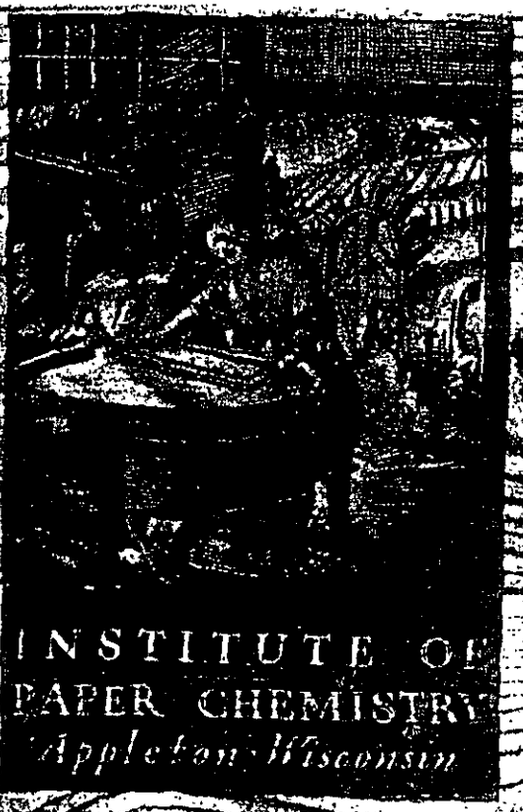

EVALUATION OF THE KNIGHT-ROWLAND COATING PROCESS

Project 1271

Progress Report One

THE INSTITUTE OF PAPER CHEMISTRY

DECEMBER 31, 1949

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INTRODUCTION

George Knight, during the course of his investigation of surface wettability, observed certain phenomena concerning the effect of a vacuum on the wettability of porous paper surfaces. The principles he deduced from these observations were recognized as having possible merit in connection with the coating of porous webs and were patented as the Knight-Rowland coating process (U. S. Patent No. 2,471,330). Project 1271 was initiated to evaluate this process with particular reference to its applicability to a continuous paper web in the Institute's laboratory coater.

THEORETICAL CONSIDERATIONS

A porous material, such as a sheet of paper, will allow (within limits) the passage of fluid substances. Thus, if a sheet of paper is used as a membrane between two chambers, one of which has a higher fluid pressure than the other, it will permit passage of the fluid until the pressures are equalized. The pressure differential existing between the two chambers serves as a driving force to move the fluid material through the interstices of the porous membrane. It can be shown that the same principle applies when the two chambers are located adjacent to each other on the same side of the sheet of paper. The wall or barrier between the two chambers is in contact with one

side of the sheet. Beneath it there is created a lateral flow of air or fluid coating material from the high-pressure to the low-pressure chamber. Depending on the porosity of the sheet, there is a tendency for any fluid in contact with the sheet on the low-pressure side of the barrier to be drawn into the sheet. Fitted tightly to the opposite side of the paper is a nonporous material. This arrangement is, in certain respects, similar to having the chambers on opposite sides of the web. The fluid in the high-pressure chamber is once again separated from that in the low-pressure chamber by a porous membrane. However, it is not limited to one direct path but may take several, utilizing those which offer the least resistance.

Knight defined these paths as "leakages." Figure 1 is an illustration of the possible fluid paths. The relative importance of the flow along each fluid path is dependent upon the porosity and smoothness of the porous material, as well as upon the pressure differential and time interval involved. From the illustration, the function of the nonporous backing material is apparent, for it can be seen that, without the backing, a significant difference in pressure between the two chambers would not exist. The backing serves to reduce the amount of leakage of air vertically through the sheet under the low-pressure chamber, confining the flow primarily to a direction along the sheet rather than through the sheet.

A logical extension of this principle is its application to

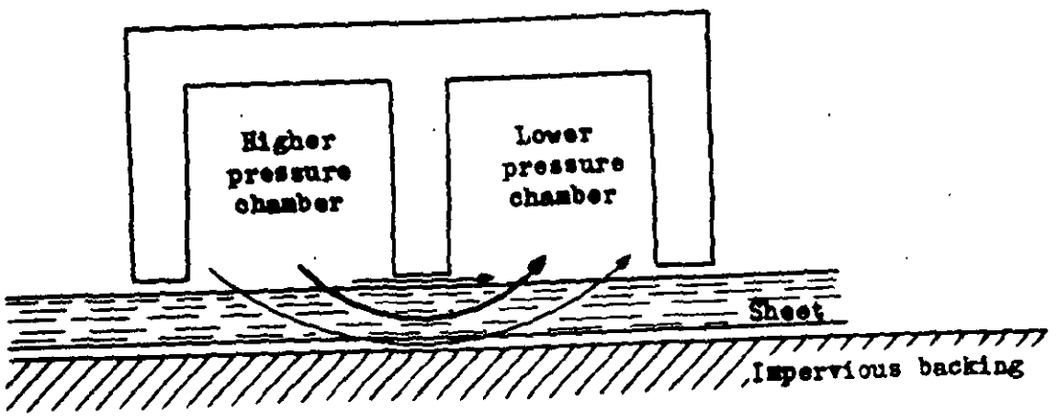

Figure 1

Schematic Illustration of Possible Fluid Paths

the coating of paper. Thus, the high-pressure chamber would contain coating color as its fluid. The other chamber could be evacuated to obtain the maximum pressure differential. Coating color, at the higher pressure, would be drawn or driven toward the evacuated chamber and penetrate the interstices of the porous sheet. Some penetration of coating material is desirable as a means of anchoring the coating to the paper, particularly in the case of surface areas which are not uniformly and readily wetted by the coating at the time of application.

Limiting the scope of the theory to one evacuated chamber, a porous web, and atmospheric pressure, it is conceivable that, as Knight states, "Vacuum has an appreciable effect on the same surface to which it is applied and at an appreciable distance from the area of application." This principle shows that a fluid material can, in a manner of speaking, be forced into a porous surface by applying a vacuum to an adjacent area of the same surface.

EXPERIMENTAL

General

Progress on this project was, and to a large extent still is, directly dependent upon the experimental equipment which was, or could be, made available for its solution. As is frequently the case, a great deal depended upon auxiliary equipment. The foundation for

development of the equipment used was a laboratory roll coater originally designed, but never entirely completed, for coating rolls of raw stock 10 inches wide and 36 inches in diameter. Before modification, it consisted of an unreeling stand and a pair of coating rolls 20 inches in diameter, one of which was surfaced with brass and one with rubber. There were no drying facilities. One of the greatest problems was to acquire adequate drying capacity.

Behind the entire project was a certain degree of urgency which made it difficult to undertake certain long range improvements in the equipment because of the time element. Therefore, it became necessary to employ temporary measures in some cases which, it was hoped, would satisfy the immediate requirements. The first of these measures was the installation of an electric hot plate as the initial step in the development of drying capacity. This furnished a temperature of 180° C. over a distance of 10 feet of travel of the web. Its capacity soon proved inadequate. A unit heater was installed to provide air circulation and to blow warm air over the hot plate. Then, as the next step, banks of infrared lamps were added. Even with these additions, the drying capacity was still inadequate.

Another possible approach to the problem of drying was to lengthen the draw of the coated web. The draw through the machine was started at 35 feet; therefore, all drying facilities had to be concentrated in that 35-foot span. This meant that, when the machine was

running at 400 ft./min., it was necessary to dry a coated sample in about five seconds. A 40-foot addition was made by constructing a tunnel of cardboard in the runners of the machine foundation. Air flowing through the tunnel was heated by a unit heater and, later, by the addition of steam-heated pipes. Air temperatures of 75° C. were recorded at the exit. Auxiliary rolls were placed in such a manner that the web made two passes through the tunnel. The next step was to install an idler roll at a considerable distance from the machine. When the web was threaded through the idler roll, the draw was increased to 90 feet, but one 20-foot pass through the tunnel drier was eliminated. Steam pipes were arranged to furnish additional heat to the web during its travel to the idler roll.

In spite of a three-fold increase in drying time and a substantial increase in the amount of heat applied, the drying facilities were far from satisfactory. Lack of proper drying led to a host of operational difficulties. For example, any coated samples which were wound wet were ruined. Because of the nature of this coating process, it is not possible to treat the entire width of the sheet and, hence, a strip of paper is left uncoated at each edge of the web. These strips of unwetted paper must bear a proportionally greater tensile stress than does the wetted body of the sheet. Therefore, it is almost impossible to control wrinkling. When the draw was lengthened, other serious problems became evident. Wrinkling was intensified, it became

more difficult to keep the web on the rolls, and the strain on the web was so great that repeated breaks necessitated frequent rethreading. Since drying was still inadequate, attempts at continuous operation were abandoned, and the draw was shortened. Samples were dried by holding them in the tunnel drier.

Description and Use of the Original Coating Device

Because of the urgency and high priority assigned to the project, it was necessary to accumulate data on the operation of the coating device even as development work on the coating machine was being carried out. Figure 2 is an illustration of the original pilot plant-scale coating head. Fluid material is fed into the pyramid-shaped chamber and flows through a rectangular orifice called the "coating slot." The width of the coating slot may be varied by using one or more of several machined metal inserts. A metal divider separates the coating mixture chamber from the vacuum chamber. Several thicknesses of dividers are available for substitution. The width of the vacuum slot may be changed in the same manner as the coating slot.

The coating head was used to coat the web from several different mounting positions on the machine. Thus, at some time, the web was coated from the top, the bottom, or in a vertical draw. The mount for the head was different for each of these positions. Experience showed that several features were desirable for a workable coating—head mount. It was determined that construction should be such that the

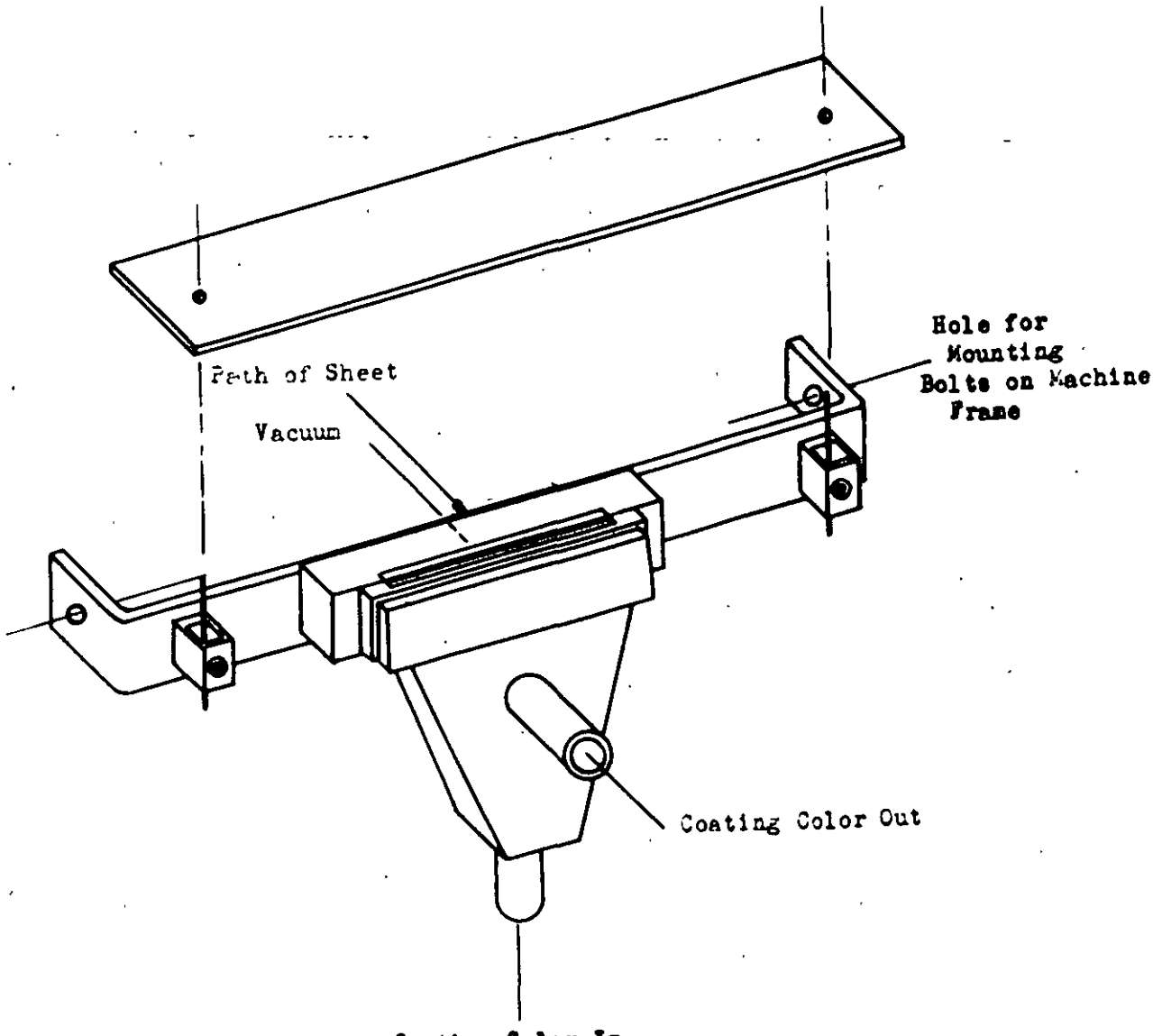

Figure 2

Coating Head and Backing Plate (original model)

coating head could be removed easily for cleaning. The mount should allow simple, yet precise adjustments to be made vertically, horizontally, and at an angle with the plane of the sheet. There must be provision for the use of a nonporous backing plate. The mount should be constructed so that a controlled and reproducible pressure can be applied between the coating head and the sheet. The mount, a part of which is illustrated in Figure 2, had some of these features. Vertical rods were bolted to opposite sides of the machine frame. Other rods were fastened horizontally to the vertical rods by right-angle clamps. The coating head was then attached to the horizontal rods by bolts and swivel clamps. Thus, the coating device could be raised or lowered at will, or easily detached. In practice it was found that the force of vacuum might hold the backing plate against the traveling web and coating surface with such pressure that the sheet was torn. Therefore, two small springs were placed over the pegs used for holding the backing plate. When the springs compressed, they limited the pressure against the sheet.

Qualitative data on the operation of the coating device revealed several serious inadequacies. Changing the width of the slots was both laborious and time consuming. Adjusting the inserts so that they presented an absolutely plane surface, an important feature if the coated surface is to be smooth, was almost impossible. Some sort of doctoring seemed to be necessary to control the weight of the coating. Such doctoring could be most effective when it is an integral part of the head. The mounting device was inadequate because it was

not precise. The coating head could not be returned exactly to its original position once it had been removed for cleaning or adjustment. Hygroexpansivity effects made coating of a wider portion of the sheet desirable. Thus, operations were interrupted for a time to permit construction of a more effective coating device embodying design features which were disclosed during experimentation with the first model.

Description and Use of the Second Coating Device

Figures 3, 4, 5, and 6* are views of the second experimental coating head and its mount. It was constructed of brass. The face of the coating head was nine inches wide in the cross-machine direction, and seven inches long in the machine direction. It coated eight inches of a sheet ten inches wide. The operation of the coating device may be visualized from the figures and accompanying key. With this device, it was possible to make positive and precise adjustment of the coating and vacuum slots, the angle of the coating face with the backing roll, and the pressure of the face against the web while in operation. The use of this coating head and the encountering of certain unforeseen difficulties made further modification of the head desirable. The doctor blade soon proved to be unsatisfactory, because samples were produced with heavier coatings on the edges than in the middle. One

* Disregard numbers in circles on Figure 6. These refer to drawings not included in this report.

Identification and Function of Various Elements of the Experimental Coating Head

(Figures 3, 4, & 5)

Mount

1. Set screw to control the clearance between coating-head face and backing roll.
2. Set screw adjustment and spring safety release for regulating pressure of coating head against the web.
3. Screw-control mechanism for varying the angle of the coating face with the backing roll.

Coating Head

4. Coating-color inlet
5. Coating-color outlet
6. Connecting pipes of the vacuum system
7. Boston gear train to vary width of the coating slot
8. Doctor blade
9. Adjusting screws for controlling height of doctor blade
10. Set screws to lock doctor in place
11. Coating slot
12. Vacuum slot
13. Boston gear train to change width of vacuum slot

Note: The arrows indicate machine direction.

Figure 3
A view of the second model coating head and its mount in operating position

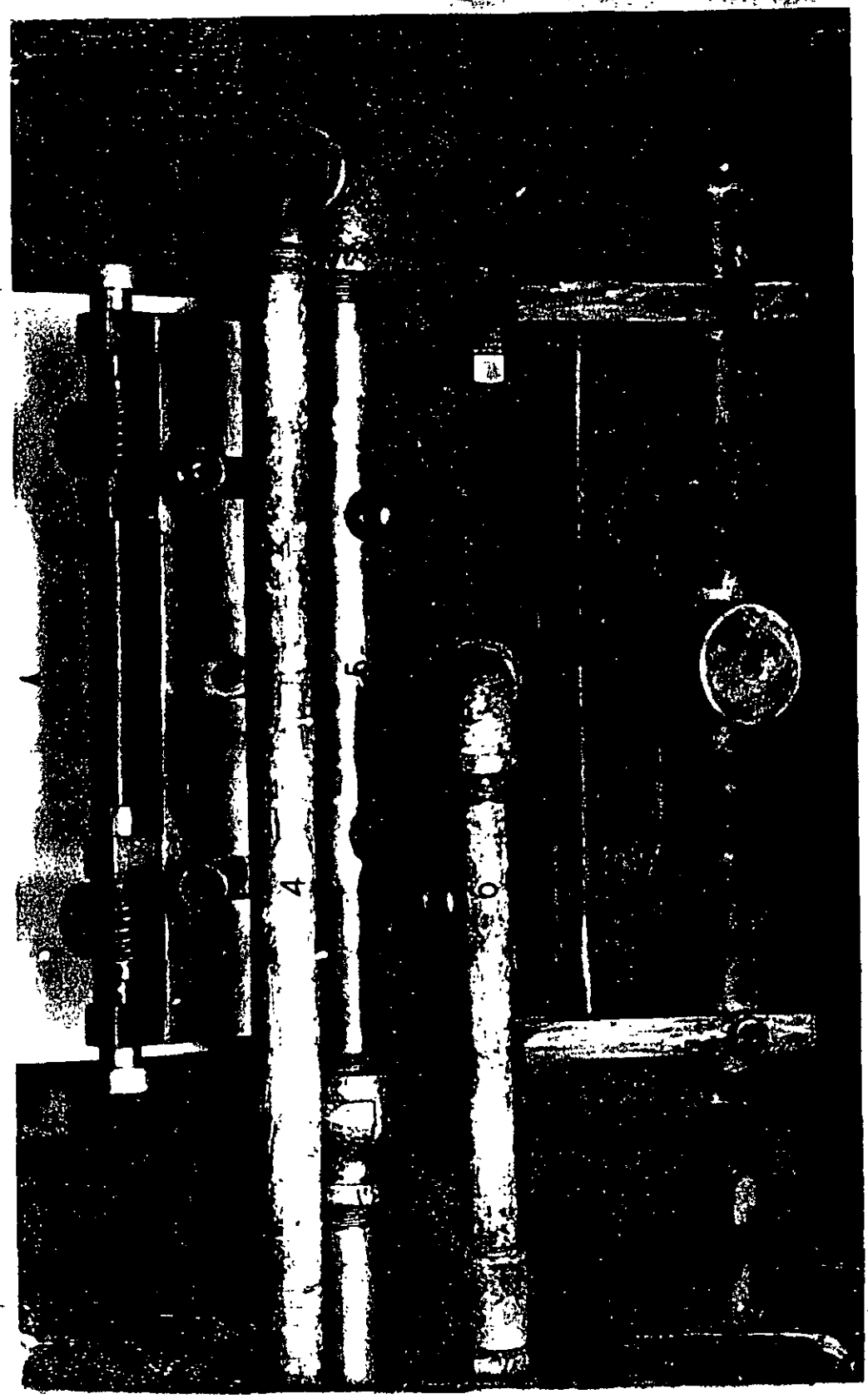

Figure 4

A view of the second model coating head in operating position

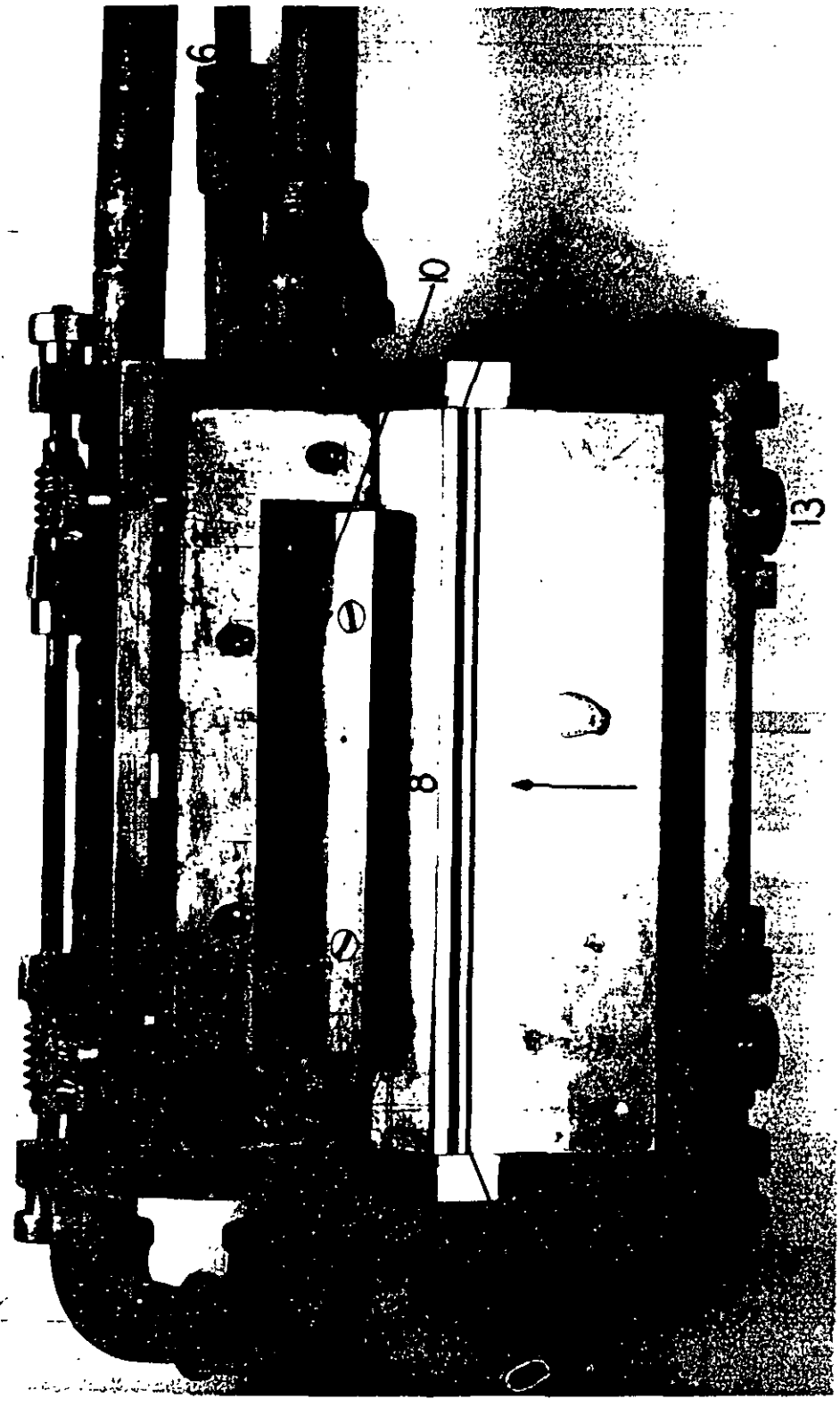

Figure 5
A view of the second model coating head face

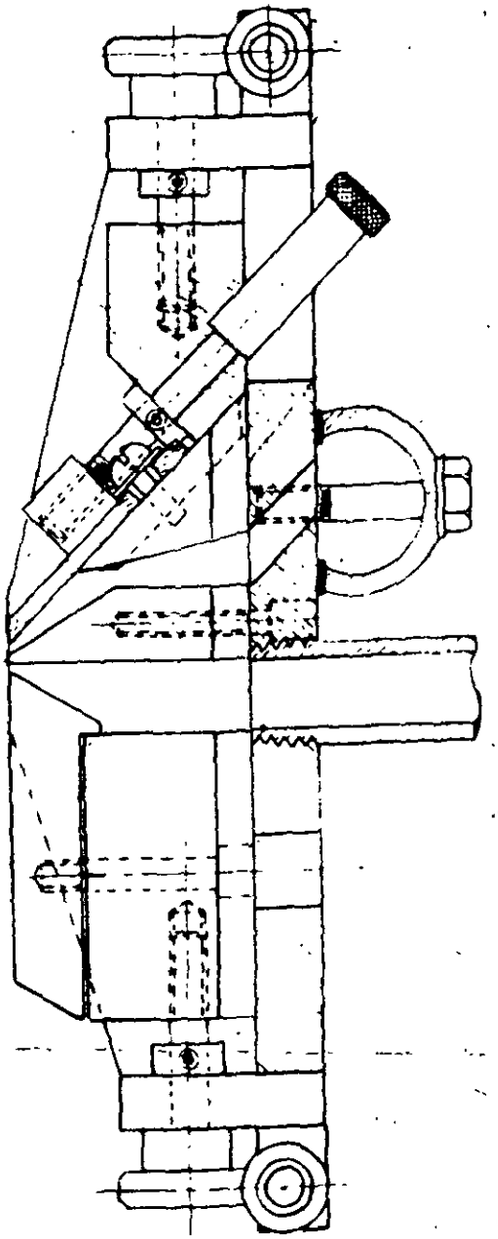

Figure 6
"Coating Head Assembly"

source of trouble was traced to the fact that the backing roll was slightly crowned, whereas the doctor had a plane surface. Grinding the doctor to the crown of the roll lessened this difficulty to some extent. However, the original head had but one adjustment screw for the doctor which was inadequate for keeping it in alignment; hence it was nearly impossible to establish exactly the right clearance across the face. Substitution of two adjusting screws helped to correct this situation. It was not possible to change the position of the doctor while in operation, since the set screws (10) had to be tight to prevent leakage. By removing the screw adjustment and safety spring on the arm of the mount, the coating head could be tilted back for cleaning. The safety spring allowed movement of the coating head to prevent damage to the coating face or backing roll if some object were to lodge between them.

Experience gained while working with the first coating head showed that a backing plate was desirable from a practical standpoint. It has been pointed out above that, theoretically, a nonporous backing material is necessary to obtain the vacuum effect. In practice it was found that a backing plate tended to overcome the spurting of coating material caused by pulsations of the feed pump and to prevent skips of coating resulting from air bubbles in the color. Another important function of a backing plate is to furnish a "bearing" surface for the doctor blade. Therefore, the new coating head was mounted so that the large-diameter rubber-coated roll would serve as a backing. Since the

roll is driven at the same speed as the sheet, it adds no drag. In addition, its surface smooths out any wrinkles in the web which might be occasioned by the coating operation.

Flow of coating material to the coating head has largely been accomplished through the use of pumps. In the first installation, a centrifigal pump was used but it had insufficient capacity, and did not operate well on high-viscosity materials. At present, a Moyno screw-type pump is in use. Coating material flows by gravity and suction to the pump from a copper storage tank. Discharge from the pump can be routed to the coating head or through a bypass back to the tank. A circulating line returns the excess coating from the head to the storage tank. The pressure of the fluid in the coating chamber is controlled by throttling the return line. In another system, the height of discharge from the head was variable, thus insuring a more precise and reproducible measure of the pressure. The fluid head at the coating slot varies with the viscosity of the coating mixture but, with normal conditions, it is not very great (of the order of 1 p/s.i.). Since the flow of coating is low, throttling of the return line is usually not necessary and most of the material pumped is routed through the bypass. Special runs made the use of the pump inadvisable. In those instances, the coating was fed to the chamber through a funnel and hose arrangement. The pressure was varied by adjusting the height of the funnel. The return line was plugged with a rubber stopper.

The vacuum chamber is connected to the general vacuum system by means of heavy walled rubber tubing and a liquid separater.

The foregoing described coating head and auxiliary equipment developed during the course of this work will be available for potential application in a wide variety of coating problems that the Institute may investigate in the future.

Procedures

An ideal procedure for this evaluation would be to start the coating machine, adjust the coating device to produce samples under various vacuum conditions or weights of coatings, and to isolate the effect of any variable for comparison in a single run. Samples free of tears and wrinkles would thereby be obtained for later study. Without adequate drying, however, this was not possible, and successful continuous operation with adequate drying has not yet been attained.

The experimental procedure was rather flexible and varied from run to run as changes were made in the drying equipment or coating head. The coating mixture was usually prepared the day before a given run. The details of the preparation method were as follows:

Preparation of Clay-Starch Coating Color

Composition

Starch	
Clinton modified, g.	1360
Water, g. plus steam condensate	3875
Clay slip	
H. T. coating clay, g.	6575
Water, g.	3065
Quadrafas (dispersing agent), g.	34
Water, g.	340
Coloring and preservative	
Fast red 2BL dye, g.	1
Lignasan, g.	12

The starch is cooked with water by the use of direct steam in a conical-bottom copper kettle. This suspension is agitated continuously with a Lightnin' mixer. The clay slip to be blended with the cooked starch is prepared in a Baker-Perkins mixer as follows: While the clay is being stirred by the mixer, the water is added slowly. After the clay has become thoroughly wetted, the Quadrafas is added. The dye solution is prepared by dissolving the dye in 200 to 300 cc. of boiling water. The starch, clay slip, dye, and Lignasan are finally mixed in the copper kettle and then stored in a covered 5-gallon can until used. Using this procedure, a coating mixture of about 40% solids is obtained.

Preparation of Carbon-Starch Coating Color

Composition

Starch	
Clinton modified, g.	685
Water, g. plus steam condensate	1985
Carbon slip	
Carbon black (Statex B Dense), g.	3425
Water (60° C.), g.	5550
Marasperse CB (dispersing agent), g.	75
Water (boiling), g.	1000

The method of preparation of the carbon slip is essentially the same as that for the clay slip. It is necessary to use water of 60° C. in order to properly wet the carbon. A color of about 18% solids with a viscosity comparable with that of a clay coating of 35 to 40% is obtained from the above formula.

Just prior to use, the color was stirred for at least 0.5 hour with a Lightnin' mixer, precautions being taken to avoid "beating" air into the color. When drying equipment was to be used, it was turned on (with the exception of the infrared lamps) one hour before the start of the run. When the first model coating head was being used, the necessary adjustments in the width of vacuum or coating slots were made before operation. It was necessary to completely disassemble the coating head to replace any of the inserts which were used for adjusting the slot widths. A somewhat different procedure was used with the second coating head. The doctor blade was set to approximately the

correct height. The head was then laid against the web and backing roll and vacuum was applied. The angle of the head was adjusted to that point that gave a maximum vacuum reading. The angle adjustment was very critical and centered about the trailing edge of the vacuum slot. This position proved to be the best with regard to quality and ease of control of coating application. The machine was then started and coating applications were made. When a few feet of paper had been coated, the feed pump and machine were stopped and the sample was examined. Any unevenness caused by misalignment of the doctor blade was corrected. This procedure was repeated until the doctor blade was in the best attainable position to make samples of the coating weight desired. Vacuum conditions or other factors were varied and samples were made. Each sample was made individually, after which time the machine was stopped, the coating head tilted back and cleaned, and the coated paper was torn out. It was then necessary to rethread the machine.

SUMMARY

A total of 29 regular coating runs were made, 11 with the first model coating head and 18 with the second model. During the course of the experimental work, coating colors of 40 to 65% solids were used in making samples of from 2 to 41 lb. (25 x 40—500 ream) coating weight. In one instance, a coated sample of 84 pounds coated weight was produced. A machine speed of 70 to 400 ft./min. was used.

Vacuum conditions from 0 to 24 inches of mercury were investigated. The last ten runs were made with coating mixtures other than starch-clay color. They are of special interest and will be discussed in some detail later in this report.

RESULTS AND CONCLUSIONS

Throughout the history of the paper industry, which is traditionally conservative, there has been a tendency to rely on rule-of-thumb experience rather than on scientific facts because the latter were lacking in many cases. Only recently have physical testing and basic research begun to catch up to the industry's needs. The coating processes like other papermaking and converting operations are inadequately fortified by good analytical tools. This lack of physical tests has been very strongly felt in this study and made it difficult to draw valid and definite efforts to conclusions from experimental work done in evaluating the utility of the Knight-Rowland coater. From this project, there is at hand a wealth of qualitative data but little of a quantitative nature. The data have been collected over the entire series of runs; hence, there will be no attempt to distinguish the results of individual experiments, except where they merit special consideration.

The collection of significant data when using the first coating head was hampered by the fact that reproducible operation could not

be achieved. It was not possible, as an operating procedure, to return the coating head to its original place when it had to be removed. Tearing and breaking of the web were all too frequent occurrences. This, of course, stopped operations until the machine had been rethreaded. Matters were further complicated by the nature of the coating color which is thixotropic—that is, it gels upon standing without agitation. Thus, the color left in the head when the machine is shut down (even though for only a few minutes) "sets" in the lines and the coating slot. This necessitates a thorough cleaning. Therefore, it was never known for certain that any two given runs were identical. Early assumption that two runs were the same led to erroneous conclusions. An example can be cited to illustrate this. A run was made using a 1/8-inch coating slot opening to produce a 40-lb. (25 x 40—500 ream basis) coating. The slot was reduced to 1/16-inch and, with other conditions apparently remaining the same, a 10-lb. coat was produced. This led to the conclusion that the width of coating slot could be used to control the weight of coating. Work with the second model coating head, however, showed that, under the conditions of its operation, the width of the coating slot had no significant control over coating weight, even when varied from 0.006 to 0.375 inch. As has been pointed out with the second model, variations in slot width could be made while coating operations were in progress. This simplified operations and facilitated the study of certain points. By way of contrast, to change the slot width of the first model, the head had to be removed from the machine

and disassembled. In reassembling it was very difficult to achieve proper alignment, so that in some cases a slightly projecting insert would act as a doctor. Or perhaps, when remounted, the angle of the coating face was not quite the same, so that the entire head acted somewhat as a doctor. These illustrations emphasize the difficulty of reaching valid conclusions.

The basis for issuance of the patent on the Knight-Rowland coating process can be summarized as the unique and novel application of vacuum. The primary concern of the evaluation of the process is to determine just what effect vacuum has when used in conjunction with standard coating materials and to translate such data so that the process may find application in industry. In addition to vacuum, there are other factors which may influence the character of a coated sample, variables which must be accounted for before the effect of vacuum can be isolated. Such things as machine speed, width of coating slot, and width of vacuum slot will be discussed, together with their effect on the coated sample.

Machine speed was found to have a slight effect on the weight of the coating. In one instance an increase in speed from 70 to 225 ft./min. reduced the coating weight from 6.8 to 4.2 lb. (25 x 40—500 ream basis). Although the work done on the effect of speed was not extensive, it might be expected from the results obtained that an increase in sheet speed would cause some reduction in coating weight.

The width of the coating slot does not necessarily control the weight of the coating as was indicated in some of the early work. When the coating slot width is decreased, difficulties are encountered from plugging with particles of coating color, which causes streaks in the coated sheet. Sample 1 is an example of such streaks. In practice, a rather large opening (1/8 inch) was used so that the greater proportion of particles would pass through without being caught. The coating slot seemed to serve no other function than to bring a large excess of coating material into contact with the web.

In working with the improved coating head, variations in the width of the vacuum slot were rather limited in scope because of the nature of the backing roll. It has been pointed out that the coating head face is a plane surface in contact with a curved backing roll. As the width of the vacuum slot is increased, the leading edge is drawn farther from the backing roll. Under these conditions, leakages other than those which might cause penetration may be of controlling importance. Usually, a vacuum slot of 3/16 inch was used.

There are certain characteristics desired by a manufacturer of coated paper for his product. Among them are printability and appearance. Great expense of time and equipment has been made in efforts to achieve these ends. It follows that any evaluation of the Knight-Rowland coater or any other coating equipment which would be of interest to the general manufacturer of coated paper would have to show that the

coater could produce a better looking and a better printing sheet than the standard which he now uses or else be easier to control or otherwise more economical to operate. An early claim for this process was the even and smooth samples produced by it. It has been found necessary, however, to control the weight of coating applied by use of a doctor blade; therefore, the appearance of the coated surface depends greatly upon the action of the doctor. The first samples were very heavy (40 to 60 pounds), so that little or no doctoring action was involved. This condition might be expected to produce very smooth surfaced samples.

Surface leakage draws coating material across the divider through "valleys" formed by individual fibers which lie on the surface of the sheet. When vacuum is used under these conditions an extremely light coat might be expected to appear more uniform than one made without vacuum. But, as the sheet is drawn under the coating slot, it is brought into contact with a large excess of color, so that the valleys and individual fibers are flooded. The doctor then scrapes off the excess, leaving the valleys full and the ridges clean. At first glance this may seem to be a desirable situation, for the sheet has, on a small scale, a more uniform caliper than existed before. But the printer is not interested in a uniform caliper only. He prefers uniform weight of coating, since the amount of coating determines the tone and receptivity of ink. The isolated, uncoated fibers may cause skips and picks in his presses. This would seem to make doubtful the application of this coater to a process of machine coating for an extremely light, uniform coating

to be used in rotogravure presses. Samples 2 and 3 are illustrations of a light coating made with and without vacuum. The surface pattern made by the doctor is more readily seen when dye and water (Sample 4) and carbon black (Sample 6) coatings are applied. For a closer examination of the surface characteristics produced by the doctor blade, refer to photographs, Figures 7 and 8.

The doctor is not an ideal method of regulating coating weight. Since it is rigid, clay particles and lint are caught under the blade and cause streaks. Actually, a run of no more than 30 seconds has been made free of streaks. The blade could usually be cleared by pushing it away from the web for a moment. When using viscous coatings, surface tension sometimes pulled coating color behind the trailing edge of the doctor to cause streaks. The doctor blade, when set for light coats, projects beyond the coating head face. Thus, in operation, a thin stream of color flows around the blade to form a border at the edge of the sheet. This can be seen in Sample 2. These things are not of great importance from a commercial standpoint, for they can be corrected by proper design . Some very good coated samples were produced (e.g., Samples 8-12), but they may be the results of proper doctoring action and not necessarily unique to the process.

Forced impregnation or penetration of the porous web by fluid substances is the principal effect attributed to vacuum. To prove that such penetration exists is very difficult for there are no good analytical

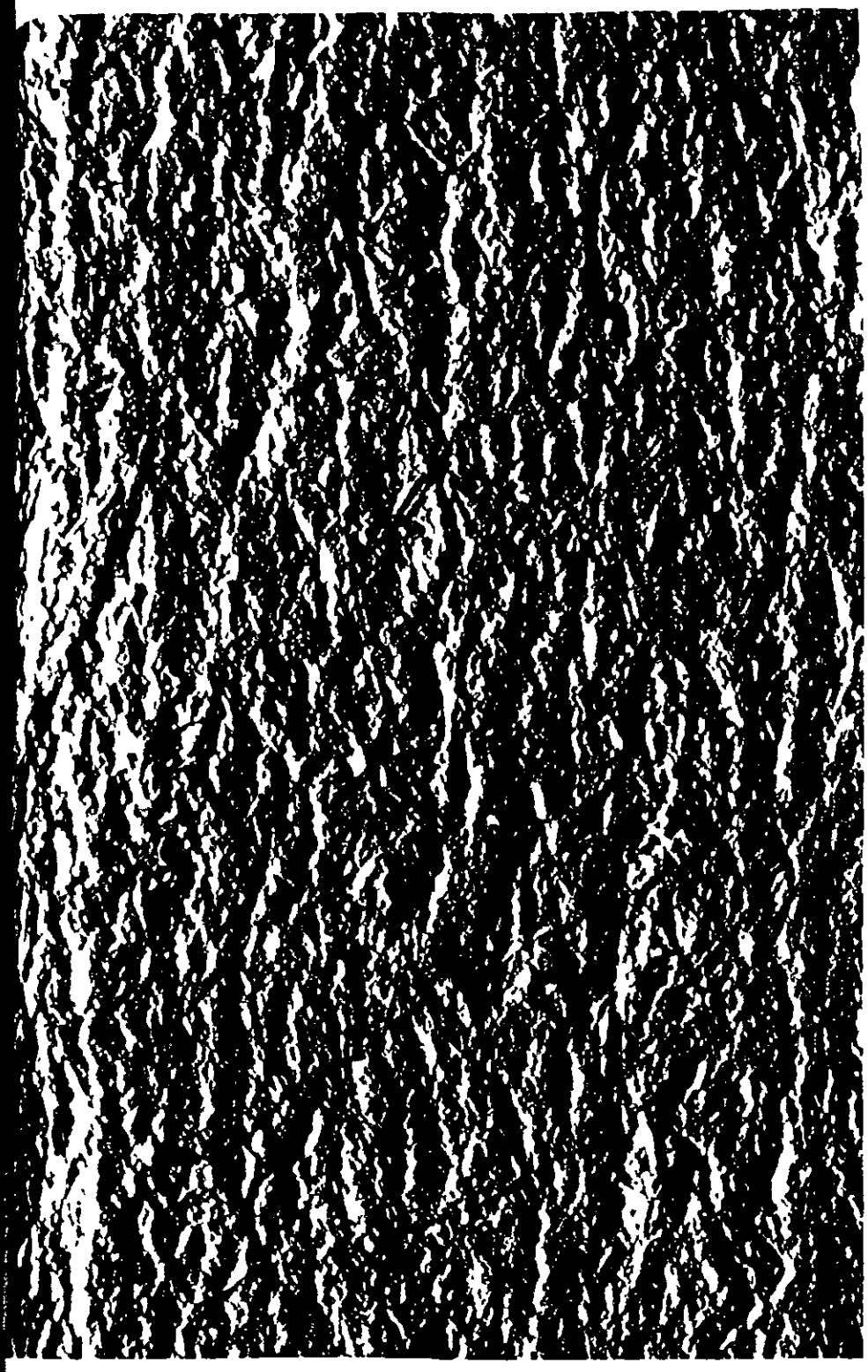

Figure 7

A photograph of the surface of a sheet coated by the Knight-Rowland coating head. The light is at an 85° angle of incidence and across the machine direction. The coated weight is 12 lbs. (25 x 40--500). Vacuum 0-inch Hg. x 20.

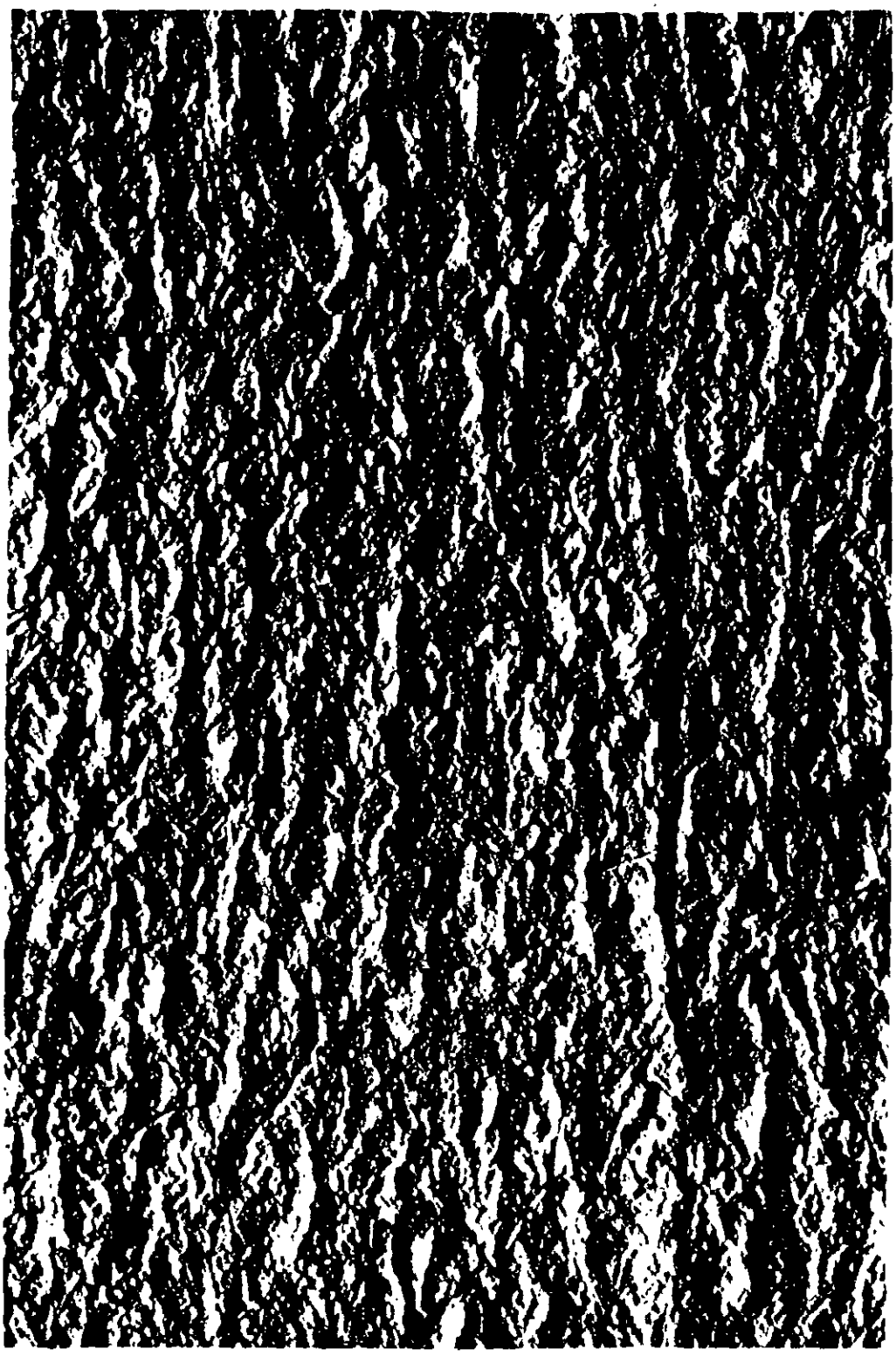

Figure 8

A photograph of the surface of a sheet coated by the Knight-Rowland coating head.
The coated weight is 14 lbs. (25 x 40--500).
Vacuum 20-inch Hg.
All other conditions are the same as those of Figure 7.

methods available for this type of penetration evaluation. Visual comparison of samples made with and without vacuum revealed nothing. Most of the starch in a coating color is associated with the water and relatively little with the clay. The water will, of course, penetrate the sheet whether vacuum is applied or not, the degree of penetration depending upon the local porosity and elapsed time before drying is completed. It is obvious, then, that a sample which has taken longer to dry than another would show more water and, consequently, more starch penetration. An analysis of the depth of penetration of starch into the sheet might, therefore, lead to an invalid conclusion. Cross sections of several coated samples made with and without vacuum were prepared. Photomicrographs of one such series are shown in Figure 9. These reveal very little if any penetration, but cannot be considered conclusive. The area examined in a magnified cross section is so small in comparison with the total area coated that no valid conclusions can be reached from a limited number of observations. If a large number of cross sections, selected according to the procedures of statistical analysis, were examined in a more extensive study, perhaps some decision could be made with confidence.

Penetration is desirable for obtaining greater anchorage of the coating particles. TAPPI has established the Dennison wax pick test as a measure of surface strength. In this work, a series of 15 samples of various weights have been tested with the Dennison wax test,

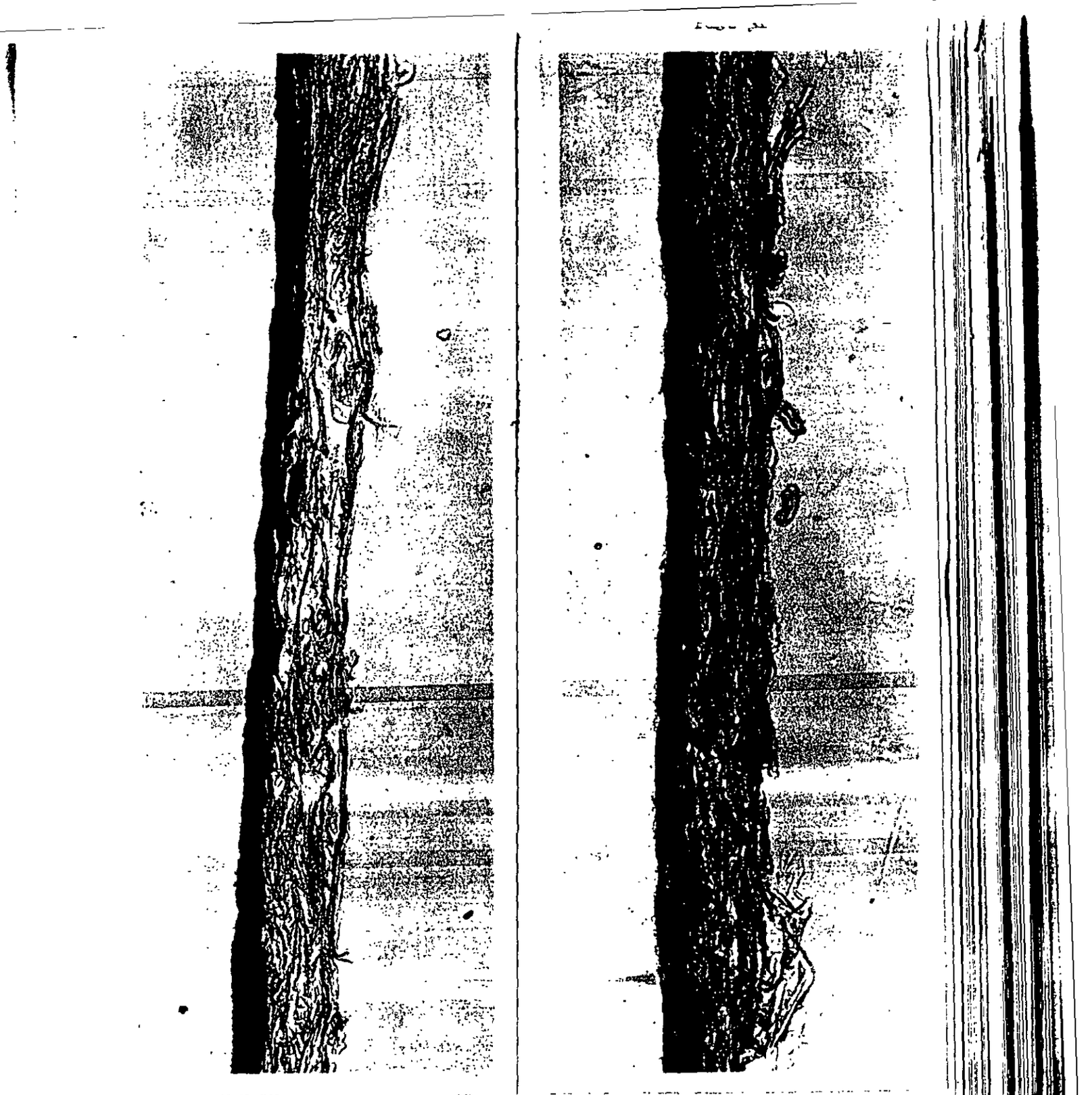

Figure 9

Photomicrographs of cross sections of paper coated with the Knight-Rowland coating head. The upper photomicrograph is of sample made without vacuum; the lower, of a sample made with 20-inches Hg. vacuum. The coated weights are 12 and 14 lbs. (25 x 40--500). The sections have been made in the machine direction. X200.

but they show no differences of practical significance between samples made with and without vacuum.

We are forced, then, to resort to some secondary, indirect method of showing penetration of the coating. A series of tests were designed to simulate defects in the sheet. Thus kerosene, ethanol, pine oil, Du Pont MP 189 wetting agent, and water were sprayed with an atomizer onto the web. Each chemical produced a characteristic pattern which vacuum could not overcome. In each case, the liquid penetrated almost instantaneously through the sheet. When drops of lubricating oil were placed on the web, it slowly penetrated the sheet. When vacuum was not used, the oil which remained on the surface fouled the coating head to such an extent that coating application was effectively blocked. When vacuum was used, it removed the excess, so that the coating application was interrupted only at those points where oil had penetrated the sheet. Much the same result was obtained when clay was dusted on the web. Without vacuum, the clay collected under the coating head until the coating application was stopped. The use of vacuum swept the surface clean, so that the coating application was unaffected. This work was repeated with normal coating color replacing the dye and water mixture. In general, vacuum was ineffective once a material had penetrated into the sheet, but it did remove those things which laid on the surface.

Surface tension might be expected to cause a bridging of coating color between two adjacent fibers so that the valley between

TABLE I

Precoat

Precoat	Coating Weight (25 x 40—500), lb.	Gurley Porosity, sec./100 cc.	TAPPI Size, sec.
Rawstock	0	34	36
0-in. vacuum	1.6	76	33
20-in. vacuum	0.8	68	33

Coating

Precoat	Vacuum, in. Hg.	Coating Weight (25 x 40—500), lb.	Dennison Wax Pick Test
Rawstock	0	40.8	8A
	20	40.8	7A
0-in. vacuum	0	37.8	7A
	20	40.6	8A
20-in. vacuum	0	33.2	8A
	20	41.6	8A

or no increase in bonding strength. Once again, however, we are confronted by a lack of precise or absolute testing methods.

One important segment of the converting industry is that which is devoted to wax treating of paper. Several experimental runs were made to test the feasibility of using the experimental coater for wax emulsion and hot-melt wax applications. A 30%-solids Kress wax emulsion was used in the first runs. The behavior of the wax emulsion

was very similar to that of the starch pigment coatings. Control of coating weight was difficult because of the low viscosity of the mixture. However, it was found that 35% or higher solids emulsions were too viscous to flow properly. Samples of wax coating weights of 0.2 to 20 lb. (25 x 40—500 ream) were produced. Samples 13-16 are examples of typical emulsion coatings. Hot-melt coatings proved to be more promising. Paraffin was melted in a can over a hot plate. The wax then flowed through rubber tubing to the coating head. The head itself was heated to slightly above the melting point of the wax by the use of strip heaters. The only difficulty experienced was that caused by freezing of the paraffin in the vacuum system. In fact, the vacuum lines became inoperative after only 30 seconds of running time and had to be cleared between tests. Coating weights of from 7 to 11¼ lb. (25 x 40—500 ream) were made. They were extremely smooth and even. The light coats filled in the valleys of the sheet, but left a great number of fibers exposed. However, there were not enough exposed fibers to bond the coated surface to another sheet when glued with a starch adhesive. A large amount of wax completely penetrated the web, but there were no apparent differences between samples made with and without vacuum. Samples 17-22 are examples of some of the hot-melt coatings.

Several wax-coated samples were subjected to water-vapor permeability tests to determine how well the wax had sealed the sheet. The precision of the tests is very greatly influenced by pinholes and wax distribution. Therefore, in order to make an adequate evaluation,

a large number of tests would have to be made. In Table II, a series of samples are listed, together with their water-vapor permeabilities. Because of the wide variations, duplicate determinations have not been averaged.

TABLE II

WATER-VAPOR PERMEABILITY OF WAX-COATED SAMPLES

Coating Weight (25 x 40—500), lb.	Vacuum, in. Hg.	Water-Vapor Permeability, g./24 hr./sq. m. Test 1	Test 2
	Kress Wax Emulsion		
0.2	0	1027	991
0.4	20	631	955
0.4*	20	1260	1180
12.5	0	414	36.9
17.5	20	15.9	18.1
17.5*	20	955	825
	Hot Melt		
7.4	0	85.3	236
9.3	23	47.4	18.4
18.6	0	0.28	0.32
19.6	23	0.41	0.52

* The wax in these samples was fused by exposing the coated surface to the heat of an infrared lamp for a few seconds.

From a purely mechanical standpoint, several interesting things might be pointed out regarding the effect of vacuum. Variations in samples within a group prevent making valid comparisons of the effect of

vacuum on coating weight. However, it is known that vacuum draws a large amount of coating into the vacuum chamber. In fact, the liquid trap in the vacuum system of three-quart capacity becomes filled in about 5 minutes of running time. It will be recalled that the vacuum system froze within 30 seconds when coating with hot-melt wax. During a normal run, the coating head presses against the web and backing roll with a pressure of 6.9 p.s.i. When a vacuum of 24 inches of mercury is applied, the pressure is increased to 7.6 p.s.i. If we assume that the difference is concentrated at the vacuum slot, then the additional pressure at the vacuum slot is 5.42 p.s.i. or 11 inches of mercury. Thus, not quite half of the available pressure drop is used in holding the web against the vacuum slot. When coating with a typical color of about 42% solids, the fluid head pressure in the coating chamber has been measured as 1.08 p.s.i. operating without vacuum. When the vacuum is turned on, the pressure drops to 0.35 p.s.i.

Knight stated that an advantage of prior application of vacuum to a porous web is that it removes a stagnant film of air which lies on the surface. This film is believed to interfere with wetting of the fibers. It is logical that, as the web passes under the coating head, a certain quantity of air is trapped on the sheet. Vacuum would remove this trapped air, while the backing roll and resistance offered by the sheet, as well as the short time interval, would prevent its replacement. Under these conditions the coating could then be applied over a surface free of air. However, it may be questionable whether the air film is the

factor controlling wetting, or whether it is merely a secondary or minor delaying factor. If drying were instantaneous, this delay might become important and would have a great effect on the quality of coating. However, drying takes a relatively long period of time. In comparison with the total time available for wetting, the delay caused by the resistance of the air film may be of little importance.

Based upon the results of the work done, it cannot be positively stated that vacuum does or does not have an effect when applied to porous webs. However, the indications are that, if there is an effect, it is very slight. The original laboratory work conducted by Knight seemed to indicate a greater effect than was evident in the pilot-scale study. Several factors might contribute to this lack of corroboration. Except for one run, all of Knight's conclusions are based upon samples coated with a dye and water mixture. Such a mixture does not have finite particle size as does a standard coating color. When standard coating colors are used, it seems logical that the web functions as a filter to prevent any penetration of pigment particles. In addition, the greater proportion of Knight's work was done with the vacuum applied after, not before, the coating color. Another important factor is the phenomena of surface leakage. This is of great magnitude, since vacuum removes the coating which flows around the edge of the doctor blade, a purely surface action. Perhaps more important is the fact that if we assume a sheet speed of only 80 ft./min. (far short of commercial operations), a given segment of the sheet is in contact with the vacuum chamber for

only 0.04 second. If the very maximum of pressure drop is assumed, it can be only 14.7 p.s.i. Thus, there is a rather mild pressure acting for an extremely short period of time. It seems probable that vacuum does not have any great control over the penetration of a material as viscous as coating color.

SUMMARY OF CONCLUSIONS

The mechanical functions of the Knight-Rowland coating process might be divided between those performed by the vacuum system and those of the coating color chamber and doctor blade. The greatest importance is attached to the vacuum action, since it determines the unique value of the process. However, from the test results, it is difficult to say that vacuum does or does not have an effect. Dennison wax pick tests showed no significant difference in surface bonding strength between comparable samples made with and without the use of vacuum. Cross sections of coated samples did not indicate that vacuum pulled the color deeper into the pores of the sheet to any apparent degree. Vacuum does, however, exhibit a sweeping or cleaning action on material lying on the surface. The use of vacuum does not necessarily guarantee a smoother, more evenly coated sheet.

In operation, the coating chamber provides a large excess of color that floods the valleys and exposed fibers of the porous web. A doctor has been found necessary in order that the weight of coating applied can be controlled. The surface characteristics are determined

by the doctoring action. Thus, the appearance and printability of the coated sheet are functions of the operation of the doctor blade and, as such, are not necessarily unique to the process.

In a laboratory study of the Knight-Rowland coater or similar equipment, potential industrial application should be a matter of primary concern. The presentation of data and conclusions drawn from them should be considered in light of future review by the industry, as well as from an academic standpoint. Coating on an industrial scale with the Knight-Rowland coater should be a rather simple, almost automatic operation. The coating head is a compact versatile unit which could be installed almost anywhere in the papermaking process machinery. It can be used to apply a great variety of fluid materials over a wide range of viscosities. However, the vacuum effect, if it does exist, may not be sufficiently prominent to warrant the expense of installation and maintenance of the necessary auxiliary equipment. With general industrial application of primary importance, it can only be concluded that the Knight-Rowland coater is of questionable value as a contribution to the coating industry.

Literature Cited

1. Knight, George D., Wettability and Absorption of Paper Surfaces. Dissertation, The Institute of Paper Chemistry. Appleton, Wis., 1947.

2. Knight, George D., and Rowland, Ben W. U.S. Patent 2,471,330 (May 24, 1949).

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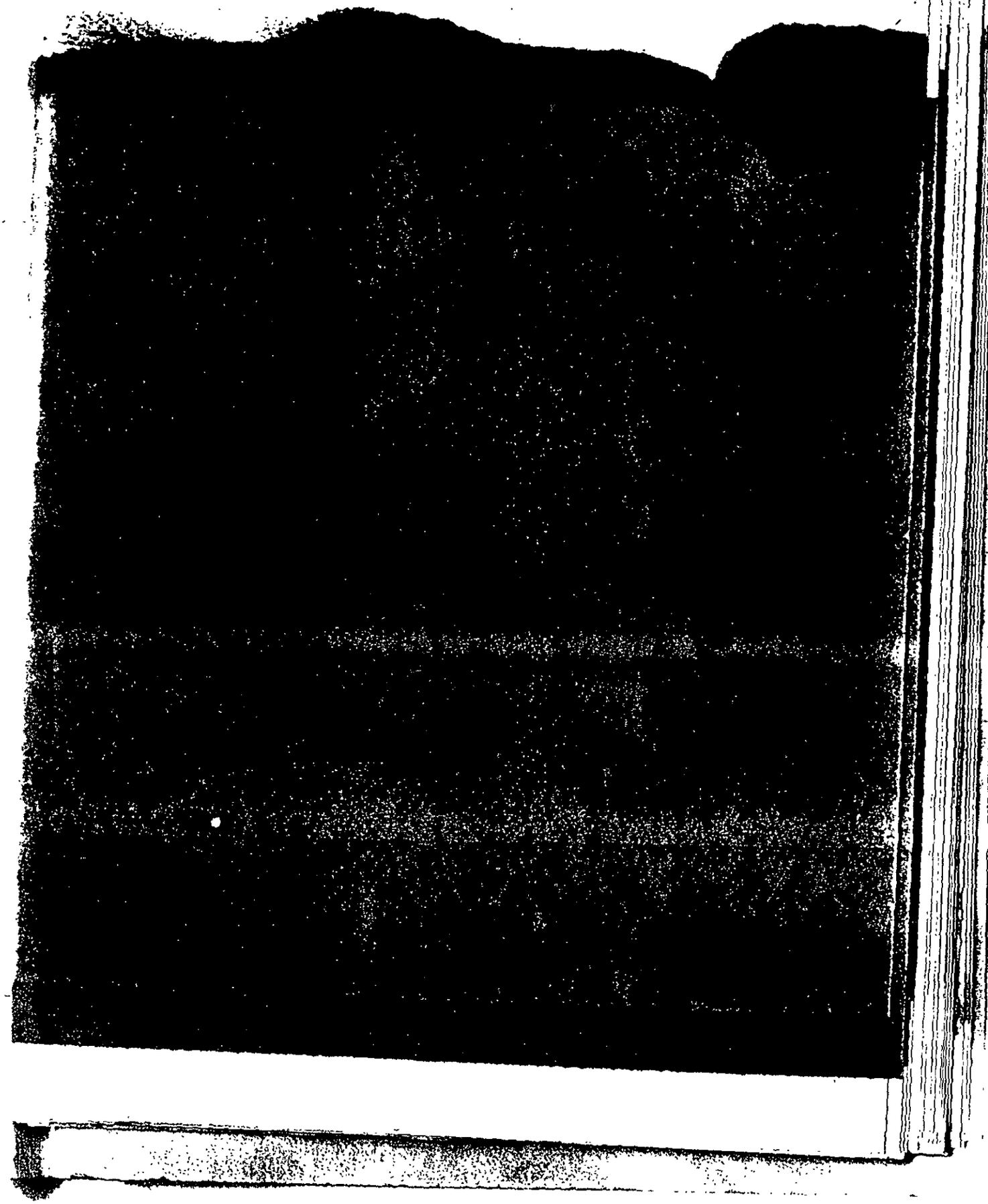
APPENDIX

Sample 1. An illustration of the streaks caused by particles which become lodged between the doctor blade and web.

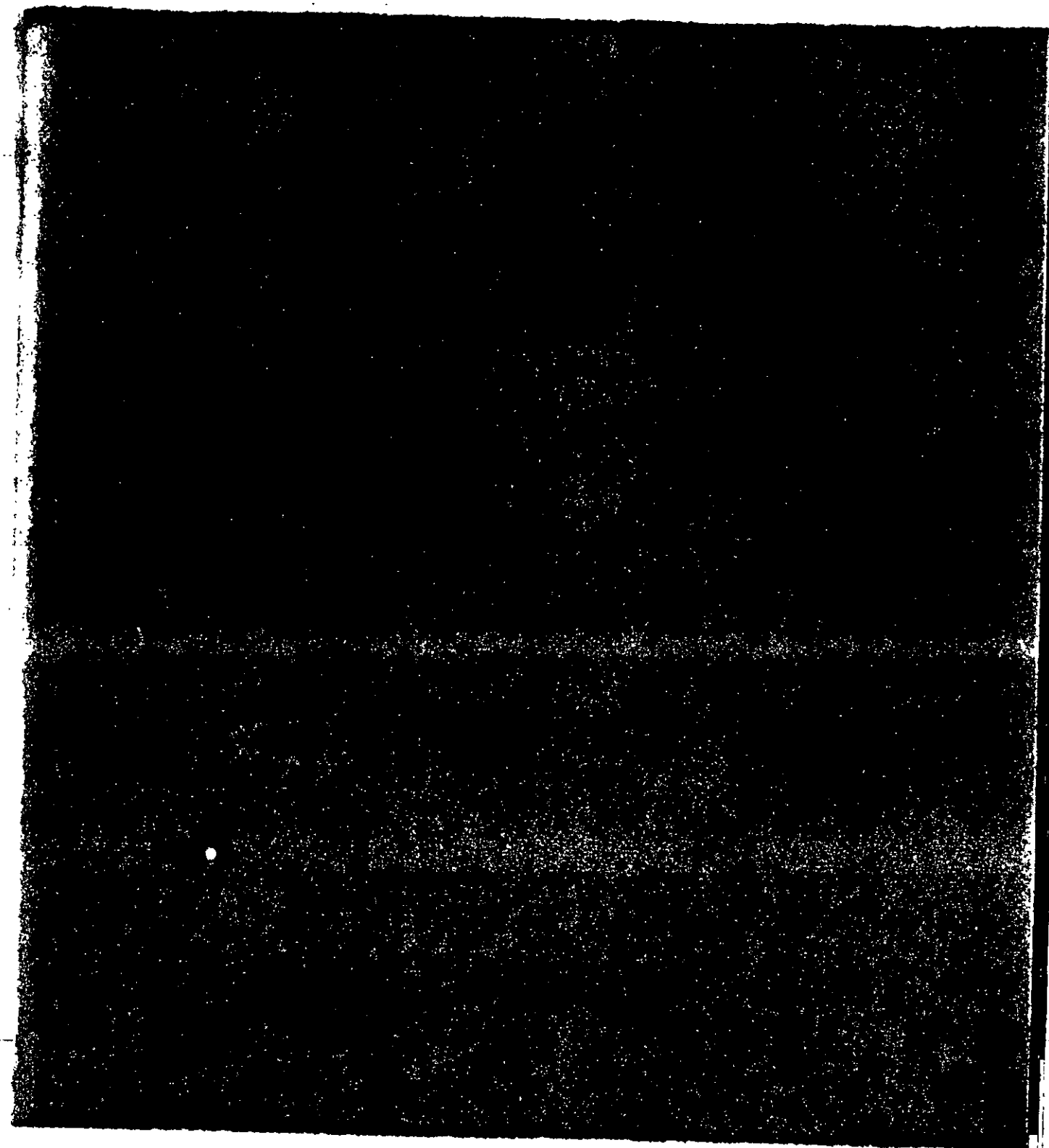
Sample 2. A light coat. Coated weight 4.2 lb.
(25 x 40—500) 0-inch Hg vacuum.

Sample 3. A light coat. Coated weight 5.1 lb. (25 x 40—500) 20-inch Hg vacuum. All other conditions were the same as those of Sample 2.

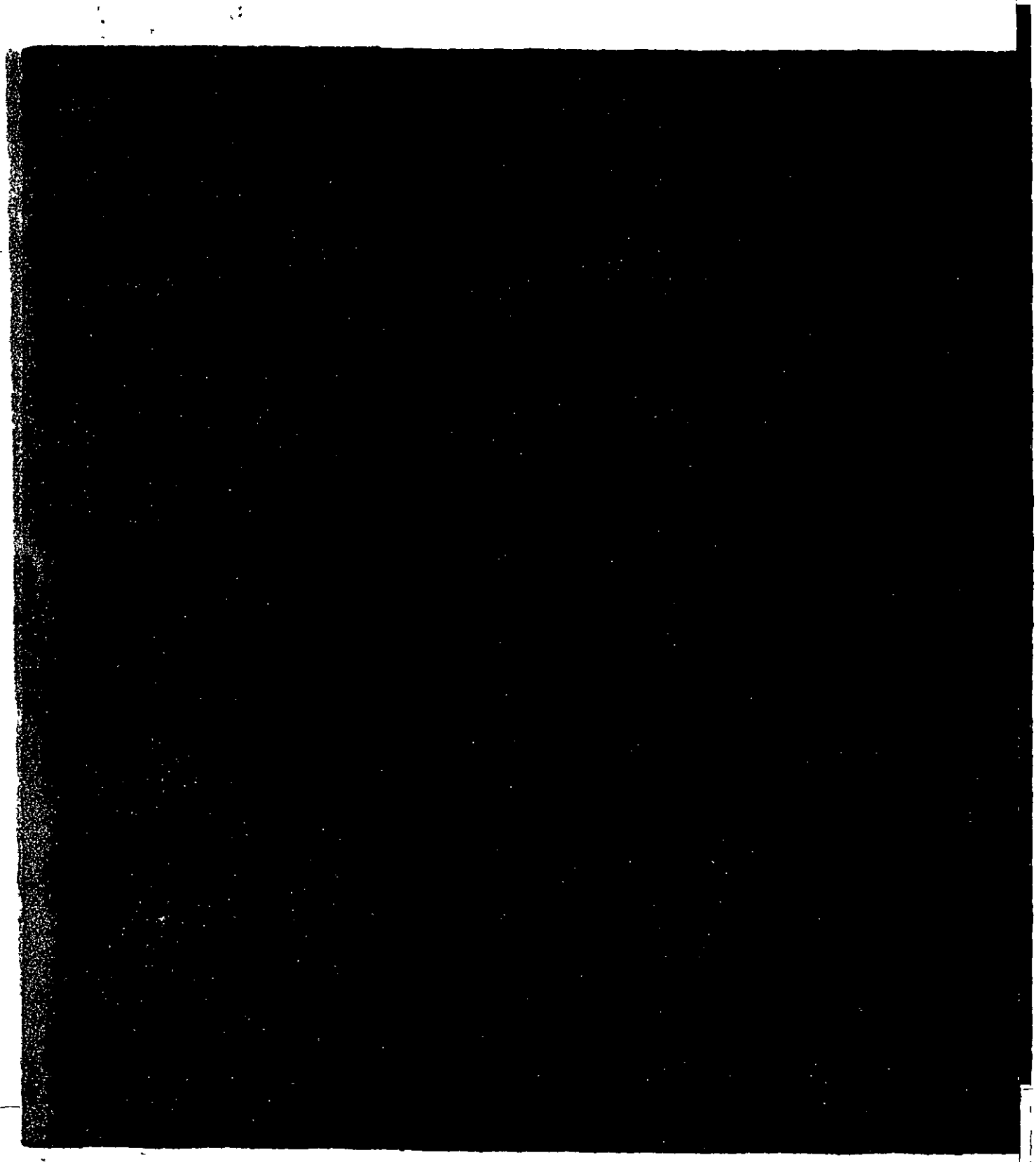
Sample 4. The surface patterns of a light coat, 0-inch Hg vacuum using dye-water coating mixture.



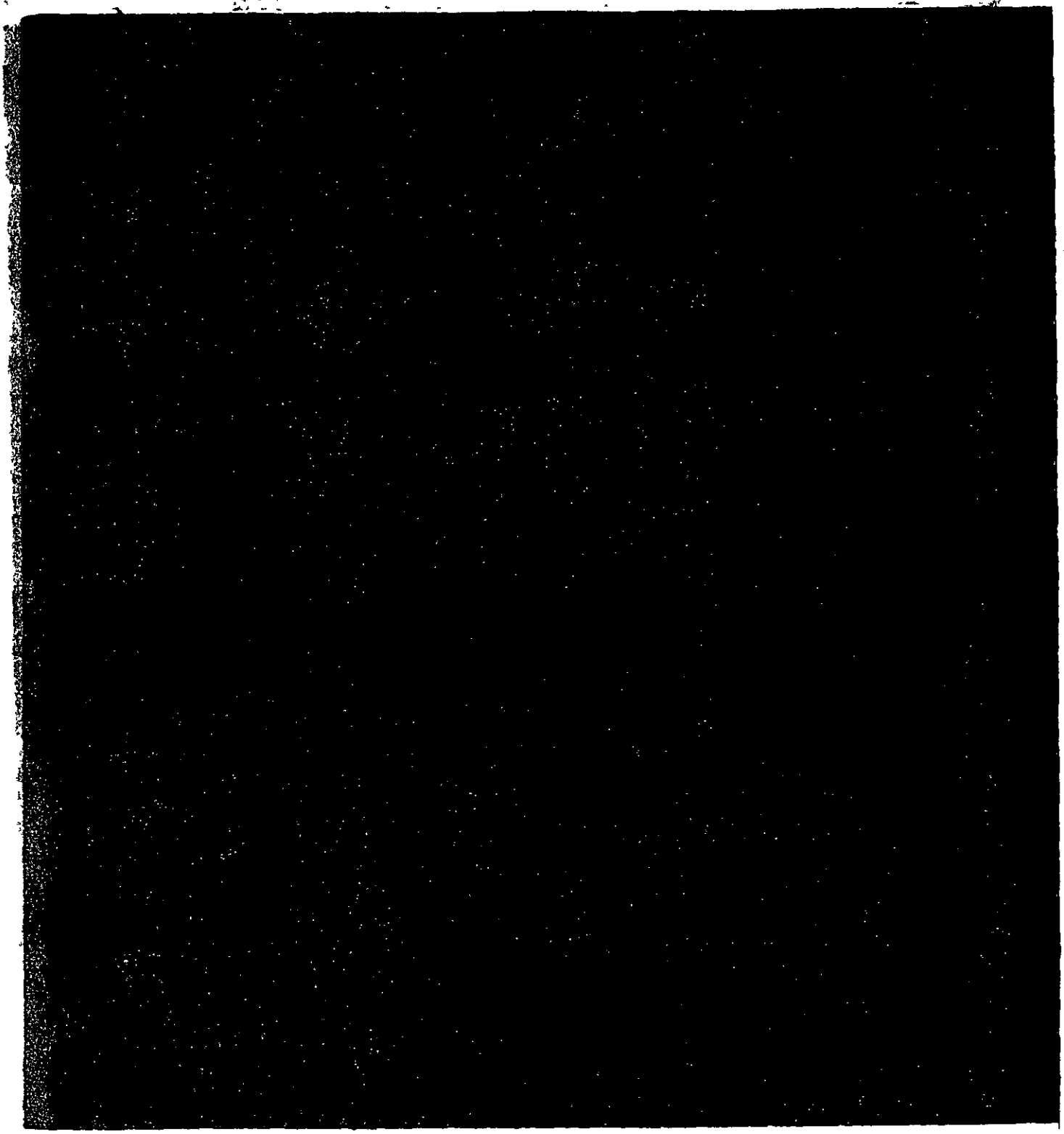
Sample 5. The surface patterns of a light coat. 20-inch Hg vacuum. All other conditions were the same as those of Sample 4.



Sample 5: The surface patterns of a light coat, 0-inch Hg vacuum, using Carbon-Black-Starch coating mixture.



Sample 7. The surface patterns of a light coat. 20-inch Hg vacuum. All other conditions were the same as those of Sample 6.



Sample 8. Coated weight 6.6 lb. (25 x 40—500); 0-inch Hg vacuum.

Sample 9. Coated weight 12.0 lb. (25 x 40--500); 0-inch Hg vacuum.

Sample 10. Coated weight 16.9 lb. (25 x 40—500); 0-inch Hg vacuum.

Sample 11: Coated weight 39.2 lb. (25 x 40--500); 0-inch Hg vacuum.

Sample 12. Coated weight 46.8 lb. (25 x 40--500); 20-inch Hg vacuum
All other conditions were the same as those of Sample 11.

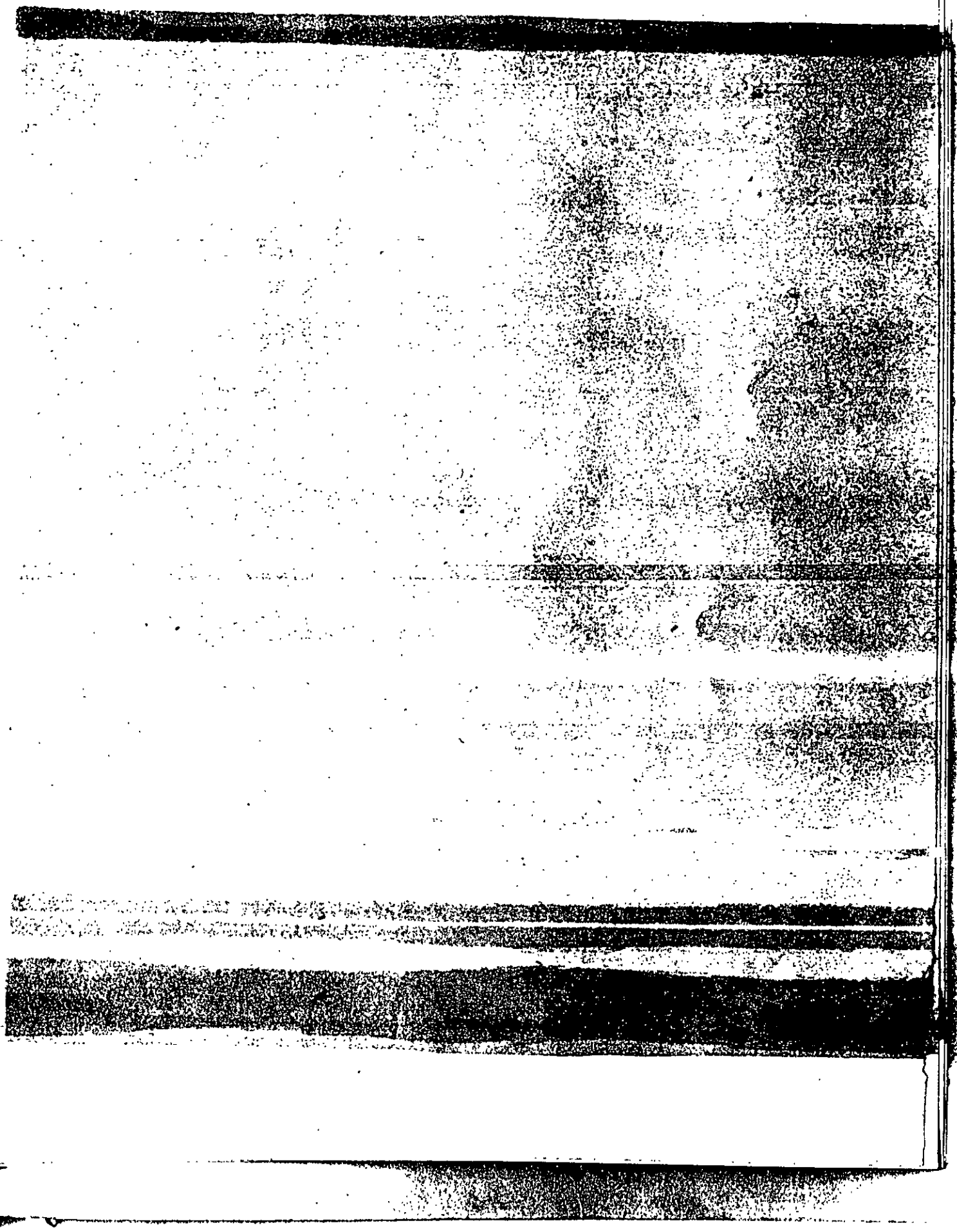
Sample 13. Wax emulsion coating. Coated weight 0.2 lb. (25 x 40--500); 0-inch Hg vacuum

Sample 14. Wax emulsion coating. Coated weight 0.4 lb. (25 x 40—500); 24-inch Hg vacuum. All other conditions were the same as those of Sample 13.

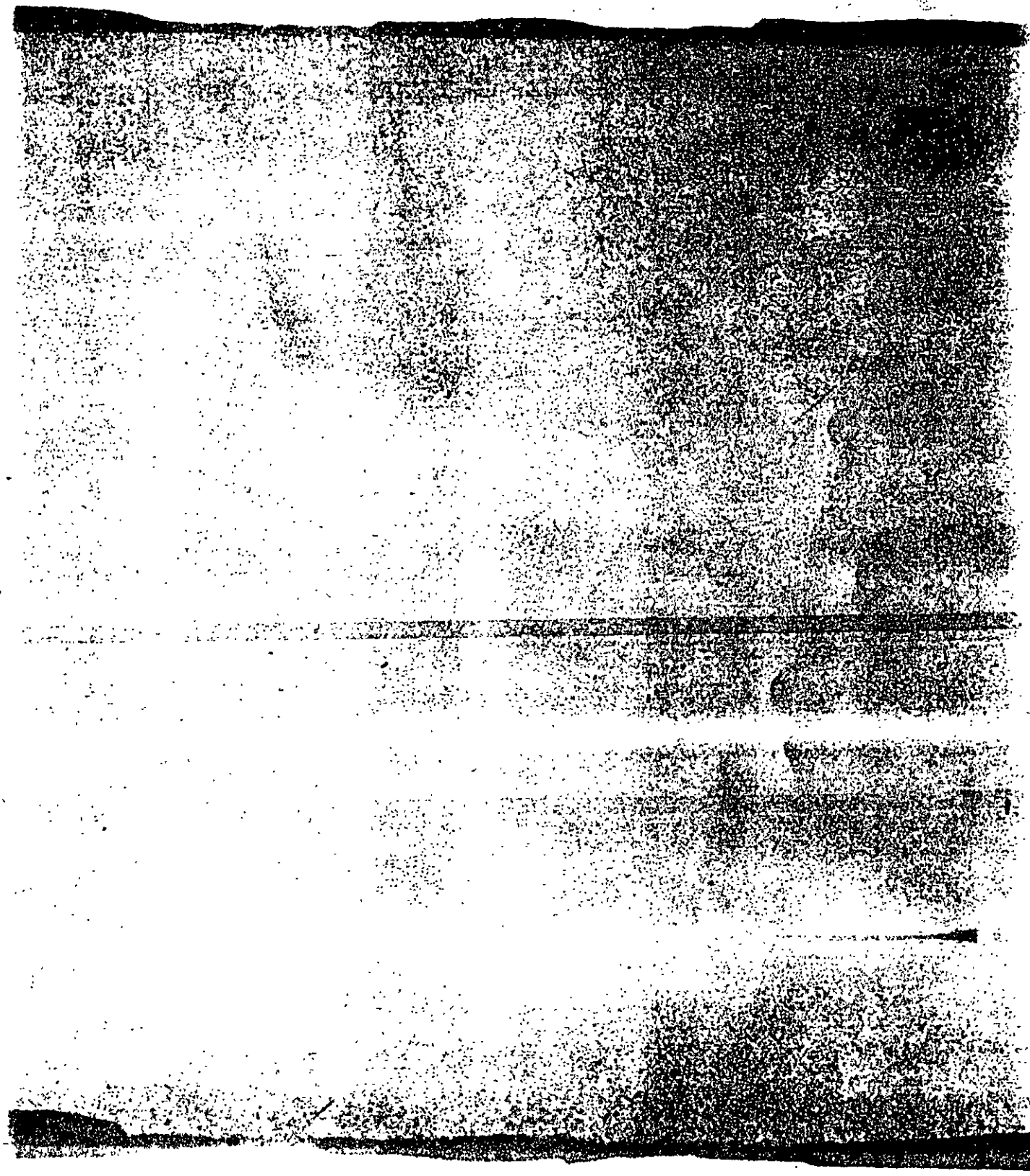
Sample 15. Wax emulsion coating. Coated weight 12.5 lb. (25 x 40—500); 0-inch Hg vacuum

Sample 16. Wax emulsion coating. Coated weight 17.5 lb. (25 x 40--500); 24-inch Hg vacuum. All other conditions were the same as those of Sample 15.

Sample 17. Hot-melt wax coating. Coated weight 7.4 lb. (25 x 40—500); 0-inch Hg vacuum

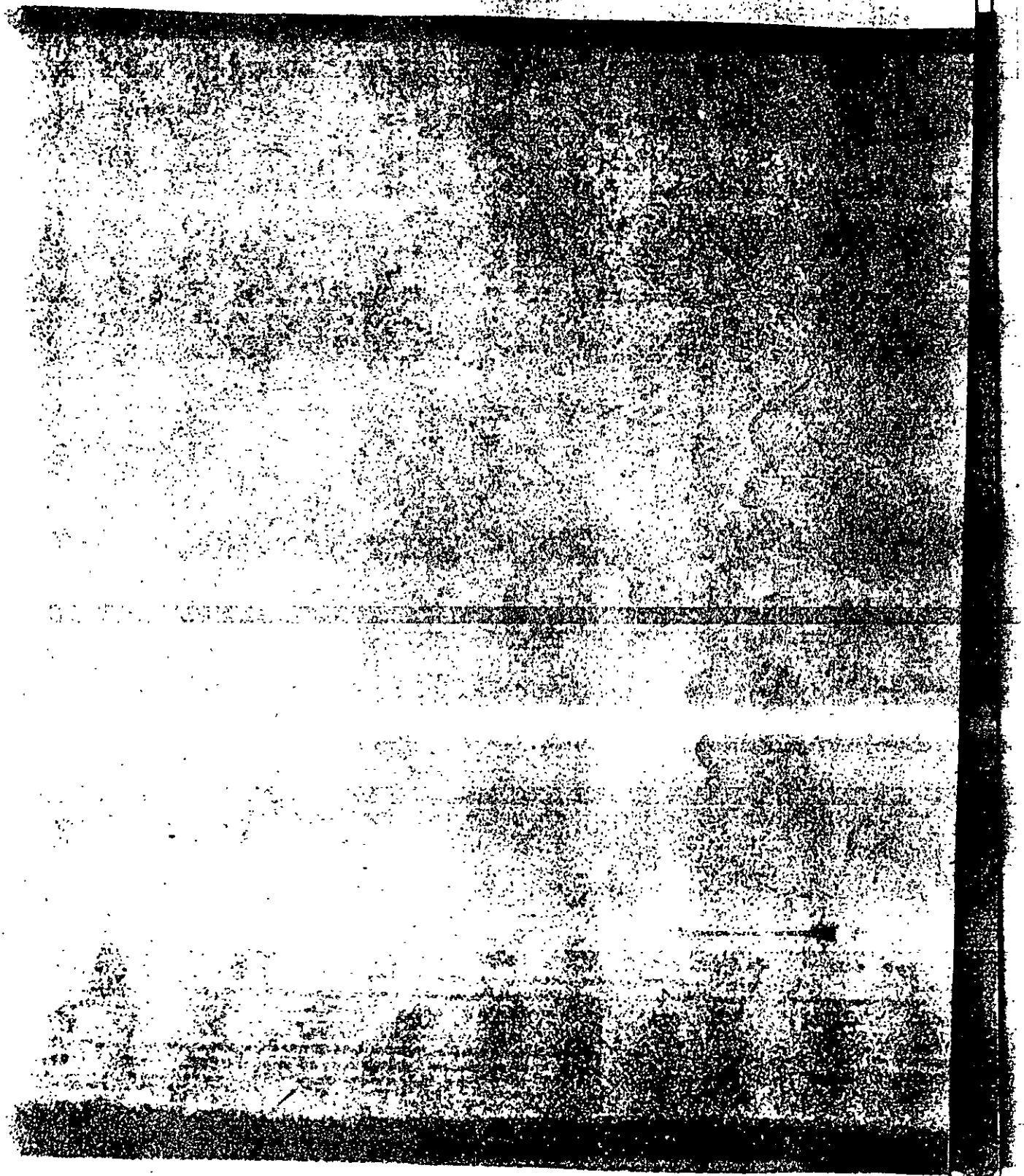


Sample 18. Hot-melt wax coating. Coated weight 19.3 lb. (25 x 40--500); 24-inch Hg vacuum. All other conditions were the same as those of Sample 17.

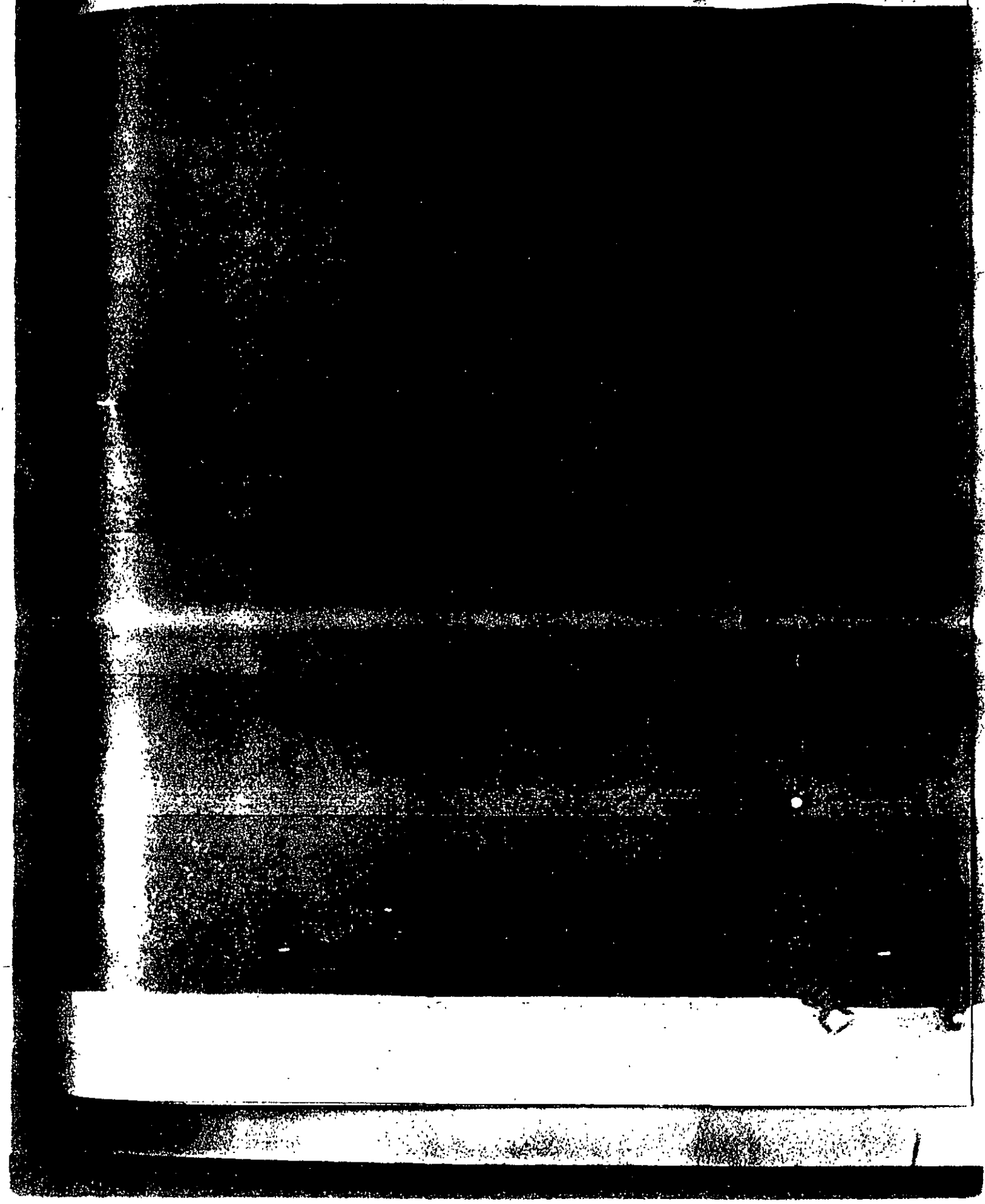


Sample 19. Hot-melt wax coating. Coated weight 14.5 lb. (25 x 40—500);
0-inch Hg vacuum

Sample 20. Hot-melt wax coating. Coated weight 14.3 lb. (25 x 40—500); 24-inch Hg vacuum. All other conditions were the same as those of Sample 19.



Sample 21. Hot-melt wax coating. Coated weight 74 lb. (25 x 40--500); 0-inch Hg vacuum



Sample 22. Hot-melt wax coating. Coated weight 69 lb. (25 x 40—500); 24-inch Hg vacuum. All other conditions were the same as those of Sample 21.