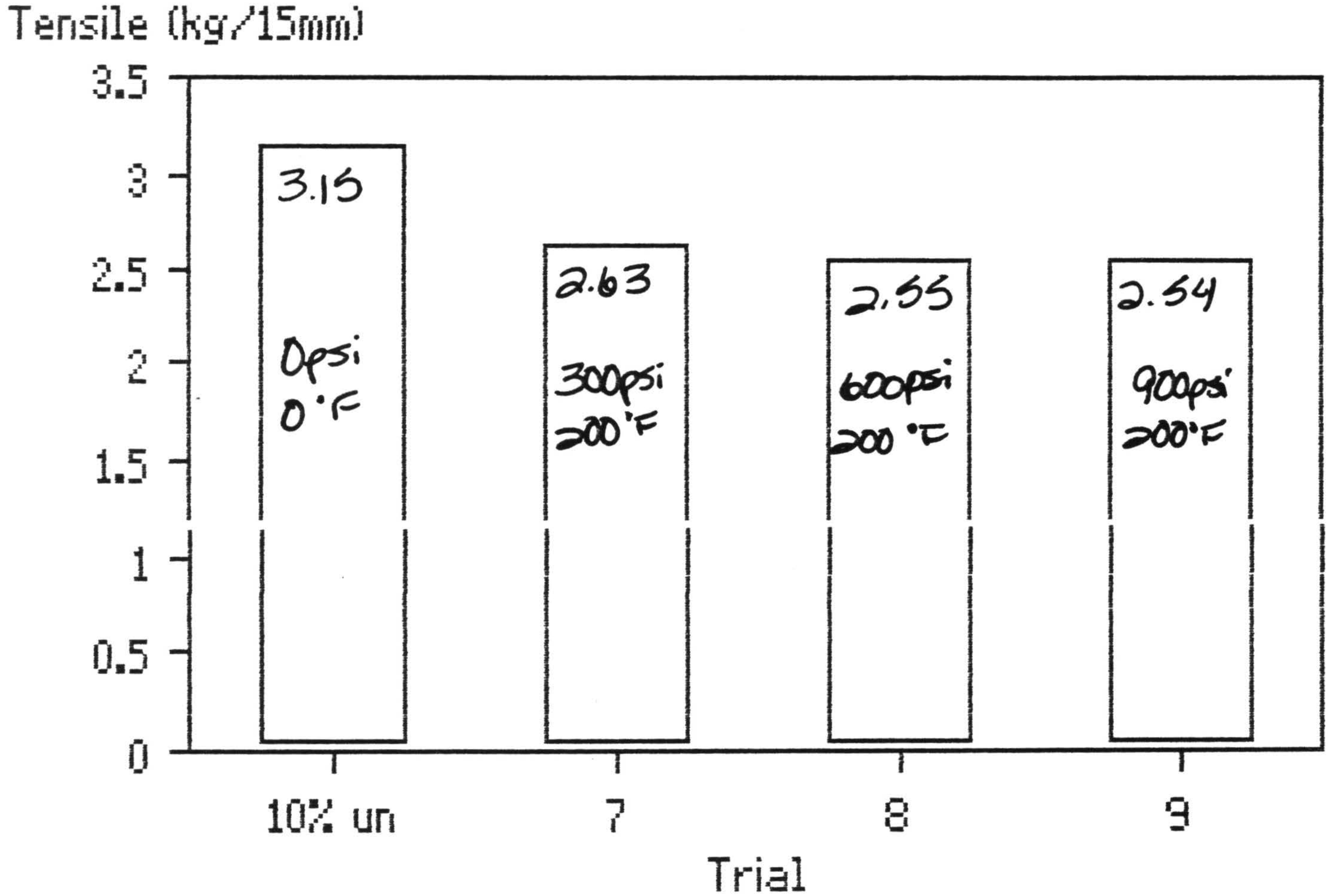

Fig. 58 -- Tensile MD for 10% Moisture Trial (200°F)

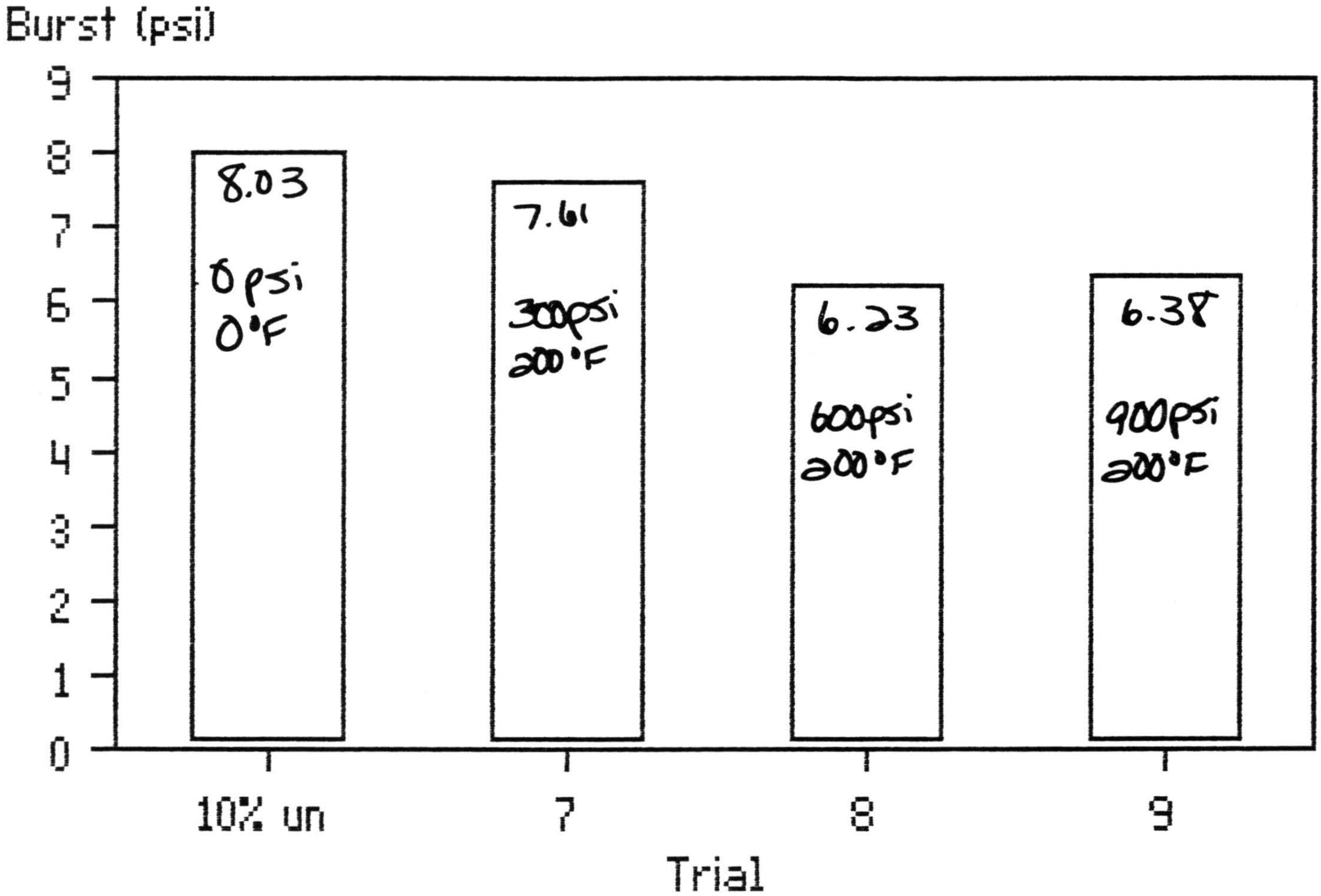

Fig. 59 -- Burst for 10% Moisture Trial (200°F)

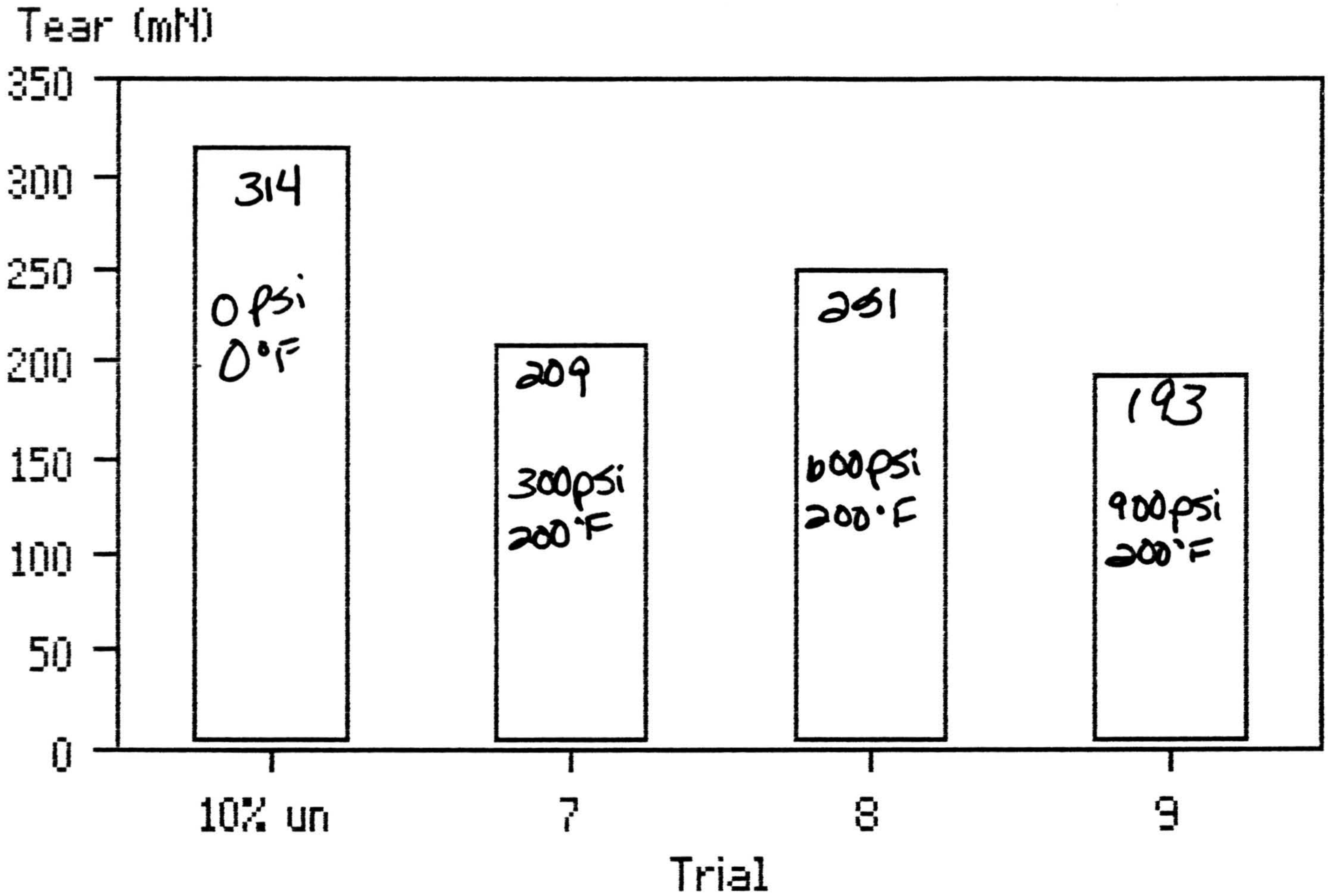

Fig. 60 . . Tear MD for 10% Moisture Trial (200°F)

DISCUSSION

Background

Rotogravure Paper

Rotogravure paper is the paper used for the rotogravure printing process (4). Rotogravure is a subcategory of newsprint (5). Characteristics required of newsprint are runability and printability (5). Runability requires the sheet to have strength to run through the printing presses without breaks, and printability requires the sheet to have high brightness, whiteness, and smoothness for good appearance and good ink coverage (5). A rotogravure furnish requires a higher ratio of softwood fibers to hardwood fibers to provide the strength of the sheet, but needs enough hardwood fibers to provide a smooth and compressible sheet (3). I will be using a groundwood pulp, which also requires a higher level of softwood fiber in it to maintain the strength after the grinding process (3). Rotogravure is usually uncoated but supercalendered to achieve the smoothness necessary for rotogravure printing (5). Uncoated groundwood-containing rotogravure paper is usually used for printing.

Blackening

Blackening is defined as the loss of opacity in the sheet during supercalendering (2). A blackened sheet is one that has been over-supercalendered (6). Moisture and temperature of the sheet can cause blackening as well as the pressure of the nips of the supercalender (2). A critical density of the sheet can be reached, which is defined as the density of the sheet at which blackening starts (2).

Moisture

Moisture is used in supercalendering to soften paper fibers, allowing them to flow (7). (Flowmobility of the fibers is the glass transition point of cellulose, hemicellulose, and lignin.) This flow allows the orientation and displacement of fibers, therefore filling voids allowing smoothness and gloss to increase (7). Therefore, the bulk of the sheet can be more easily reduced in the nip (1,7). Reduced bulk improves smoothness and gloss (1). Back and Carlson used moisture parameters of 3, 5, and 9% to induce blackening in their experiment (2). Blackening occurs at higher moisture (2). Deeg recommends a moisture of 8.0-8.5% for a higher nip pressure and a moisture of 9.0-10.0% for a lower nip pressure for uncoated groundwood rotogravure paper (7).

Temperature

Heat is also used during supercalendering to soften paper fibers, allowing them to flow (1). The temperature can be reduced with an increase in moisture of the sheet to achieve flowmobility of the fibers. Too high of a temperature can result in hot spots on the supercalender filled rolls (7). Cold or lukewarm temperatures cause the sheet to wrinkle in the supercalender (8). The temperature of the sheet is obtained by heating the surface of the supercalender rolls. Schiller recommends supercalender rolls to be heated to at least 150^{o}F (8). Deeg recommends a temperature range of 185-203^{o}F (7). Deeg explains that higher running temperatures can be used for uncoated groundwood rotogravure paper due to lower nip pressure

required. Back and Carlson experimented with temperatures of 68, 122, and 176°F to induce blackening (2). Blackening occurs at higher temperatures (2). Steam showers can also be used to further heat the paper and induce moisture, but these showers are not recommended for uncoated paper (8).

<u>Pressure</u>

Pressure is used in supercalendering to reduce bulk, which improves smoothness and gloss (2,7). Pressure on the sheet is obtained through nip loadings of the supercalender rolls. Schiller states that excessive pressure is one of the main causes of overheating filled rolls (8). He recommends pressures under 1600 pli. Deeg recommends a low nip pressure of 230 daN/m for uncoated groundwood rotogravure paper (7). Back and Carlson experimented with pressures of 35, 140, 280, and 350 kg/cm^2 to induce blackening (2). Blackening occurs at high pressures (2).

<u>Basis Weight</u>

Basis weight variation does not seem to be a variable that directly affects blackening. Its relationship to caliper and density (inverse bulk) indirectly affects blackening. Bulk is defined as caliper divided by basis weight. Caliper variations are affected mostly by basis weight variations. Bulk is the inverse of density; therefore, the critical density is affected by caliper and basis weight. A supercalender will calender to a constant bulk rather than to a constant caliper. Thus, caliper and basis weight variations only indirectly affect blackening (1). A basis weight range used by

Back and Carlson was 50-60 g/m^2 to induce blackening (2). The critical density was determined to be approximately 0.88 g/cm^3 for their ranges of parameters (6).

Optical Properties of Unsupercalendered Paper

Supercalendering decreases the surface area of the sheet, therefore less light can be reflected off the sheet (8). Therefore, brightness decreases as a result of supercalendering. Opacity increases as the sheet is supercalendered and then sharply decreases when the sheet reaches the critical density (2).

Physical Properties of Unsupercalendered Paper

Strength of the sheet is important for the web to run through the gravure printing presses without breaks. Tensile and tear are the primary sheet properties important for the strength of the sheet (3). Smoothness of the sheet, accomplished by supercalendering, is important to decrease the void space for better printability (7). Bulk is important to allow the sheet to be compressible so that the gravure ink cells can contact more surface area (4).

Analysis

The results I obtained from the trials was rather disappointing. As theory states, opacity should increase before blackening occurs and then decrease sharply upon its presence. The ranges of temperatures, moistures, and pressures were already too severe of conditions, thus creating blackening even at the least severe conditions. The opacity for supercalender conditions were decreasing as more severe supercalender conditions were used, but the

opacity was higher than that of the uncalendered conditions. The other disappointment was that some of the results show trends, but the differences of the actual values for the data were not significant enough to justify concretely that the trends were due to blackening severity. The differences in values could very possibly be due to experimental testing error as well blackening effects. If time and equipment limitations allowed, I would run a wider range of moistures, temperatures, and pressures to be sure that the trends presented are results of blackening. The data obtained for testing of the different trials is presented in Table 1, and selected data is presented for related trials in Tables 2-9. Table 2 presents 6% moisture trial data, all trials at 200°F. Table 3 presents 8% moisture trial data, all trials at 200°F. Table 4 presents 10% moisture trial data, all trials at 300psi with varying temperatures. Table 5 presents 10% moisture trial data, all trials at 600 psi with varying temperatures. Table 6 presents 10% moisture trial data, all trials at 900 psi with varying temperatures. Table 7 presents 10% moisture data, all trials at 150°F with varying pressures. Table 8 presents 10% moisture data, all trials at 175°F with varying pressures. Table 9 presents 10% moisture data, all trials at 200°F with varying pressures. Graphical representation of Tables 2-9 is presented in Figures 1-36.

As discussed earlier, the opacities in Fig. 1 are questionable. The data doesn't follow a particular trend. This could be due to experimental error during testing. This could also be due to the

fact that, from the data, moisture appears to have the most significant effect on blackening. An increase in moisture content increases blackening. 6% would thus produce the least severe blackening of all the trials. Severe blackening did not occur during this trial, even with the high temperature of 200°F and increasing pressures. The calendering action was a success, as can be seen in Figures 2-4. The brightness was reduced as supercalendering severity increased due to the fibers being conformed into a smoother sheet, thus allowing less light scattering. Color increases slightly at first due to the initial increase in opacity. The smoother sheet causes less light to be scattered, as mentioned earlier, and more light to be absorbed into the sheet. Thus, the opacity increases initially which causes an initial increase in color, color being a function of light absorption. The color then procedes to decrease slightly as severity of supercalender increases. The color meter used was a Macbeth system, and seemed to produce less varying results than the opacity and brightness meters. Thus, the trend in color results is most probably due to slight blackening rather than experimental or equipment error. The color loss that was produced over the range of pressures was very slight, thus severe blackening had not yet occurred, as was shown in the opacity results. The density results also show that supercalendering produced a more compact sheet as pressures were increased, which is a known result of supercalendering. The density results do show that severe compaction had not yet occurred, as the results are narrowly varying. It can be

assumed that the critical density, where severe blackening occurs, had not yet been reached.

The 8% trial opacity results in Fig. 5 show no particular trend. The opacities decrease initially and then increase. This is probably due to experimental error in the test equipment, because the color show trends similar to those for the 6% trial. The color results, presented in Fig. 7, show more significant variability between the different pressures than did the 6% color results. The color values are lower than those for the 6% trial, also. Therefore, it is evident that a more significant form of blackening resulted for the 8% trial than for the 6% trial. Brightness, presented in Fig. 6, follows the same trend as for the 6%, thus proving that supercalendering was effective and became more severe with the increase in pressure. The density results (Fig. 8) follow an increasing trend with the increase in pressures, with the exception of trial 11. This value is unusually lower than the other results. This could be the reason that the opacity results were trendless. The only explanation possible for this density value is the possibility of higher nip pressures being exerted on the sheet than the gauges showed during that run. It is doubtful that experimental error or equipment error was the cause because the opacity data shows unusual values for this run, also.

Figures 29-32 represent data for the 10% moisture trial at a constant temperature of 200^{o}F, therefore this data is comparable to the data for the 6% and 8% trials. The opacity values shown in Fig.

29 show a decreasing trend for all pressures. It is safe now to assume that severe blackening has occurred. This is evident in that there is no initial rise in opacity, but only decreasing values. Severe blackening has occurred due to the higher moisture content present. The decrease in opacities is not widely varying for the different pressures, therefore, once again it is safe to assume that the pressure loadings used did not create the severe blackening conditions. Color values, presented in Fig. 31, follow the decreasing trend, proving that increased blackening occurred with increased pressures. Brightness (Fig. 30) follows the same trend as in the previous casees, therefore, the different nip loadings did accomplish increased calendering. The density (Fig. 32) values follow an increasing trend for increasing pressures, thus also proving that increased calendering action took place.

Figures 21-24 represent the 10% moisture trial at constant temperature of 150°F and varying pressures. Figures 25-28 represent the 10% moisture trial at constant temperature of 175°F and varying pressures. The opacity values in Fig. 21 show a slightly increasing trend, possibly proving that the low temperature was not high enough to induce severe blackening. The opacity values in Fig. 25 show a decreasing trend for all pressures, thus proving that severe blackening had been achieved at this temperature. Fig. 22 and Fig. 23 back up Fig. 21 in proving that blackening had not yet been induced. The color remains about the same for all pressures, as does the brightness. The density (Fig. 24) shows that calendering was

accomplished, but not severely. This is because the density values do not widely vary for increasing pressures. Fig. 26 shows that brightness follows a decreasing trend, which is expected from this increasing blackened sheet. Fig. 27 shows that color also decreases, thus proving, along with opacity results, that blackening had been induced. The density values in Fig. 28 prove that calendering action was accomplished.

Figures 9-12 represent the 10% moisture trial at constant pressure of 300 psi and varying temperatures. Figures 13-16 represent the 10% moisture trial at constant of 600 psi and varying temperatures. Figures 9-12 and Figures 13-16 show no trends for any test. The values are not widely varying for the different temperatures. This proves that the temperature range used was not wide enough or severe enough in combination with the 300 and 600 psi pressures to induce blackening. The 900 psi trial was the most severe supercalendering trial performed on the 10% moisture paper and did provide evidence that some blackening occurred as temperatures were increased. This data is presented in Figures 17-20. The density is questionably lower for the 200^{o}F than for the other temperatures, thus not following the increasing trend. This trial must have been subjected to either lower temperature or lower nip loading than recorded. This value is not low due to equipment or experimental error because the opacity, brightness, and color values are slightly off, also. The opacity, presented in Fig. 17, shows a

decreasing trend for all temperatures. Because of the absence of an initial rise in opacity, severe blackening has already occurred. The color values, presented in Fig. 19, show a decreasing trend, proving that blackening increased as a function of increasing temperature. The brightness values remained approximately the same for all temperatures, thus possibly proving that a near maximum compaction of fibers had been achieved, due to being exposed to the most severe blackening conditions.

As can be seen in Fig. 33, opacity, in general, is not a good measure of blackening severity. Opacity was used in this experiment to determine at what degree blackening was occurring, but it did not always correlate with the other data. Opacity would probably be a good measure of blackening if the range of conditions was broader, thus producing a more noticeable blackening effect. Opacity could also be a valid measure of blackening if a meter that produced less variable results than the meter used in this experiment were used. The color meter seemed to produce less varying and therefore more accurate data than the opacity meter. As can be seen in Fig. 35, color is a very valid measure of blackening. As discussed in above discussion, the most significant cause of blackening in this experiment was the increase in moisture. Fig. 35 shows wide variability in color measurements for different moisture contents, following this trend. Also shown in this graph for each moisture content is the initial rise in color. The brightness graphs (Fig.

34) and the density graphs (Fig. 36) are presented to prove that the calendering action was actually accomplished as the severity of conditions increased. The decrease in brightness proves that the sheet became smoother, and the increase in density proves that the sheet became lower in caliper (a result of calendering). Brightness and density cannot be used to measure blackening, but can be used as a back up to the color and opacity methods of measurement. These tests can be used to ensure that calendering is being accomplished and, therefore, blackening is what is being seen in the opacity and color measurements.

The strength properties are represented in Tables 10-17. Graphical representations of the tables are presented in Figures 37-60. The best that can be said about the strength of a blackened sheet is that, overall, it decreases with increased calendering. Experimental error appears to be great in these test values. When looking at tensile graphs, most of the graphs are decreasing with increased calendering severity. This is true for most of the burst graphs. Most of the tear graphs appear to decrease, then increase, then decrease again. This proves that upon initial calendering, tear strength is lost, then is gained again and lost again as calendering severity is increased. The tensile and burst values for the most severe calendering condition of 10% moisture, 200°F (Table 17) would be expected to be much lower than those of the least severe calendering condition of 6% moisture, 200°F. This is opposite of the data obtained. Therefore, there must be substantial experimental

error and equipment error causing these values to be off, or else actual calendering conditions varied from those recorded. No conclusions can be made from this data as to whether the blackening directly affects strength properties.

CONCLUSION AND RECOMMENDATIONS

The data collected proves that blackening increases as moisture, nip pressure, and roll temperature increase. In this experiment, the varying moisture content produced the widest range of blackening severity. The 10% moisture content paper supercalendered at 200°F and 900 psi produced the most blackened sheet. The 6% moisture content sheet supercalendered at 200°F showed the least severe effects of blackening, with virtually no blackening action occuring. The 8% moisture content sheet supercalendered at 200°F showed signs of slight blackening. A safe nip loading range would be the 300-600 psi range to avoid blackening. A safe moisture level to avoid blackening would be the 6% level. A safe temperature range would be the 150-175°F range. The most valid measurement of blackening was the use of the Macbeth color meter. Opacity can be used as a valid measurement, but in this experiment, the conditions were not severe enough to produce widely varying opacity results.

Literature cited

1. Agronin, M., Tappi 66 (10): 96-99 (1983).

2. Back, S. E., and Carlson, L. J., Paper Technology 16 (5): 309-313 (1975).

3. Kline, J. E., "Paper and Paperboard: Manufacturing and Converting Fundamentals: San Francisco, Miller Freeman Publications, Inc., 1982, pp. 149-150, 169-173.

4. Adams, J. M., and Faux, D. D., "Printing Technology", 2nd ed., North Scituate, Mass., Breton, 1982, pp. 454-455.

5. Smook, G. A., "Handbook for Pulp and Paper Technologists:, Atlanta, Tappi, 1982, pp. 272-273, 286-289, 325.

6. Hunger, G. K., Tappi 50 (7): 372-379 (1967).

7. Deeg, R. F., Tappi 64 (10): 51-54 (1981).

8. Schiller, F., Pulp and Paper 54 (7): 164-166 (1980).