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The Effect of Drying Conditions on the Surface Properties of a Commercial Coating

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The air temperatures and velocities were varied in the tunnel dryer of a commercial coater to determine the effects on the coated surface. Laboratory drawdowns were also made using the same coating color and basestock only dried under different conditions. The coated sheets were then tested for IGT, Dennison wax pick, K&N ink receptivity, Smoothness, Scheid and Gloss to determine any relationships between drying rate and surface properties.

THE EFFECT OF DRYING CONDITIONS ON THE SURFACE PROPERTIES OF A COMMERCIAL COATING

The primary purpose of the adhesive is to anchor the coating pigment to the substrate and to bind the pigment particles together. Starch adheres thru hydrogen bonds formed by the carboxyl groups along the chain. The adhesive must wet the surface of the pigment particles and the substrate in order for molecular nearness to make attractive forces operative. (1)

The coating is keyed to the paper by an intimate filling of the undercut regions about the surface fibers. The effectiveness of these keys in anchoring the coating depends on the mechanical strength of the coating. When unkeyed portions of the coating separate from the sheet a very thin film of coating remains attached to the sheet so that failure can be attributed to low mechanical strength of a zone in the coating itself and not a failure of the coating to fiber interface. This zone is approximately one micron away from the coating-fiber interface which is weaker than either the substrate or the main body of the coating. (2) The mechanical strength is a function of the amount and quantity of adhesive used, method of cutting, mixing and clays used. The controlling factor for picking is the mechanical strength of the adhesive and the rawstock and not the firmness of the bond between the adhesive and the substrate. (2)

The porosity of the surface affects adhesion because the capillaries of a porous surface carry away some of the adhesive

thus making it unavailable. According to Dappen, (3), the amount of adhesive lost to the substrate through penetration is 3 - 4 per cent along with 28 - 33 per cent water in a starch adhered system. Some factors in rawstock preparation which affect penetration of starch from the coating into the substrate are:

1. Increasing density of rawstock reduces penetration.
2. Increasing amount of size in the rawstock reduces penetration with the greatest effects found in low density rawstock.
3. Increasing moisture content increases penetration in unsized rawstock, with little or no effect on the sized sheets. (4)

Coatings applied to a substrate with small pores loses more adhesive to the substrate than to a substrate with large pores. (5) This effect could be due to the greater capillary action exerted by the small pores in relation to the large pores. When a coating is applied to a porous substrate and rapidly dried with hot air, the coating retains more adhesive than a coating dried at room temperature. However, the coating dried rapidly has less strength. (5) This could be due to less time for adhesive to migrate into the substrate and less orientation of the adhesive in the coating. By less orientation of the adhesive it is meant that the adhesive molecules do not have time to draw the particles together and the adhesive migrates towards the surface of the coating, drawn there by the evaporation of the liquid phase of the coating.

According to Heiser and Cullen, (6), the principal direction of adhesive migration, whether towards the substrate on surface, is dependent on the drying rate and the quantity of binder migration is inversely proportional to the total coating solids, with high solids coatings having less binder migration than low solids coatings. The direction of adhesive migration will be towards the substrate in slow drying with the migration to the surface being proportional to the drying rate. (6)

When coatings are applied to nonporous substrates and dried rapidly with hot air, they have less strength and fail nearer the substrate than coatings dried by natural convection. (5) The coating dried on a nonporous substrate has no pores, which act on the coating through capillary action, to draw the adhesive towards the substrate. The water begins to evaporate at the surface and the particles at the surface of the coating pack closer together and increase in solids content. As more water is removed, the surface of the coating loses all its water and then, through capillaries formed in the coating proper, the water is drawn from further and further down into the coating. (3) The drying continues until the water is removed from the coating. There is a layer of weakness formed very near the substrate by this migration of adhesive which causes a layer of less strength to form at the junction of the nonporous substrate and the coating.

When a starch-clay coating is applied to a porous substrate, such as paper, and the color subsequently air dried, the starch

content in the coating is very uniform. When this same coating is dried by a forced air blast the starch migrated towards the heat source. (3) According to Gaspar, lower temperature surface drying may improve the strength of coatings and the coating rawstock interface due to slower fusion of the adhesive resulting in bond formations more uniform and less subject to stresses set up by rapid drying.

The unbonded surface area of coatings increases as the particle size of the clay decreases. This can be explained with regards to the size and number of particles per unit volume, which increases with smaller particle size, thus the adhesive must cover a larger surface with the same amount of material. Large particle clay gives poor orientation with regards to the plane of the rawstock due to the rapid flow of vehicle from the large inter-particle spaces. The particles are immobilized before they can realign in the plane of the rawstock. This effect is noticed most in light-weight coatings. According to Kraske, a heavier weight coating will retain more adhesive than a light-weight coating, and the pore distribution appears to be strongly dependent upon the particle size of the clay. Supercalendering will produce a realignment of the clay particles, but does so with the rupture of bonds and a shift in pore distribution. The adhesive demand of a coating color decreases as the solids content increases. (7)

The IGT tester can be used to measure the pick strength of pigment coatings. The amount of adhesive necessary for a given pick strength is dependent primarily upon the amount of

adhesive migration into the rawstock during drying, and the degree of particle orientation in the dried coating. (8) The coating weight appears to have little effect on the IGT or Dennison wax values, however, the substrate, if nonporous, will give a higher IGT and wax value although it will decrease with increasing coating weight. This can be explained by the smoothness of the nonporous substrate allowing more contact between adhesive and base. According to Libby & Casey, there is no relationship between the wax number of a coating and the penetration depth of the adhesive into the substrate. The wax number seems to be more affected by the strength of the rawstock than the depth of penetration. (9)

OBJECT

It has been theorized that there exists a relationship between the rate of water removal from a coating and its subsequent surface physical properties. It is hoped that this experiment will find such a relationship and that from this an optimum temperature and method of drying can be obtained for the properties desired in the finished product.

It is hoped that this experiment will be of some value to the coating industry and that if a correlation is shown to exist between drying rates and the physical properties of the coated sheet that this experiment will be extended to include other types of adhesives and other variables such as grade of basestock, internal sizing, surface sizing, etc. in the future.

This report originally started as a comparison of the surface properties of a clay-starch coated sheet and the effects of drying rates. However, due to the kindness of the Kalamazoo Paper Company and the availability of a commercial coater, the coating studied in this report was a casein latex color, which was being run on the coater at that time. The laboratory procedure was modified to incorporate this color.

EXPERIMENTAL

Through the co-operation of the Kalamazoo Paper Company, the author was permitted control of a large air knife coater on which seven rolls of a commercial C_1S paper were coated. All variables were held as constant as possible varying only the temperature and air flow rate in the first three zones of the tunnel dryer. This was done to determine if any effects on the surface of the coated sheet could be seen.

The coating color was prepared in a Kady mill and consisted of 35 parts clay, 4.5 parts casein, and 1.7 parts latex. This same color was used for the laboratory drawdowns.

The data obtained from the above trial are listed in Tables 2-A and 2-B. The values for the physical tests are plotted versus average temperature for zones 1 & 2, average air flow for zones 1, 2, & 3, and the product of the first two averages. This was done in order to obtain a single value for the drying conditions. The values for S-9 and S-34 were not used for the graphs as the final percent relative humidity of the paper was not in line with the rest of the run.

Drawdowns were made in the laboratory using the same basestock and coating color as used in the mill run. The coating was applied to the wire side of the basestock with a #20 Mayer rod at 25.6 percent solids. Aluminum foil was also coated to determine the effects of a non-porous base.

The Samples were dried by the following methods:

1. AIR DRIED - The coated samples were allowed to dry under room conditions, 72°F and 50 percent relative humidity.

2. OVEN - The samples were dried in a forced air oven at 200°F, and in this process both sides of the sheet were exposed to the heated air simultaneously.

3. HOT PLATE - The samples were dried by placing the uncoated side next to the heated surface of a Noble & Wood hot plate at 265°F and holding them with the aid of wooden rods until dry.

4. INFRA RED - The samples were placed, coated side up, under a gas fired infra red heater and allowed to dry at 360°F. It should be noted that the gas pressure was insufficient to cause the heating unit to glow red.

The test results from the above procedure may be found in Table 1.

The drawdowns were made in the normal manner with the substrate held on a flat glass plate. The samples were transferred from the plate to the drying apparatus, placed as near the plate as possible to minimize the time between coating and drying, and held until thoroughly dry.

The samples were conditioned 24 hours and calendered four nips at 35# per lineal inch on a laboratory calender. The samples were again conditioned for 24 hours before testing. The samples were tested according to TAPPI procedure, unless otherwise noted.

DATA

LABORATORY DRAWDOWNS

TABLE 1

SAMPLE	ON PAPER				ON ALUMINUM FOIL			
	OVEN	INFRA RED	ROOM	HOT PLATE	OVEN	INFRA RED	ROOM	HOT PLATE
COAT WEIGHT (#/25X38-500)	10.0	14.3	11.1	10.4	8.8	11.3	8.8	9.8
TEMPERATURE °F	200	360	72	265	200	360	72	265
GURLEY SMOOTHNESS SEC.	450	475	773	494	---	---	---	---
HUNTER GLOSS	47.1	38.2	49.5	43.1	59.6	55.8	71.5	64.3
K&N INK (B1 - B2)	38.0	36.5	38.5	38.5	---	---	---	---
DENNISON WAX	7	6.5	7	6.5	16.7	16	14	15.3
SCHEID (INCHES FROM HOR.)	17	21	14	16	---	---	---	---
IGT *1	120	98	128	70	265	220	413	403

*1 - #5 IPI, 35 Kg. - For Paper
#8 IPI, 50 Kg. - For Aluminum Foil

TABLE 2-A

MILL TRIAL DATA

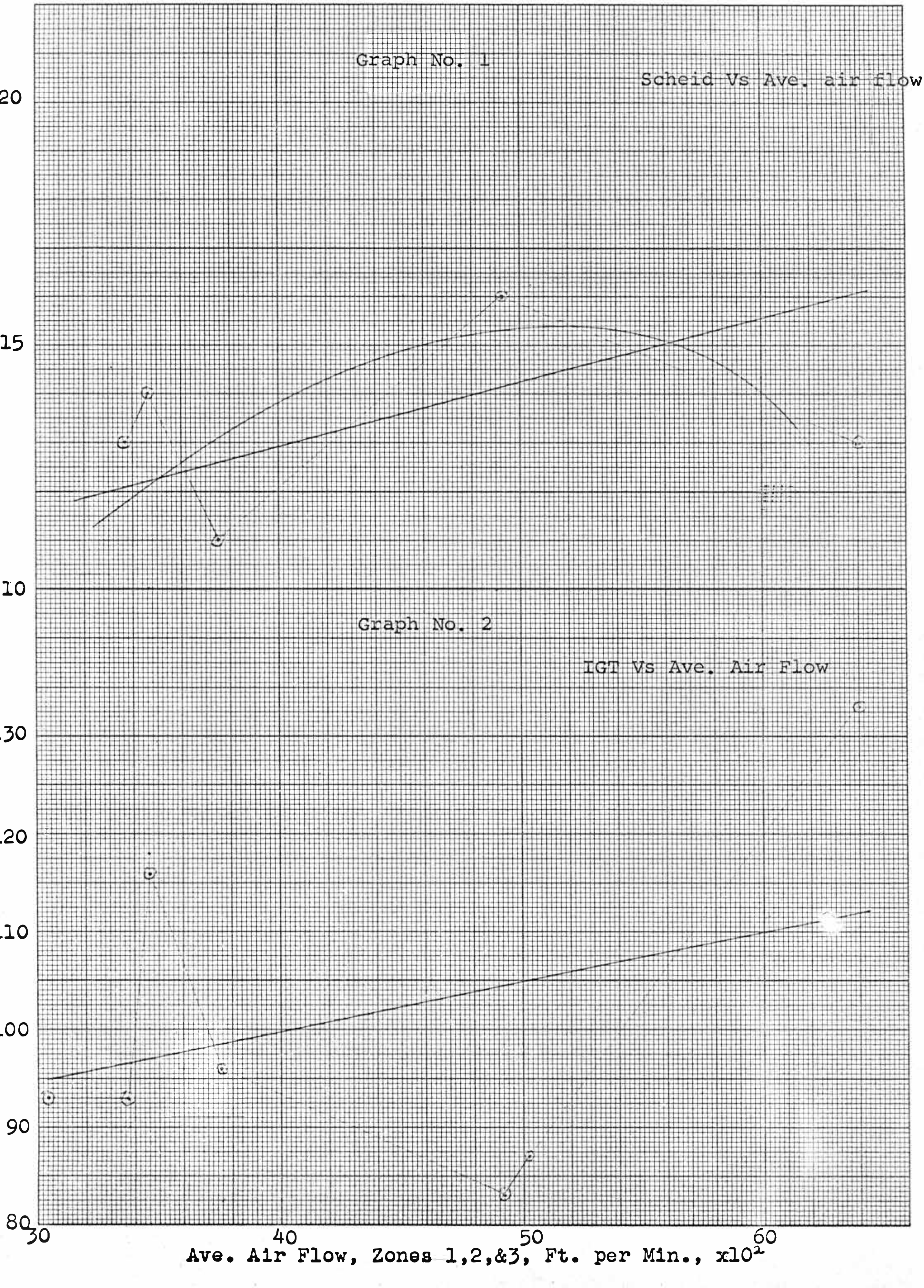
SAMPLE	S-31	S-8	S-6	S-33	S-9	S-34	S-32
COAT WEIGHT (#/25X38-500)	12.0	11.4	11.0	10.7	9.6	12.7	12.1
% R.H.,@ 80°F	51.5	51.4	50.3	49.1	39.5	58.0	51.5
GURLEY SMOOTHNESS, SEC.	604	800	1045	635	640	750	580
HUNTER GLOSS	45.3	47.3	52.4	49.6	50.9	50.6	49.9
K&N INK (B1 - B2)	29.0	32.0	30.0	28.0	33.0	26.0	30.5
DENNISON WAX	6.3	6.3	6	6.3	6	7	6.3
SCHEID (INCHES FROM HOR.)	13	16	14	13	15	14	11
IGT, #4 IPI, 35 Kg.	133	83	116	93	93	87	96

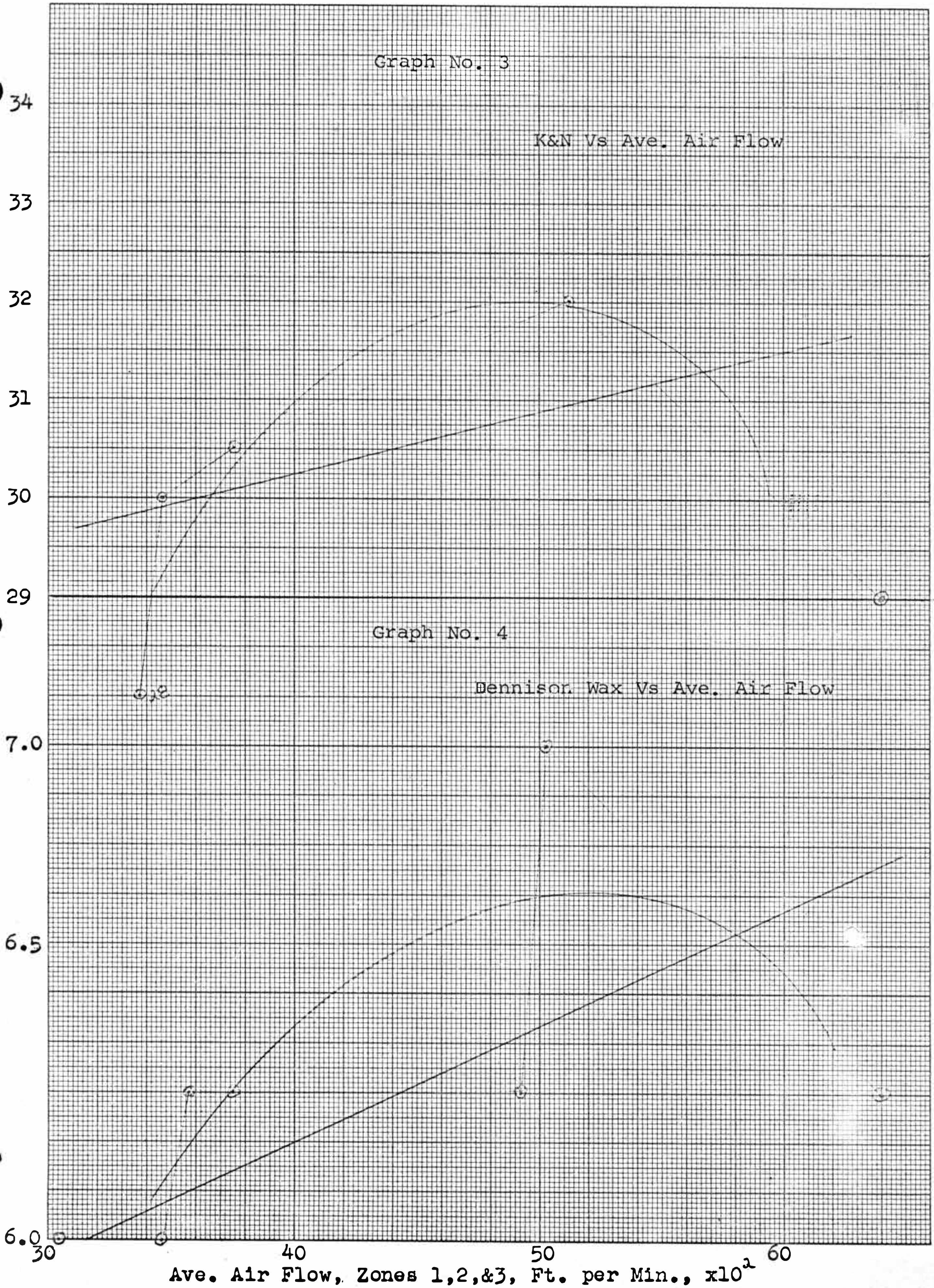
NOTE: Sets 9 & 34 not used for graphs as the % R.H. isn't in line with other values.

TABLE 2-B

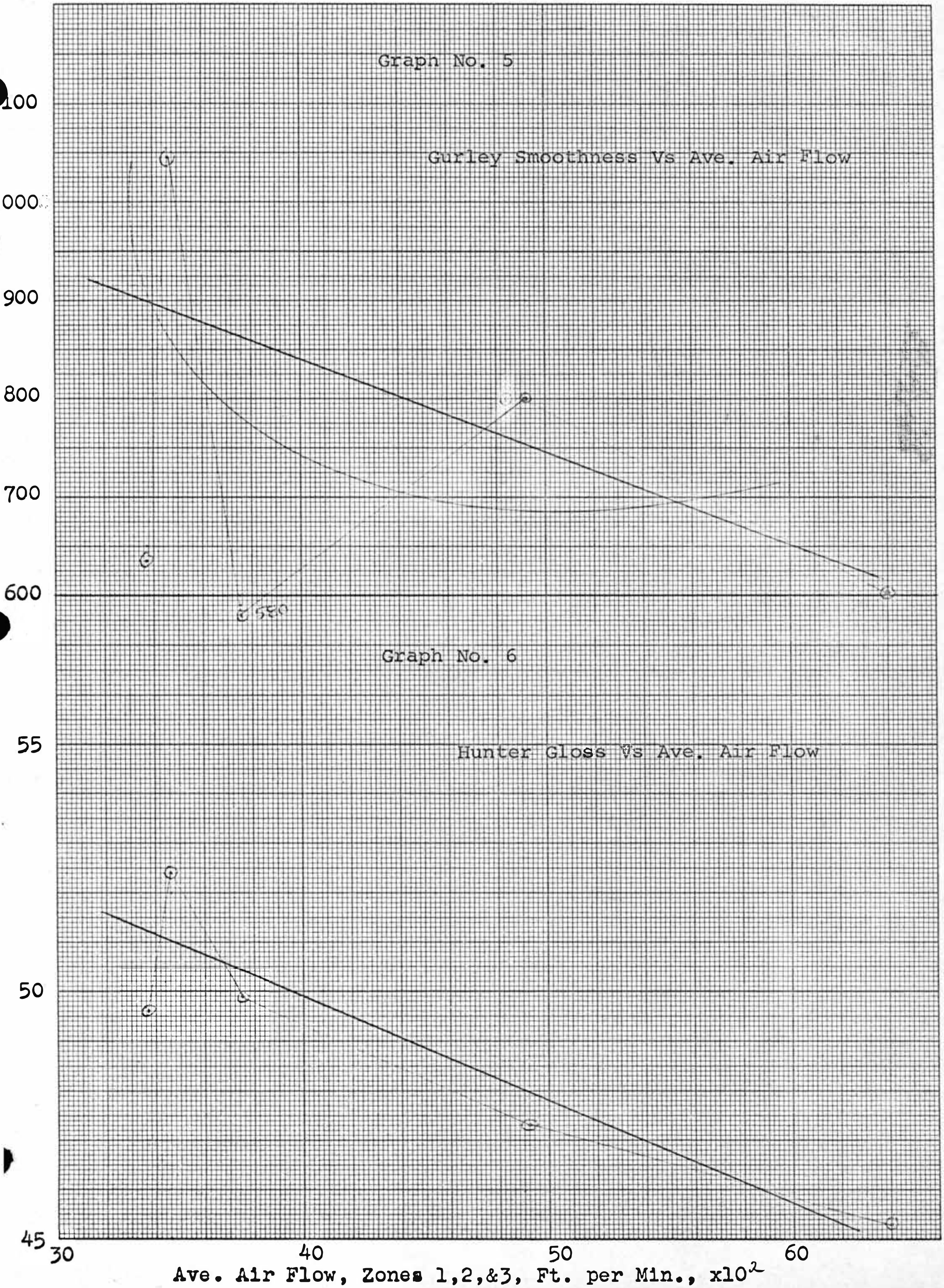
MILL TRIAL DATA

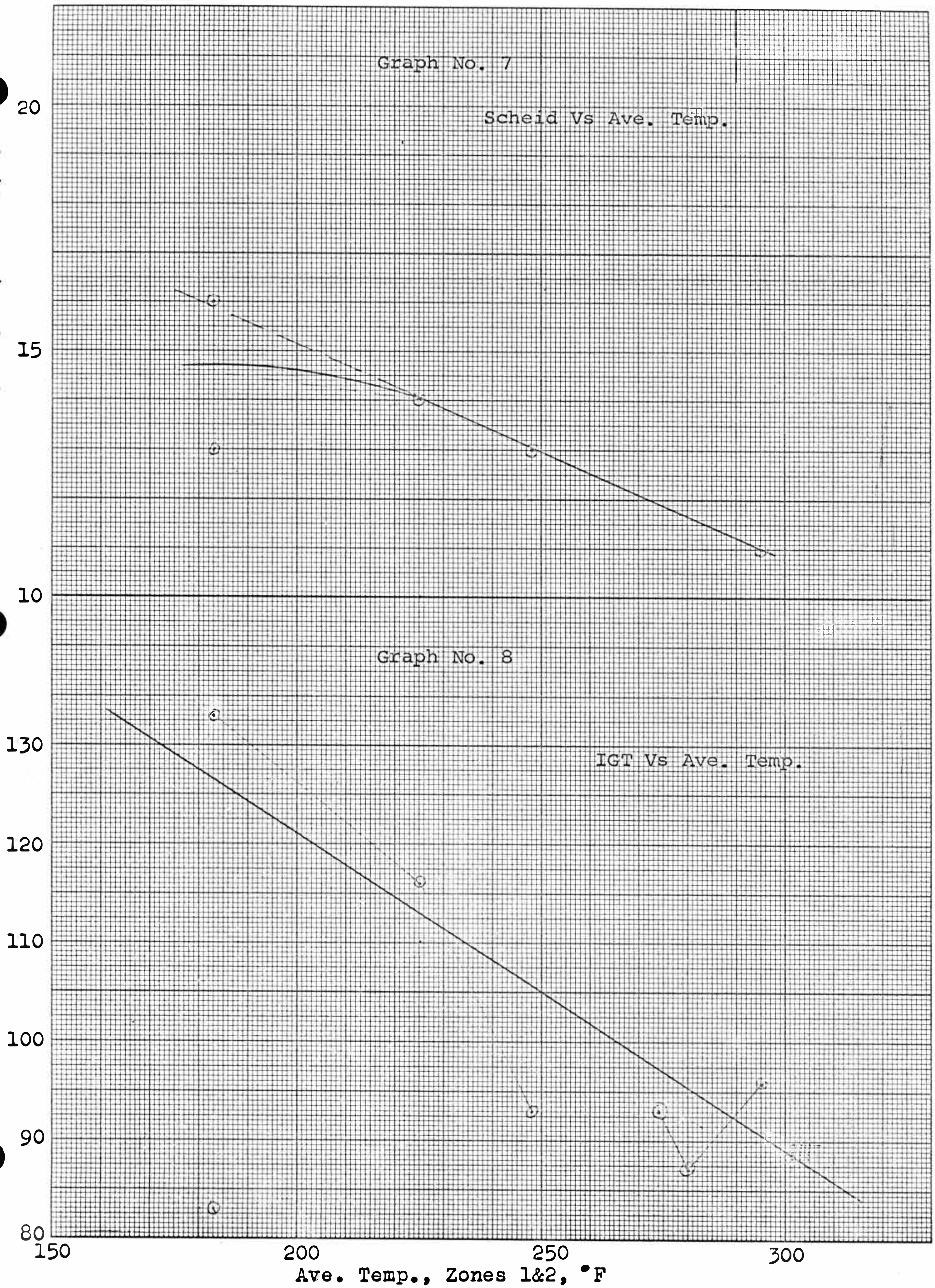
SAMPLE	S-31	S-8	S-6	S-33	S-9	S-34	S-32
ZONE 1, °F	155	175	225	248	282	283	290
ZONE 2, °F	210	190	225	247	265	266	300
ZONE 3, °F	280	280	280	280	280	280	280
ZONE 1, FT./MIN.	2450	2450	2600	2700	2850	2680	2720
ZONE 2, FT./MIN.	8150	3720	4330	3450	2830	5700	2720
ZONE 3, FT./MIN.	8600	8600	3450	3950	3450	6650	5800
ZONE 1 & 2 (A) AVE. °F	183	183	225	248	274	280	295
ZONE 1, 2, & 3 (B) AVE. FT./MIN.	6400	4920	3460	3370	3040	5010	3750
(A) (B) °F FT./MIN. X 10^6	1.171	.900	.078	.836	.833	1.403	1.106

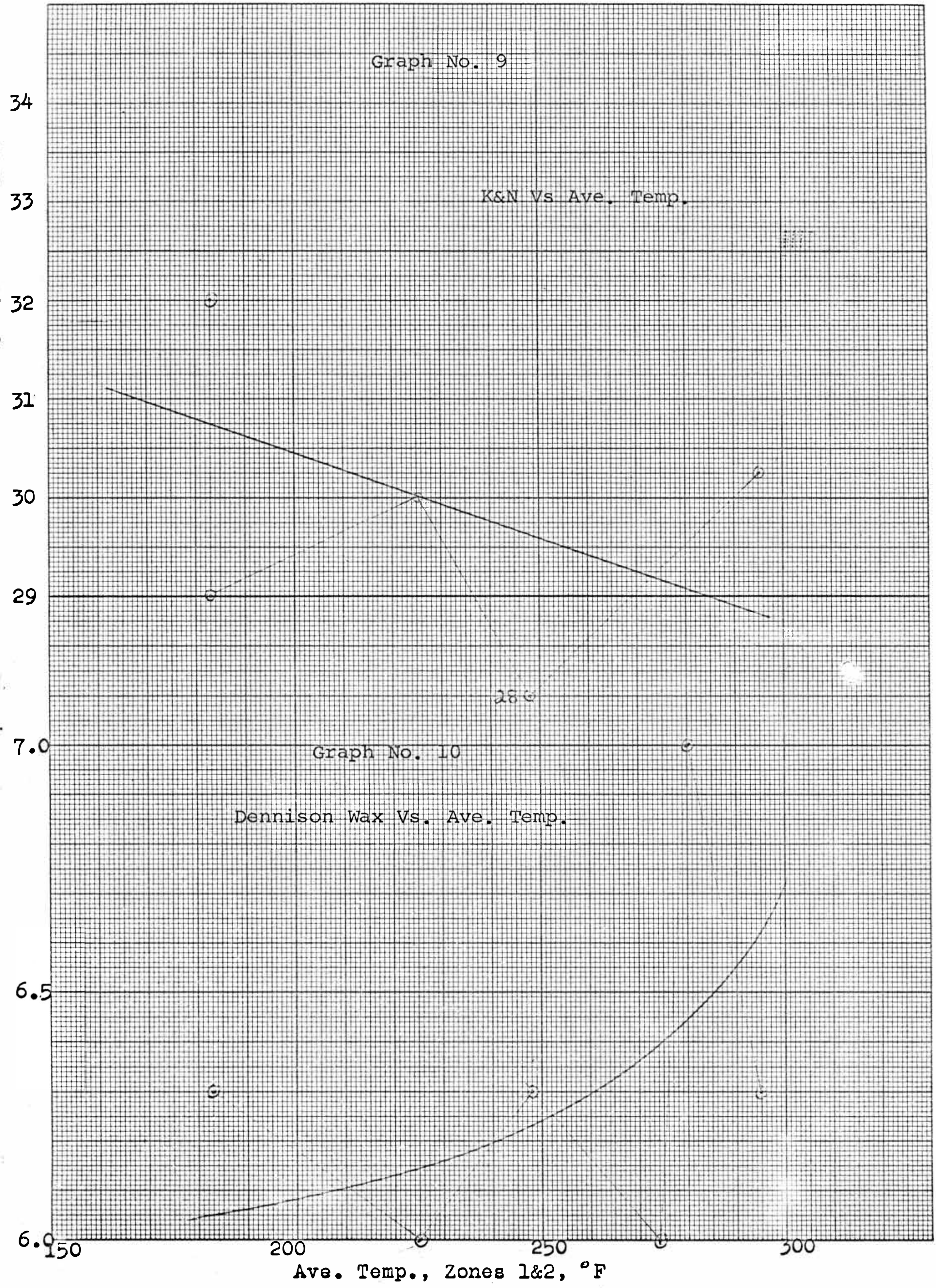

Graph No. 1
Scheid Vs Ave. air flow
Graph No. 2
IGT Vs Ave. Air Flow
20
15
10
130
120
110
100
90
80
30
40
50
60
Ave. Air Flow, Zones 1,2,&3, Ft. per Min., x10²

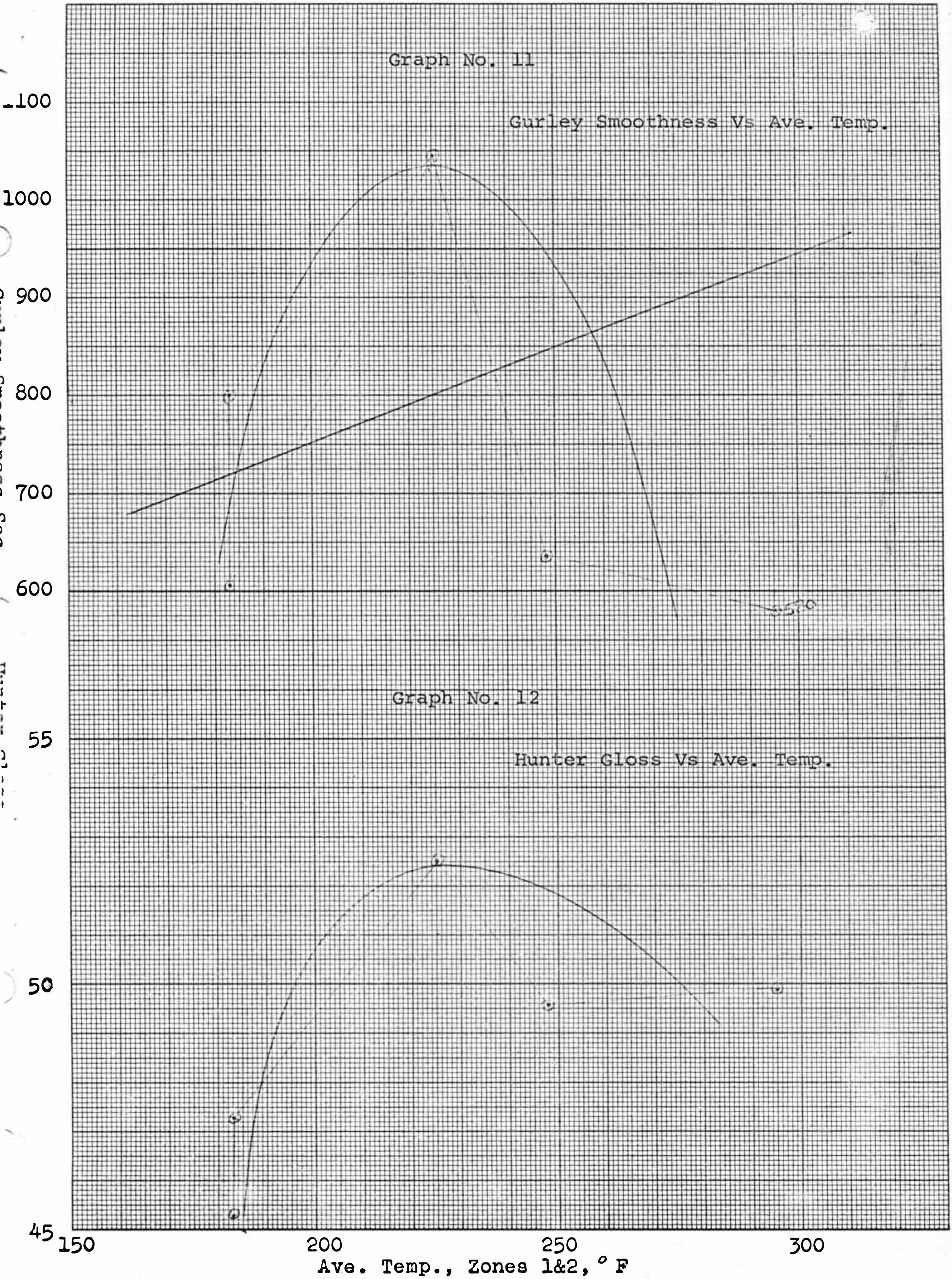


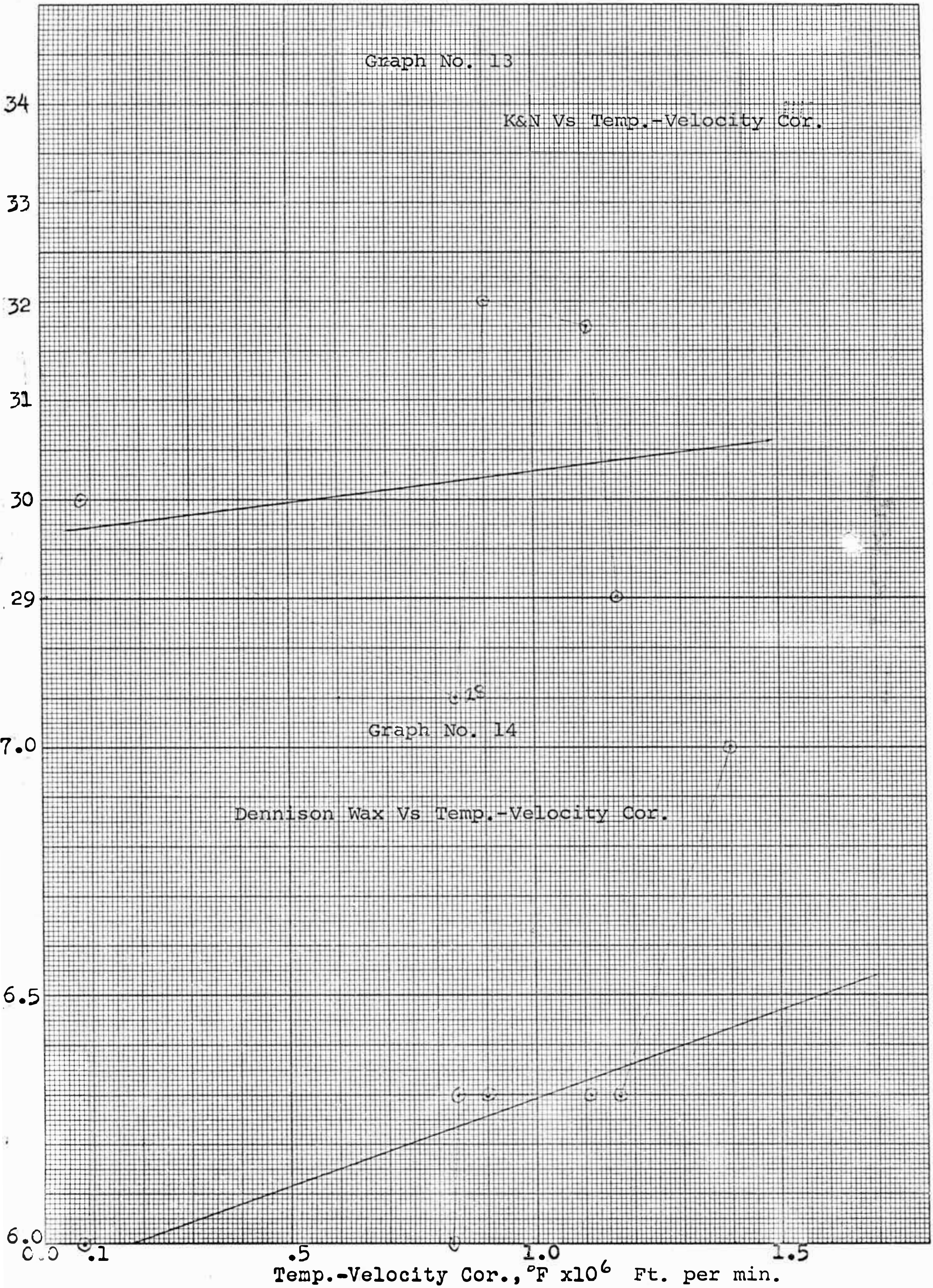
Graph No. 3
K&N Vs Ave. Air Flow
Graph No. 4
Dennison Wax Vs Ave. Air Flow
34
33
32
31
30
29
28
7.0
6.5
6.0
30
40
50
60
Ave. Air Flow, Zones 1,2,&3, Ft. per Min., x10²

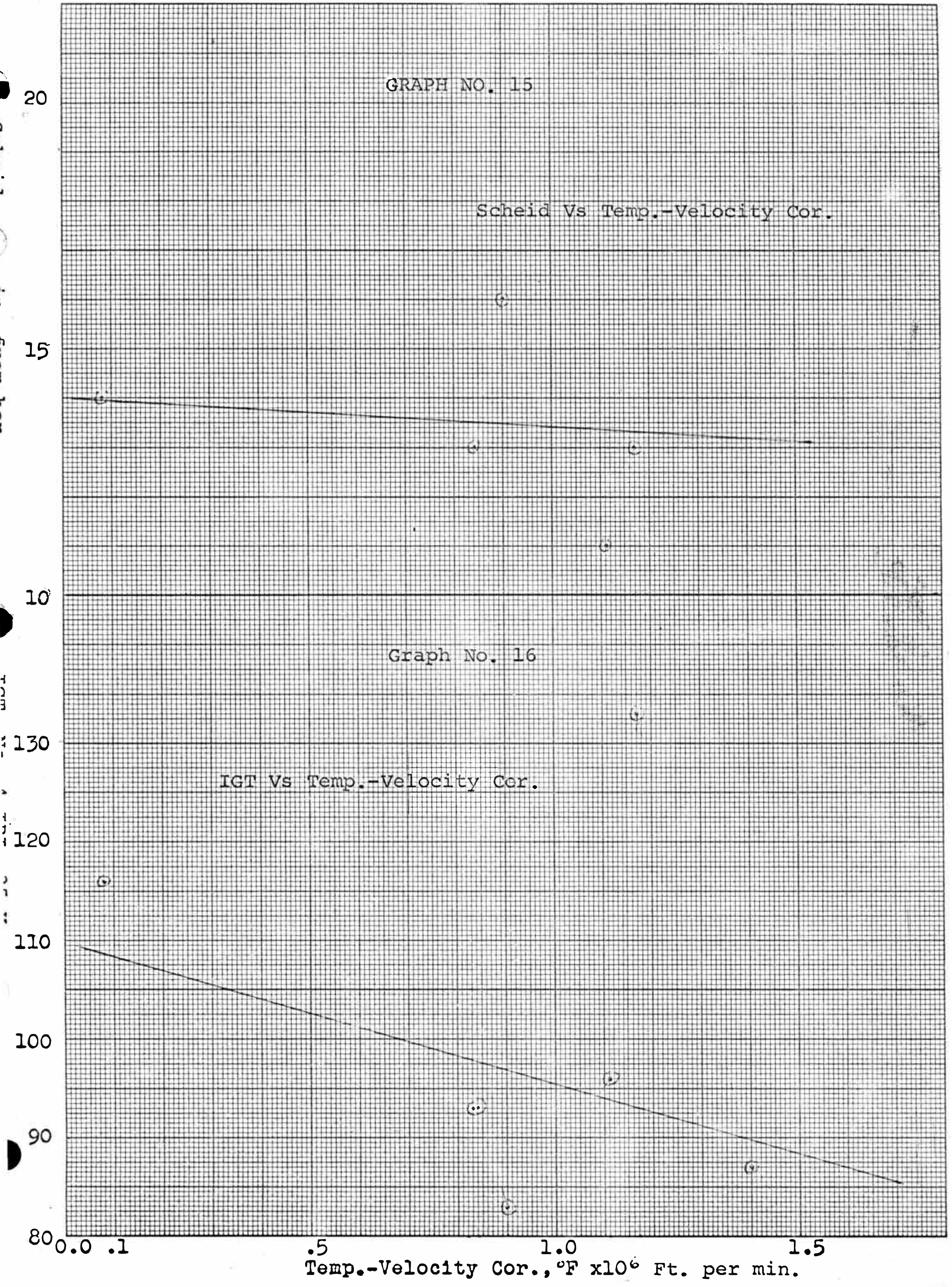

Graph No. 5
Gurley Smoothness Vs Ave. Air Flow
100
000
900
800
700
600
550
Graph No. 6
Hunter Gloss Vs Ave. Air Flow
55
50
45
30
40
50
60
Ave. Air Flow, Zones 1,2,&3, Ft. per Min., x10²

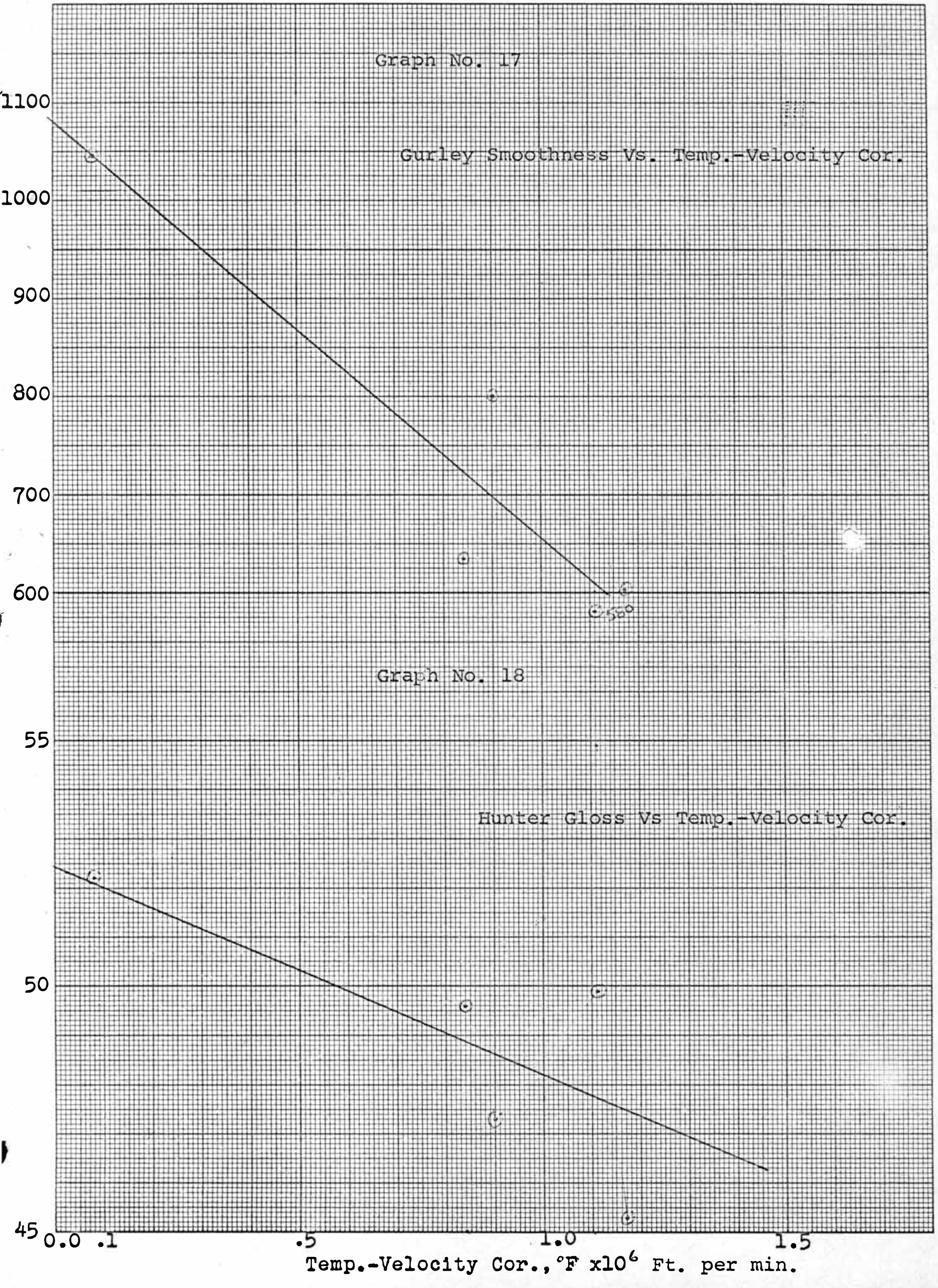

Graph No. 7
Scheid Vs Ave. Temp.
20
15
10
Graph No. 8
IGT Vs Ave. Temp.
130
120
110
100
90
80
150
200
250
300
Ave. Temp., Zones 1&2, °F


Graph No. 9
K&N Vs Ave. Temp.
34
33
32
31
30
29
28
Graph No. 10
Dennison Wax Vs. Ave. Temp.
7.0
6.5
6.0
150
200
250
300
Ave. Temp., Zones 1&2, °F


Graph No. 11
Gurley Smoothness Vs Ave. Temp.
Graph No. 12
Hunter Gloss Vs Ave. Temp.
100
1000
900
800
700
600
55
50
45
150
200
250
300
Ave. Temp., Zones 1&2, °F


Graph No. 13
K&N Vs Temp.-Velocity Cor.
34
33
32
31
30
29
Graph No. 14
Dennison Wax Vs Temp.-Velocity Cor.
7.0
6.5
6.0
0.0
.1
.5
1.0
1.5
Temp.-Velocity Cor., °F x10⁶ Ft. per min.


GRAPH NO. 15
Scheid Vs Temp.-Velocity Cor.
Graph No. 16
IGT Vs Temp.-Velocity Cor.
20
15
10
130
120
110
100
90
80
0.0
.1
.5
1.0
1.5
Temp.-Velocity Cor., °F x10⁶ Ft. per min.


Graph No. 17
Gurley Smoothness Vs. Temp.-Velocity Cor.
1100
1000
900
800
700
600
580
Graph No. 18
Hunter Gloss Vs Temp.-Velocity Cor.
55
50
45
0.0 .1
.5
1.0
1.5
Temp.-Velocity Cor., °F x10^6 Ft. per min.

CONCLUSION

LABORATORY: As can be seen from Table 1, the coating on the aluminum foil has much greater strength by both the IGT and Dennison wax tests. This could be attributed to the fact that more adhesive remained in the pigment on the aluminum foil while on the paper basestock the adhesive migrated into the substrate and was lost. This is in agreement with the results obtained by Eames (5).

In looking at the results of the tests on the aluminum foil it can be seen that the gloss for the sheets dried at room temperature is the highest and the infra red dried sheets lowest. The gloss on the hot plate dried sheets is second and the oven values third. The sheets dried at room temperature should have a uniform distribution of adhesive throughout the coating layer. The sheets dried with infra red will have the adhesive migrating towards the surface which would cause lower gloss due to the increased amount of casein on the surface. The sheets dried on the hot plate and in the oven should have the adhesive migrating towards the foil then going back into the pigment. The substrate is not porous and there is not any place for the adhesive and water to go except to be carried back into the pigment by the evaporation process.

The values obtained for Dennison wax and IGT are not reliable enough to base any predictions on, other than the one previously mentioned with regards to their surface being stronger than the

surface of the coatings on the paper. The reason for the doubts as to the reliability of these tests is the non-uniformity of the coating applied to the foil. This could be seen in looking at the coated sheet. There were bands of thicker coating across the sheet which were caused by the Mayer rod skipping over a dent in the foil, etc., causing it to deposit a thicker layer here. The values for the gloss were taken in areas where the coating appeared uniform.

The sheets were too smooth to run smoothness and Scheid tests and when the K&N ink receptivity test was tried the coating came off with the ink when it was wiped from the surface.

The results of the tests run on the paper substrate seem to show that in general the sheet dried at room conditions have the best surface properties, and the sheets dried in the oven are next best with hot plate sheets third and the infra red sheets last. It should be noted here that the sheets dried in the oven should be similar to those dried at room conditions only at an elevated temperature as the sheets in the oven had the heated air circulated on both sides of the sheet simultaneously.

The values obtained show the sheets dried at room conditions have the highest smoothness and that the other values for the three remaining sheets show little difference. It is suggested that this is due to the uniformity of the adhesive content in the coating dried at room conditions and that the other samples have lower smoothness values due to the non-uniformity of the adhesive in the coating caused by migration at the elevated

temperatures. It is expected that the smoothness of the hot plate dried sheet would be greater than that of the infra red dried sheet. This is due to the adhesive migration towards the heated surface leaving more pigment and less adhesive on the surface of the hot plate sheet, clay finishes better than casein, thus a higher value. As for the reason the oven dried sheet has the lowest smoothness, it is suggested that the increased temperature and/or the influence of the air on the sheet has an effect on smoothness, however this does not show up in the gloss and Scheid measurements.

The values obtained for K&N ink and Dennison wax show little difference between samples and it appears that the rate of drying and method have little effect on these properties. However, the wax values seem to substantiate Kraske's theory that the adhesive is more uniform in an air dried sheet and that due to adhesive migration in the infra red and hot plate samples, a zone of weakness was created near the coating - substrate innerface causing lower wax values to be obtained.

The results of the gloss and Scheid testing seem to show a trend such that the Scheid is related to gloss in that a lower Scheid number is obtained when a glossier sheet is read. The highest values for gloss and lowest Scheid values, were obtained with the room and oven dried samples and that the next best values were obtained with the hot plate. The infra red dried sheets had the poorest values. The infra red sheets could show poorer results due to adhesive migration towards the

surface and the increased rate of water removal which could cause a rougher surface or one that would not finish well. The hot plate sheets would be expected to have better values due to the adhesive migration into the substrate leaving pigment, in a more concentrated layer near the surface, which should give a higher finish. The room and oven dried samples should have a more uniform adhesive distribution (10) and it is suggested that the lower temperatures would not have set or dried the latex as hard and this would then allow the latex to flow upon calendering giving a better finish.

The results obtained from the IGT test show that the samples dried at room conditions and the oven dried samples have the highest values. This could again be attributed to the uniformity of the adhesive throughout the coating. The infra red samples have the next highest values and could be due to more adhesive remaining in the coating with less penetration into the substrate, this is as expected because of the adhesive migration towards the heated surface (10). The hot plate samples have the lowest values due to adhesive migration into the sheet.

COATER EXPERIMENT

The test results were plotted against:

1. The average air flow, in feet per minuts, for zones 1, 2 and 3.

2. The average temperature, in ^{o}F, for zones 1 and 2. Zone 3 had a constant temperature of $280^{o}F$.

3. A composite of 1 and 2 which was obtained by multiplying the average temperature by the average air flow. This was done in order to try and correlate both values and give a single value for the temperature and velocity. The reliability of this method is doubtful and these graphs were not interpreted in the results. They are only inserted to give a general idea of the results. The author could not find a method by which the temperature and air flow could be related easily.

These graphs are numbered 1 through 18 and are on pages 12 through 20 of this report.

The best line was drawn through the values plotted.. There were only five values used for all the graphs, except the ones for IGT and Dennison wax, as the percent relative humidity of sets 9 and 34 was not in accordance with the other values. Sets 9 and 34 were included in the graphs of IGT and Dennison wax because it was felt that the percent relative humidity difference would have little effect on these values.

SCHEID: From Graphs 1 and 7 it appears that the Scheid decreases with decreasing air flow rate and decreases with increasing temperature. This should prove useful in that by increasing the temperature and decreasing the air flow a sheet with lower Scheid values would be produced.

IGT: From Graphs 2 and 8 it appears that IGT pick increases with decreasing temperature and increasing air velocity. This seems to follow the results obtained in the laboratory with the infra red dried sheets VS the air dried sheets.

K&N: It can be seen from Graphs 3 and 9 that the K&N ink receptivity seems to increase with increasing air flow, to a point, then to decrease. The effect of temperature is hard to interpret, but it appears that the K&N ink receptivity decreases with increasing temperature.

DENNISON WAX: The Dennison wax pick seems to increase with increasing temperature and air flow as shown in Graphs 4 and 10.

SMOOTHNESS: The Gurley smoothness, Graphs 5 and 11, appear to increase with decreasing temperature and to increase, with increasing air flow, to a point then decrease.

GLOSS: From Graphs 6 and 12 it seems that the Hunter Gloss increases with decreasing air flow and increases with increasing temperatures.

The results obtained from this procedure are in no way complete. Many more trials must be made in order to obtain more values for the graphs. As can be seen from the graphs, the best line to fit the points is hard to determine.

It is hoped that the results of this report will prove beneficial and that this topic will be pursued and expanded.

Suggestions for further work:

1. The hand sheets remaining after testing are available and could be sectioned to determine the adhesive distribution in the coating and substrate.

2. A study of the relationship of Scheid to Gloss.

3. A more complete study of the effects of air flow and temperature in the tunnel dryer.

4. The study of a starch-clay coating, as was originally intended by the author.

5. A study of other adhesive and pigment systems and substrates.

BIBLIOGRAPHY

1. Dyck, A.W.J. Adhesives in the Paper Industry
   Fritz Publications Inc. 1960
2. Singleterry, C.R. Paper Trade Journal
   113 #18: 37-40 (October 30, 1941)
3. Dappen, J.W. Tappi
   34 #7: 324-35 (July, 1951)
4. Casey, J.P. & Libby, C.E. Paper Trade Journal
   127 #25: 83-90 (December 16, 1948)
5. Eames, A.C. Tappi
   43 #1: 2-10 (January, 1960)
6. Heiser, E.J. & Cullen, D.W. Tappi
   48 #8: 80-85A (August, 1965)
7. Hemstock, G.A. & Swanson, J.W. Tappi
   40 #10: 833-38 (October, 1957)
8. Hemstock, G.A. & Swanson, J.W. Tappi
   40 #10: 794-801 (October, 1957)
9. Casey, J.P. & Libby, C.E. Paper Trade Journal
   127 #26: 35-41 (December 23, 1948)
10. Kraske, D.J. Tappi
    43 #1: 73-82 (January, 1960)
11. Gaspar, L.A. Thesis WMU 1962
    "The Effect of Drying Conditions on the Surface Strength of Clay Coated Paper."

BIBLIOGRAPHY

1. Bhargaua, R.L. and Robertson, J.H., Tappi 42#5: 385-389 (May,1959).
2. Carlson, B.L., Tappi 44#3: 212-213A (March, 1961).
3. Casey, J.P. and Libby, C.E., Paper Trade Journal, 127#25: 83-90 (Dec. 16, 1948).
4. Casey, J.P. and Libby, C.E., Paper Trade Journal, 127#26: 35-41 (Dec. 23, 1948).
5. Clark, C.B. and Ramsay, H.L., Tappi 48#11: 609-612 (Nov., 1965).
6. Dappen, J.W., Tappi 34#7: 324-35 (July, 1951).
7. Eames, A. C., Tappi 43#1: 2-10 (Jan., 1960).
8. Eisele, K.M., Pulp and Paper Magazine of Canada 60#C: 153-156 (Convention, 1959).
9. Heiser, E.J. and Cullen, D.W., Tappi 48#8: 80-85A (Aug., 1965).
10. Hemstock, G.A. and Swanson, J.W. Tappi 40#10: 833-838 (Oct., 1957).
11. Hemstock, G.A., Tappi 45#2: 158-158A (Feb., 1962).
12. Kirk, L.A., The Paper Maker, Supplement: 50-56 (Oct., 1965).
13. Kraske, D.J., Tappi 43#1: 73-82 (Jan., 1960).
14. Singleterry, C.R., Paper Trade Journal 113#18: 37-40 (Oct. 30, 1941).