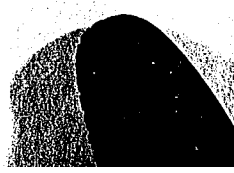

THE PHYSICAL PROPERTIES OF ELECTROLYTIC NICKEL DEPOSITS FROM SOLUTIONS CONTAINING ADDITIONS OF VARIOUS ORGANIC SUBSTANCES

By

John Wallace Pearce

A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Chemistry

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Approved H. T. Ewing

JOHN WALLACE PEARCE

ABSTRACT

The physical properties, appearance and surface roughness of Watts nickel solution deposits have been studied and compared with the properties obtained when small additions of organic substances were present in the depositing solution. Nickel deposits were obtained from a Hull-type cell which yields a wide current density range of metal deposition on a single cathode. The groups of organic compounds added to the Watts nickel solution included reducing carbohydrates, polymers, and unsaturated aliphatic compounds, carbonyl compounds, dyes and phenols. The effects on a Watts nickel solution deposit of single additions of these compounds, additions in the presence of 2,7-naphthalene disulfonic acid and, for the carbonyls compounds, additions in the presence of cobalt sulfate and a nickel organic acid salt were reported. Some exploratory data for predipping the cathode in a solution of a proven brightener or covering with filter paper previous to deposition in a Watts nickel solution was also reported.

Appearance tables have been constructed using the terminology suggested by "Metalfinishing Guide Book-Directory, 1950" for each general addition outlined and photographs of the appearance effects have been included. Surface roughness effects have been

evaluated at 9.0 and 6.5 amp./sq. dm. Roughness data tables have been constructed to report the surface data and curves have been included as possible interpretations of the trends observed in the roughness data. A table of decreasing brightener strength based on optimum appearance effects has also been included.

Functionality of the organic molecule has been suggested as a vital requisite for desirable modification of the nickel deposit. Structural isomers of nitrophenol varied in effect on the deposit. This was observed less markedly in the base of the amino-phenols. Degree of unsaturation tended to be important and directly related to modifying of the deposit. The possibility of a pi-complex metallo-organic compound in the cathode layer was suggested. Trends toward some correlation between oxidation potential of the carbonyl compounds studied and their brightening properties were discussed and interpreted in view of a postulated metal hemi-acetal intermediate species. The views of Mathers, who proposed the theory of the importance of complex compounds in metal deposit modification, were considered qualitatively and extended to the use of organic additions for modifying a nickel deposit. Based on the items discussed, some favorable agreement was indicated. The results were not definitely

concluded toward the view of Mathers, however, since adsorption phenomena were not eliminated as a possible explanation.

Two new brighteners, Monastral Blue and PVM/MA, were reported.

ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to Dr. Dwight T. Ewing whose privileged association, kind inspiration, and interest are highly valued. The writer is also greatly indebted to Dr. E. J. Miller and Mr. P. Coleman for their indispensable help in obtaining the included metal surface photographs. The many helpful suggestions of the Guidance Committee and fellow students are gratefully acknowleged.

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INTRODUCTION

It is known that the presence of organic substances in nickel plating solutions markedly affects the physical properties of electrolytic nickel. No general correlation with the type of such organic compounds and the nature of the electrodeposited nickel has been formulated. This investigation is a study of the effect of the addition of various organic compounds to nickel sulfate solutions on appearance and other surface properties.

Schlötter (1) has found that aromatic polysulfonates added to solutions of nickel sulfate reduce the crystal size and yield a high-gloss compact, adherent deposit. However, the range of current density, temperature, and concentration of the solution is narrow. This range for acceptable deposits is greatly improved by adding optimum concentrations of another organic substance.

Pinner, Soderberg, and Baker (2) have divided addition agents into two fairly distinct classes. In the first class, they have assigned cobalt salts, aryl sulfonamides, aryl sulfonimides, aryl sulfonic acids as well as aryl polysulfonic acids. These substances are characterized by not necessarily yielding bright deposits but giving grain refinement to the deposit. The second class included cadmium and zinc salts, sodium formate, aldehydes, ketones, and amino polyaryl

methanes. By combining substances of the two classes, maximum brightness and smoothening are obtained.

In addition to the organic compounds pointed out by Pinner et al., gum tragacanth (3), lead citrate (4), sulfonated oleoresins and natural resins (5), sodium formate (6), azo compounds (7), sulfite cellulose (8), safranine compounds (9), mercaptopyrimidines (10), starchates (11), thiourea (12), sulfurized gelatin (13), and carboxymethyl cellulose (14) have been claimed to give acceptable deposits of nickel.

However, although many organic substances used as addition agents favorably modify the deposit, very little is known about the manner in which these addition agents act. At least four theories have been proposed to explain the mechanism of bright electrodeposition. We shall briefly consider them here in order of their appearance in the literature.

1. Adsorption Theory. In his "Axioms of Electroplating," W. D. Bancroft (15, 16) offered as his fourth axiom: "The crystal size is decreased when there are present at the cathode surface, substances which are adsorbed by the deposited metal." R. Taft and H. E. Messmore (17) explain their data on the electrodeposition of copper in the presence of gelatin, most directly, by assuming that

the copper deposited by the current adsorbs gelatin on its surface. P. K. Frölich (18) demonstrated the contamination of deposited nickel with organic matter when deposited in the presence of gelatin. He found Bancroft's idea of an adsorbed film of the addition agent at the cathode highly hypothetical. Frölich suggested that experimental results were unavailable to corroborate the theory. Further, he pointed out that work reported by Holmes and Child (19) with gelatin and an emulsifying agent, which represented optimum conditions for film formation, was unable to establish any concentration of gelatin at solution interfaces.

2. Reducing Agent Theory. E. F. Kern (20) observed that reducing agents such as polyhydroxyphenols, tannins, and aromatic amines refined the grain deposits of copper, lead, and silver. Oxidative anions such as nitrate and perchlorate did not, however, yield such favorable results. He suggested: "The function of an addition agent in an electrolyte is to maintain a reducing menstruum around the cathode which, in turn, causes the deposit to form denser and smoother."

Henricks (21) has maintained that this reducing agent theory is untenable. He based his decision on the observation that fine-grained metal deposits can be obtained from tin perchlorate solutions, acid copper baths containing nitrates, and chromic acid baths.

3. Complex Ion Theory. F. C. Mathers (22) has suggested that effective addition agents form complex ions with the depositing metal. Investigations based on refining silver deposits to yield smooth, hard, entirely adherent cathodes from silver nitrate, nitric acid baths containing tartaric acid led to this concept. G. Fuseya et al. (23) found that silver and copper formed complex ions with metaphosphoric acid, tartaric acid, and glycocoll which were positively charged. These were the substances which entered into the cathode deposits, increased their weight, and caused the crystal size to be smaller. Sugars and higher alcohols, on the other hand, did not form significant complexes with copper and silver and did not in any way, or only very slightly, affect the cathode deposit.

From the studies of Pauli (24) and J. Matula and M. Matsumura (25), it was interpreted that protein has the property of forming complex cations with metal ions. N. Isgarischew (26) ascertained the existence of complex cations, composed of gelatin and zinc or copper ions. He attributed the favorable effect of gelatin as an addition agent to this complex-forming property. According to his view, the growth of crystals is retarded upon adding gelatin since the velocity of separation of free metallic ions from complex ions is not great.

This view is to be sharply differentiated from that of G. Fuseya et al. (23) in their effort to develop the complex ion theory. Here, while the property of forming complex cations is an essential to make gelatin a good addition agent, the codeposition of the complex cations with metallic ions will be the principal cause of hindrance to crystal growth.

4. Cathode Interference Theory. L. B. Hunt (27) has concluded that the crystalling structure of an electrodeposited metal will be governed by the relation of the metal ion concentration in the cathode film to the concentration of the other constituents of that film. If the proportion of metal ions to inert particles is comparatively high, there will be little interference with crystal growth and coarsely crystalline deposits will result. If the proportion is low due to a low degree of dissociation, complex ion formation, high hydration of the metal ions, or presence of colloid matter that has migrated cataphoretically into the film or has been joined therein, there will be considerable interference with crystal growth, with consequent formation of many nuclei. The contents of the cathode layer were considered as composed of species approaching, leaving the layer, and those randomly found in the layer. Species considered approaching the cathode layer besides the metal ions are other cations

such as hydrogen, complex cations, water dipoles, and colloidal bodies which are cathode migrant. Leaving the layer are anions, complex anions, and water dipoles. Randomly found in the layer are undissociated molecules and solvent molecules.

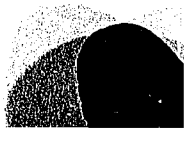
The first event on the approach of a cation to the cathode will be the loss of its anionic atmosphere, which will be followed by the loss of the solvent sheath or the complex portion of the ion. The latter may remain adsorbed to a slight extent and thus be included in the deposit. Molecules adsorbed from the cathode will return into solution, whereas colloidal matter will not, but may accumulate temporarily as a diaphragm, a short distance from the cathode, prior to its redistribution by diffusion or electrophoresis. Further, certain colloidal particles, more particularly those consisting of basic matter, will be adsorbed more firmly and in greater amount owing to their attachment to the metal ion, and will behave in a manner similar to complex ions.

Hunt's theory of interference has been given considerable support by considerations of the mechanism of lattice formation, the electron theory of metals, metallic cohesion, interfacial phenomena, inclusion of basic matter in the deposit, and the deposition of foreign cations. It was suggested that changes in polarization could not be

expected to account for the variations in structure of electrodeposited metals. Rather, each species present in the electrolyte must be considered on its own merits with respect to the forces acting upon it and its behavior under these forces.

J. A. Hendricks (21) has extended the views of Hunt. He has considered that a brightening process may be compared with the Liesegang phenomena which is often explained as a periodic supersaturation and precipitation. For bright deposition, a pulsating adsorption of a colloid and the deposition could explain the production of a striated deposit.

Perhaps more significantly, Hendricks pointed out the parallelism between brighteners and their properties as "inhibitors" or inhibitor properties of their reduction products. He assumed the following steps in his mechanism: (a) an active center of metal at a higher potential than the surrounding crystals; (b) electrolytic reduction of adjacent brighteners at the higher potential, (c) temporary halt of growth of inhibited point, (d) uninhibited layer continues to grow until each in turn increases potential and becomes filmed with inhibitor, (e) filmed cathode shifts to cathode deposition, and (f) repetition of the adsorption cycle.



CHEMICALS USED

Ferrous sulfate, Baker and Adamson.

Cobalt sulfate, Merck.

Nickel sulfate, Harshaw, plater's grade.

Nickel carbonate, Bakers C. P.

Nickel chloride, Bakers C. P.

Nickel formate.

Boric acid, Merck A. C. S. Specification.

Electrolytic Nickel anodes.

Steel cathodes.

Activated carbon, Norit A.

Sodium hydroxide, Baker.

Sodium meta-silicate, Eimer and Amend C. P.

Trisodium phosphate.

Sodium carbonate.

Sodium acetate, Mallinckrodt, A. C. S. Specification.

Carbon tetrachloride.

2,7-Naphthalene disulfonic acid, Eastman White Label.

Glyceraldehyde, prepared by Dr. Speck.

D-Xylose, Phanstiehl C. P.

D-Glucose, Phanstiehl C. P.

Lactose hydrate, Phanstiehl C. P.

Raffinose hydrate, Eastman White Label.

Dextrin, Phanstiehl C. P.

Camphor, Du Pont.

p-Bromoacetophenone, Eastman White Label.

Cinnamaldehyde, Redistilled, Eastman White Label.

Acetaldehyde, Eastman White Label.

Chloral, Eastman White Label.

Pyruvic acid, Eastman White Label.

Butyl chloral, prepared by Dr. Goerner.

beta-Methyl umbelliferone, Koppers.

Methyl cellulose, Dow, viscosity 400 centipoises.

Polymethyl vinyl ether-maleic anhydride, Gen. Aniline & Film; hereafter also referred to as PVM/MA.

Polyvinyl alcohol, Du Pont Elvanol 51-05.

Acrylic acid, Goodrich Glacial.

"Monastral" Blue BG, Du Pont.

Clayton Yellow, National Aniline.

4,4'-Dihydroxybiphenyl, Dow.

3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl, prepared by Dr. Hart.

Phenol, Redistilled, Dow.

o-Nitrophenol, Eastman White Label.

p-Nitrophenol, Eastman White Label.

Chloracetic acid, Eastman White Label.

Formic acid, Bakers C. P.

o-Aminophenol hydrochloride, Eastman White Label.

p-Aminophenol hydrochloride, Eastman White Label.

Catechol, Eastman White Label.

Resorcinol, Eastman White Label.

beta-Naphthol, Eastman White Label.

1,4-Butynediol.

Ethyl pyruvate, prepared by a Fischer esterification of pyruvic acid and ethyl alcohol and distillation with reduced pressure.

Glyoxal, Matheson 30% solution.

Primuline Yellow, National Aniline.

Methylene Blue N. F. IX, National Aniline.

Toluidine Blue O, National Aniline.

EXPERIMENTAL

The Solution

In order to observe the effects of organic substances upon a nickel deposit, a standard Watts nickel-plating solution was used. This solution is of practical importance for dull-nickel deposition and is the basic formula for most of the present bright-nickel plating solutions (28). The composition of this solution was:

Nickel sulfate	240 g./1.
Nickel chloride	45 g./1.
Boric acid	30 g./1.

Because of the effects of impurities in electroplating solutions on electrodeposits, reported by Ewing and Gordon (29) careful purification of all electroplating solutions was carried out prior to their use in this investigation. Chemically pure or electroplater's grade salts were used and further purified according to the procedure suggested by Project 5 of the American Electroplaters' Society (30). This procedure has been fully described in the reference but, briefly, consists of the following treatment: (1) a high pH (approximately 5.5) precipation of impurities followed by filtration, (2) a low current density electrolysis, using an electrolytic nickel anode and a corrugated

cathode at cathode current density of 5 amperes per square foot of projected cathode area, for 100 ampere-hours per gallon of solution, and (3) a carbon treatment of the nickel solution. Chemically pure nickel carbonate and sulfuric acid were used to adjust the pH of the solution. Electrolysis was carried out at pH 2.2, which is the usual acidity of low pH Watts nickel-plating solution. Activated carbon treatment consisted of an addition of 15 grams per liter of Norit A to the hot solution, cooling and filtering.

The Cell

For this investigation, metal deposition was carried out in a Hull-type cell (31). In this manner, a large span of current densities could be observed on a single cathode. A rectangular glass container $2\frac{1}{2}$ inches by 5-1/4 inches, and deep enough to hold 1 liter of plating solution, held the contents of the cell. Anodes of electrolytic nickel were placed at one end of the cell. At the other end, cathodes of 0.016 inch mild steel, having dimensions 2 inches by 4-1/16 inches (32), were placed so that the longer dimension of the cathode spanned the narrower dimension of the museum jar and the leading edge of the cathode was 1-7/8 inches from the anode, while the trailing edge was 5 inches from the anode. Figure 1 illustrates a top view of the cell. Three amperes of current were

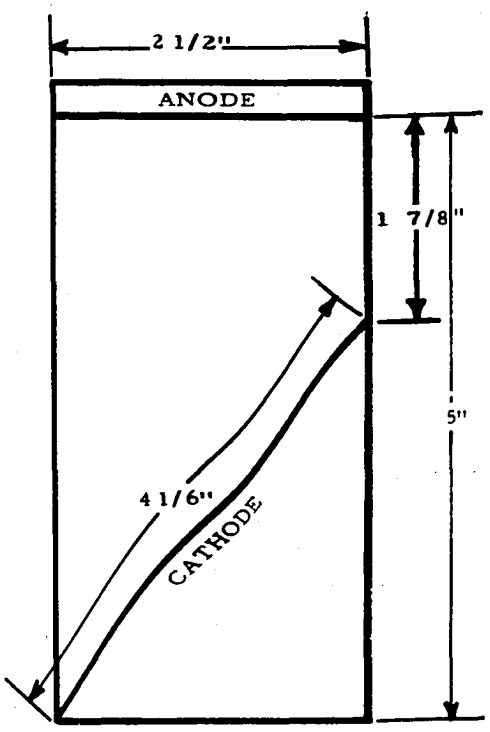


FIGURE 1. A TOP VIEW OF THE CELL USED FOR DEPOSITION AT VARIANT CURRENT DENSITY.

passed for 20 minutes (33). Figure 2 shows a plot of current density versus observed plating range for this procedure.

The electrolytic nickel anodes were dipped in 20 percent HCl, washed with redistilled water and placed in an 8 ounce cotton drill-cloth anode bag prior to immersion in the cell. In order to reduce contamination by the anode bag during electrodeposition, all anode bags were desized before use. This procedure consisted of boiling the cloth in 0.001N. hydrochloric acid for 15 minutes, washing with distilled water, washing with 0.001N. sodium carbonate solution, and finally washing with copious amounts of distilled water. Before using the desized anode bags, they were rinsed carefully with doubly distilled water.

Before deposition, cathodes were cleaned in a conventional manner. This consisted of: (1) preliminary degreasing in carbon tetrachloride, (2) anodic electrocleaning for 2 minutes at 10 amperes per square decimeter, (3) dipping in 20 percent hydrochloric acid, and (4) rinsing with double distilled water. Immersion rinses were necessary between steps (2) and (3). The alkaline electrocleaner had the following composition:

Sodium hydroxide	21	g./l.
Sodium meta-silicate	15	g./l.
Trisodium phosphate	18	g./l.
Sodium carbonate	6	g./l.
Sodium acetate	7.5	g./l.

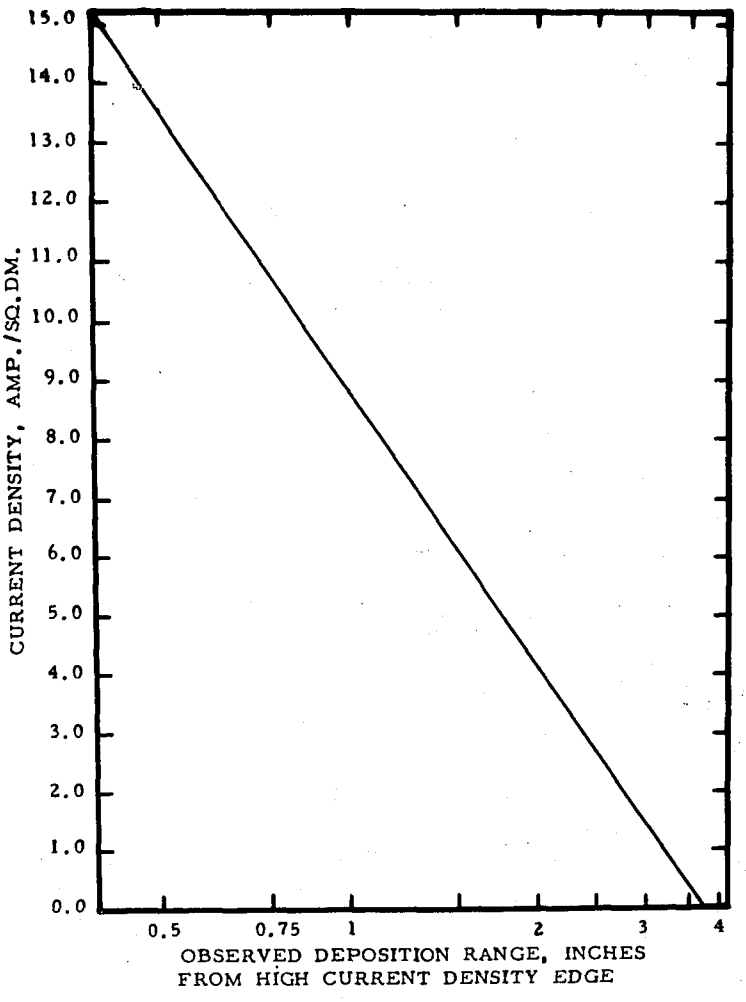


FIGURE 2. CURRENT DENSITY DISTRIBUTION OVER THE CATHODE IN A HULL CELL.

This cleaner was renewed every few days.

Appearance of the Deposit

Based on the current density distribution of Figure 2, a set of appearance tables were assembled using terminology set down in Metal Finishing (32) to describe the deposit over the range observed. Gradations between a semibright and dull deposit seemed inadequate, however, so the relative terms, haze and haze-bright were inserted. The term haze was used to interpolate between dull deposits and semibright deposits where grain refinement is visible. A haze-bright panel area was interpolated between bright and semibright. Normally, in this case, the deposit is markedly bright with an imperfect cast to be classified haze-bright.

In the general scheme, the first broad group of panels illustrate the effect of single addition agents on the deposit obtained from a Watts nickel-plating solution. This group is compared with panels obtained from the pure Watts nickel solution under the same conditions of temperature and pH. Effects were observed at temperatures 25°, 35°, 55°, and 75° C. for solutions at pH 2.2 and 3.8. The amount of variance from these conditions is indicated in the appearance tables. In no case was a solution used for more than one addition

agent effect. Always, new purified nickel solution was used for the next addition agent.

The first group of panels comprise effects of organic substituents which broadly may be classed as carbohydrates (reducing), carbonyl, polymers, dyes, and phenols. The carbohydrates represent the more common classes from triose to polymeric carbohydrate. The carbonyl group were in the main chosen for their relative oxidation potential. The polymers represent the more common water soluble types. The phenols were chosen to illustrate isomeric and structural effects.

The second broad group of panels were deposited with nickel in order to compare the effects of single addition agents, or representatives of the classes of single addition agents, with effects in the presence of 2,7-naphthalene disulfonic acid. Here, concentration of the organic constituent was varied and deposition normally was carried out at 65° C. and pH 3.80.

Next, a group of alloy deposits of nickel were made. Here carbonyl substituents were added to the equivalent of a classical Weisberg nickel-cobalt plating solution (34) in order to observe the effect of replacing formaldehyde or nickel formate or both. The choice of carbonyls was based on results obtained from the first group of panels.

Three solutions extending alloy deposition to iron were also attempted.

Finally, based on the results of thiazine dyes obtained in group one, some cathodes were predipped before deposition in a variant manner.

Roughness of the Deposit

The roughness of electrodeposits was evaluated on a model SA-2 Brush Surface Analyzer. The instrument consisted of a motor-driven pick-up arm, a calibrating amplifier, a direct inking oscillograph, and a RMS (root mean square) meter. This instrument has been carefully explained and illustrated elsewhere (35).

Since the metal panels obtained in this study represented a range of current density, it was necessary to isolate current densities on each panel for smoothness evaluation. Values of 9.0 and 6.5 amperes per square decimeter were chosen. These values are found at 1 and $1\frac{1}{2}$ inches, respectively, from the high current density edge of the panel when it is plated in the cell described above. Therefore, a small metal template was constructed to identify the areas on each panel and the pick-up arm of the surface analyzer was allowed to traverse the deposited surface in a direction normal to the

current density variation. Both profilographs, which are obtained from the direct inking oscillograph, and RMS values of the surface were obtained.

Because we were not particularly interested in the smoothening action of the deposits but rather in the relative smoothness of each deposit, smoothness of the basis metal was not always measured. However, several samples of the basis metal were evaluated for smoothness and the span of surface smoothness of the basis metal was enclosed by straight lines on all graphs.

DATA AND INTERPRETATION

A group of appearance tables have been constructed describing the individual panels with current density limitations. An outline of data has been included in order to point out the organization of these tables. In order to describe the panel appearance, normally, appropriate terms were used starting with the high current density end of the panel and identifying each current zone with the proper remarks.

Following the appearance tables for each group of organic compounds investigated, black and white photographs of the metal panels are included. Each photographed panel contains the numbers of the solution as well as the individual panel number, identical with the numbers contained in the appearance tables. The individual panels were numbered at the low current density end of the panel. Thus, in all cases, the high current density end of the panel is located at the bottom of the panel while the low current density end is located at the top of the panel.

Following the appearance data, tables of the same general organization have been constructed to report surface roughness data of the deposit. In a similar manner, following each group of organic

compounds investigated, plots of surface roughness were included. The lines connecting points of measured roughness are intended only as possible interpretations of the trends of the roughness data.

Outline of Data

A. Single Addition Agent Effects.

I. Watts Solution Panels.

II. Carbohydrates (reducing).

a. Solution 7 - Glyceraldehyde.

b. Solution 3 - Xylose.

c. Solution 4 - Glucose.

d. Solution 5 - Lactose hydrate.

e. Solution 6 - Raffinose hydrate (nonreducing).

f. Solution 8 - Dextrin.

III. Polymers and Unsaturated Aliphatic Compounds.

a. Solution 9 - Methyl cellulose.

b. Solution 16 - Polyvenyl alcohol.

c. Solution 43 - Acrylic acid.

d. Solution 53 - 1,4-Butynediol.

e. Solution 10 - PVM/MA.

f. Solution 101, 102, 103 - Molecular weight variance of PVM/MA.

IV. Carbonyl Compounds.

a. Solution 11 - Camphor.

b. Solution 12 - p-Bromoacetophenone.

c. Solution 13 - Cinnamaldehyde.

d. Solution 26 - Acetaldehyde.

e. Solution 17 - Chloral.

f. Solution 14 - Pyruvic acid.

g. Solution 40 - Butyl chloral.

h. Solution 15 - beta-Methylumbelliferone.

V. Dyes.

a. Solution 28 - Monastral Blue (Phthalocyanine).

b. Solution 31 - Clayton Yellow.

c. Solution 32 - Primuline Yellow.

d. Solution 33 - Methylene Blue.

e. Solution 34 - Toluidine Blue.

VI. Phenols.

a. Solution 30 - 4,4'Dihydroxybiphenyl.

b. Solution 27 - 3,5,3',5'-Tetranitro-
-4,4'-dihydroxybiphenyl.

c. Solution 41 - Phenol.

d. Solution 42 - o-Nitrophenol.

e. Solution 48 - p-Aminophenol hydrochloride.

f. Solution 49 - o-Aminophenol hydrochloride.

g. Solution 50 - Catechol.

h. Solution 51 - Resorcinol.

i. Solution 52 - beta-Naphthol.

B. 2,7-Naphthalene disulfonic Acid and Single Addition Agent Effects.

VII. 2,7-naphthalene disulfonic acid only.

VIII. Carbohydrate (reducing).

a. Solution 371 - Glucose.

IX. Carbonyl Compounds.

a. Solution 381 - Chloral.

X. Polymer and Unsaturated Aliphatic Compounds.

a. Solution 361 - PVM/MA.

b. Solution 46 - Acrylic acid.

c. Solution 531 - 1,4-Butynediol.

XI. Dyes.

a. Solution 351 - Monastral Blue.

b. Solution 311 - Clayton Yellow.

Solution 321 - Primuline Yellow.

c. Solution 331 - Methylene Blue.

Solution 341 - Toluidine Blue.

XII. Phenols.

a. Solution 301 - 4,4'-Dihydroxybiphenyl.

b. Solution 271 - 3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl.

c. Solution 411 - Phenol.

d. Solution 421 - o-Nitrophenol.

e. Solution 47 - p-Nitrophenol.

f. Solution 481 - p-Aminophenol.

g. Solution 491 - o-Aminophenol.

h. Solution 501 - Catechol.

i. Solution 511 - Resorcinol.

j. Solution 521 - beta-Naphthol.

C. Alloy-Carbonyl Effects.

XIII. Nickel Cobalt.

a. Solution 18 - Cinnamaldehyde.

b. Solution 19 - Chloral with ammonium sulfate.

c. Solution 20 - Chloral.

d. Solution 24 - Acetaldehyde.

e. Solution 29 - Ethyl pyruvate.

Glyoxal.

f. Solution 39 - Butyl Chloral.

g. Solution 44 - Chloracetic acid and chloral.

h. Solution 45 - Acrylic acid and chloral.

XIV. Nickel Iron.

a. Solution 21 - Chloral, nickel formate, tartaric acid.

b. Solution 22 - Ferrous sulfate, chloral.

c. Solution 25 - Nickel propionate, chloral.

D. External Treatment of Cathode.

XV. Solution 23 - Filter paper and cinnamaldehyde.

Solution 312 - Dipping in Clayton Yellow.

Solution 332 - Dipping in Methylene Blue.

Table 1. Solutions 1 and 2; the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
12	2.20	25	Exfoliate. Dull above 14.0 amp./sq.dm.;* haze 14.0 to 3.2 amp./sq.dm.; under, dull.
13	2.20	35	Dull to haze above 14.0 amp./sq.dm.; dull 14.0 to 1.0 amp./sq.dm.; under, dull.
14	2.20	54	Dull.
15	2.30	74	Dull.
22	3.50	25	Exfoliate. Haze above 14.0 amp./sq.dm.; semibright 14.0 to 9.0 amp./sq.dm.; under, haze.
23	3.50	35	Bright at high current density edge. Dull to haze.
24	3.70	54	Dull above 2.1 amp./sq.dm.; under, haze.
25	3.80	74	Dull above 14.0 amp./sq.dm.; haze 14.0 to 3.2 amp./sq.dm.; under, dull.

* Amperes per square decimeter.

Table 2. Solution 7; the effect of glyceraldehyde in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Glyceraldehyde
740	2.21	23	Exfoliate. Haze above 9.0 amp./sq.dm.; semibright 9.0 to 1.6 amp./sq.dm.; under, haze.
730	2.24	34	Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 9.7 amp./sq.dm.; under, haze.
720	2.17	54	Haze high current density edge. Dull.
710	2.12	73	Dull.
71	3.76	23	Exfoliate above 14.0 amp./sq.dm. Bright above 2.1 amp./sq.dm.; under, haze.
72	3.60	35	Bright high current density edge, haze.
73	3.60	55	Dull above 9.0 amp./sq.dm.; haze 9.0 to 2.6 amp./sq.dm.; under, dull.
74	3.85	76	Dull.
			2.0 g./l. Glyceraldehyde
750	2.20	26	Exfoliate. Haze above 9.7 amp./sq.dm.; haze-bright 9.7 to 6.4 amp./sq.dm.; under, haze.
760	2.20	35	Haze-bright above 11.8 amp./sq.dm.; under, haze.
770	2.27	55	Haze.

Table 2 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
780	2.20	76	Dull.
78	3.70	26	Exfoliate. Haze above 9.0 amp./sq.dm.; semibright 9.0 to 5.9 amp./sq.dm.; under, haze.
77	3.70	35	Exfoliate. Haze.
76	3.82	54	Semibright above 15.1 amp./sq.dm.; dull 15.1 to 1.6 amp./sq.dm.; under, dark, dull.
75	3.88	75	Dull

Table 3. Solution 3; the effect of xylose in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Xylose
35	2.15	26	Exfoliate. Haze above 14.0 amp./sq.dm.; haze to semibright 14.0 to 3.2 amp./sq. dm.; under, haze.
36	2.20	35	Haze high current density edge. Haze to semibright above 11.8 amp./sq.dm.; under, haze.
37	2.18	54	Dull.
38	2.18	73	Dull.
31	3.75	27	Exfoliate. Haze at high current density. Bright above 8.6 amp./sq.dm.; under, haze.
32	3.70	34	Bright above 14.0 amp./sq.dm. under, haze to dull.
33	3.85	55	Dull.
34	3.85	72	Dull.
			2.0 g./l. Xylose
330	2.17	24	Exfoliate. Haze above 9.0 amp./sq.dm.; semibright 9.0 to 4.3 amp./sq.dm.; under, haze.
340	2.20	35	Haze at high current density edge. Semibright above 13.0 amp./sq.dm.; under, dull.

Table 3 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
320	2.20	54	Dull.
310	2.13	73	Dull.
350	3.60	24	Exfoliate above 10.8 amp./sq.dm. Bright above 25 amp./sq.dm.; under, haze.
360	3.75	36	Haze.
370	3.80	59	Dull.
380	3.78	73	Dull.

Table 4. Solution 4; the effect of glucose in concentration of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Glucose
45	2.00	26	Exfoliate. Haze above 9.7 amp./sq.dm.; haze to semibright 9.7 to 4.3 amp./sq.dm.; under, haze.
46	2.25	35	Haze at high current density edge. Haze to semibright above 10.8 amp./sq.dm.; under, haze.
47	2.20	54	Dull.
48	2.20	73	Dull.
41	3.50	27	Haze above 14.0 amp./sq.dm.; semibright 14.0 to 7.6 amp./sq.dm.; under, haze.
42	3.45	34	Haze at high current density edge. Semibright above 10.8 amp./sq.dm.; under, haze.
43	3.30	55	Dull to haze.
44	3.30	72	Dull.
			2.0 g./l. Glucose
430	2.17	24	Exfoliate above 15.1 amp./sq.dm. Haze above 9.0 amp./sq.dm.; semibright 9.0 to 3.2 amp./sq.dm.; under, haze.
440	2.20	35	Haze at high current density edge. Haze to semibright above 6.5 amp./sq.dm.; under, dull.

Table 4 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
420	2.21	54	Bright to haze at high current density edge. Dull.
410	2.25	73	Dull.
450	3.85	24	Exfoliate above 11.8 amp./sq.dm. Haze above 9.0 amp./sq.dm.; bright 9.0 to 2.1 amp./sq.dm.; under, haze.
460	3.57	36	High current density bright ring. Haze above 7.0 amp./sq.dm.; under, dull.
470	3.75	59	Dull.
480	3.65	73	Dull.

Table 5. Solution 5; the effect of lactose hydrate in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Lactose Hydrate
55	2.28	26	Haze above 9.7 amp./sq.dm.; semibright 9.7 to 1.0 amp./sq.dm.; under, haze.
56	2.23	35	Haze at high current density edge. Haze-bright above 9.7 amp./sq.dm.; under, haze.
57	2.26	54	Haze-bright above 14.0 amp./sq.dm.; under, haze, pitted.
58	2.26	73	Dull.
51	3.70	27	Exfoliate above 14.0 amp./sq.dm. Haze above 11.8 amp./sq.dm.; under, semibright.
52	3.73	34	Semibright, pitted above 9.0 amp./sq.dm.; under, haze.
53	3.80	55	Dull and pitted
54	3.80	72	Dull.
			2.0 g./l. Lactose Hydrate
530	2.20	24	Exfoliate. Haze above 7.0 amp./sq.dm.; haze-bright 7.0 to 1.0 amp./sq.dm.; under, haze.
540	2.22	35	Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 8.6 amp./sq.dm.; under, dull.
520	2.21	54	Haze at high current density edge. Dull, pitted.

Table 5 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
510	2.20	73	Dull, pitted.
550	3.62	24	Exfoliate. Pitted, haze above 10.8 amp./sq. dm.; under, bright.
560	3.50	36	Haze at high current density edge. Bright above 9.7 amp./sq.dm.; under, haze.
570	3.88	59	Dull.
580	3.87	73	Dull.

Table 6. Solution 6; the effect of raffinose hydrate in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Raffinose Hydrate
65	2.22	26	Exfoliate. Haze above 9.0 amp./sq.dm.; haze-bright 9.0 to 3.2 amp./sq.dm.; under, haze.
66	2.22	35	Haze-bright above 10.8 amp./sq.dm.; under, haze.
67	2.20	54	Haze above 1.0 amp./sq.dm.; under, dull, pitted.
68	2.20	73	Dull.
61	3.82	27	Exfoliate. Haze above 11.8 amp./sq.dm.; haze-bright 11.8 to 1.0 amp./sq.dm.; under, haze.
62	3.85	34	Haze-bright above 11.8 amp./sq.dm.; under, haze.
63	3.70	55	Dull, pitted.
64	3.70	72	Dull, pitted.
			2.0 g./l. Raffinose Hydrate
630	2.13	24	Haze, exfoliate above 11.8 amp./sq.dm. haze-bright 11.8 to 1.0 amp./sq.dm.; under, haze.
640	2.22	35	Haze at high current density edge. Haze-bright above 9.7 amp./sq.dm.; under, haze.

Table 6 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
620	2.18	54	Haze.
610	2.18	73	Dull.
650	3.88	24	Exfoliate, haze above 10.8 amp./sq.dm.; under, bright.
660	3.72	36	Haze-bright above 14.0 amp./sq.dm.; under, haze.
670	3.88	59	Dull.
680	3.70	73	Dull, pitted.

Table 7. Solution 8; the effect of dextrin in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Dextrin
840	2.25	23	Exfoliate above 14.0 amp./sq.dm. Haze above 2.6 amp./sq.dm.; under, semibright.
830	2.25	34	Haze above 10.8 amp./sq.dm.; haze-bright 10.8 to 6.5 amp./sq.dm.; under, haze.
820	2.17	54	Bright above 8.1 amp./sq.dm.; under, haze.
810	2.12	73	Semibright at high current density edge. Dull.
81	3.80	23	Exfoliate above 14.0 amp./sq.dm. Haze above 5.4 amp./sq.dm.; under, haze-bright.
82	3.83	35	Haze above 4.3 amp./sq.dm.; bright 4.3 to 1.0 amp./sq.dm.; under, haze to dull.
83	3.80	55	Haze-bright above 6.5 amp./sq.dm.; under, haze to dull.
84	3.75	76	Dull.
			2.0 g./l. Dextrin
850	2.25	26	Exfoliate above 14.0 amp./sq.dm. Haze.
860	2.20	35	Haze above 1.0 amp./sq.dm.; under, bright.
870	2.18	55	Semibright above 5.4 amp./sq.dm.; under, haze.

Table 7 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
880	2.24	76	Haze at high current density edge. Dull.
88	3.70	26	Exfoliate above 14.0 amp./sq.dm. Haze above 1.6 amp./sq.dm.; under, haze-bright.
87	3.88	35	Haze above 3.2 amp./sq.dm.; under, semi-bright.
86	3.88	54	Bright above 10.8 amp./sq.dm.; haze 10.8 to 2.1 amp./sq.dm.; under, dull.
85	3.73	75	Haze at high current density edge. Dull.

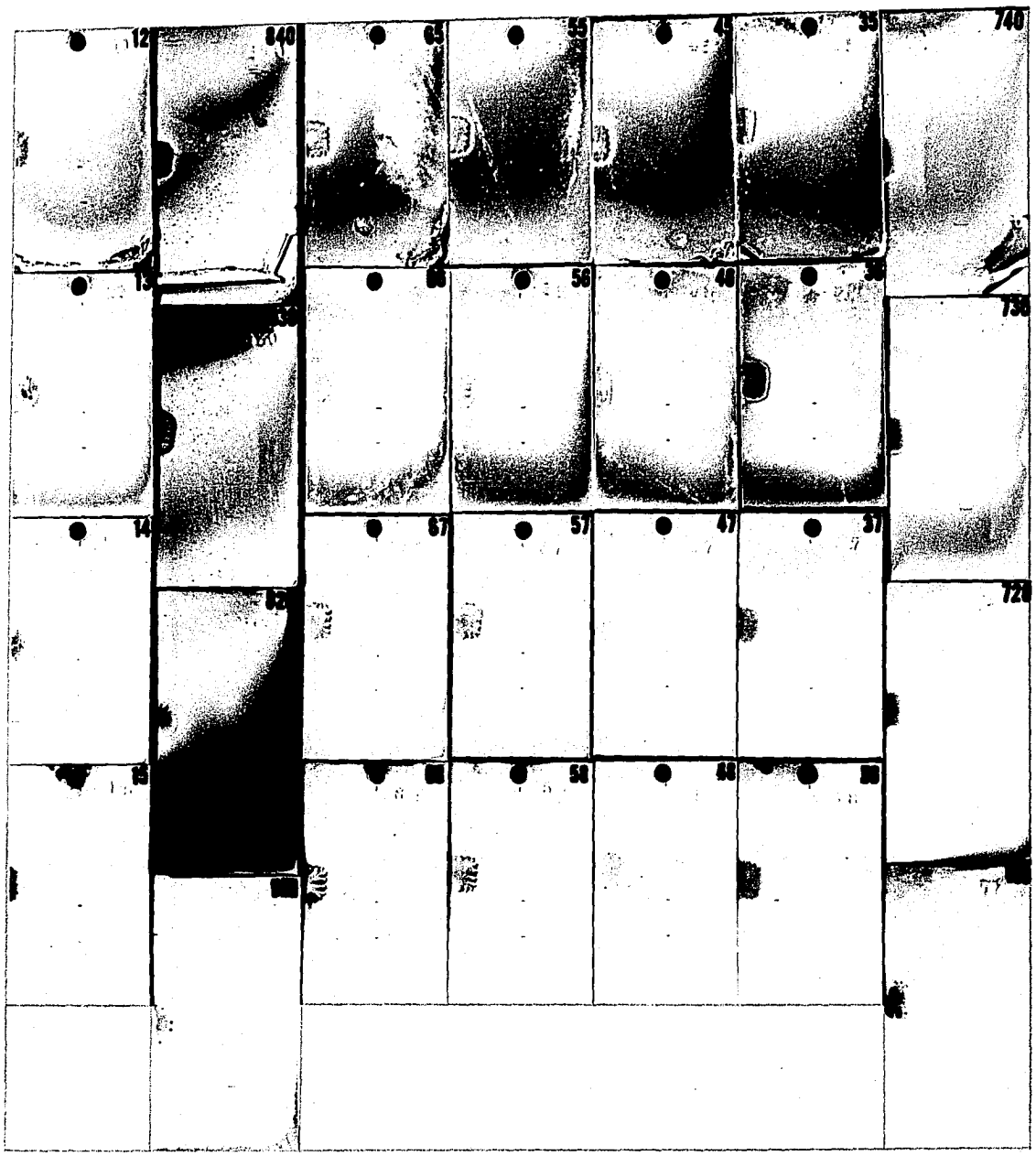


Figure 3. The effect of carbohydrates on the appearance of Watts nickel deposits at pH 2.2.

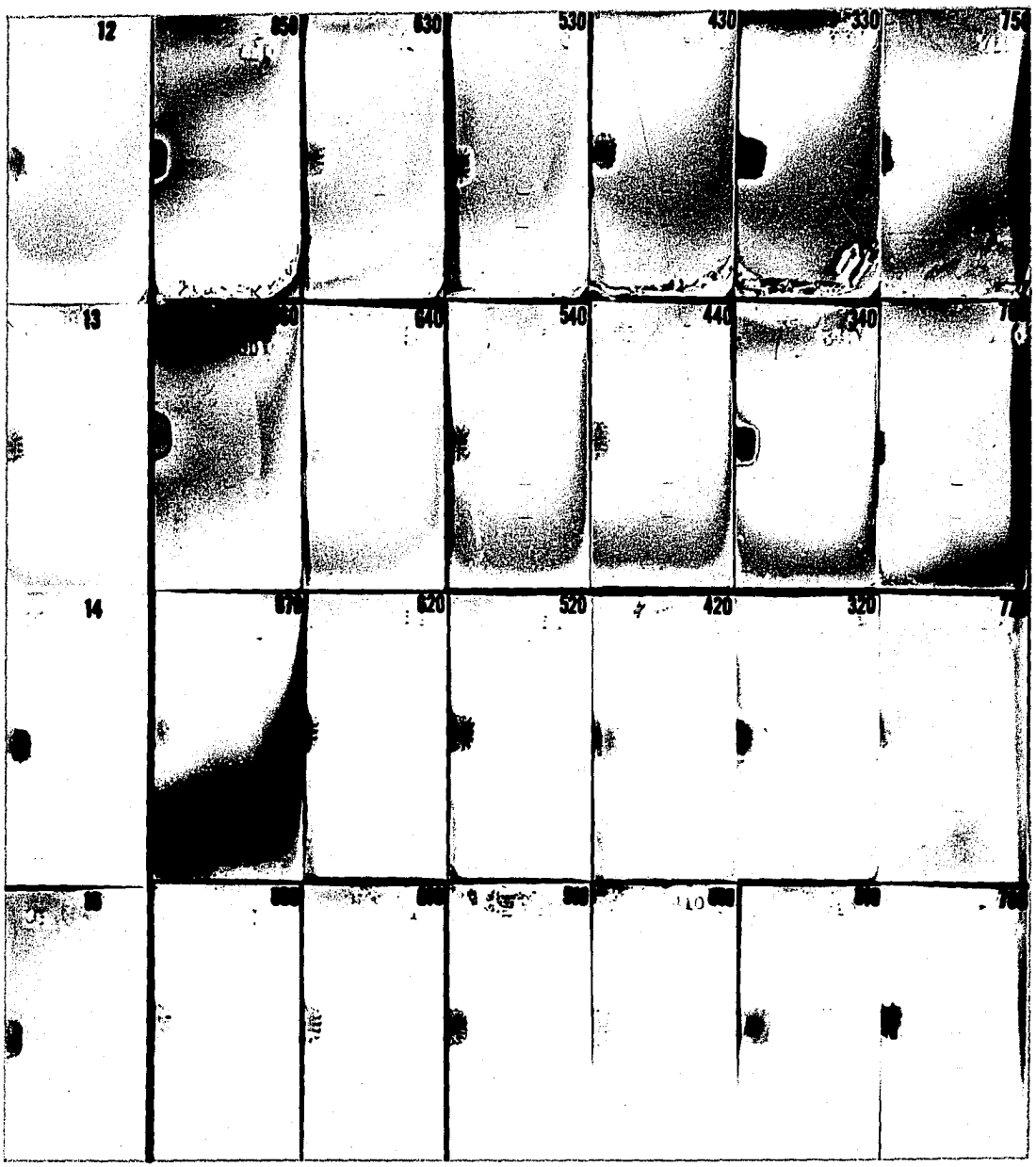


Figure 4. The effect of carbohydrates on the appearance of Watts nickel deposits at pH 2.2.

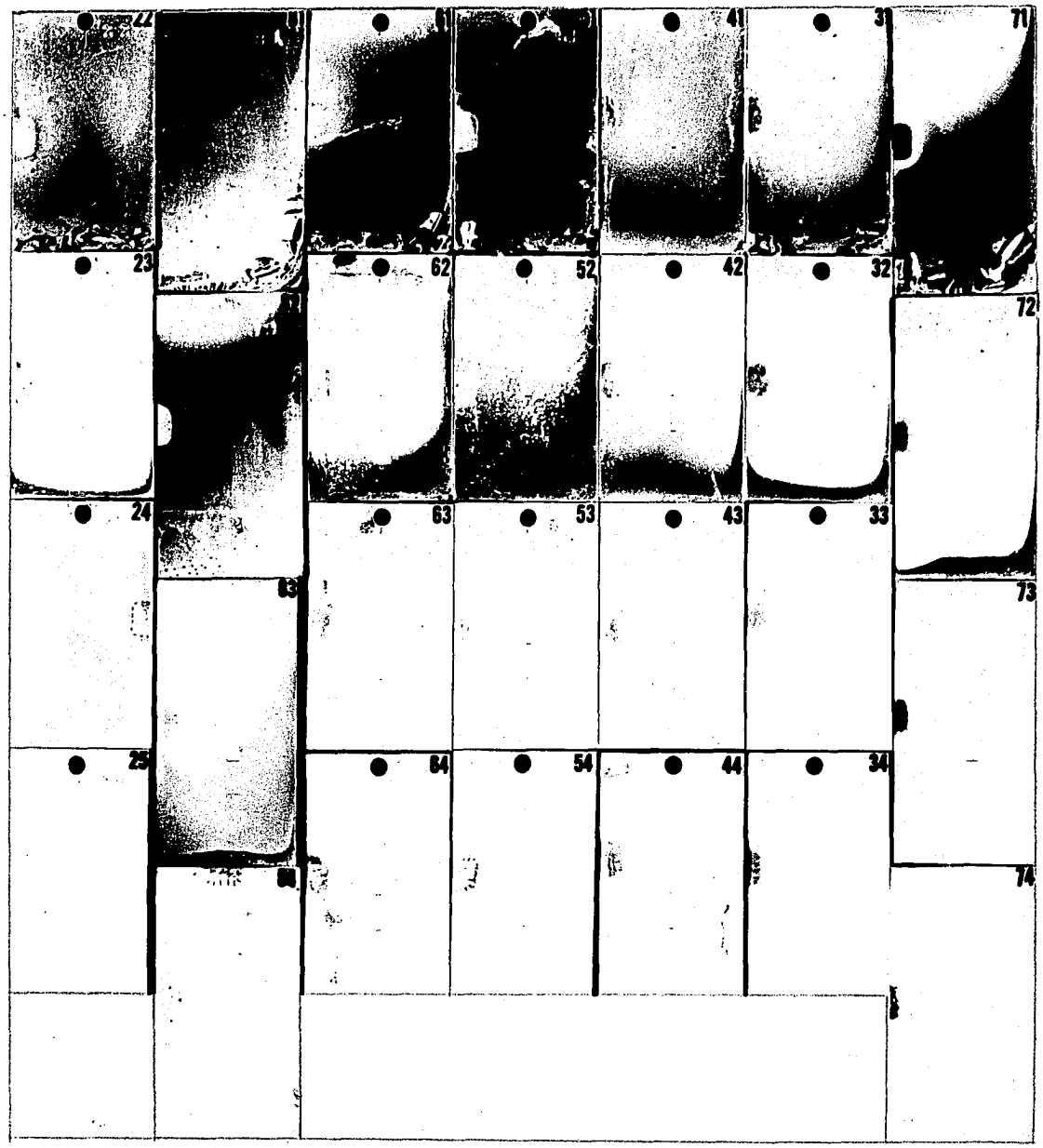


Figure 5. The effect of carbohydrates on the appearance of Watts nickel deposits at pH 3.8.

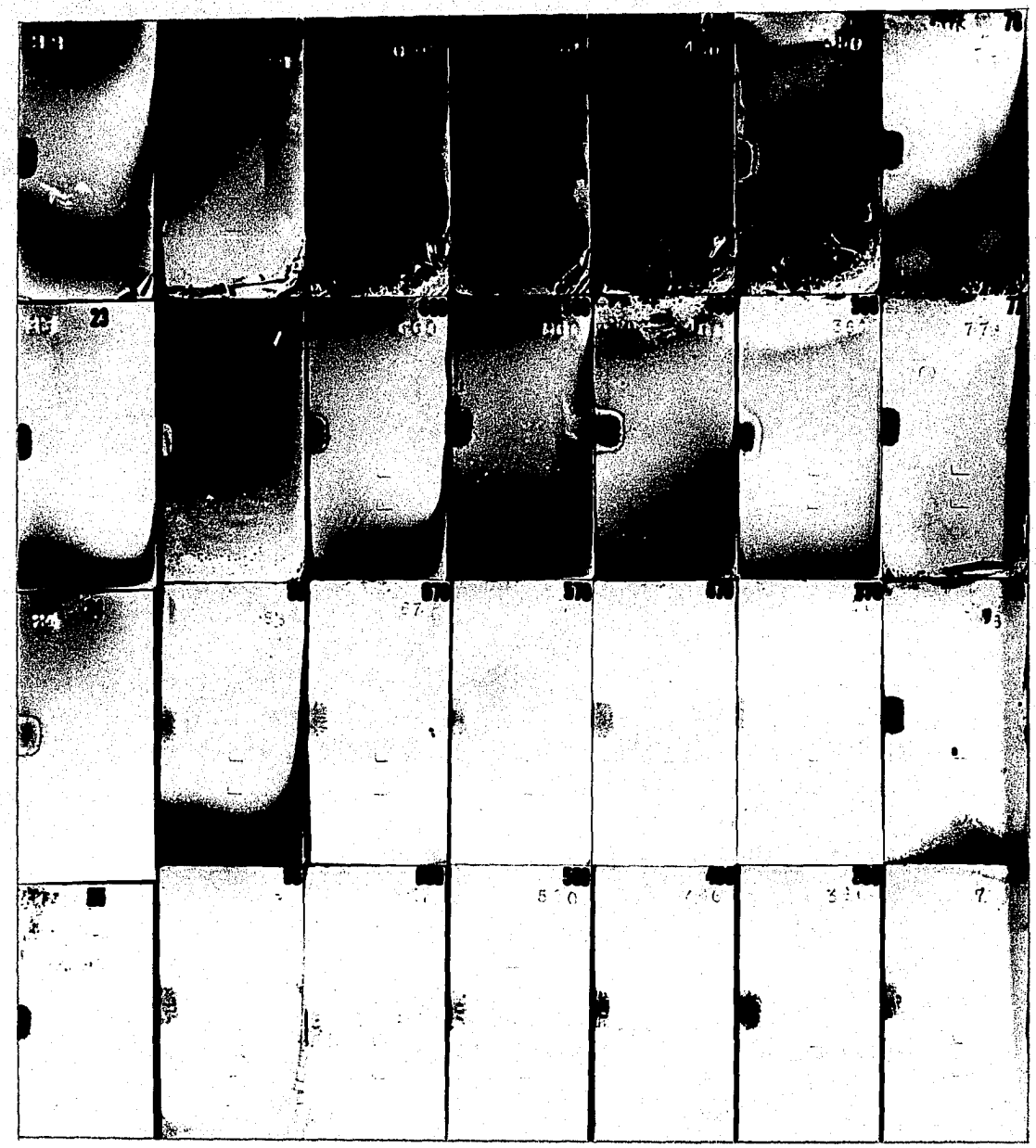


Figure 6. **The effect of carbohydrates on the appearance of Watts nickel deposits at pH 3.8.**

Table 8. Solution 9; the effect of methyl cellulose in concentration of 0.5 g./l. on the appearance of Wtts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
910	2.20	28	Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 2.6 amp./sq.dm.; under, haze.
920	2.20	37	Haze at high current density edge. Haze-bright above 8.6 amp./sq.dm.; under, haze.
930	2.20	57	Dull.
940	2.25	75	Dull, dark.
94	3.82	28	Haze above 15.1 amp./sq.dm.; haze-bright 15.1 to 10.8 amp./sq.dm.; under, haze.
93	3.70	39	Dull above 2.6 amp./sq.dm.; under, haze.
92	3.65	58	Dull.
91	3.81	73	Dull, dark.

Table 9. Solution 16; the effect of polyvinyl alcohol in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1640	2.21	23	Exfoliate. Haze, pitted.
1630	2.20	37	Haze above 1.0 amp./sq.dm.; under, bright.
1620	2.20	56	Haze above 8.6 amp./sq.dm.; under, haze-bright.
1610	2.20	75	Haze above 11.8 amp./sq.dm.; under, haze to milky.
164	3.65	25	Exfoliate. Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 8.6 amp./sq.dm.; under, haze.
163	3.80	36	Haze at high current density edge. Bright above 15.1 amp./sq.dm.; haze 15.1 to 2.1 amp./sq.dm.; under, bright.
162	3.82	56	Dull above 14.0 amp./sq.dm.; bright ring at 14.0 amp./sq.dm.; under, haze.
161	3.75	75	Dull, dark.

Table 10. Solution 43; the effect of acrylic acid in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Acrylic Acid
4310	2.25	25	Exfoliate. Haze-bright above 10.8 amp./sq.dm.; under, dull.
4320	2.25	38	Haze-bright above 11.8 amp./sq.dm.; under, haze.
4330	2.50	55	Haze above 2.6 amp./sq.dm.; under, dull, pitted.
4340	2.25	74	Haze above 14.0 amp./sq.dm.; under, dull, dark.
431	3.88	24	Exfoliate. Bright above 11.8 amp./sq.dm.; under, haze.
432	3.55	35	Semibright at high current density edge. Haze above 2.6 amp./sq.dm.; under, dull.
433	3.55	55	Haze at high current density edge. Dull, dark.
434	3.85	73	Dull, dark.
			2.0 g./l. Acrylic Acid
4350	2.20	24	Exfoliate at high current density edge. Semibright above 10.8 amp./sq.dm.; under, haze.
4360	2.25	35	Haze at high current density edge. Haze-bright above 10.8 amp./sq.dm.; haze 10.8 to 2.6 amp./sq.dm.; haze-bright, pitted 2.6 to 2.1 amp./sq.dm.; under, haze.

Table 10 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
4370	2.25	56	Haze-bright above 11.8 amp./sq.dm.; under, dull.
4380	-	70	Dull, dark.
435	3.85	24	Exfoliate. Bright above 11.8 amp./sq.dm.; under, dull.
436	3.75	35	Haze-bright above 14.0 amp./sq.dm.; under, haze to dull.
437	3.78	55	Dull.
438	3.85	75	Dull, dark.

Table 11. Solution 53; the effect of 1,4-butynediol in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. 1,4-Butynediol
5310	2.20	26	Exfoliate. Haze above 10.8 amp./sq.dm.; haze-bright 10.8 to 4.8 amp./sq.dm.; under, haze.
5320	2.20	38	Haze at high current density edge. Haze-bright above 14.0 amp./sq.dm.; under, haze. Haze-bright ring at 2.6 amp./sq.dm.
5330	2.20	54	Haze above 15.1 amp./sq.dm.; under, dull.
5340	2.22	74	Dull, pitted above 9.7 amp./sq.dm.; under, haze, pitted.
531	3.70	25	Exfoliate. Bright, pitted above 5.4 amp./sq.dm.; under, haze-bright.
532	3.80	36	Bright.
533	3.70	57	Haze-bright, pitted above 15.1 amp./sq.dm.; under, bright.
534	3.75	75	Haze-bright, pitted.
			2.0 g./l. 1,4-Butynediol
5350	2.20	27	Exfoliate. Bright, pitted.
5360	2.20	37	Exfoliate. Bright, pitted.
5370	2.20	55	Bright, pitted.

Table 11 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
5380	2.20	75	Semibright, pitted.
535	3.60	26	Exfoliate. Bright, pitted.
536	3.70	35	Exfoliate. Bright, pitted.
537	3.80	55	Bright, pitted.
538	3.75	75	Semibright.

Table 12. Solution 10; the effect of PVM/MA* (polymethyl vinyl ether-maleic anhydride) in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
104	2.20	28	Exfoliate. Bright.
103	2.22	39	Bright, spotted white.
102	2.25	58	Haze above 13.0 amp./sq.dm.; under, haze-bright, spotted white.
101	2.10	73	Haze above 11.8 amp./sq.dm.; under, haze-bright and stress cracked, spotted white.
1010	2.50	28	Exfoliate. Bright.
1020	2.70	37	Bright.
1030	2.75	57	Haze above 11.8 amp./sq.dm.; haze-bright 11.8 to 4.3 amp./sq.dm.; under, haze.
1040	3.00	75	Haze to dull.
1050	2.20	73	Haze above 10.8 amp./sq.dm.; under, bright.

* Specific viscosity, 2.6.

Figure 7. **The effect of polymers and unsaturated aliphatic compounds on the appearance of Watts nickel deposits at pH 2.2.**

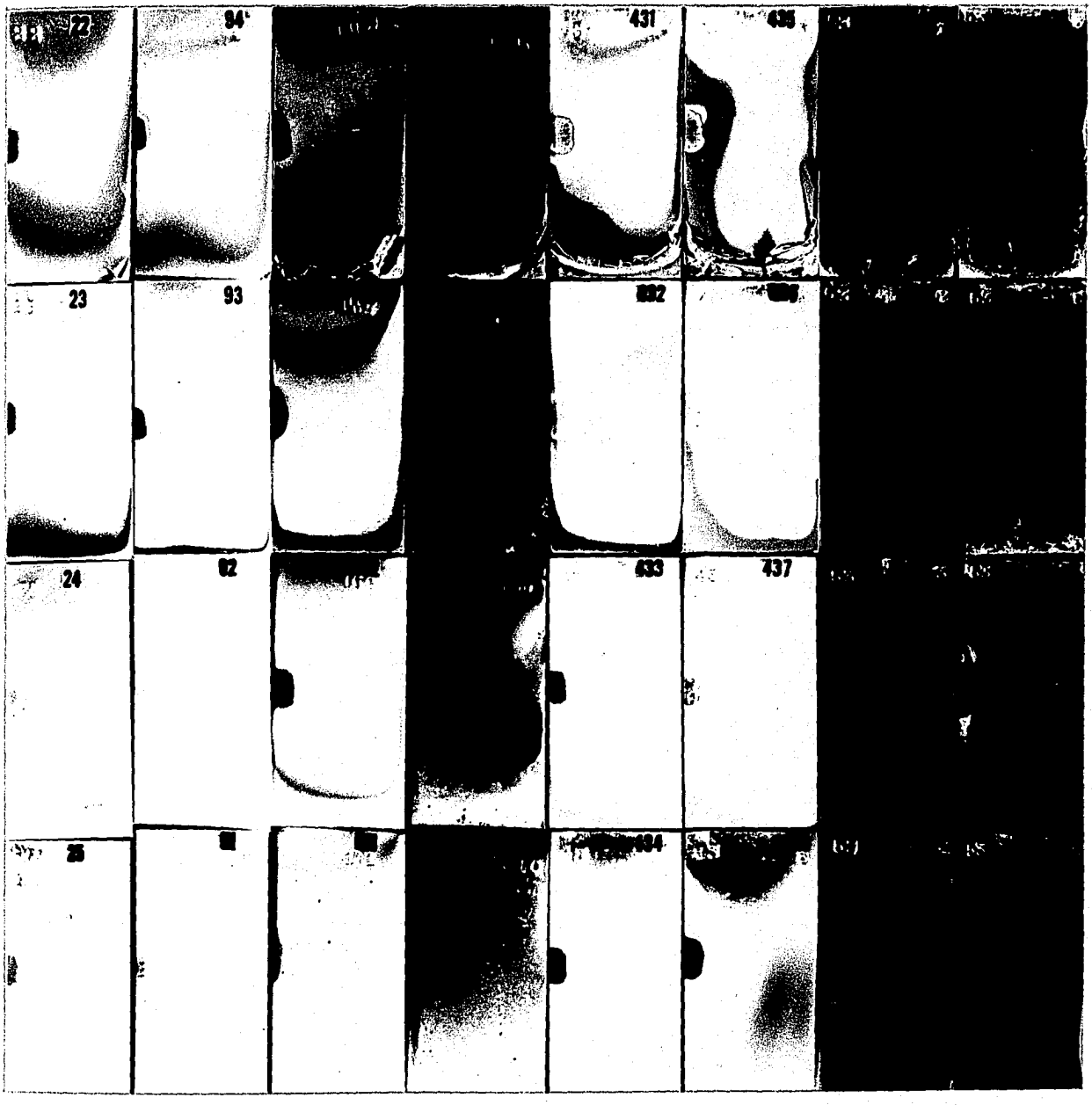


Figure 8. The effect of polymers and unsaturated aliphatic compounds on the appearance of Watts nickel deposits at pH 3.8.

Table 13. Solutions 101, 102, and 103; the effect of the specific viscosity of the PVM/MA (polymethyl vinyl ether maleic anhydride) on the appearance of Watts nickel solution deposits with increasing concentrations of copolymer. (Solution 101 specific viscosity, 0.4; Solution 102 specific viscosity, 2.6; Solution 103 specific viscosity, 3.2.)

Panel No.	pH	Temp. (° C.)	Addition (g. PVM/MA)	Total Addition (g. PVM/MA)	Cathode Appearance
1011	3.82	57	0.1	0.1	Dull to haze.
105*	2.20	75	0.1	0.1	Dull to haze.
1031	2.80	57	0.1	0.1	Dull to haze.
1012	2.60	55	-	0.1	Dull to haze.
106*	2.30	56	-	0.1	Dull to haze.
1032	2.65	55	-	0.1	Dull to haze.
1013**	2.54	55	0.2	0.3	Dull above 6.5 amp./sq. dm.; under, haze to bright, pitted.
1023	2.62	55	0.2	0.3	Dull above 7.6 amp./sq. dm.; under, haze to bright, pitted.
1033	2.60	55	0.2	0.3	Dull above 1.0 amp./sq. dm.; under, haze to bright, pitted.
1014	2.70	58	-	0.3	Dull, pitted, treed.

Table 13 (Continued)

Panel No.	pH	Temp. (° C.)	Addition (g. PVM/MA)	Total Addition (g. PVM/MA)	Cathode Appearance
1024	2.80	58	-	0.3	Dull above 8.6 amp./sq. dm.; under, haze
1034	2.72	58	-	0.3	Dull above 1.0 amp./sq. drm.; under, haze to bright.
1015	2.62	56	0.1	0.4	Dull above 6.5 amp./sq. dm.; under, bright, pitted, stressed.
1025	2.65	56	0.1	0.4	Dull above 10.8 amp./ sq.dm.; under, bright to haze.
1035	2.55	56	0.1	0.4	Dull to haze.
1016	2.74	56	0.1	0.5	Dull above 9.7 amp./sq. dm.; under, bright, stressed, pitted.
1026	2.65	56	0.1	0.5	Dull above 10.8 amp./ sq.dm.; under, bright to haze, stressed.
1036	2.64	56	0.1	0.5	Dull to haze above 2.1 amp./sq.dm.; under, bright, pitted.
1017	2.82	65	0.1	0.6	Dull above 8.6 amp./sq. dm.; under, bright, stressed, pitted.

Table 13 (Continued)

Panel No.	pH	Temp. (° C.)	Addition (g. PVM/MA)	Total Addition (g. PVM/MA)	Cathode Appearance
1027	2.65	65	0.1	0.6	Bright to haze, stressed.
1037	2.65	65	0.1	0.6	Dull to haze above 3.2 amp./sq.dm.; under, bright, pitted.
1018	2.95	65	-	0.6	Bright, stressed above 1.0 amp./sq.dm.; under, dull, black.
1028	2.83	65	-	0.6	Dull above 10.8 amp./sq.dm.; under, bright to haze, stress.
1038	2.75	65	-	0.6	Dull to haze above 7.6 amp./sq.dm.; under, bright, pitted.

* Solution 102.

** All plates numbering 3 or greater from the solutions demonstrated the polymer actually depositing on the cathode.

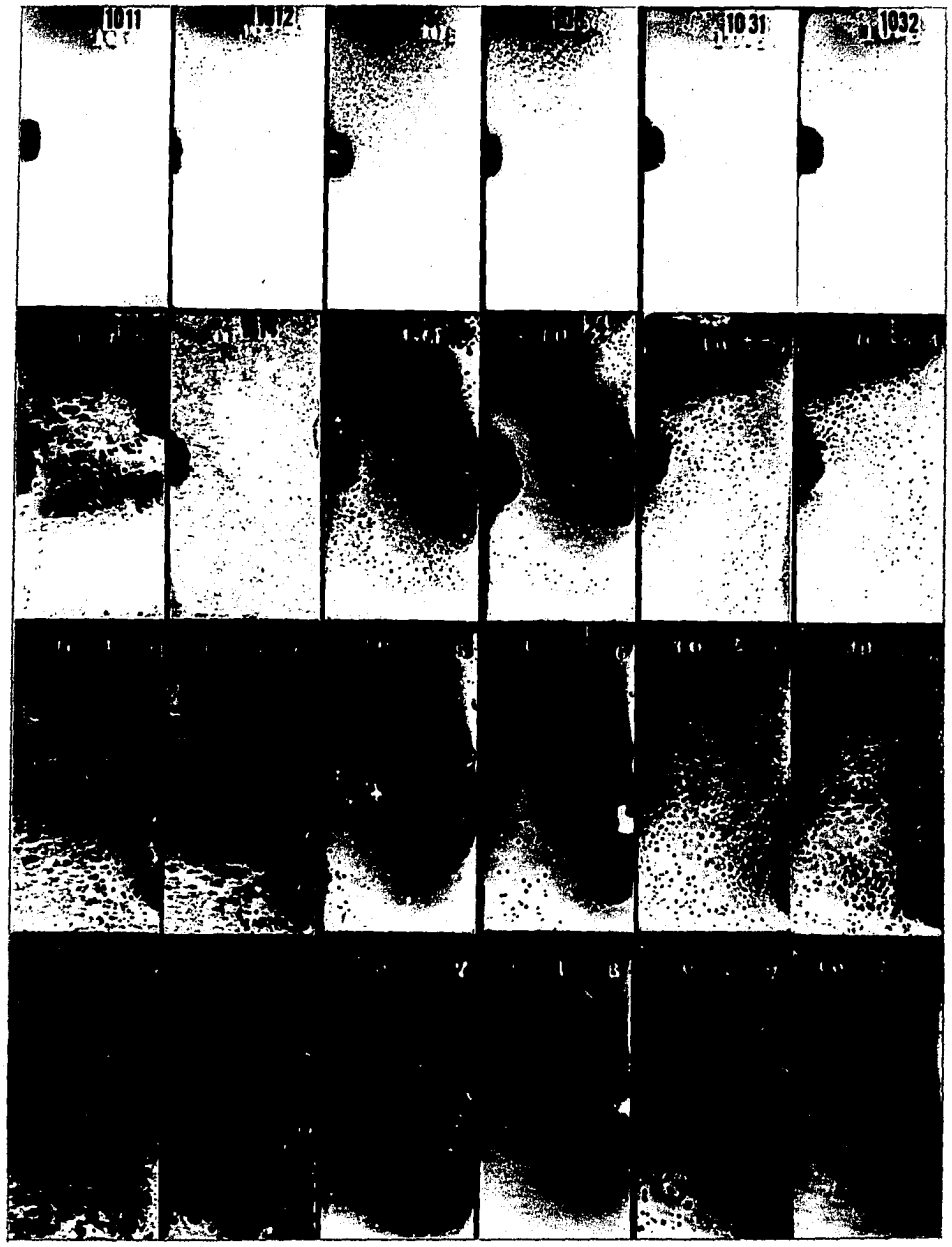


Figure 9. The effect of specific viscosity of PVM/MA on the appearance of Watts nickel solution deposits.

Table 14. Solution 11; the effect of camphor in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1110	2.21	28	Haze above 11.8 amp./sq.dm.; haze-bright 11.8 to 2.1 amp./sq.dm.; under, haze.
1120	2.25	37	Haze above 15.1 amp./sq.dm.; haze-bright 15.1 to 10.8 amp./sq.dm.; under, haze.
1130	2.25	57	Haze at high current density edge. Dull.
1140	2.20	75	Dull, pitted.
114	3.70	28	Exfoliate, haze above 11.8 amp./sq.dm.; haze-bright 11.8 to 6.5 amp./sq.dm.; under, haze.
113	3.82	39	Haze-bright at high current density edge. Dull.
112	3.70	58	Dull.
111	3.72	74	Dull.

Table 15. Solution 12; the effect of p-bromoacetophenone in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1210	2.13	28	Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 3.2 amp./sq.dm.; under, haze.
1220	2.24	37	Haze at high current density edge. Haze-bright above 6.5 amp./sq.dm.; under, haze.
1230	2.20	57	Haze above 15.1 amp./sq.dm.; under, dull, pitted.
1240	2.25	75	Dull, pitted.
124	3.75	28	Exfoliate. Bright above 8.1 amp./sq.dm., haze 8.1 to 1.0 amp./sq.dm.; under, haze-bright.
123	3.75	39	Bright at high current density edge. Haze to dull above 3.2 amp./sq.dm.; haze-bright 3.2 to 2.6 amp./sq.dm.; under, dull.
122	3.80	58	Haze-bright above 11.8 amp./sq.dm.; under, dull.
121	3.65	74	Dull, dark, pitted.

Table 16. Solution 13; the effect of cinnamaldehyde in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1340	2.22	25	Burned, exfoliate above 11.8 amp./sq.dm.; under, haze, pitted.
1330	2.20	38	Haze, pitted.
1320	2.18	53	Dull, pitted.
1310	2.18	75	Dull, pitted.
134	3.77	25	Burned, exfoliate above 7.0 amp./sq.dm.; haze-bright 7.0 to 3.2 amp./sq.dm.; under, haze.
133	3.80	38	Haze, pitted.
132	3.50	58	Haze, pitted above 10.8 amp./sq.dm.; under, dull.
131	3.80	75	Dull, dark.

Table 17. Solution 26; the effect of acetaldehyde in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
2610	2.20	26	Exfoliate. Semibright above 1.6 amp./sq. dm.; under, haze.
2620	2.25	38	Haze at high current density edge. Semi-bright above 8.6 amp./sq.dm.; under, haze.
2630	2.28	55	Dull.
2640	2.20	75	Dull.
264	3.80	26	Burned above 15.1 amp./sq.dm.; bright 15.1 to 8.6 amp./sq.dm.; under, haze.
263	3.70	38	Bright at high current density edge. Dull.
262	3.80	55	Dull to haze.
261	3.82	75	Dull.

Table 18. Solution 17; the effect of chloral in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1740	2.20	23	Exfoliate above 11.8 amp./sq.dm. Haze-bright above 2.1 amp./sq.dm.; under, haze.
1730	2.25	37	Haze-bright above 11.8 amp./sq.dm.; under, haze.
1720	2.22	56	Dull.
1710	2.25	75	Dull, pitted above 2.1 amp./sq.dm.; under, haze.
174	3.80	25	Exfoliate. Haze-bright above 6.5 amp./sq.dm.; under, haze.
173	3.80	36	Bright above 11.8 amp./sq.dm.; under, haze.
172	3.75	56	Haze above 8.6 amp./sq.dm.; under, haze-bright.
171	3.78	75	Dull, pitted.

Table 19. Solution 14; the effect of pyruvic acid in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1440	2.18	25	Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 2.1 amp./sq.dm.; under, haze.
1430	2.20	38	Haze-bright above 14.0 amp./sq.dm.; under, haze.
1420	2.10	53	Dull.
1410	2.10	75	Dull, dark.
144	3.73	25	Exfoliate above 14.0 amp./sq.dm.; bright 14.0 to 7.0 amp./sq.dm.; under, haze.
143	3.50	38	Bright at high current density edge. Dull.
142	3.50	58	Dull above 10.8 amp./sq.dm.; under, dull, pitted, dark.
141	3.60	75	Dull, pitted, dark.

Table 20. Solution 40; the effect of butyl chloral in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Butyl Chloral
410	2.13	25	Exfoliate above 11.8 amp./sq.dm.; haze-bright 11.8 to 5.4 amp./sq.dm.; under, haze.
420	2.25	38	Haze at high current density edge. Haze-bright above 14.0 amp./sq.dm.; under, haze.
430	2.50	55	Haze-bright at high current density edge. Dull.
440	2.25	74	Dull above 6.5 amp./sq.dm.; under, dull, dark.
401	3.70	24	Exfoliate above 11.8 amp./sq.dm.; under, haze.
402	3.50	35	Dull above 9.0 amp./sq.dm.; under, haze.
403	3.65	55	Haze-bright at high current density edge. Haze.
404	3.65	73	Haze.
			2.0 g./l. Butyl Chloral
450	2.22	24	Exfoliate above 11.8 amp./sq.dm.; under, bright.
460	2.20	35	Haze above 2.6 amp./sq.dm.; under, bright.
470	2.25	56	Dull above 9.7 amp./sq.dm.; under, bright.

Table 20 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
480	-	70	Dull at high current density edge. Haze-bright above 14.0 amp./sq.dm.; under, haze, dark.
405	3.70	24	Exfoliate above 11.8 amp./sq.dm.; under, haze-bright.
406	3.60	35	Haze above 6.5 amp./sq.dm.; under, semi-bright.
407	3.60	55	Haze-bright above 13.0 amp./sq.dm.; under, haze.
408	3.80	75	Haze.

Table 21. Solution 15; the effect of beta-methyl umbelliferone in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
1540	2.22	25	Burned, exfoliate above 11.8 amp./sq.dm.; haze-bright 11.8 to 1.0 amp./sq.dm.; under, haze.
1530	2.20	38	Haze-bright above 8.6 amp./sq.dm.; under, haze.
1520	2.18	53	Haze to dull.
1510	2.20	75	Dull.
154	3.80	25	Burned and exfoliate above 6.5 amp./sq.dm.; under, haze.
153	3.75	38	Haze at high current density edge. Haze-bright above 13.0 amp./sq.dm.; under, haze.
152	3.88	58	Dull.
151	3.80	75	Dull.

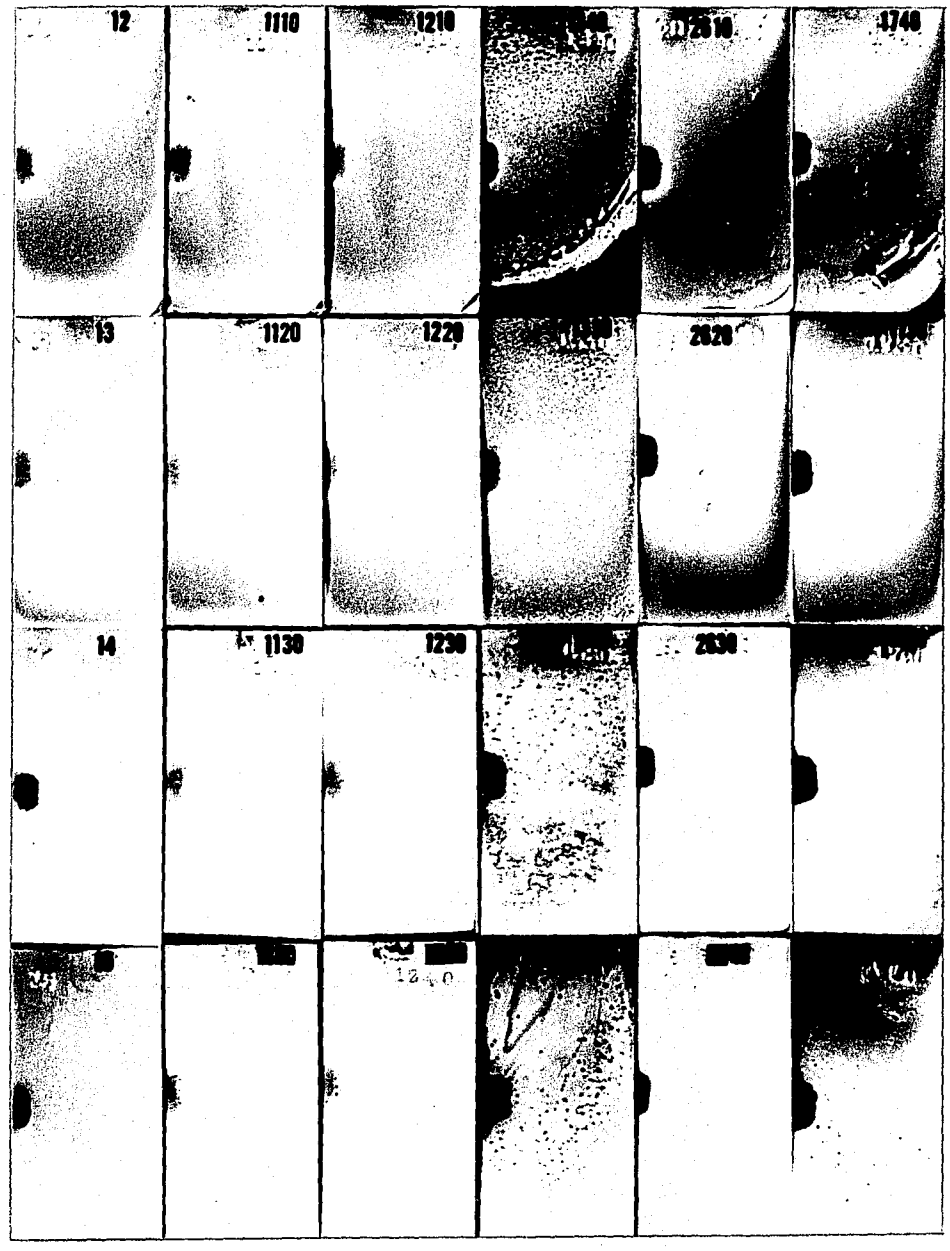


Figure 10. The effect of carbonyl compounds on the appearance of Watts nickel deposits at pH 2.2.

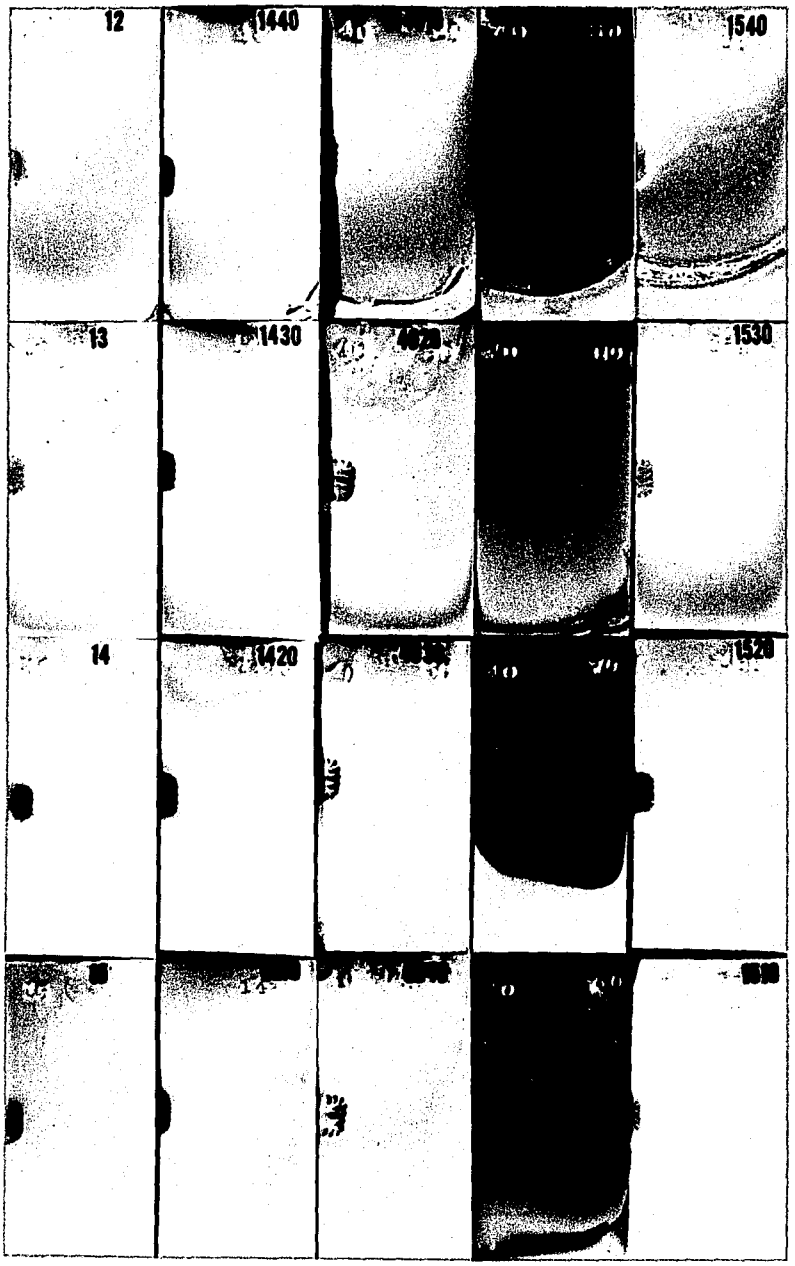


Figure 11. **The effect of carbonyl compounds on the appearance of Watts nickel deposits at pH 2.2.**

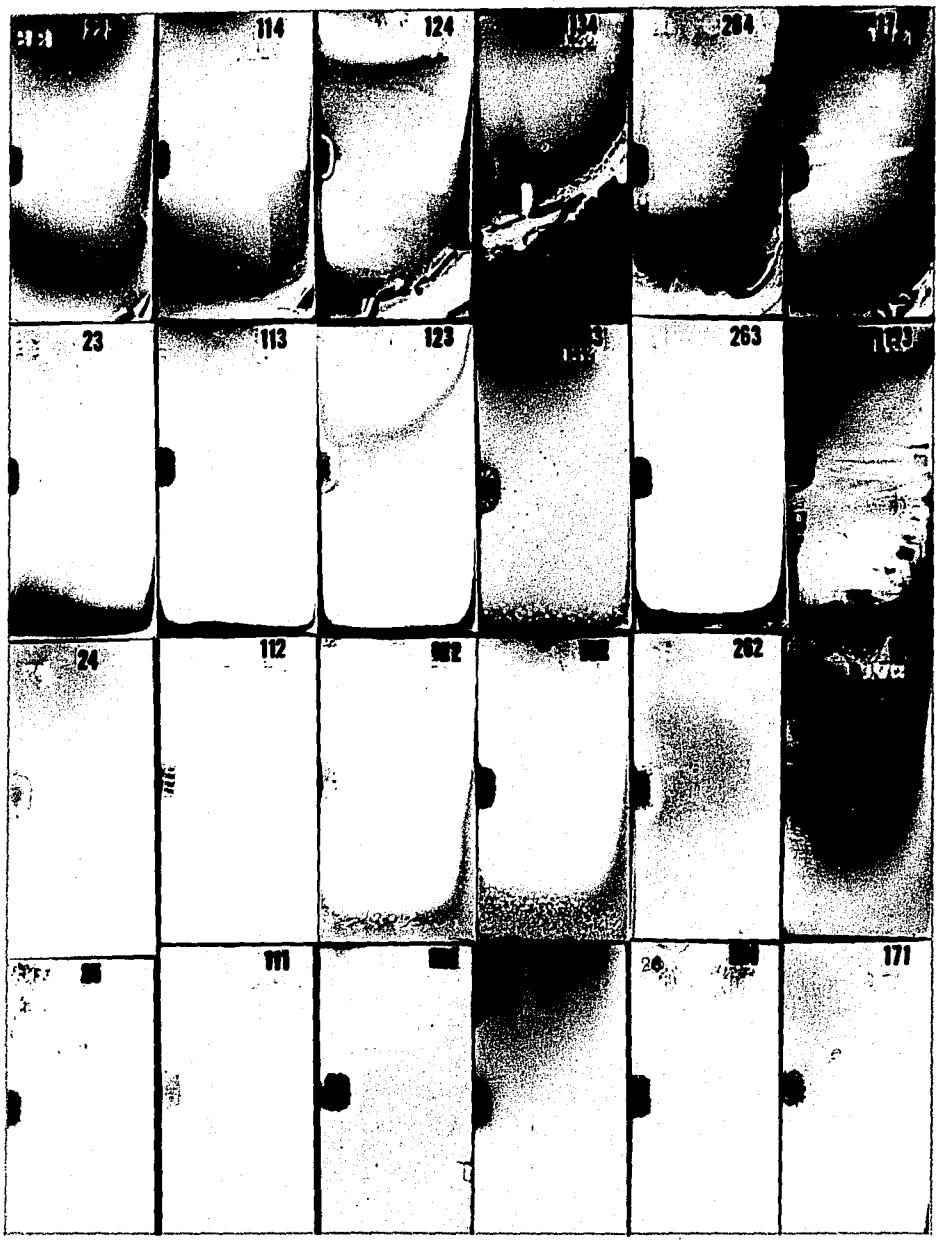


Figure 12. The effect of carbonyl compounds on the appearance of Watts nickel deposits at pH 3.8.

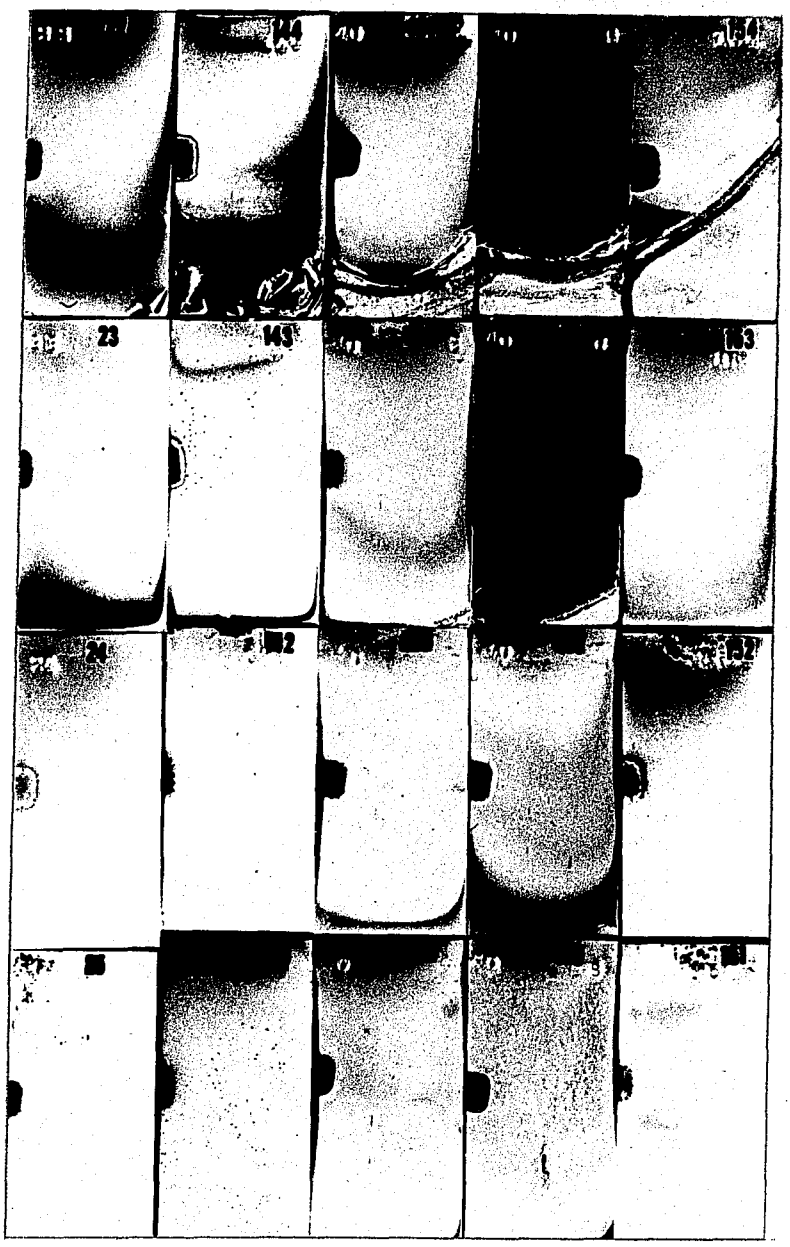


Figure 13. **The effect of carbonyl compounds on the appearance of Watts nickel deposits at pH 3.8.**

Table 22. Solution 28; the effect of Monastral Blue* in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
2810	2.20	26	Haze above 10.8 amp./sq.dm.; semibright 10.8 to 4.3 amp./sq.dm.; under, haze.
2820	2.17	38	Haze at high current density edge. Semi-bright above 10.8 amp./sq.dm.; under, dull.
2830	2.24	55	Dull, blue spots.
2840	2.22	75	Dull, blue spots.
284	3.60	26	Burned at high current density edge. Haze, pitted above 11.8 amp./sq.dm.; haze-bright 11.8 to 4.3 amp./sq.dm.; under, haze.
283	3.50	38	Haze-bright at high current density edge. Dull, blue spots.
282	3.70	55	Dull, blue spots.
281	3.80	75	Dull, blue spots.

* It was necessary to use trace amounts of sodium lauryl sulfonate and a few drops of ethanol to suspend the dye.

Table 23. Solution 31; the effect Clayton Yellow in 0.5 g./l. concentration on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
3110	2.20	27	Haze, streaked.
3120	2.17	35	Haze, streaked-bright above 1.0 amp./sq.dm.
3130	2.20	55	Haze-bright, pitted above 11.8 amp./sq.dm.; haze 11.8 to 1.0 amp./sq.dm.; under, bright streak, haze.
3140	2.21	75	Dull at high current density edge. Haze, pitted above 6.5 amp./sq.dm.; under, dull.
311	3.90	27	Haze to semibright.
312	3.68	37	Haze above 10.8 amp./sq.dm.; dull 10.8 to 4.3 ampl/sq.dm.; under, haze.
313	3.65	56	Dull above 10.8 amp./sq.dm.; under, haze.
314	3.70	72	Dull, dark.

Table 24. Solution 32; the effect of Primuline Yellow in 0.5 g./l. concentration on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
3210	2.12	27	Haze.
3220	2.18	37	Haze above 1.0 amp./sq.dm.; under, bright.
3230	2.20	56	Haze-bright ring above 13.0 amp./sq.dm. Dull.
3240	2.20	71	Dull above 10.8 amp./sq.dm.; haze-bright 10.8 to 5.9 amp./sq.dm.; under, haze.
321	3.60	27	Haze above 5.4 amp./sq.dm.; under, haze-bright.
322	3.64	37	Semibright at high current density edge. Haze above 9.7 amp./sq.dm.; dull 9.7 to 4.3 amp./sq.dm., under, dark gray, dull.
323	3.85	56	Haze at high current density ring. Dull, dark above 9.7 amp./sq.dm.; under, haze to dull.
324	3.88	72	Dull, dark.

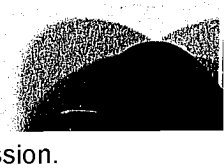
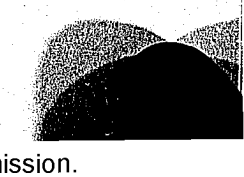


Table 25. Solution 33; the effect of Methylene Blue in 0.5 g./l. concentration on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
3310	2.20	27	Dye deposited preferentially, burned at high current density edge.
3320	2.20	37	Dye deposited preferentially, strained nickel at high current density edge.
3330	2.25	56	Dye deposited preferentially; above 3.2 amp./sq.dm.; strained nickel.
3340	2.25	71	Dye deposited preferentially; above 14.0 amp./sq.dm.; under, strained nickel.
331	3.60	27	Dye deposited, treed nickel, burned at high current density edge.
332	3.60	37	Dye deposited, treed nickel, strained.
333	3.50	56	Dye deposited, treed nickel; above 4.3 amp./sq.dm., strained.
334	3.00	72	Dye deposited, treed nickel; above 6.5 amp./sq.dm., strained.

Table 26. Solution 34; the effect of Toluidine Blue in 0.5 g./l. concentration on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
3410	2.20	28	Dye deposited preferentially, burned at high current density edge.
3420	2.20	37	Dye deposited preferentially.
3430	2.25	56	Dye deposited preferentially, sparse treed nickel.
3440	2.22	74	Dye deposited, treed nickel.
341	3.80	27	Dye deposited, treed nickel, burned at high current density edge.
342	3.70	37	Dye deposited, treed nickel; above 10.8 amp./sq.dm., treed.
343	3.80	56	Dye deposited, treed nickel above 14.0 amp./ sq.dm. Strained at high current density edge.
344	3.10	72	Dye deposited, treed nickel; strained above 14.0 amp./sq.dm.



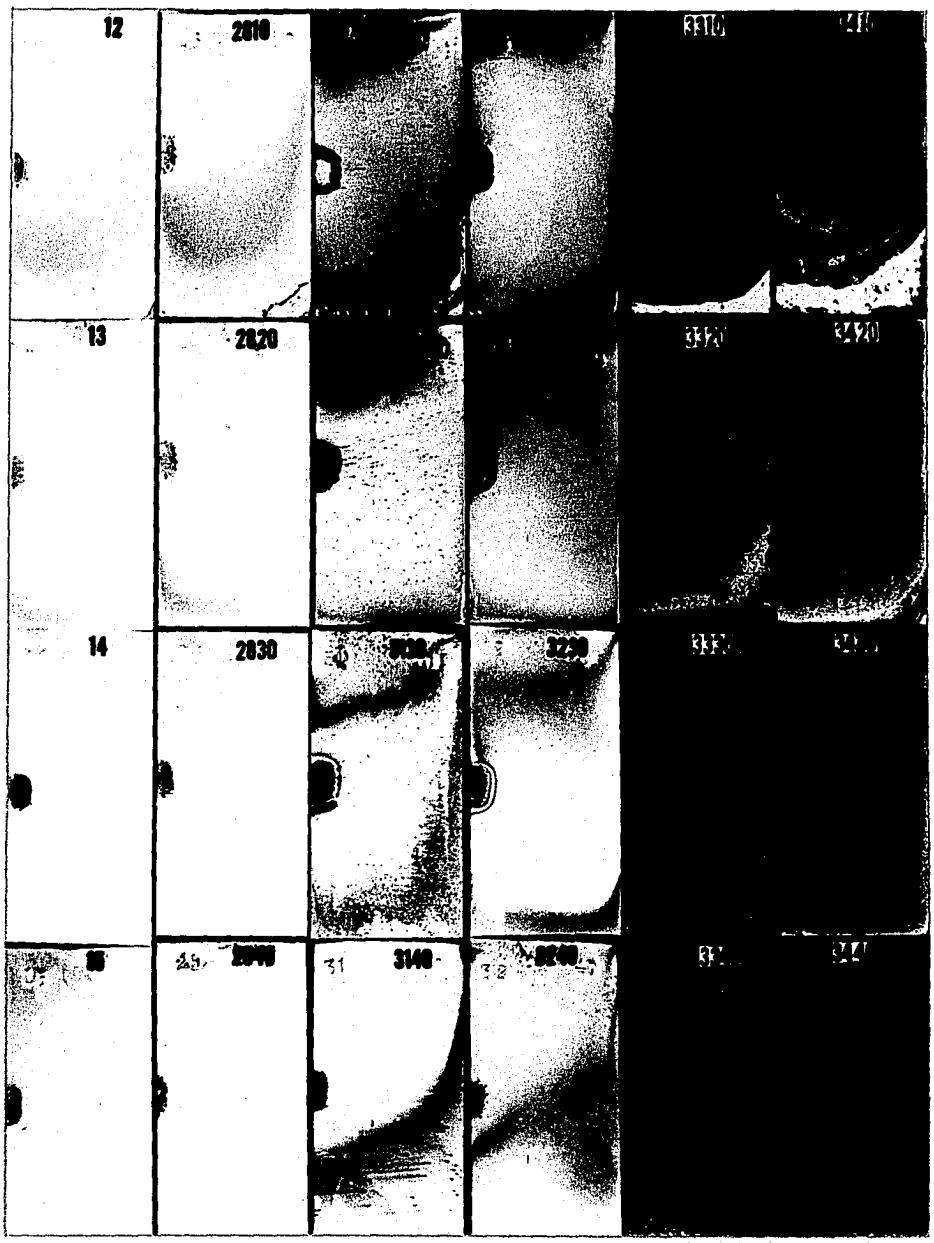


Figure 14. The effect of dyes on the appearance of Watts nickel deposits at pH 2.2.

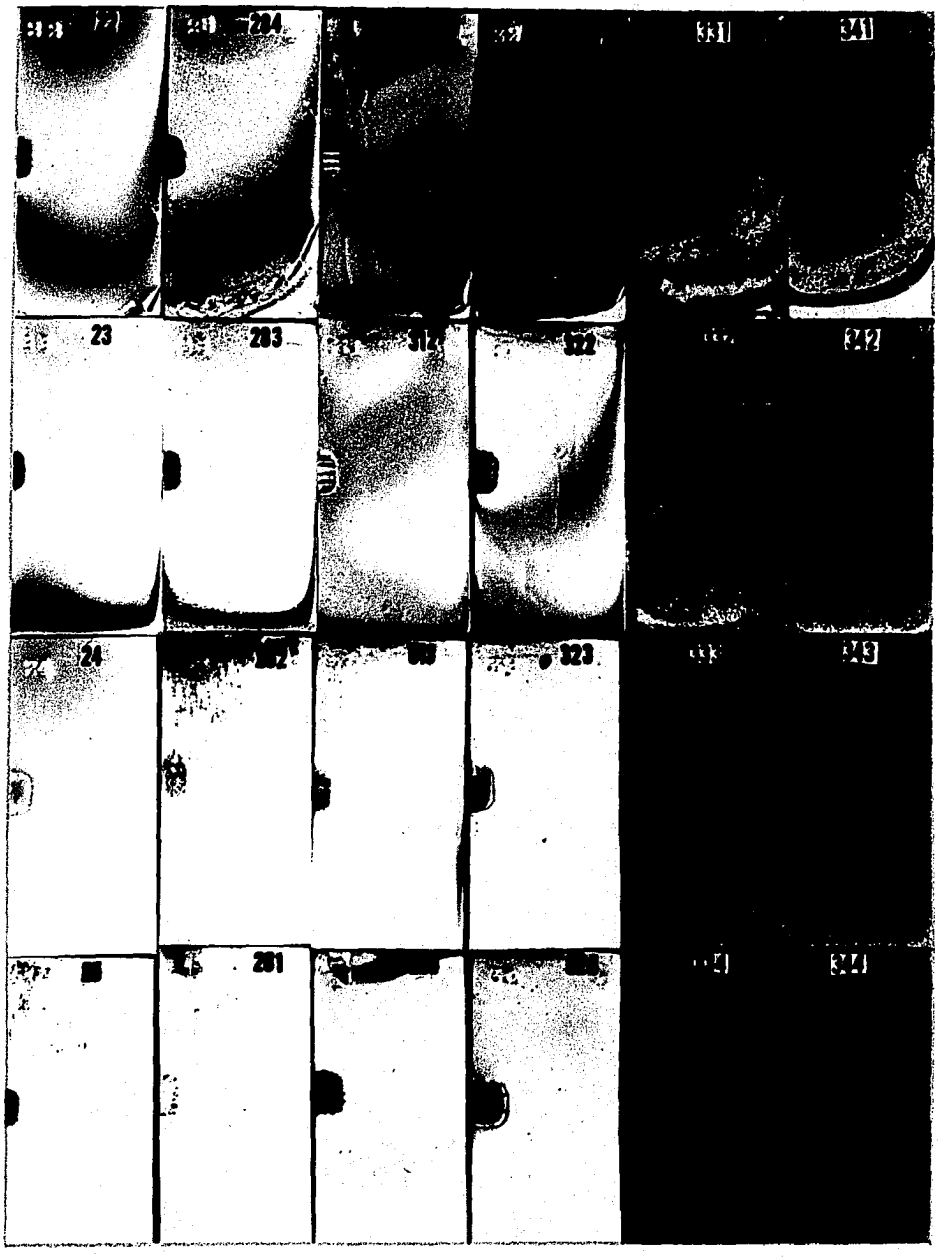


Figure 15. The effect of dyes on the appearance of Watts nickel deposits at pH 3.8.

Table 27. Solution 30; the effect of 4,4'-dihydroxybiphenyl in concentration of 0.3 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
3010	3.60	26	Exfoliate at high current density edge. Haze above 4.3 amp./sq.dm.; under, dull.
3020	3.82	37	Haze above 10.8 amp./sq.dm.; under, dull.
3030	3.80	55	Haze to dull above 11.8 amp./sq.dm.; under, dull.
3040	3.80	75	Dull, haze-bright ring at 11.8 amp./sq.dm.
301	2.19	27	Exfoliate at high current density edge. Semibright above 6.5 amp./sq.dm.; under, haze.
302	2.20	37	Semibright at high current density edge. Haze above 9.0 amp./sq.dm.; under, dull.
303	2.20	54	Haze at high current density edge. Dull.
304	2.27	77	Dull above 1.0 amp./sq.dm.; haze 1.0 to 0.5 amp./sq.dm.; under, dull.

Table 28. Solution 27; the effect of 3,5,3',5'-tetranitro 4,4'-dihydroxybiphenyl in concentration of 0.3 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
2710	2.22	26	Burned, stressed above 8.6 amp./sq.dm.; under, bright.
2720	2.18	38	Haze above 1.0 amp./sq.dm.; under, bright.
2730	2.26	55	Bright above 3.2 amp./sq.dm.; under, dull.
2740	2.20	75	Bright above 1.0 amp./sq.dm.; under, dull.
274	2.80	26	Burned above 2.1 amp./sq.dm.; under, haze-bright.
273	2.80	38	Burned above 10.8 amp./sq.dm.; under, haze-bright.
272	3.55	55	Burned at high current density edge. Exfoliate to rough above 6.5 amp./sq.dm.; under, haze-bright.
271	3.70	75	Haze-bright, rough above 8.6 amp./sq.dm.; under, semibright.
275	2.55	63	Bright above 3.8 amp./sq.dm.; under, haze.
[Five grams of 2,7-naphthalene disulfonic acid was added to the solution and deposits made at 65° C.]			
276	3.40		Bright, stress at high current density.
277	2.88		Bright, stress at high current density.
278	3.33		Bright, some roughness.

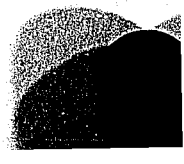


Table 28 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
279	5.55		Bright above 5.4 amp./sq.dm.; under, haze-bright.
2711	5.16		Bright above 5.4 amp./sq.dm.; under, haze-bright.
2712	3.05		Bright above 4.3 amp./sq.dm.; under, haze-bright.

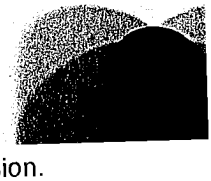


Table 29. Solution 41; the effect of phenol in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
4110	2.50	25	Haze, exfoliate above 14.0 amp./sq.dm.; haze to semibright 14.0 to 9.0 amp./sq.dm.; under, haze.
4120	2.20	38	Haze at high current density edge. Semibright above 10.8 amp./sq.dm.; under, haze.
4130	2.50	55	Dull.
4140	2.25	74	Dull.
411	3.00	24	Exfoliate above 14.0 amp./sq.dm.; semibright 14.0 to 2.6 amp./sq.dm.; under, haze.
412	3.30	35	Semibright above 13.0 amp./sq.dm.; under, haze.
413	3.75	55	Dull.
414	3.55	73	Dull above 14.0 amp./sq.dm.; dull, dark 14.0 to 2.1 amp./sq.dm.; under, haze.
[Five grams of 2,7-naphthalene disulfonic acid added to the solution.]			
415	3.50	24	Exfoliate, bright above 11.8 amp./sq.dm.; under, bright.
416	3.70	35	Bright.
417	3.20	56	Bright above 11.8 amp./sq.dm.; under, haze.
418	-	70	Haze.

Table 30. Solution 42; the effect of o-nitrophenol in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
4210	2.50	25	Exfoliate, haze above 11.8 amp./sq.dm.; under, haze.
4220	2.22	38	Haze above 9.0 amp./sq.dm.; semibright 9.0 to 2.6 amp./sq.dm.; under, haze.
4230	2.50	55	Dull, pitted.
4240	2.00	74	Dull above 11.8 amp./sq.dm.; under, dull, dark.
421	3.50	24	Exfoliate, haze above 13.0 amp./sq.dm.; semibright 13.0 to 7.6 amp./sq.dm.; under, haze.
422	3.72	35	Semibright at high current density edge. Dull.
423	3.70	55	Dull, pitted.
424	3.80	73	Dull above 6.5 amp./sq.dm.; under, dull, dark.
[Five grams of 2,7-naphthalene disulfonic acid added to the solution.]			
425	3.75	24	Exfoliate and bright above 11.8 amp./sq. dm.; under, bright.
426	3.80	35	Bright.
427	3.62	56	Bright.
428	-	70	Bright above 6.5 amp./sq.dm.; under, haze-bright.

Table 31. Solution 48; the effect of p-aminophenol hydrochloride in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
		0.5 g./l. p-Aminophenol Hydrochloride	
4810	2.20	25	Exfoliate. Haze at high current density edge. Semibright above 5.4 amp./sq.dm.; under, haze.
4820	2.20	37	Semibright at high current density edge. Haze above 9.7 amp./sq.dm.; semibright 9.7 to 3.2 amp./sq.dm.; under, haze.
4830	2.22	55	Dark haze, cracked above 4.3 amp./sq.dm.; under, dull, dark.
4840	2.20	73	Dark haze, cracked above 14.0 amp./sq.dm.; under, dull, cracked.
481	3.78	26	Bright, exfoliate above 10.8 amp./sq.dm.; under, bright, cracked.
482	3.60	38	Exfoliate. Haze, cracked above 3.8 amp./ sq.dm.; under, haze, exfoliate.
483	3.86	56	Haze, exfoliate.
484	3.80	76	Dark, exfoliate and cracked.
		2.0 g./l. p-Aminophenol Hydrochloride	
4850	2.22	27	Haze, exfoliate above 14.0 amp./sq.dm.; under, bright.
4860	2.22	38	Exfoliate. Haze at high current density edge. Bright.

Table 31 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
4870	2.22	58	Bright, exfoliate above 14.0 amp./sq.dm.; semibright 14.0 to 7.6 amp./sq.dm.; under, haze.
4880	2.22	75	Bright above 14.0 amp./sq.dm.; haze 14.0 to 9.7 amp./sq.dm.; under, dull, dark.
485	3.60	26	Bright, exfoliate above 14.0 amp./sq.dm.; bright 14.0 to 3.2 amp./sq.dm.; under, bright, exfoliate.
486	3.50	38	Bright, exfoliate.
487	3.75	54	Bright, exfoliate.
488	3.85	74	Bright, exfoliate.

Table 32. Solution 49; the effect of o-aminophenol hydrochloride in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
		0.5 g./l. o-Aminophenol Hydrochloride	
4910	2.20	25	Exfoliate at high current density edge. Haze above 2.1 amp./sq.dm.; under, semibright.
4920	2.22	37	Haze above 9.7 amp./sq.dm.; haze-bright 9.7 to 4.3 amp./sq.dm.; under, semibright.
4930	2.18	55	Dull, cracked above 8.6 amp./sq.dm.; under, haze.
4940	2.20	73	Dull, dark. Haze ring at 14.0 amp./sq. dm.
491	3.60	26	Exfoliate. Dark, haze, cracked.
492	3.80	38	Exfoliate. Dark, haze, cracked.
493	3.86	56	Dark, dull, cracked.
494	3.65	76	Dark, dull, cracked.
		2.0 g./l. o-Aminophenol Hydrochloride	
4950	2.23	27	Haze, cracked above 10.8 amp./sq.dm.; haze-bright, cracked 10.8 to 3.2 amp./ sq. dm.; under, semibright.
4960	2.20	38	Cracked, exfoliate, haze above 6.5 amp./ sq.dm.; under, semibright.
4970	2.24	58	Haze.

Table 32 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
4980	2.23	75	Haze, cracked above 4.3 amp./sq.dm.; dull, black.
495	3.75	26	Exfoliate, dull above 10.8 amp./sq.dm.; under, dark, haze, cracked.
496	3.80	38	Haze, exfoliate above 10.8 amp./sq.dm.; under, dark, cracked, haze-bright.
497	3.70	54	Dull, exfoliate above 13.0 amp./sq.dm.; under, dark, haze, cracked.
498	3.80	74	Dull, exfoliate, black above 15.1 amp./sq. dm.; under, dark, dull, cracked.

Table 33. Solution 50; the effect of catechol in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Catechol
5010	2.20	25	Exfoliate. Dull above 10.8 amp./sq.dm.; under, haze.
5020	2.20	37	Semibright at high current density edge. Haze, pitted above 9.7 amp./sq.dm.; dull 9.7 to 2.6 amp./sq.dm.; under, haze.
5030	2.25	55	Haze above 14.0 amp./sq.dm.; under, dull, pitted.
5040	2.20	73	Dull.
501	3.80	26	Exfoliate. Haze above 14.0 amp./sq.dm.; semibright 14.0 to 7.6 amp./sq.dm.; under, haze.
502	3.80	38	Haze at high current density edge. Haze-bright above 14.0 amp./sq.dm.; under, dull.
503	3.90	56	Dull.
504	3.65	76	Dull.
			2.0 g./l. Catechol
5050	2.20	27	Exfoliate. Haze-bright above 3.8 amp./sq. dm.; under, haze.
5060	2.20	38	Haze at high current density edge. Haze-bright above 11.8 amp./sq.dm.; dull 11.8 to 2.6 amp./sq.dm.; under, haze.

Table 33 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
5070	2.25	58	Haze-bright at high current density edge. Dull.
5080	2.25	75	Dull.
505	3.83	26	Exfoliate. Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 8.6 amp./sq.dm.; under, haze.
506	3.85	38	Haze-bright at high current density edge. Haze above 4.3 amp./sq.dm.; under, haze-bright to haze.
507	3.80	54	Dull, pitted above 2.1 amp./sq.dm.; under, haze.
508	3.80	74	Dull, pitted.

Table 34. Solution 51; the effect of resorcinol in concentrations of 0.5 g./l. and 2.0 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
			0.5 g./l. Resorcinol
5110	2.20	25	Exfoliate. Haze above 10.8 amp./sq.dm.; semibright 10.8 to 5.4 amp./sq.dm.; under, haze.
5120	2.20	37	Haze at high current density edge. Semi-bright above 10.8 amp./sq.dm.; under, haze. Haze-bright ring at 2.6 amp./sq.dm.; pitted.
5130	2.20	55	Pitted at high current density. Dull.
5140	2.20	73	Pitted at high current density. Dull.
511	3.83	26	Exfoliate. Haze, pitted above 14.0 amp./sq. dm.; haze-bright 14.0 to 9.7 amp./sq.dm.; under, haze.
512	3.80	38	Haze at high current density edge. Bright above 13.0 amp./sq.dm.; under, dull.
513	3.60	56	Dull.
514	3.75	76	Dull, pitted at low current densities.
			2.0 g./l. Resorcinol
5150	2.23	27	Exfoliate at high current density edge. Haze, pitted above 13.5 amp./sq.dm.; haze-bright 13.5 to 6.5 amp./sq.dm.; under, haze.
5160	2.20	38	Haze at high current density edge. Semi-bright above 10.8 amp./sq.dm.; under, haze. Haze bright ring at 2.6 amp./sq.dm.; pitted.

Table 34 (Continued)

Panel No.	pH	Temp. (° C.)	Cathode Appearance
5170	2.20	58	Pitted at high current density. Dull.
5180	2.20	75	Dull.
515	3.78	26	Burned at high current density edge. Haze above 14.0 amp./sq.dm.; haze-bright 14.0 to 8.6 amp./sq.dm.; under, haze.
516	3.85	38	Haze at high current density edge. Haze-bright above 14.0 amp./sq.dm.; under, haze to dull.
517	3.80	54	Dull.
518	3.70	74	Haze above 11.8 amp./sq.dm.; under, dull.

Table 35. Solution 52; the effect of beta-napthol in concentration of 0.5 g./l. on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
5210	2.20	26	Burned, exfoliate above 8.6 amp./sq.dm.; haze-bright 8.6 to 6.5 amp./sq.dm.; under, haze.
5220	2.20	38	Burned, exfoliate above 10.8 amp./sq.dm.; haze 10.8 to 0.5 amp./sq.dm.; under, dull, dark.
5230	2.22	54	Burned at high current density edge. Dull, dark.
5240	2.21	74	Haze at high current density edge. Dull, dark.
521	3.70	25	Burned, exfoliate above 9.7 amp./sq.dm.; haze-bright 9.7 to 1.0 amp./sq.dm.; under, haze.
522	3.70	36	Burned, exfoliate above 10.8 amp./sq.dm.; haze-bright 10.8 to 9.0 amp./sq.dm.; under, haze.
523	3.70	57	Bright at high current density edge. Haze.
524	3.78	75	Haze.

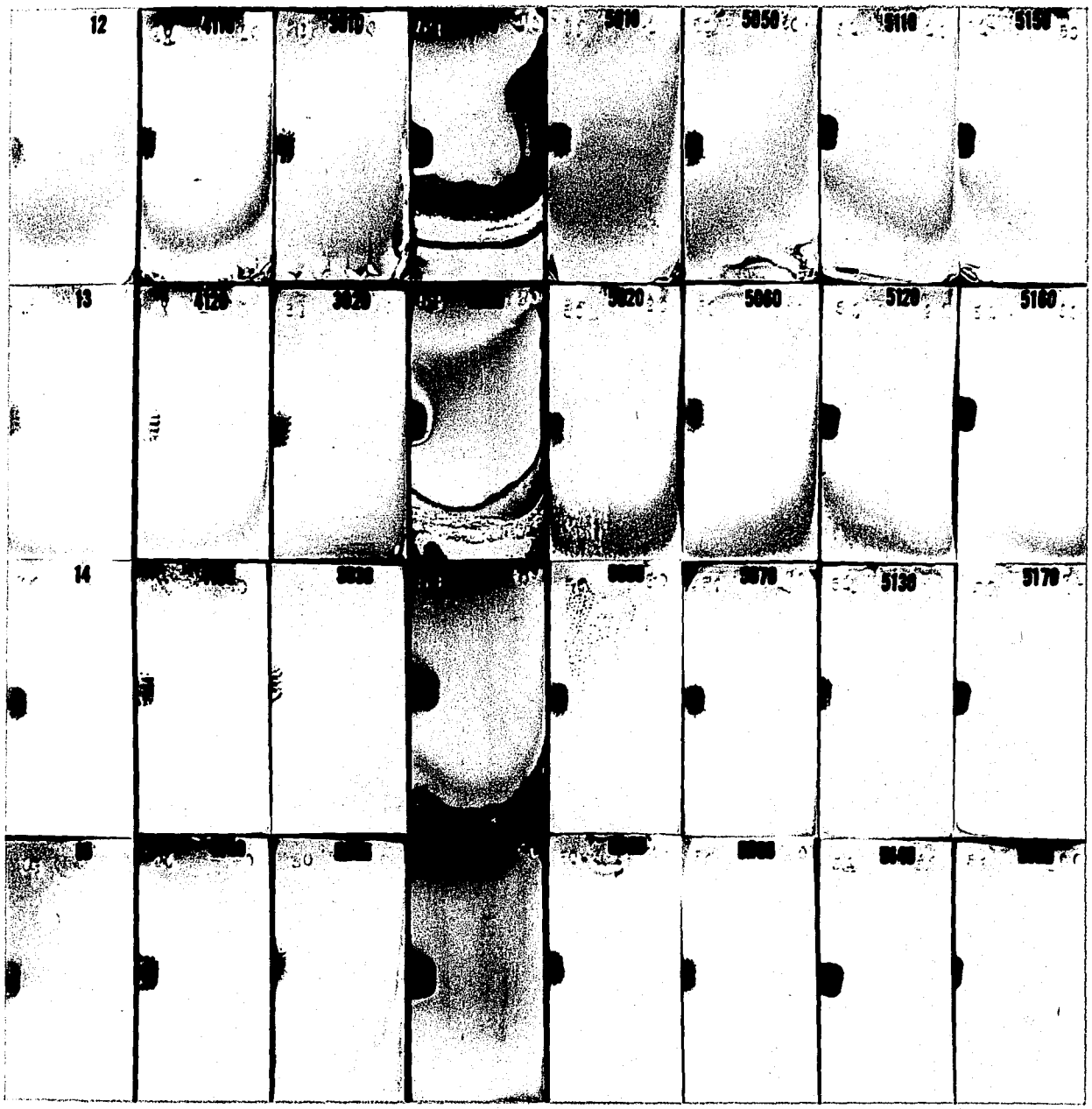


Figure 16. The effect of phenols on the appearance of Watts nickel deposits at pH 2.2.

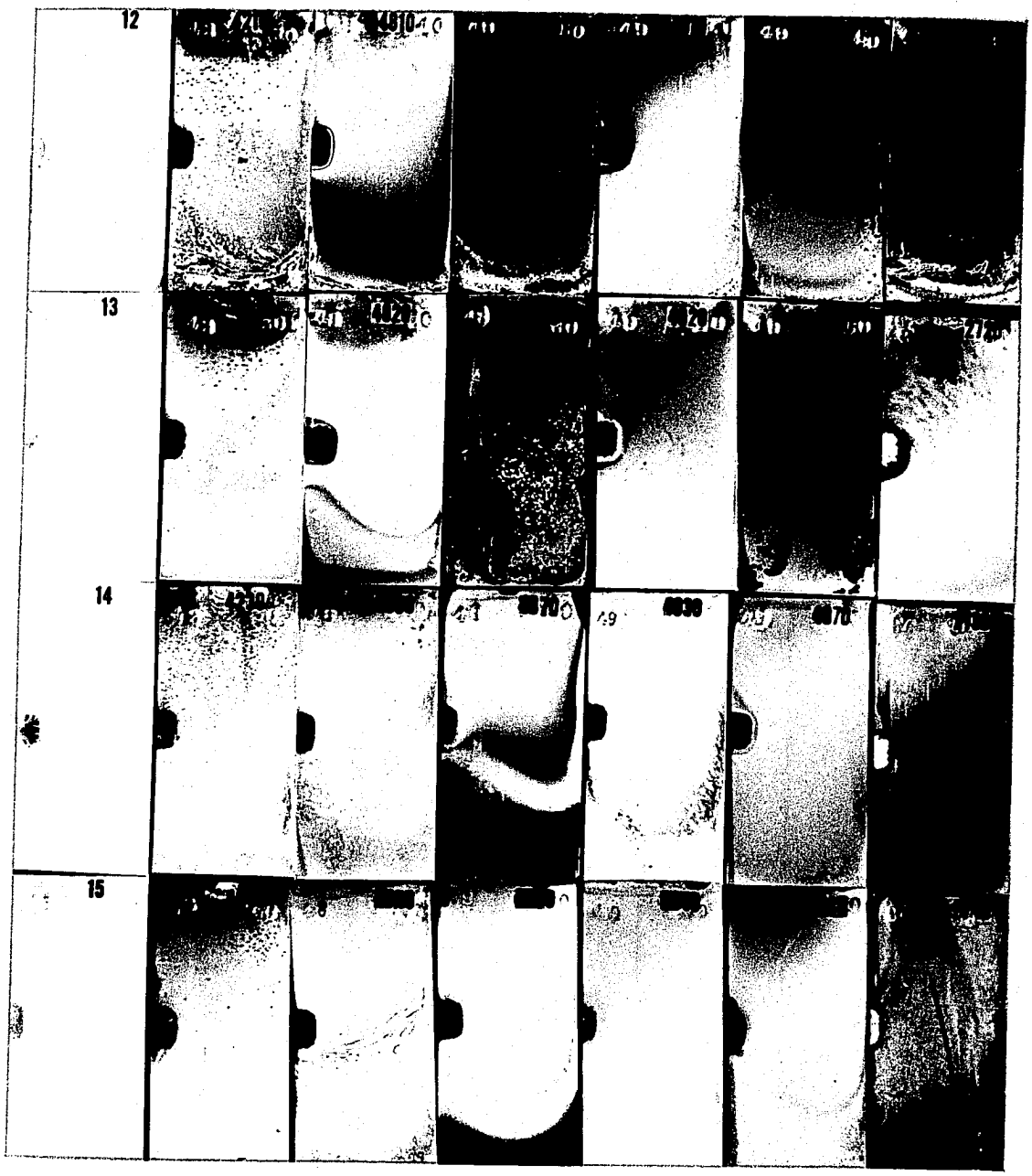


Figure 17. The effect of phenols on the appearance of Watts nickel deposits at pH 2.2.

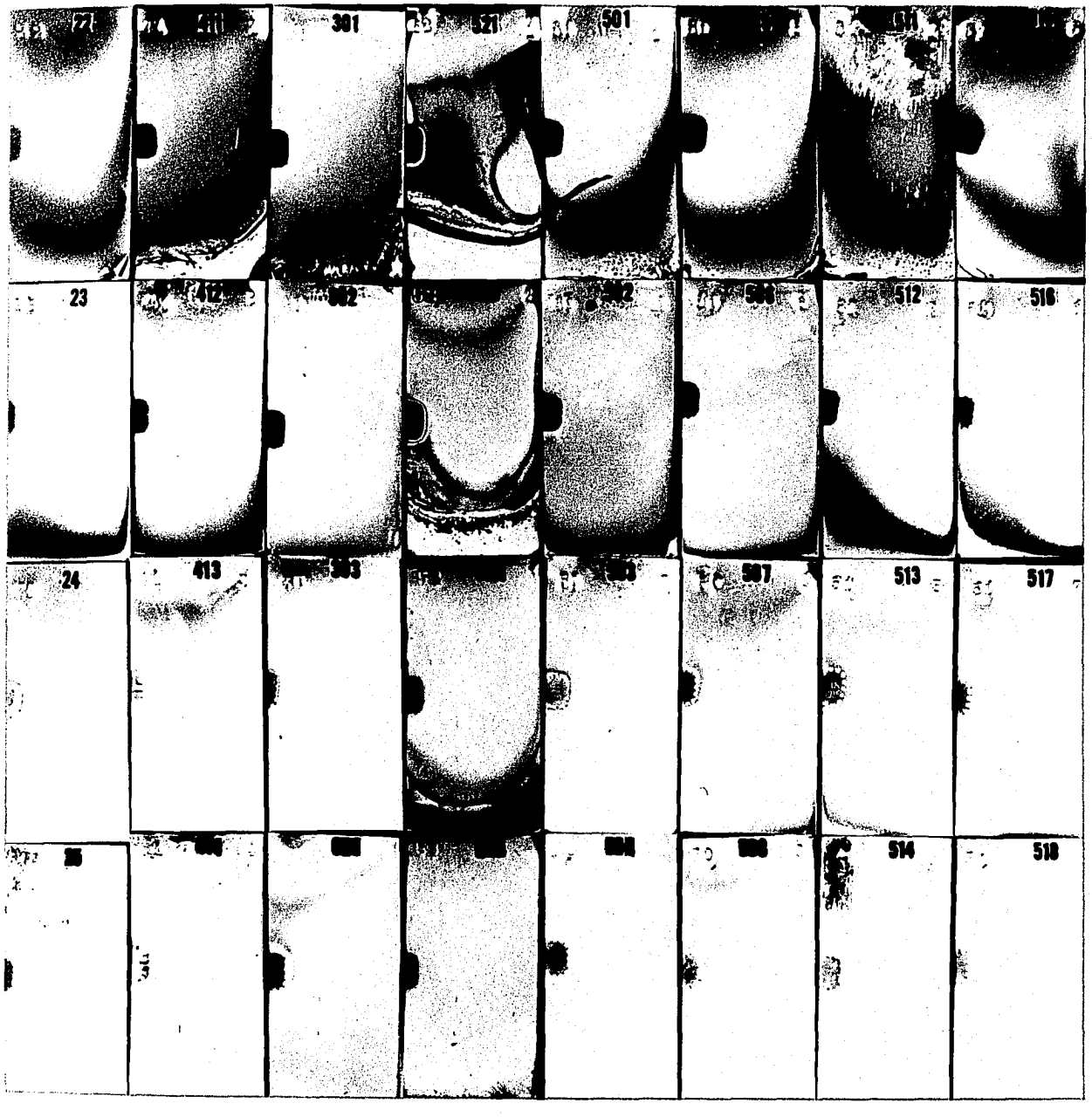


Figure 18. The effect of phenols on the appearance of Watts nickel deposits at pH 3.8.

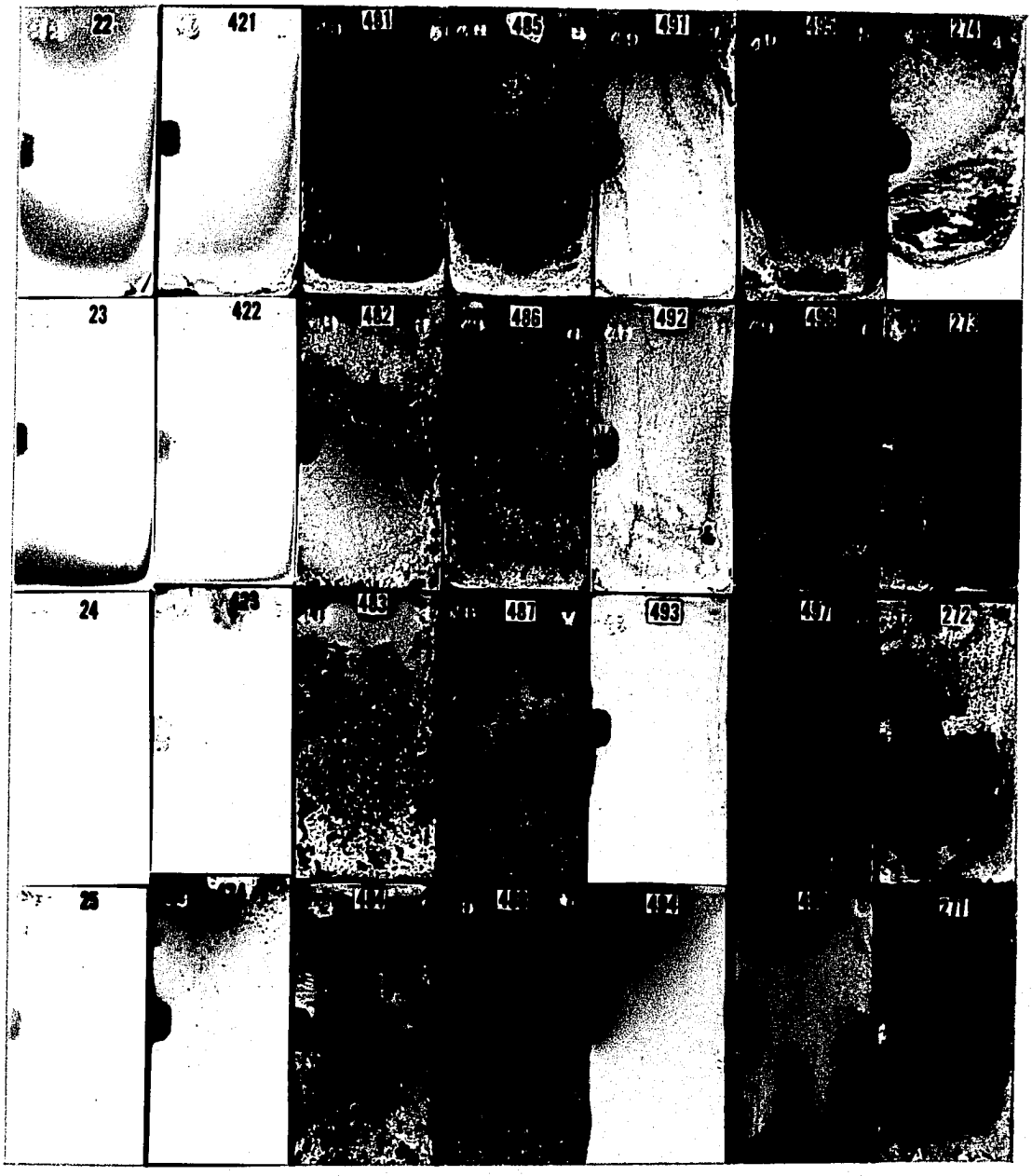


Figure 19. The effect of phenols on the appearance of Watts nickel deposits at pH 3.8.

Table 36. The effect of 5 g./l. of 2,7,-naphthalene disulfonic acid on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cathode Appearance
411-1	3.50	25	Dull, exfoliate above 11.8 amp./sq.dm.; under, bright.
411-2	3.60	35	Dull, exfoliate at high current density edge. Bright.
411-3	3.60	48	Bright above 4.3 amp./sq.dm.; under, dull.
421-3	3.70	58	Bright, pitted above 9.7 amp./sq.dm.; under, dull, pitted.
421-2	3.70	62	Bright, pitted above 14.0 amp./sq.dm.; under, dull.
421-1	3.60	67	Haze.

Table 37. Solution 371; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of glucose on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Glucose		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
371-1	3.80	64	-	-	Haze, pitted.
371-2	3.50	67	0.001	0.001	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-3	3.53	65	0.002	0.003	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-4	3.70	66	0.004	0.007	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-5	3.65	65	0.008	0.015	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-6	3.88	65	0.016	0.031	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-7	3.72	65	0.032	0.063	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-8	3.85	65	0.064	0.127	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-9	3.76	65	0.128	0.255	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
371-10	3.82	65	0.256	0.511	Bright above 14.0 amp./sq. dm.; under, haze, pitted.

Table 37 (Continued)

Panel No.	pH	Temp. (° C.)	Glucose: Addition (g.)	Glucose: Total Addition (g.)	Cathode Appearance
		The Effect of Temperature at Concentration of Panel 371-10			
371-11		25			Bright above 11.8 amp./sq. dm.; under, haze to dull.
371-12		38			Bright.
371-13		52			Bright.
371-14		60			Haze-bright, pitted.
		Treated Solution with 0.5 g./l. of Activated Carbon			
371-15		60			Haze above 11.8 amp./sq. dm.; bright 11.8 to 2.1 amp./sq.dm.; under, haze.

Table 38. Solution 381; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
381-1	3.77	64	-	-	Haze, pitted.
381-2	3.63	67	0.02	0.02/0.03	Bright, pitted above 14.0 amp./sq.dm.; under, haze.
381-3	3.80	65	0.04	0.06/0.09	Bright, pitted above 14.0 amp./sq.dm.; under, haze.
381-4	3.62	66	0.08	0.14/0.21	Bright, pitted above 10.8 amp./sq.dm.; under, haze.
381-5	3.62	65	0.16	0.30/0.45	Bright, pitted above 10.8 amp./sq.dm.; under, haze.
381-6	3.78	65	0.32	0.62/0.93	Mottled haze and bright.
381-7	3.65	65	0.64	1.26 1.89	Haze at high current density edge. Bright.
381-8	3.85	65	0.74	2.00/3.01	Bright above 10.8 amp./sq. dm.; haze 10.8 to 4.3 amp./sq.dm.; bright.
381-9	3.85	65	2.0	4.00/6.03	Haze.
381-10	3.50	65	4.0	8.00/12.06	Haze-bright above 5.4 amp./sq.dm.; under, haze.

Table 38 (Continued)

Panel No.	pH	Temp. (° C.)	Chloral Addition (ml.)	Chloral Total Addition (ml./g.)*	Cathode Appearance
			The Effect of Temperature at Concentration of Panel 381-10		
381-11		28			Burned above 11.8 amp./sq.dm.; bright 11.8 to 5.4 amp./sq.dm.; under, dull.
381-12		38			Bright, pitted above 8.6 amp./sq.dm.; under, dull.
381-13		52			Bright, pitted.
381-14		60			Bright.
			Treated Solution with 15 g./l. of Activated Carbon		
381-15		60			Bright at high current density edge. Haze-bright above 5.4 amp./sq.dm.; under, haze.

* Weights calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

Table 39. Solution 361; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of PVM/MA* (polymethyl vinyl ether and maleic anhydride) on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	PVM/MA Addition (g.)	PVM/MA Total Addition (g.)	Cathode Appearance
361-1	3.79	64	-	-	Haze.
361-2	3.75	67	0.001	0.001	Bright above 14.0 amp./sq. dm.; under, haze.
361-3	3.35	65	0.002	0.003	Bright above 14.0 amp./ sq.dm.; under, haze.
361-4	3.30	66	0.004	0.007	Bright above 14.0 amp./sq. dm.; under, haze.
361-5	2.90	65	0.008	0.015	Bright above 14.0 amp./sq. dm.; under, haze.
361-6	3.20	65	0.016	0.031	Bright above 10.8 amp./sq. dm.; under, haze-bright.
361-7	3.02	65	0.032	0.063	Bright, few white spots.
361-8	3.05	65	0.064	0.127	Bright above 4.3 amp./sq. dm.; under, haze-bright.
361-9	3.05	65	0.128	0.255	Bright above 3.2 amp./sq. dm.; under, haze-bright.
361-10	3.00	65	0.256	0.511	Dull, rough with bright undertone.

Table 39 (Continued)

Panel No.	pH	Temp. (° C.)	PVM/MA Addition (g.)	PVM/MA Total Addition (g.)	Cathode Appearance
			The Effect of Temperature at Concentrations of Panel 361-10		
361-11		28			Dull at high current density. Bright.
361-12		38			Bright.
361-13		52			Bright.
361-14		60			Bright.
			Treated Solution with 15 g./l. Activated Carbon		
361-15		60			Bright above 5.4 amp./sq. dm.; under, haze.

* Specific viscosity, 2.6.

Table 40. Solution 46; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of acrylic acid on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Acrylic Acid		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
46-1	3.75	65	-	-	Bright above 14.0 amp./sq. dm.; under, haze.
46-2	3.72	65	0.001	0.001	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
46-3	3.72	65	0.002	0.003	Bright above 14.0 amp./sq. dm.; under, haze, pitted
46-4	3.80	65	0.004	0.007	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
46-5	3.70	64	0.008	0.015	Bright above 11.8 amp./sq. dm.; under, haze, pitted.
46-6	3.61	64	0.016	0.031	Bright, pitted above 11.8 amp./sq.dm.; under, haze, pitted.
46-7	3.60	65	0.032	0.063	Bright, pitted above 11.8 amp./sq.dm.; under, haze, pitted.
46-8	3.45	64	0.064	0.127	Bright above 7.6 amp./sq. dm.; under, haze, pitted.
46-9	3.49	66	0.128	0.255	Bright above 4.3 amp./sq. dm.; under, haze.

Table 40 (Continued)

Panel No.	pH	Temp. (° C.)	Acrylic Acid		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
46-10	3.35	66	0.256	0.511	Bright above 1.6 amp./sq. dm.; under, haze.
46-11	3.23	65	0.512	1.023	Bright above 10.8 amp./ sq.dm.; under, dull.
46-12	3.10	67	1.024	2.047	Dull, cracked above 9.7 amp./sq.dm.; under, bright.

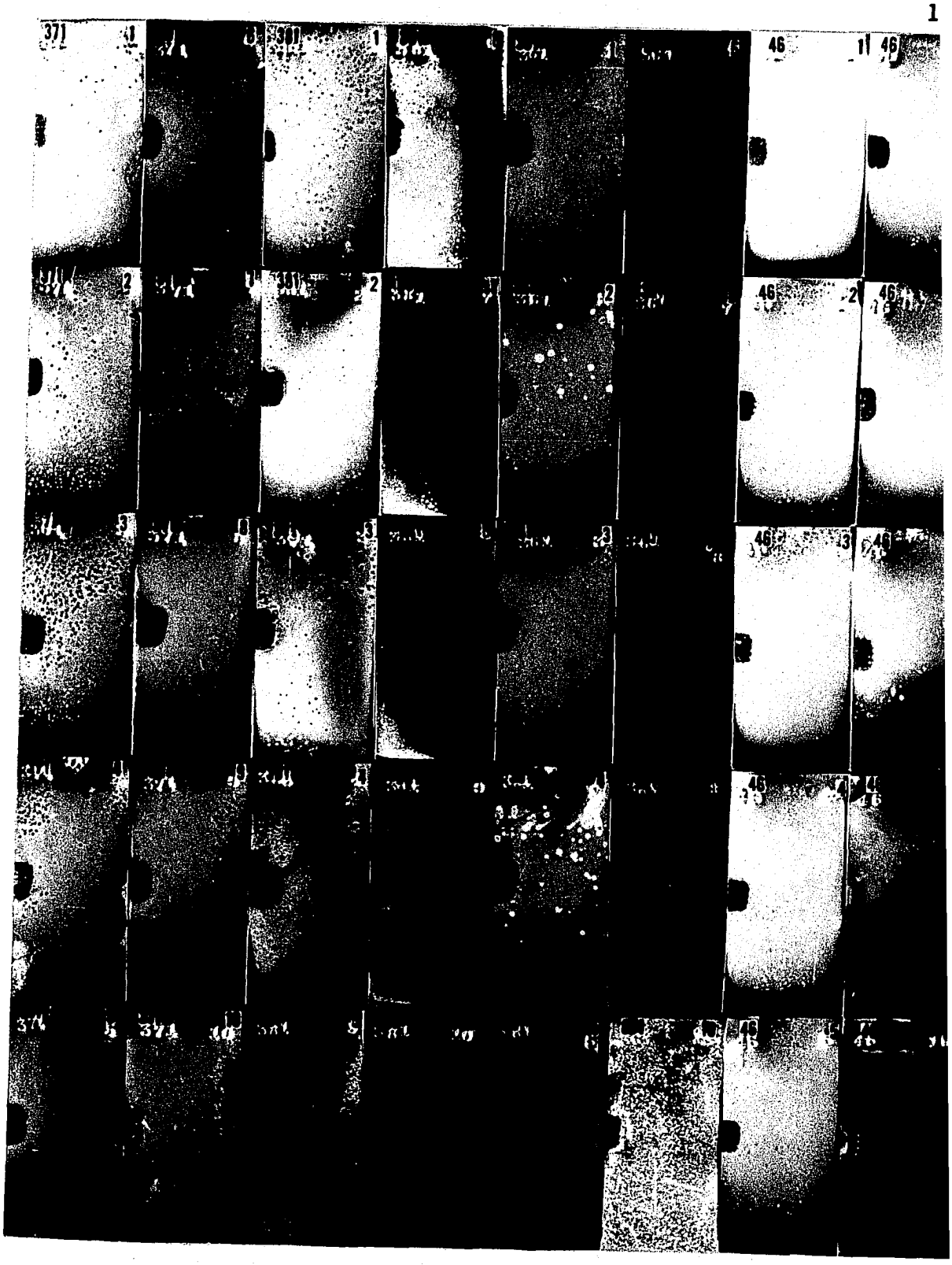


Figure 20. The effect of increasing concentrations of glucose, chlora
PVM/MA, acrylic acid, and 2,7-naphthalene disulfonic aci
on the appearance of Watts nickel deposits.

Table 41. Solution 531; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of 1,4-butynediol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	1,4-Butynediol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
531-1	3.80	68	-	-	Bright at high current density edge. Haze.
531-2	3.80	65	0.001	0.001	Bright at high current density edge. Haze.
531-3	3.75	65	0.002	0.003	Bright above 14.0 amp./sq. dm.; under, haze.
531-4	3.80	65	0.004	0.007	Bright above 14.0 amp./sq. dm.; under, haze.
531-5	3.80	65	0.008	0.015	Bright above 14.0 amp./sq. dm.; under, haze.
531-6	3.80	65	0.0016	0.031	Bright above 14.0 amp./sq. dm.; under, haze.
531-7	3.78	65	0.032	0.063	Bright above 5.4 amp./sq. dm.; under, haze-bright.
531-8	3.80	65	0.064	0.127	Haze-bright at high current density ring. Bright.
531-9	3.70	65	0.128	0.255	Haze-bright ring 15.1 amp./sq.dm. Bright.
531-10	3.80	65	0.256	0.511	Bright above 6.5 amp./sq. dm.; under, haze.

Table 42. Solution 351; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of Monastral Blue on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Monastral Blue Addition (g.)	Monastral Blue Total Addition (g.)	Cathode Appearance
351-1	3.72	64	-	-	Haze.
351-2	3.80	67	0.001	0.001	Haze.
351-3	3.60	65	0.002	0.003	Haze.
351-4	3.80	66	0.004	0.007	Haze.
351-5	3.50	65	0.008	0.015	Haze.
351-6	3.90	65	0.016	0.031	Haze.
351-7	3.80	65	0.032	0.063	Haze.
351-8	3.60	65	0.064	0.127	Haze.
351-9	3.78	65	0.128	0.255	Bright above 1.6 amp./sq. dm.; under, haze.
351-10	3.85	65	0.256	0.511	Bright.
		The Effect of Temperature at Concentration of Panel 351-10			
351-11		28			Bright above 11.8 amp./sq. dm.; under, haze.
351-12		38			Bright.

Table 42 (Continued)

Panel No.	pH	Temp. (° C.)	Monastral Blue: Addition (g.)	Monastral Blue: Total Addition (g.)	Cathode Appearance
351-13		52			Bright.
351-14		60			Bright.
		Treated Solution with 15 g./l. of Activated Carbon			
351-15		60			Haze at high current density edge. Bright above 4.3 amp./sq.dm.; under, haze.

Table 43. Solution 311; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of Clayton Yellow on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Clayton Yellow		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
311-1	3.45	62	-	-	Bright above 6.5 amp./sq. dm.; under, haze.
311-2	-	62	0.001	0.001	Bright above 6.5 amp./sq. dm.; under, haze.
311-3	3.45	62	0.002	0.003	Bright above 5.4 amp./sq. dm.; under, haze.
311 4	3.28	62	0.004	0.007	Bright above 6.5 amp./sq. dm.; under, haze.
311-5	3.40	63	0.008	0.015	Bright above 4.3 amp./sq. dm.; under, haze.
311-6	3.35	63	0.016	0.031	Bright above 3.2 amp./sq. dm.; under, haze-bright.
311-7	3.30	64	0.032	0.063	Bright.
311-8	3.00	62	0.064	0.127	Bright.
311-9	3.00	62	0.128	0.255	Bright. Haze-bright ring at high current density.
311-10	3.20	62	0.256	0.511	Bright. Haze-bright ring at high current density.

Table 43 (Continued)

Panel No.	pH	Temp. (° C.)	Clayton Yellow: Addition (g.)	Clayton Yellow: Total Addition (g.)	Cathode Appearance
[Solution 311 was treated with 15 g. of activated carbon at 65° C., filtered, and cathode was plated in the customary manner.]					
311-11	3.10	62			Bright above 1.6 amp./sq. dm.; under, haze.
[Cathode was plated at 3 amps. for 22.5 amp. hours.]					
311-12		62			Bright. Treed at high current density.
[Cathode was plated in the customary manner.]					
311-13	3.00	62			Bright above 10.8 amp./sq. dm.; under, haze.

Table 44. Solution 321; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of Primuline Yellow on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Primuline Yellow		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
321-1	3.45	62	-	-	Bright above 6.5 amp./sq. dm.; under, haze.
321-2	-	62	0.001	0.001	Bright above 6.5 amp./sq. dm.; under, haze.
321-3	2.70	62	0.002	0.003	Bright above 6.5 amp./sq. dm.; under, haze.
321-4	2.75	62	0.004	0.007	Bright above 6.5 amp./sq. dm.; under, haze.
321-5	2.90	62	0.008	0.015	Bright above 4.3 amp./sq. dm.; under, haze-bright.
321-6	3.20	63	0.016	0.031	Bright above 3.2 amp./sq. dm.; under, haze-bright.
321-7	3.15	62	0.032	0.063	Bright.
321-8	3.30	62	0.064	0.127	Bright.
321-9	3.30	62	0.128	0.255	Bright. Haze ring at high current density.
321-10	3.28	62	0.256	0.511	Bright. Haze ring at high and low current density.

Table 44 (Continued)

Panel No.	pH	Temp. (° C.)	Primuline Yellow: Addition (g.)	Primuline Yellow: Total Addition (g.)	Cathode Appearance
[Solution 321 was treated with 15 g. of activated carbon at 65° C., filtered, and cathode was plated in the customary manner.]					
321-11	3.20	62			Bright above 1.6 amp./sq. dm.; under, haze.
[Cathode was plated at 3 amps. for 22.5 amp. hours.]					
321-12	-	62			Bright. Treed at high current density.
[Cathode was plated in the customary manner.]					
321-13	3.12	62			Bright above 6.5 amp./sq. dm.; under, haze.

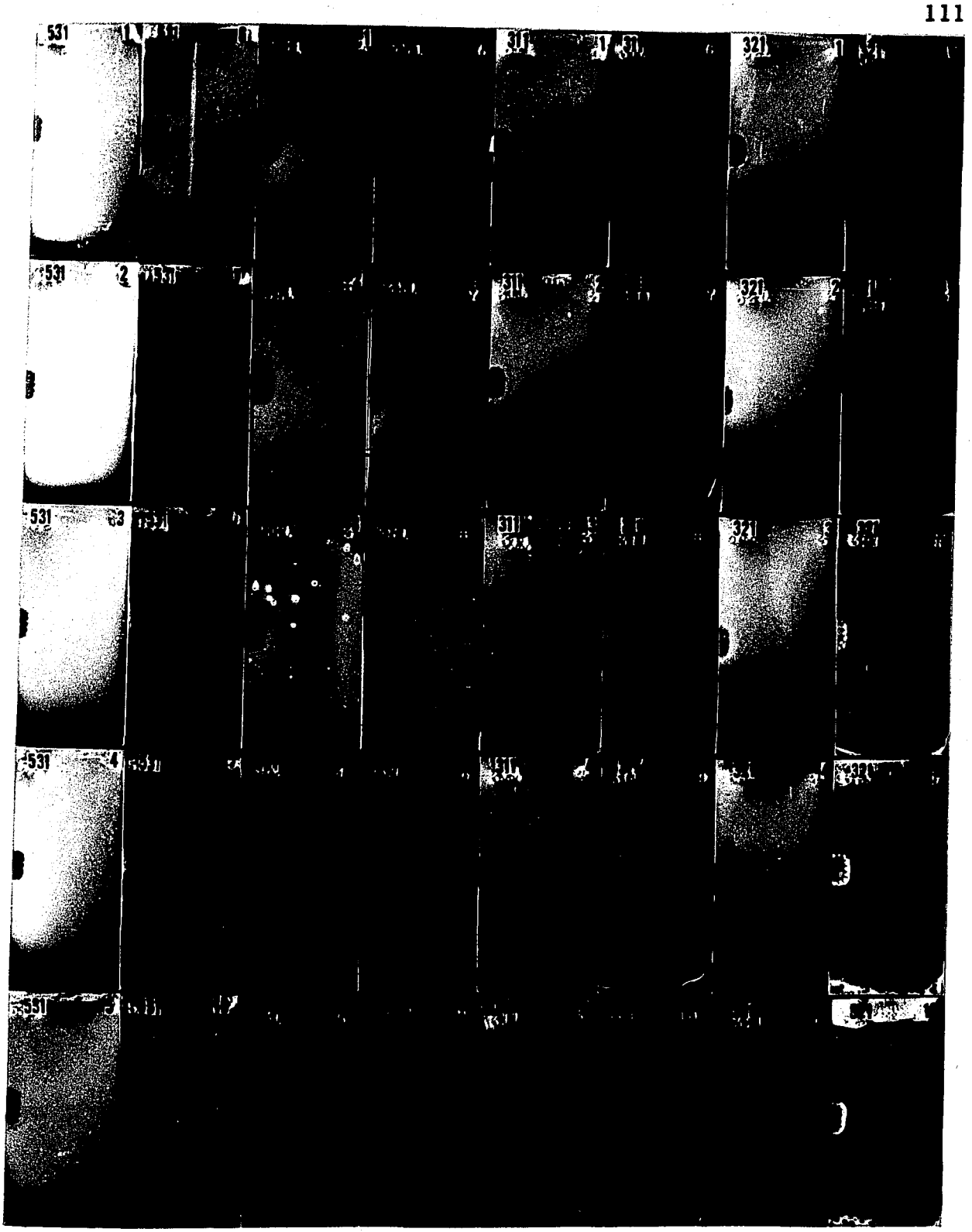


Figure 21. The effect of increasing concentrations of 1,4-butynediol and dyes; and 2,7-naphthalene disulfonic acid on the appearance of Watts nickel deposits.

Table 45. Solution 331; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of Methylene Blue on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Methylene Blue		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
331-1	3.52	62	-	-	Bright above 14.0 amp./sq. dm.; haze 14.0 to 1.0 amp./sq.dm.; under, bright.
331-2	-	62	0.001	0.001	Haze-bright above 1.0 amp./sq.dm.; under, dull.
331-3	3.40	62	0.002	0.003	Bright above 1.0 amp./sq. dm.; under, dull.
331-4	2.85	62	0.004	0.007	Bright.
331-5	3.10	62	0.008	0.015	Bright above 1.6 amp./sq. dm.; under, haze.
331-6	3.25	63	0.016	0.031	Bright above 4.3 amp./sq. dm.; under, haze.
331-7	3.10	62	0.032	0.063	Bright above 10.8 amp./sq. dm.; under, haze, exfoliate, colored.
331-8	3.30	63	0.064	0.127	Haze-bright, exfoliate, cracked, colored.

[Solution 331 was treated with 15 g. of activated carbon at 65° C., filtered, and the cathode was plated in the usual manner.]

Table 45 (Continued)

Panel No.	pH	Temp. (° C.)	Methylene Blue: Addition (g.)	Methylene Blue: Total Addition (g.)	Cathode Appearance
331-11	3.35	62			Semibright above 3.2 amp./sq.dm.; under, haze.
[Cathode was plated at 3 amps. for 22.5 amp. hours.]					
331-12	-	62			Semibright. Treed at high current density.
[Cathode was plated in the customary manner.]					
331-13	3.32	62			Dull above 10.8 amp./sq. dm.; under, semibright.

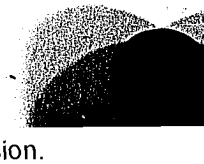


Table 46. Solution 341; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of Toluidine Blue on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Toluidine Blue		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
341-1	3.20	62	-	-	Semibright.
341-2	-	62	0.001	0.001	Semibright.
341-3	3.30	62	0.002	0.003	Bright above 5.4 amp./sq. dm.; under, semibright.
341-4	3.00	63	0.004	0.007	Bright (vividly) above 8.6 amp./sq.dm.; under, dull.
341-5	3.00	63	0.008	0.015	Bright above 1.6 amp./sq. dm.; under, haze.
341-6	3.20	64	0.016	0.031	Bright above 3.2 amp./sq. dm.; under, haze.
341-7	3.20	62	0.032	0.063	Bright, exfoliate, colored above 7.6 amp./sq.dm.; under, haze.
341-8	3.32	62	0.064	0.127	Haze-bright, exfoliate, cracked, colored.
[Solution 341 was treated with 15 g. of activated carbon at 65° C. and permitted to stand overnight, filtered, and the cathode was plated in the usual manner.]					
341-11	3.40	62			Dull above 11.8 amp./sq. dm.; under, semibright.

Table 46 (Continued)

Panel No.	pH	Temp. (° C.)	Toluidine Blue: Addition (g.)	Toluidine Blue: Total Addition (g.)	Cathode Appearance
[Cathode was plated at 3 amps. for 22.5 amp. hours.]					
341-12	-	62			Dull, treed above 2.1 amp./sq.dm.; under, semibright.
[Cathode was plated in the customary manner.]					
341-14	3.40	62			Dull above 10.8 amp./sq. dm.; under, semibright.

Table 47. Solution 301;the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of 4,4'-dihydroxybiphenyl on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	4,4'-Dihydroxybiphenyl		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
301-1	3.60	67	-	-	Haze-bright above 14.0 amp./sq.dm.; under, haze, pitted.
301-2	3.75	64	0.001	0.001	Haze-bright above 14.0 amp./sq.dm.; under, haze, pitted.
301-3	3.65	66	0.002	0.003	Haze-bright above 14.0 amp./sq.dm.; under, haze, pitted.
301-4	3.80	64	0.004	0.007	Haze-bright above 14.0 amp./sq.dm.; under, haze, pitted.
301-5	3.85	64	0.008	0.015	Haze-bright above 11.8 amp./sq.dm.; under, haze, pitted.
301-6	3.95	65	0.016	0.031	Haze-bright above 11.8 amp./sq.dm.; under, haze, pitted.
301-7	4.05	64	0.032	0.063	Haze-bright above 8.6 amp./sq.dm.; under, haze, pitted.

Table 47 (Continued)

Panel No.	pH	Temp. (° C.)	4,4'-Dihydroxybiphenyl Addition (g.)	4,4'-Dihydroxybiphenyl Total Addition (g.)	Cathode Appearance
301-8	3.15	63	0.064	0.127	Haze-bright above 6.5 amp./sq.dm.; under haze, pitted.
301-9	3.25	63	0.128	0.255	Haze-bright above 4.3 amp./sq.dm.; under, haze.
301-10	3.45	65	0.256	0.511	Haze-bright above 11.8 amp./sq.dm.; under, haze, pitted.
		Effect of Temperature at Concentration of Panel 301-10			
301-12	3.85	47			Bright pitted above 11.8 amp./sq.dm.; under, haze.
301-14	3.70	24			Exfoliate haze above 11.8 amp./sq.dm.; bright 11.8 to 3.8 amp./sq.dm.; under, haze.
301-15	3.80	35			Exfoliate above 11.8 amp./sq.dm.; under, bright.
301-16	3.60	55			Bright above 11.8 amp./sq.dm.; under, haze.
301-17	3.72	75			Bright pitted above 11.8 amp./sq.dm.; under, haze, pitted.

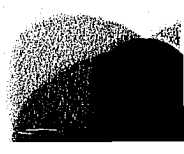


Table 48. Solution 271; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of 3,5,3', 5'-tetranitro-4,4'-dihydroxybiphenyl on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
271-1	3.83	67	-	-	Bright above 14.0 amp./sq.dm.; under, haze.
271-2	3.70	64	0.001	0.001	Bright above 11.8 amp./sq.dm.; haze-bright 11.8 to 1.6 amp./sq.dm.; under, bright.
271-3	3.75	66	0.002	0.003	Bright above 3.2 amp./sq. dm,; under, haze.
271-4	3.60	64	0.004	0.007	Bright above 13.0 amp./sq. dm.; under, haze.
271-5	3.23	64	0.008	0.015	Bright at high current density edge. Haze.
271-6	3.85	65	0.016	0.031	Exfoliate at high current density edge. Haze.
271-7	4.55	64	0.032	0.063	Exfoliate at high current density edge. Bright above 11.8 amp./sq.dm.; under, haze.

Table 48 (Continued)

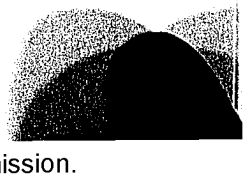
Panel No.	pH	Temp. (° C.)	3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
271-8	3.62	63	0.064	0.127	Exfoliate at high current density edge. Bright above 10.8 amp./sq.dm.; under, haze.
271-9	3.20	63	0.128	0.255	Trace exfoliation. Bright above 10.8 amp./sq.dm.; under, haze.
271-10	3.72	65	0.256	0.511	Exfoliate. Haze-bright above 8.6 amp./sq.dm.; under, haze.
271-11	3.00	67	-	0.511	Trace exfoliation. Bright above 10.8 amp./sq.dm.; under, haze.
		Effect of Temperature at Concentration of Panel 271-10			
271-12	4.45	47			Bright, exfoliate.
271-14	3.20	24			Dull above 3.2 amp./sq. dm.; under, bright.
271-15	3.60	35			Exfoliate. Haze-bright above 3.2 amp./sq.dm.; under, bright.

Table 48 (Continued)

Panel No.	pH	Temp. (° C.)	3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
271-16	3.60	55			Exfoliate. Haze-bright above 6.5 amp./sq.dm.; under, haze.
271-17	3.72	75			Exfoliate. Haze-bright above 11.8 amp./sq.dm.; under, haze.

Table 49. Solution 411; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of phenol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Phenol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
411-4	3.50	63	0.001	0.001	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
411-5	3.50	65	0.002	0.003	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
411-6	3.65	65	0.004	0.007	Bright above 11.8 amp./sq. dm.; under, haze, pitted.
411-7	3.80	65	0.008	0.015	Bright above 11.8 amp./sq. dm.; under, haze, pitted.
411-8	3.60	66	0.016	0.031	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
411-9	3.68	66	0.032	0.063	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
411-10	3.82	64	0.064	0.127	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
411-11	3.85	66	0.128	0.255	Bright above 14.0 amp./sq. dm.; under, haze, pitted.
411-12	3.80	65	0.256	0.511	Bright above 11.8 amp./sq. dm.; under, haze, pitted.



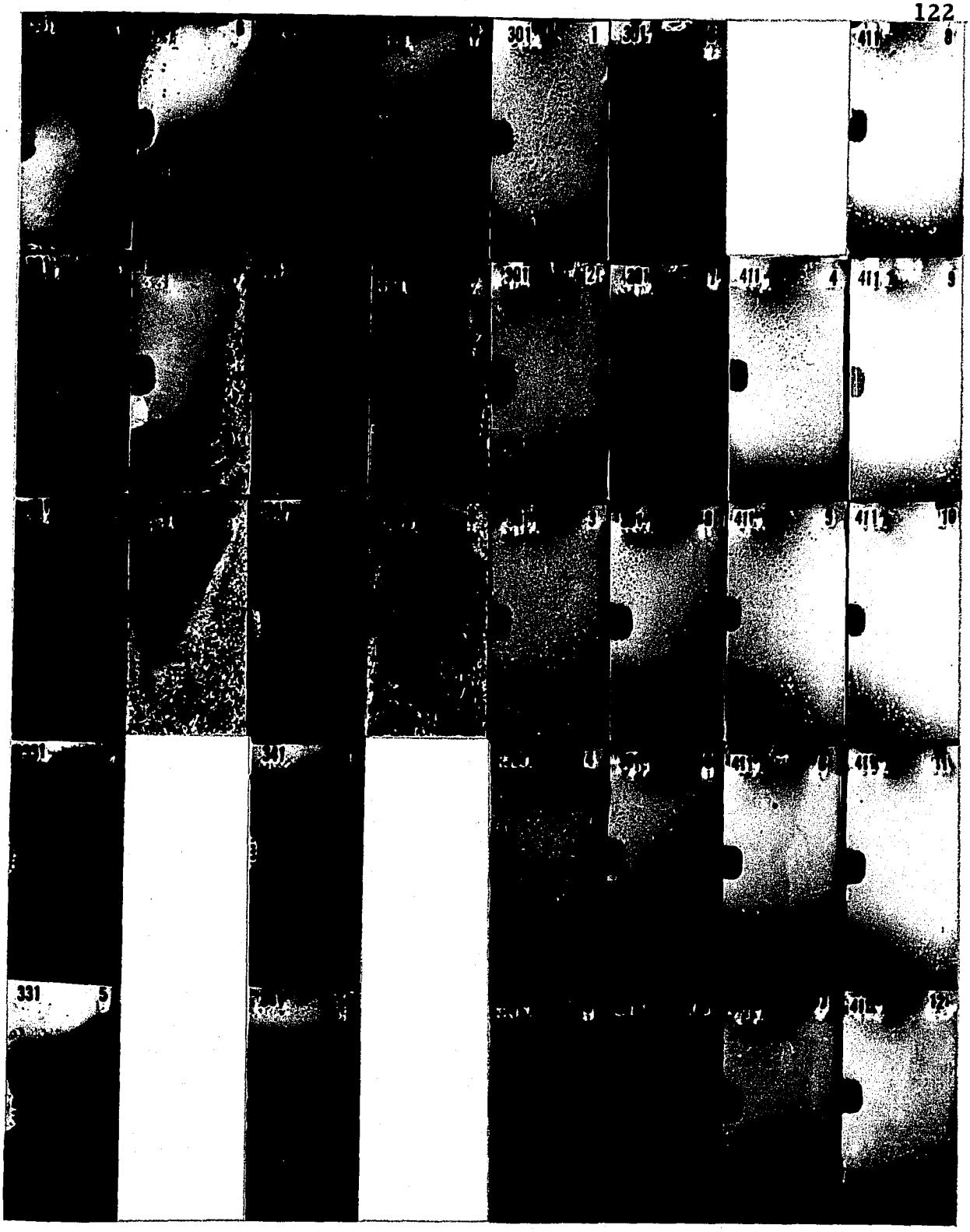


Figure 22. The effect of increasing concentrations of dyes and of phenols and 2,7-naphthalene disulfonic acid on the appearance of Watts nickel deposits.

Table 50. Solution 421; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of o-nitrophenol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	o-Nitrophenol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
421-4	3.60	63	0.001	0.001	Bright above 11.8 amp./sq. dm.; under, haze, pitted.
421-5	3.80	65	0.002	0.003	Bright above 8.6 amp./sq. dm.; under, haze, pitted.
421-6	3.65	65	0.004	0.007	Bright above 5.4 amp./sq. dm.; under, haze, pitted.
421-7	3.50	65	0.008	0.015	Bright.
421-8	3.65	66	0.016	0.031	Bright.
421-9	3.80	66	0.032	0.063	Haze-bright, pitted.
421-10	3.75	64	0.064	0.127	Haze-bright, pitted.
421-11	3.82	66	0.128	0.255	Haze, pitted.
421-12	3.75	65	0.256	0.511	Haze, pitted.

Table 51. Solution 47; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of p-nitro phenol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	p-Nitrophenol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
47-1	3.55	65	-	-	Bright above 14.0 amp./sq. dm.; under, haze.
47-2	3.85	65	0.001	0.001	Bright above 11.8 amp./sq. dm.; under, haze.
47-3	3.55	65	0.002	0.003	Bright above 11.8 amp./sq. dm.; under, haze.
47-4	3.80	65	0.004	0.007	Bright above 11.8 amp./sq. dm.; under, haze, pitted.
47-5	3.80	64	0.008	0.015	Bright above 11.8 amp./sq. dm.; under, haze, pitted.
47-6	3.88	64	0.016	0.031	Bright above 10.8 amp./sq. dm.; under, haze, pitted.
47-7	3.50	65	0.032	0.063	Bright above 9.0 amp./sq. dm.; under, haze-bright.
47-8	3.86	64	0.064	0.127	Haze above 11.8 amp./sq. dm.; haze-bright 11.8 to 2.1 amp./sq.dm.; under, haze, pitted.
47-9	3.20	66	0.128	0.255	Haze above 11.8 amp./sq. dm.; under, bright, exfoliate.
47-10	3.80	66	0.256	0.511	Bright, exfoliate.

Table 52. Solution 481; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of p-amino phenol hydrochloride on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	p-Aminophenol Hydrochloride		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
481-1	3.80	65	-	-	Bright above 14.0 amp./sq. dm.; under, haze.
481-2	3.82	64	0.001	0.001	Bright above 5.4 amp./sq. dm.; under, haze.
481-3	3.78	65	0.002	0.003	Bright above 4.3 amp./sq. dm.; under, haze.
481-4	3.80	65	0.004	0.007	Bright.
481-5	3.80	65	0.008	0.015	Bright.
481-6	3.82	64	0.016	0.031	Bright.
481-7	3.86	65	0.032	0.063	Bright.
481-8	3.80	64	0.064	0.127	Semibright to haze.
481-9	3.75	65	0.128	0.255	Semibright to haze, cracked.
481-10	3.80	65	0.256	0.511	Semibright to haze, cracked.
The Effect of Temperature at Concentration of Panel 481-10					
481-11	3.50	35			Haze.

Table 52 (Continued)

Panel No.	pH	Temp. (° C.)	p-Aminophenol Hydrochloride		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
481-12	3.75	49			Haze, cracked.
481-13	3.80	59			Haze, cracked.

Table 53. Solution 491; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of o-amino phenol hydrochloride on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	o-Aminophenol Hydrochloride		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
491-1	3.65	65	-	-	Bright at high current density edge. Haze.
491-2	3.80	64	0.001	0.001	Bright above 14.0 amp./sq. dm.; under, haze.
491-3	3.75	65	0.002	0.003	Bright above 10.8 amp./sq. dm.; under, haze.
491-4	3.80	65	0.004	0.007	Bright above 4.3 amp./sq. dm.; under, haze-bright.
491-5	3.75	65	0.008	0.015	Bright.
491-6	3.75	64	0.016	0.031	Bright.
491-7	3.84	65	0.082	0.063	Haze-bright above 4.3 amp./sq.dm.; under, bright.
491-8	3.75	64	0.064	0.127	Bright above 3.8 amp./sq. dm.; under, haze.
491-9	3.79	65	0.128	0.255	Semibright to haze.
491-10	3.75	65	0.256	0.511	Haze, cracked.

Table 53 (Continued)

Panel No.	pH	Temp. (° C.)	o-Aminophenol Hydrochloride		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
			The Effect of Temperature at Concentration of Panel 491-10		
491-11	3.60	35			Haze, exfoliate, cracked.
491-12	3.80	49			Haze, exfoliate, cracked.
491-13	3.80	59			Haze, cracked.

Table 54. Solution 501; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of catechol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Catechol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
501-1	3.70	65	-	-	Bright at high current density edge. Haze.
501-2	3.83	64	0.001	0.001	Bright at high current density edge. Haze.
501-3	3.70	65	0.002	0.003	Bright at high current density edge. Haze.
501-4	3.82	65	0.004	0.007	Bright; pitted above 15.1 amp./sq.dm.; under, haze.
501-5	3.85	65	0.008	0.015	Bright, pitted above 15.1 amp./sq.dm.; under, haze.
501-6	3.74	64	0.016	0.031	Bright, pitted above 14.0 amp./sq.dm.; under, haze.
501-7	3.83	65	0.032	0.063	Bright above 15.1 amp./ sq.dm.; under, haze.
501-8	3.75	64	0.064	0.127	Bright above 15.1 amp./ sq.dm.; under, haze.
501-9	3.80	65	0.128	0.255	Bright, pitted above 15.1 amp./sq.dm.; under, haze.
501-10	3.80	65	0.256	0.511	Bright, pitted above 15.1 amp./sq.dm.; under, haze.

Table 54 (Continued)

Panel No.	pH	Temp. (° C.)	Catechol Addition (g.)	Catechol Total Addition (g.)	Cathode Appearance
501-14	3.80	65	0.512	1.023	Haze-bright at high current density edge. Haze.
		The Effect of Temperature at Concentration of Panel 501-10			
501-11	3.50	35			Bright, pitted above 3.2 amp./sq.dm.; under, haze.
501-12	3.50	49			Haze-bright above 7.6 amp./sq.dm.; under, haze.
501-13	3.70	59			Haze-bright above 9.0 amp./sq.dm.; under, haze.

Table 55. Solution 511; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of resorcinol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Resorcinol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
511-1	3.70	65	-	-	Bright at high current density edge. Haze.
511-2	3.85	64	0.001	0.001	Bright at high current density edge. Haze.
511-3	3.85	65	0.002	0.003	Bright at high current density edge. Haze.
511-4	3.80	65	0.004	0.007	Bright at high current density edge. Haze.
511-5	3.75	65	0.008	0.015	Bright at high current density edge. Haze.
511-6	3.75	64	0.016	0.031	Bright above 10.8 amp./sq. dm.; under, haze.
511-7	3.80	65	0.032	0.063	Bright above 14.0 amp./sq. dm.; under, haze.
511-8	3.70	64	0.064	0.127	Bright above 11.8 amp./sq. dm.; under, haze.
511-9	3.60	65	0.128	0.255	Bright above 10.8 amp./sq. dm.; under, haze.
511-10	3.70	65	0.256	0.511	Bright above 9.7 amp./sq. dm.; under haze.

Table 55 (Continued)

Panel No.	pH	Temp. (° C.)	Resorcinol Addition (g.)	Resorcinol Total Addition (g.)	Cathode Appearance
511-14	3.60	65	0.512	1.023	Bright above 14.0 amp./sq. dm.; under, haze.
			The Effect of Temperature at Concentration of Panel 511-10		
511-11	3.50	35			Haze at high current density edge. Haze-bright.
511-12	3.70	49			Bright above 8.6 amp./sq. dm.; under, haze.
511-13	3.80	59			Bright above 9.7 amp./sq. dm.; under, haze.

Table 56. Solution 521; the effect of 5.0 g./l. of 2,7-naphthalene disulfonic acid and increasing concentrations of beta-napthol on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	beta-Napthol		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
521-1	3.80	68	-	-	Bright at high current density edge. Haze.
521-2	3.82	65	0.001	0.001	Bright at high current density edge. Haze.
521-3	3.80	65	0.002	0.003	Bright above 10.8 amp./sq. dm.; under, haze, pitted.
521-4	3.80	65	0.004	0.007	Bright above 8.6 amp./sq. dm.; under, haze, pitted.
521-5	3.80	65	0.008	0.015	Bright above 8.6 amp./sq. dm.; under, haze, pitted.
521-6	3.80	65	0.016	0.031	Bright above 6.5 amp./sq. dm.; under, haze, pitted.
521-7	3.80	65	0.032	0.063	Haze at high current density edge. Bright, pitted above 4.3 amp./sq.dm.; under, haze, pitted.
521-8	3.80	65	0.064	0.127	Haze above 15.1 amp./sq. dm.; bright 15.1 to 2.6 amp./sq.dm.; under, haze-bright.

Table 56 (Continued)

Panel No.	pH	Temp. (° C.)	beta-Napthol Addition (g.)	beta-Napthol Total Addition (g.)	Cathode Appearance
521-9	3.80	65	0.128	0.255	Haze above 9.7 amp./sq. dm.; under, haze-bright.
521-10	3.60	65	0.256	0.511	Haze above 8.1 amp./sq. dm.; under, haze-bright.

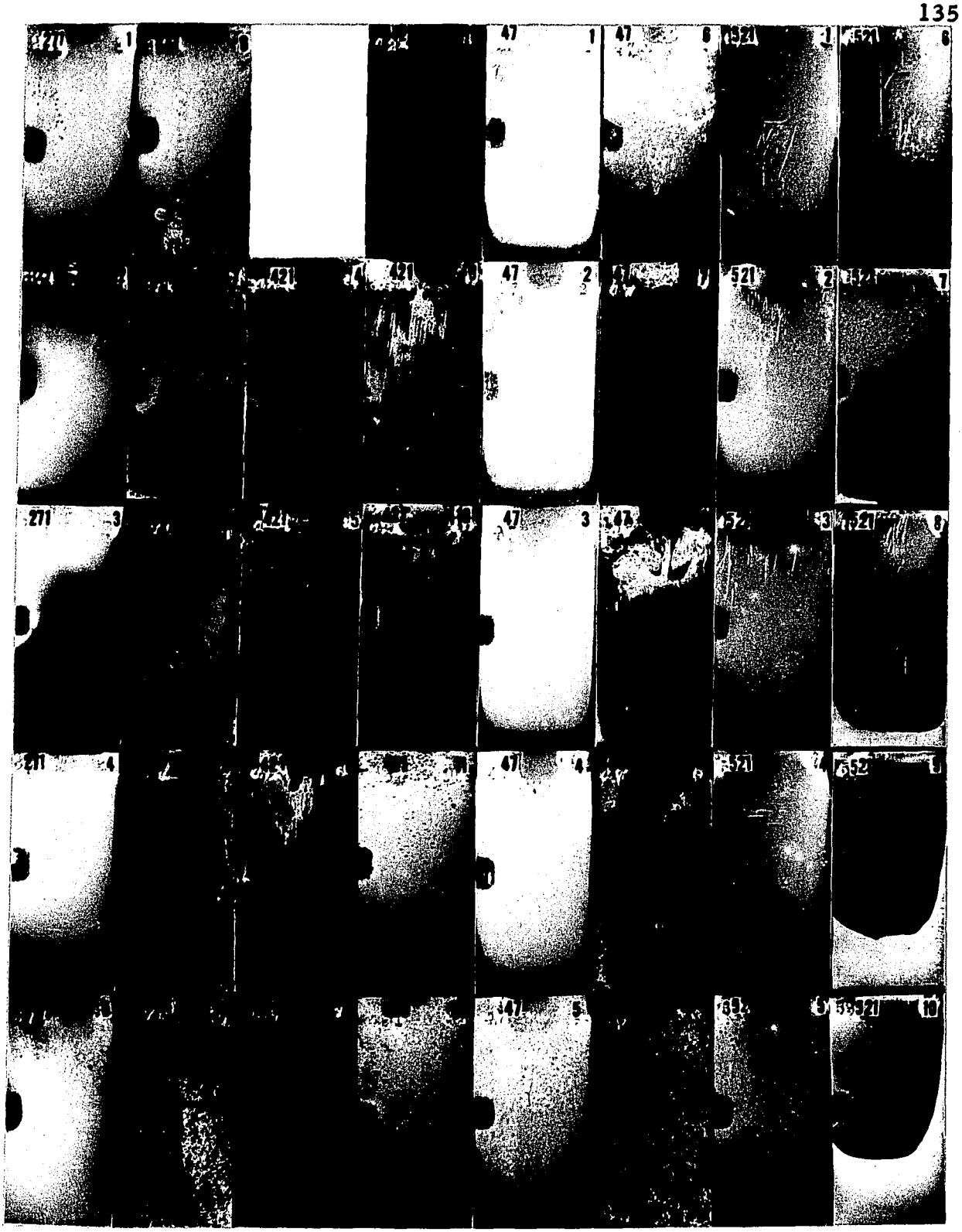


Figure 23. The effect of increasing concentrations of phenols and 2,7-naphthalene disulfonic acid on the appearance of Watts nickel deposits.

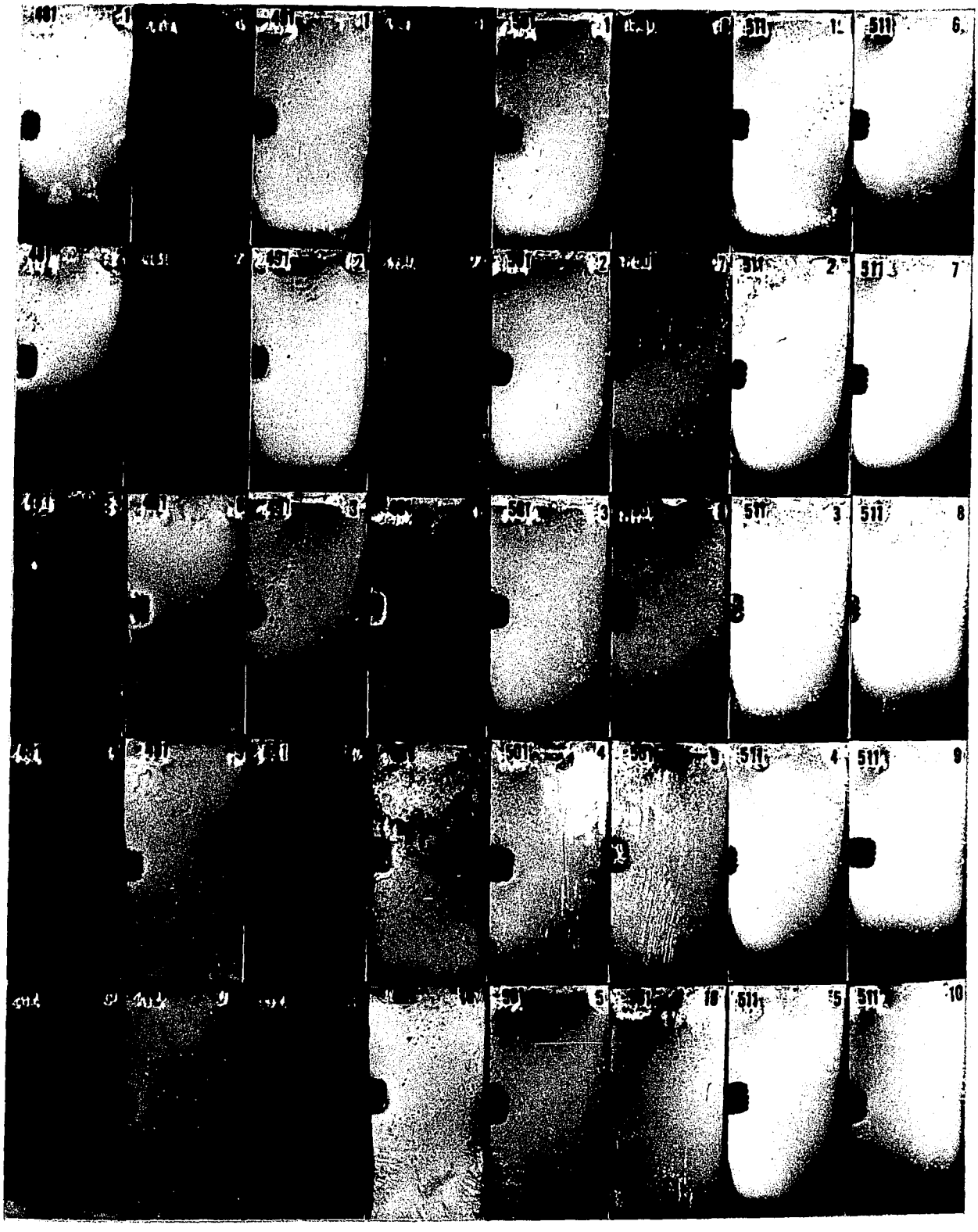


Figure 24. The effect of increasing concentrations of phenols and 2,7-naphthalene disulfonic acid on the appearance of Watts nickel deposits.

Table 57. Solution 18; the effect of 45 g./l. nickel formate, 15 g./l. cobalt sulfate, and increasing concentration of cinnamaldehyde on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Cinnamaldehyde		Cathode Appearance
			Total Addition (ml.)	Addition (ml./g.)	
181	3.80	65	-		Haze above 2.1 amp./sq. dm.; under, bright.
182	3.80	65	-		Haze above 3.2 amp./sq. dm.; under, bright.
183	3.80	65	0.5	0.5/ 0.55*	Haze above 5.4 amp./sq. dm.; under, bright.

* Weights calculated using handbook value for specific gravity of cinnamaldehyde 1.110 20°/20°.

Table 58. Solution 19; the effect of 45 g./l. nickel formate, 15 g./l. cobalt sulfate, addition of ammonium sulfate, and increasing concentrations of chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral Addition (ml.)	Chloral Total Addition (ml./g.)	Cathode Appearance
191	3.80	55	-	-	Haze.
192	3.80	65	-	-	Haze above 3.2 amp./sq. dm.; under, bright.
193	3.80	65	1 g. $(NH_4)_2SO_4$	-	Haze above 3.2 amp./sq. dm.; under, bright.
194	3.80	65	0.5	0.5/ 0.75*	Haze above 6.5 amp./sq. dm.; under, bright.
195	-	65	0.5	1.0/ 1.50	Haze above 6.5 amp./sq. dm.; under, bright.
196	-	65	0.5	1.5/ 2.25	Bright.
197	-	65	0.5	2.0/ 3.01	Haze above 3.2 amp./sq. dm.; under, bright.
198	-	65	-	2.0/ 3.01	Haze above 3.2 amp./sq. dm.; under, bright.

* Weights calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

Table 59. Solution 20; the effect of 45 g./l. of nickel formate, 15 g./l. of cobalt sulfate, and increasing concentrations of chloral hydrate on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral Hydrate		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
201	3.83	63	-	-	Haze above 1.6 amp./sq. dm.; under, bright.
202	3.80	65	0.5	0.5/0.75	Haze above 7.6 amp./sq. dm.; under, bright.
203	3.85	63	0.5	1.0/1.51	Haze above 11.8 amp./sq. dm.; under, bright.
204	3.90	66	0.5	1.5/2.25	Bright.
205	4.05	63	-	1.5/2.25	Bright.
206	3.78	65	-	1.5/2.25	Haze above 9.7 amp./sq. dm.; under, bright.
207	3.87	65	-	1.5/2.25	Haze above 10.8 amp./sq. dm.; under, bright.
208	3.90	65	0.5	2.0/3.01	Haze at high current density edge. Bright.

* Weights calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

Table 60. Solution 24; the effect of 45 g./l. of nickel formate, 15 g./l. of cobalt sulfate, and increasing concentration of acetaldehyde on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Acetaldehyde		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
241	3.85	66	-	-	Haze above 1.6 amp./sq. dm.; under, bright.
242	3.85	63	0.5	0.5/ 0.39	Haze above 1.6 amp./sq. dm.; under, bright.
243	3.90	64	0.5	1.0/ 0.78	Haze above 3.2 amp./sq. dm.; under, bright.
244	3.83	72	0.5	1.5/ 1.17	Haze above 1.0 amp./sq. dm.; under, haze-bright.
245	3.82	67	0.5	2.0/ 1.56	Haze above 5.4 amp./sq. dm.; under, haze-bright.
246	3.80	65	0.5	2.5/ 1.95	Haze above 7.6 amp./sq. dm.; under, bright.
247	-	65	0.5	3.0/ 2.35	Haze above 8.6 amp./sq. dm.; under, bright.
248	3.92	65	0.5	3.5/ 2.74	Haze to dull above 8.6 amp./sq.dm.; under, bright.
249	-	66	0.5	4.0/ 3.13	Haze to dull above 7.6 amp./sq.dm.; under, bright.

* Weights calculated using handbook value for specific gravity of acetaldehyde 0.783 18°/4°.

Table 61. Solution 29; the effect of 45 g./l. of nickel formate, 15 g./l. of cobalt sulfate, and increasing concentration of ethyl pyruvate and glyoxal on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Ethyl Pyruvate Addition (ml.)	Ethyl Pyruvate Total Addition (ml./g.)	Cathode Appearance
291	3.50	63	-	-	Haze above 1.0 amp./sq. dm.; under, bright.
292	3.50	67	0.5	0.5/ 0.53*	Haze above 1.0 amp./sq. dm.; under, bright.
293	3.60	67	0.5	1.0/ 1.06	Haze above 1.6 amp./sq. dm.; under, bright.
294	-	67	0.5	1.5/ 1.59	Haze above 1.6 amp./sq. dm.; under, bright.
295	3.82	67	-	1.5/ 1.59	Haze above 2.6 amp./sq. dm.; under, bright.
296	-	67	0.5	2.0/ 2.12	Haze above 2.6 amp./sq. dm.; under, bright.
297	3.82	68	-	2.0/ 2.12	Haze above 2.6 amp./sq. dm.; under, bright.
Solution Treated with 15.0 g./l. of Activated Carbon, Filtered					
298	3.70	68	30% Glyoxal 1	1/ 0.31**	Haze above 2.6 amp./sq. dm.; under, bright.

Table 61 (Continued)

Panel No.	pH	Temp. (° C.)	30% Glyoxal Addition (ml.)	30% Glyoxal Total Addition (ml./g.)	Cathode Appearance
299	3.70	67	1	2/ 0.62	Haze above 2.6 amp./sq. dm.; under, bright.
2910	3.82	63	2	4/ 1.24	Haze above 3.2 amp./sq. dm.; under, bright.
2911	3.80	65	2	6/ 1.85	Haze above 2.6 amp./sq. dm.; under, bright.
2912	3.75	65	2	8/ 2.47	Haze-bright above 2.6 amp./sq.dm.; under, bright.
2913	3.62	65	2	10/ 3.09	Haze-bright above 2.6 amp./sq.dm.; under, bright
2914	4.00	66	2	12/ 3.71	Haze-bright above 2.6 amp./sq.dm.; under, bright.
2915	4.05	67	2	14/ 4.33	Haze-bright to haze.
2916	3.90	67	2	16/ 4.95	Haze above 2.6 amp./sq. dm.; under, bright.
2917	3.90	66	4	20/ 6.19	Haze-bright.
2918	-	65	-	20/ 6.19	Haze-bright.

* Weights calculated using handbook value for specific gravity of ethyl pyruvate of 1.060 16°/4°.

** Weights calculated using handbook value for specific gravity of glyoxal 1.14 20°.

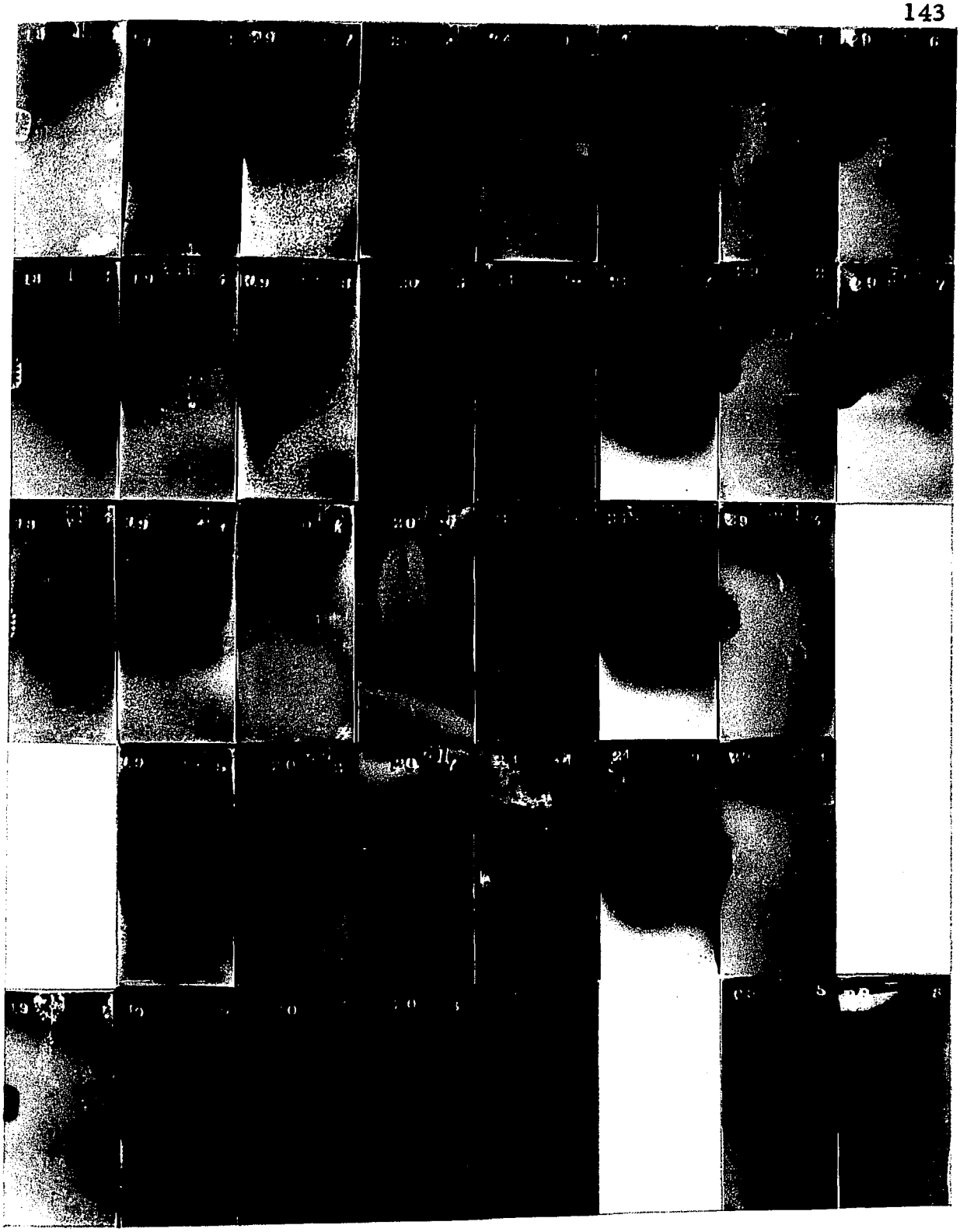


Figure 25. Nickel-cobalt deposits and the effect of increasing concentrations of carbonyl compounds.

Table 62. Solution 39; the effect of 45 g./l. of nickel formate, 15 g./l. of cobalt sulfate, and increasing concentrations of butyl chloral hydrate on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Butyl Chloral Hydrate		Cathode Appearance
			Addition (g.)	Total Addition (g.)	
391	3.70	65	-	-	Haze.
392	3.75	65	0.1	0.1	Haze.
393	3.65	67	0.2	0.3	Haze.
394	3.70	67	0.2	0.5	Haze above 1.6 amp./sq. dm.; under, bright.
395	3.72	66	0.5	1.0	Haze above 2.6 amp./sq. dm.; under, bright.
396	3.75	68	0.5	1.5	Haze above 3.8 amp./sq. dm.; under, bright.
397	3.78	68	1.0	2.5	Haze at high current density edge. Bright.
398	-	67	1.0	3.5	Haze above 1.6 amp./sq. dm.; under, bright.
399	3.60	70	-	3.5	Haze-bright.

Table 63. Solution 44; the effect of 75 g./l. of nickel chloroacetate, addition of cobalt sulfate, and increasing concentrations of chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
441	2.50	63	-	-	Bright above 14.0 amp./sq. dm.; under, dull, dark.
442	3.80	65	-	-	Dull.
443	3.95	65	15 g. $CoSO_4$	-	Dull.
444	4.03	66	0.1	0.1/0.15	Dull to haze above 14.0 amp./sq.dm.; haze 14.0 to 4.3 amp./sq.dm.; under, bright.
446	4.03	66	0.2	0.3/0.45	Dull to haze above 11.8 amp./sq.dm.; under, bright.
445	4.10	64	0.4	0.7/1.053	Dull to haze at high current density edge. Bright.
447	4.12	66	0.8	1.5/2.26	Dull to haze high current density edge. Bright.
448	4.15	65	1.0	2.5/3.76	Bright.
449	4.30	65	1.0	3.5/5.27	Bright.

Table 63 (Continued)

Panel No.	pH	Temp. (° C.)	Chloral		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
4410	4.38	65	1.0	4.5/6.77	Bright.
4411	4.48	66	1.0	5.5/8.27	Bright.
4412	4.69	65	1.0	6.5/9.77	Bright above 11.8 amp./sq. dm.; under, haze.

* Weights calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

Table 64. Solution 45; the effect of 55.0 g./l. of nickel acrylate, addition of cobalt sulfate, and increasing concentrations of chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
451	4.00	63	-	-	Exfoliate above 14.0 amp./sq./dm. Green deposit above 5.4 amp./sq.dm.; under, bright.
452	4.10	65	-	-	Exfoliate above 0.8 amp. sq.dm.; under, bright.
453	4.30	65	15 g. $CoSO_4$	-	Exfoliate above 10.8 amp./sq.dm.; under, haze-bright.
454	4.50	66	0.1	0.1/0.15	Green above 4.3 amp./sq. dm.; under, haze-bright.
456	4.55	66	0.2	0.3/0.45	Green, entire range.
455	4.85	64	0.4	0.7/1.05	Powdery green deposit.
457	5.15	66	0.8	1.5/2.26	Powdery green deposit.
458	5.28	65	1.0	2.5/3.76	Powdery green deposit.
459	5.48	65	1.0	3.5/5.27	Powdery green deposit.

Table 64 (Continued)

Panel No.	pH	Temp. (° C.)	Chloral Addition (ml.)	Chloral Total Addition (ml./g.)*	Cathode Appearance
4510	5.50	65	1.0	4.5/6.77	Powdery green deposit.

* Weights calculated using handbook values for specific gravity of chloral 1.505 25°/4°.

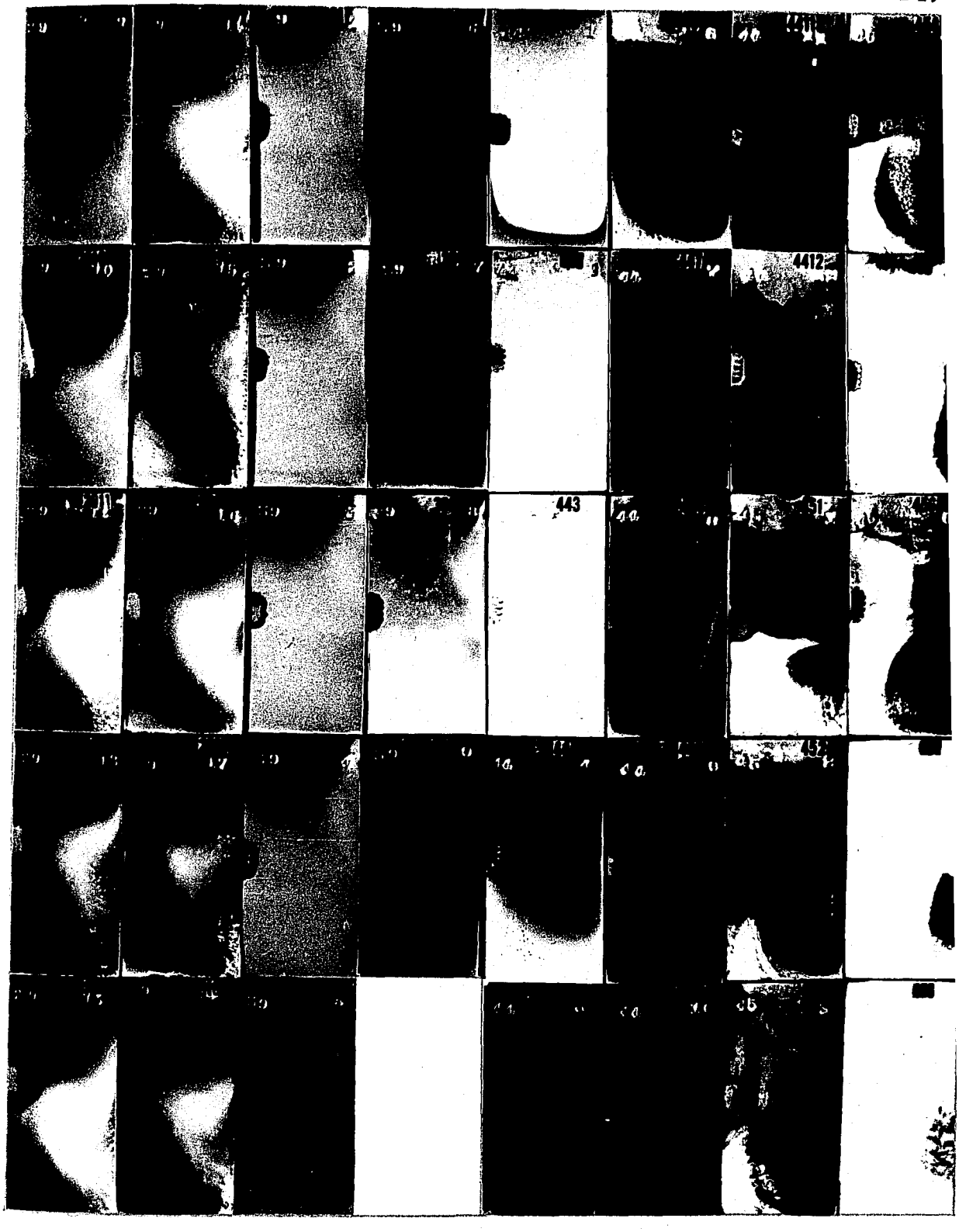


Figure 26. Nickel-cobalt deposits and the effect of increasing concentrations of carbonyl compounds.

Table 65. Solution 21; the effect of 12.5 g/.l. of ferrous sulfate and increasing concentrations of chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
211	3.87	63	-	-	Dull above 5.4 amp./sq. dm.; under, haze-bright.
212	3.67	65	0.5	0.5/ 0.75	Haze above 1.6 amp./sq. dm.; under, haze-bright.
213	4.00	63	0.5	1.0/ 1.50	Bright above 9.7 amp./sq. dm.; under, haze.
214	3.73	66	0.5	1.5/ 2.25	Bright above 10.8 amp./ sq.dm.; under, haze.
215	3.25	63	45 g. Nickel Formate	1.5/ 2.25	Bright at high current density edge. Haze above 6.5 amp./sq.dm.; under, bright.
216	2.70	65	10 g. Tartaric Acid	1.5/ 2.25	Haze, cracked.
217	3.85	65	-	1.5/ 2.25	Haze, cracked.
218	3.90	65	10 g. Ferrous Sulfate	1.5/ 2.25	Haze, cracked.

* Weights calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

Table 66. Solution 22; the effect of additions of ferrous sulfate, tartaric acid, and chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Ferrous Sulfate Addition (g.)	Ferrous Sulfate Total Addition (g.)	Cathode Appearance
221	3.52	68	5	5	Haze at high density edge. Dull and pitted.
222	3.80	66	5	10	Dull above 10.2 amp./sq. dm.; under, haze.
223	3.72	62	5	15	Dull, pitted above 3.2 amp./sq.dm.; under, haze.
224	3.72	70	5	20	Dull, pitted above 9.7 amp./sq.dm.; under, haze-bright, pitted.
225	3.80	65	5	25	Haze, pitted above 4.3 amp./sq.dm.; under, haze-bright, pitted.
226	3.55	67	-	-	Haze, pitted above 3.2 amp./sq.dm.; under, haze-bright, pitted.
227	3.28	65	-	-	Dull, dark.
228	3.74	65	10 g. Tartaric Acid	-	Dull, dark, cracked.
229	3.75	64	1 ml. Chloral	1 ml./ 1.505 g.*	Dull, dark above 9.7 amp./ sq.dm.; under, haze-bright, cracked.

Table 66 (Continued)

Panel No.	pH	Temp. (° C.)	Ferrous Sulfate Addition (g.)	Ferrous Sulfate Total Addition (g.)	Cathode Appearance
2210	-	62	-	1 ml./ 1.505 g..	Dull at high current density edge. Haze-bright above 13.0 amp./sq.dm.; under, haze, dark.

* Weight calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

Table 67. Solution 25; the effect of 12.5 g./l. of ferrous sulfate, 50 g./l. of nickel propionate, and increasing concentrations of chloral on the appearance of Watts nickel solution deposits.

Panel No.	pH	Temp. (° C.)	Chloral		Cathode Appearance
			Addition (ml.)	Total Addition (ml./g.)*	
251	4.50	66	-	-	Dull, dark.
252	4.50	66	0.5	0.5/0.75	Dull, cracked.
253	4.48	64	0.5	1.0/1.50	Haze at high current density edge. Haze-bright above 5.4 amp./sq.dm.; under, haze.
254	4.60	72	-	-	Haze, cracked.

* Weights calculated using handbook value for specific gravity of chloral 1.505 25°/4°.

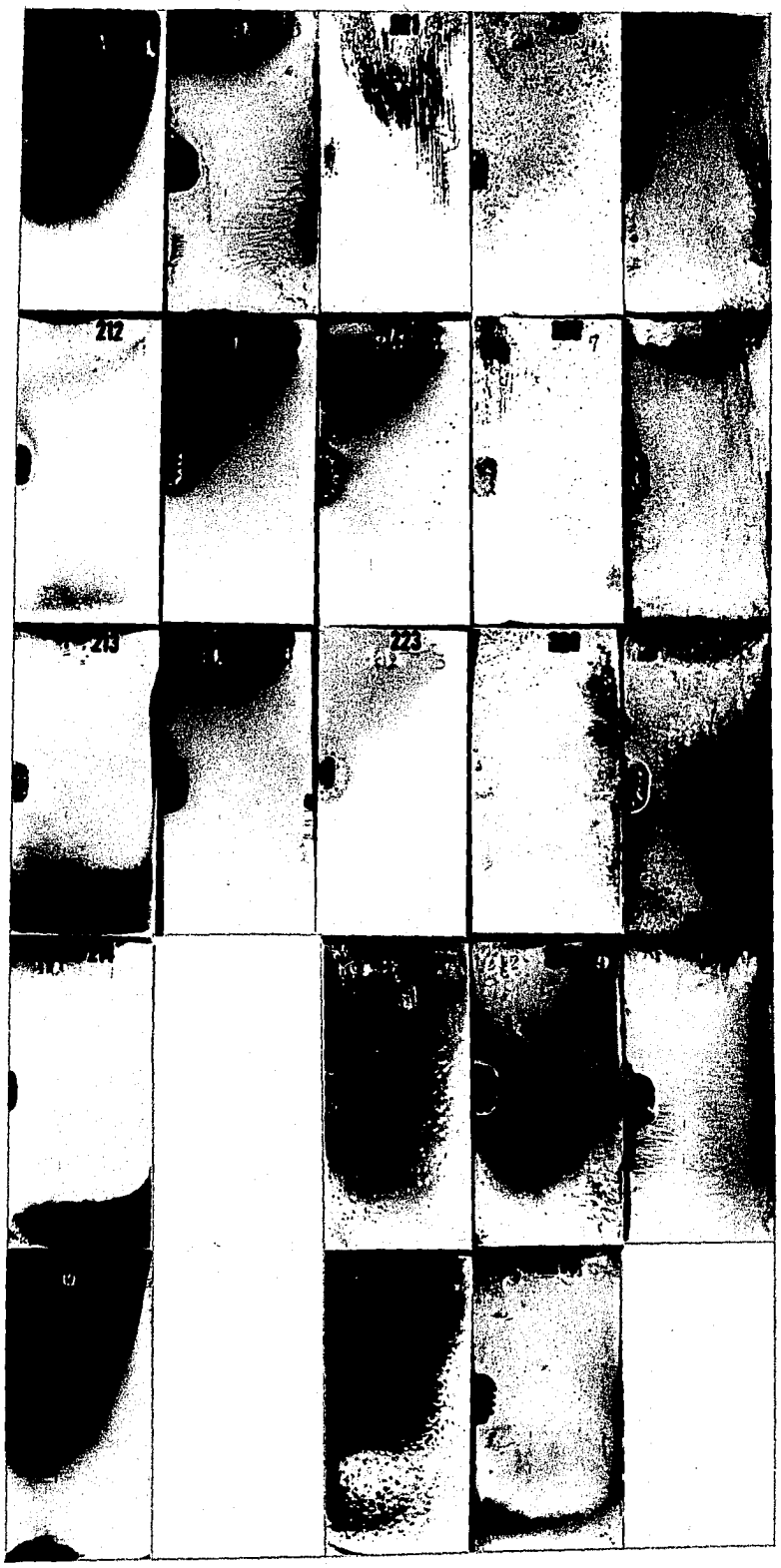


Figure 27. Nickel-iron deposits and the effect of various additions.

Table 68. Solution 23; the effect on the cathode of filter paper in close contact and predipping in cinnamaldehyde.

Panel* No.	Temp. (° C.)	Treatment of Cathode	Cathode Appearance
231	68	None	Dull.
232	66	Wrapped in two thicknesses of Whatman No. 1, 11 cm. filter paper.	Pitted, more reflectant than control.
233	60	Same as above.	Pitted, more reflectant than control.
234	70	Same as above.	Pitted, more reflectant than control.
235	65	Dipped once in a lens of cinnamaldehyde floating on a Watts solution.	Haze-bright, light interference pattern.
238	78	Same as above (solid formation in lens).	Haze-bright, exfoliate above 2.1 amp./sq.dm.; under, no deposit.
237	49	Same as above.	Haze, treed above 4.3 amp./sq.dm.; under, bright with interference.
236	26	Same as above.	High current density, burned, dull.

* The pH of the solution was 3.8 and depositions were caried out for twenty minutes.

Table 69. Solution 312; the effect of predipping the cathode in a nickel solution containing Clayton Yellow on the appearance of Watts nickel solution deposits (pH, 3.2; dipped twenty times; 20 minutes deposition; 3 amperes).

Panel* No.	Temp. (° C.)	Dip Solution	Dip Solution Temp. (° C.)	Cathode Appearance
312-1	60	31	25	Dull.
312-2**	57	31	25	Haze-bright.
312-3	55	31	60	Dull above 11.8 amp./sq.dm.; haze 11.8 to 1.0 amp./sq.dm.; under, dull.
312-4	24	31	64	Exfoliate at high current density edge. Haze-bright above 6.5 amp./sq.dm.; under, haze.
312-5	25	311	57	Exfoliate at high current density edge. Haze-bright above 8.6 amp./sq.dm.; under, haze.
312-6	60	311	58	Dull.

* The pH of the Watts nickel solution was 3.2, the cathode was dipped twenty times and depositions were carried out for 20 minutes.

** Deposited from Solution 311.

Table 70. Solution 332; the effect of dipping the cathode in a nickel solution containing Methylene Blue on the appearance of Watts nickel solution deposits.

Panel[1] No.	Temp. (° C.)	pH	Dip Solution	Dip Solution Temp. (° C.)	Cathode Appearance
332-1[2]	60	3.15	-	-	Dull at high current density edge. Haze above 1.0 amp./sq.dm.; under, dull.
332-2[2]	60	3.30	33	25	Dull at high current density edge. Haze above 1.6 amp./sq.dm.; under, dull.
332-3[2]	62	3.45	331	60	Dull.
332-4	64	3.45	33	66	Dull at high current density edge. Haze above 2.6 amp./sq.dm.; under, dull.
332-5	61	4.05	33	31	Dull at high current density edge. Haze above 2.6 amp./sq.dm.; under, dull.
332-6	61	4.10	33	45	Dull at high current density edge. Haze above 2.6 amp./sq.dm.; under, dull.
332-7	60	4.21	33	63	Dull at high current density edge. Haze above 4.3 amp./sq.dm.; under, dull.

Table 70 (Continued)

Panel[1] No.	Temp. (° C.)	pH	Dip Solution	Dip Solution Temp. (° C.)	Cathode Appearance
332-8	61	5.10	33	57	Dull, pitted at high current density edge. Haze above 1.0 amp./sq.dm.; under, dull.
332-9	62	3.52[3]	33	43	Haze at high current density edge. Bright.
332-10	60	3.50[3]	-	-	Haze at high current density edge. Bright.
000	62	4.50	-	-	Dull.
332-11[4]	25	5.40	33	61	Exfoliate at high current density edge. Haze-bright above 4.3 amp./sq.dm.; under, haze.
332-12	25	5.40	-	-	Exfoliate at high current density edge. Haze-bright above 6.5 amp./sq.dm.; under, haze.

[1] The pH of the solution was 3.2, the cathode was dipped twenty times, and depositions were carried out for 10 minutes.

[2] Deposited 20 minutes.

[3] Deposited from Solution 331.

[4] Cathode dried after dip.

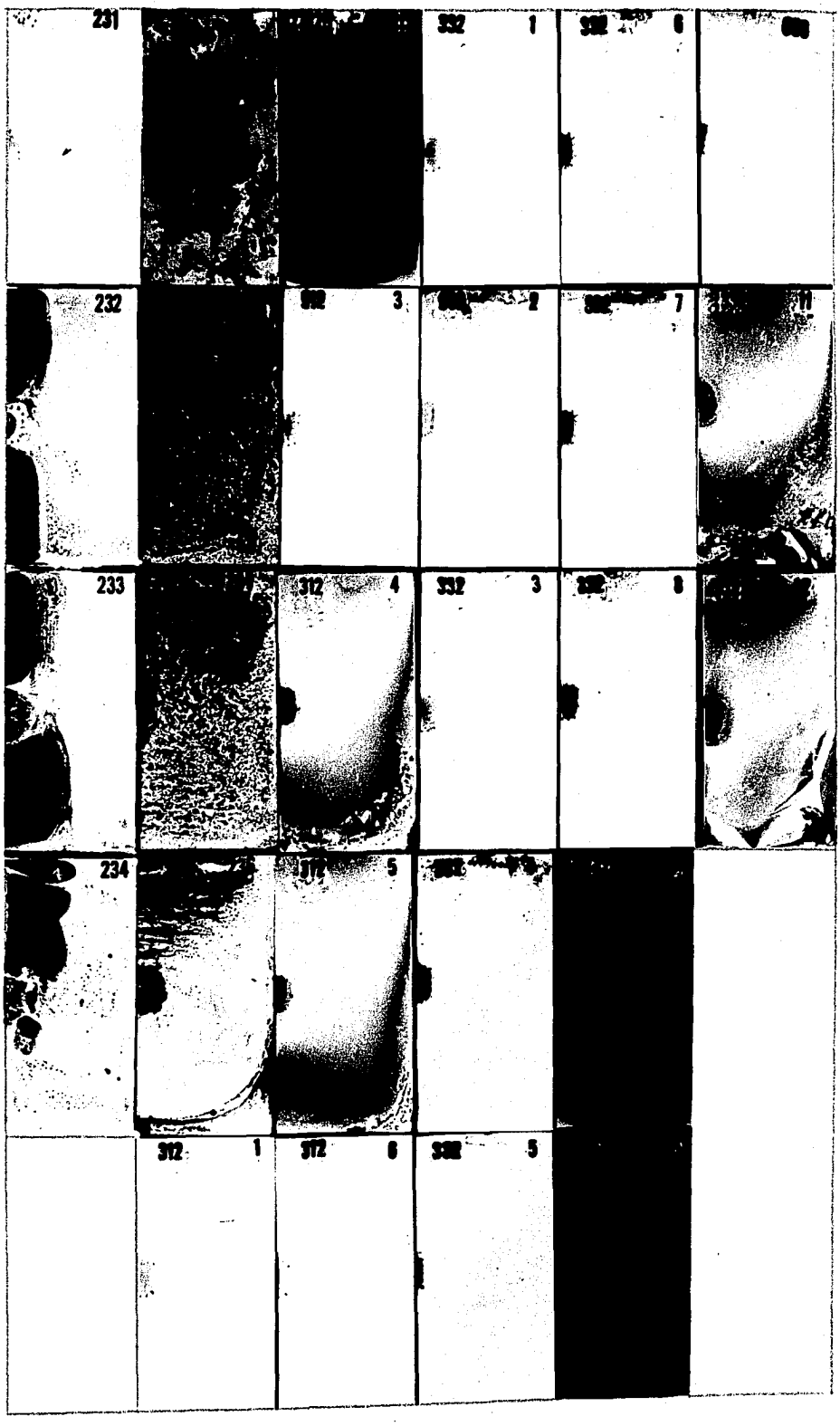


Figure 28. The effect of predipping or filter paper in close contact with the cathode, on the appearance of Watts nickel deposits.

Table 71. RMS surface roughness of Watts panels.

Panel No.	RMS Roughness (microinches)	
	9.0 amp./sq.dm.	6.5 amp./sq.dm.
	pH 2.2	
12	3.2	1.8
13	3.8	4.2
14	7.2	6.6
15	4.4	3.6
	pH 3.8	
22	2.6	3.4
23	2.8	2.8
24	4.4	4.8
25	8.0	8.4

Table 72. RMS surface roughness effects of carbohydrates.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Glyceraldehyde			Dextrin	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
740	2.8	1.8	840	4.0	4.0
730	0.7	1.4	830	5.8	4.8
720	6.0	4.0	820	2.2	1.9
	[pH 3.8]			[pH 3.8]	
71	3.2	3.0	81	2.9	2.2
72	2.6	1.0	82	6.0	4.0
73	2.2	1.4	83	7.6	6.0
74	3.2	2.4	84	7.4	6.0
	[2.0 g./l., pH 2.2]			[2.0 g./l., pH 2.2]	
750	2.4	1.4	850	5.2	4.2
760	3.6	2.4	860	5.8	3.8
770	2.8	2.0	870	5.6	4.6
780	0.9	2.0	880	9.2	8.6
	[pH 3.8]			[pH 3.8]	
78	4.2	7.5	88	3.8	4.4
77	2.6	3.2	87	5.2	5.2
76	2.6	3.6	86	5.2	4.2
75	8.4	8.4	85	5.2	6.0

Table 72 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Xylose			Glucose	
	[0.5 g./1., pH 2.2]			[0.5 g./1., pH 2.2]	
330	3.6	4.2	430	3.4	2.8
340	2.4	3.6	440	2.8	3.6
320	8.4	7.2	420	8.4	8.4
310	4.2	4.4	410	9.0	7.2
	[pH 3.8]			[pH 3.8]	
350	2.6	1.2	450	2.3	2.4
360	3.8	3.4	460	3.8	4.4
370	3.2	2.6	470	4.4	4.0
380	4.2	4.6	480	4.2	3.6
	Lactose			Raffinose	
	[0.5 g./1., pH 2.2]			[0.5 g./1., pH 2.2]	
530	3.2	3.8	630	2.2	3.2
540	3.8	4.4	640	1.6	0.8
520	6.8	7.0	620	3.2	3.6
510	5.6	5.8	610	4.0	3.4
	[pH 3.8]			[pH 3.8]	
550	5.4	3.2	650	2.0	1.2
560	4.8	4.4	660	1.4	1.2
570	4.0	4.0	670	1.2	1.2
580	7.2	8.2	680	4.4	2.2

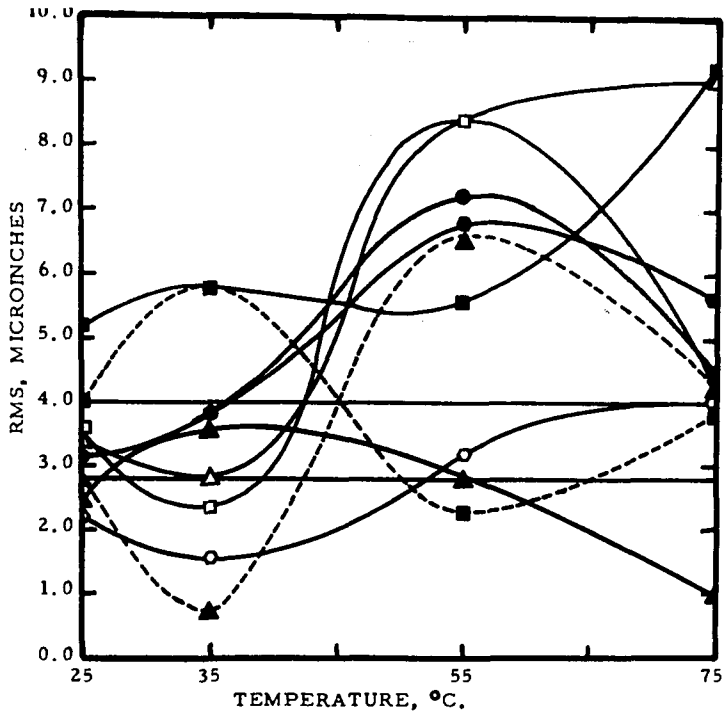


FIGURE 29. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 9.0 AMP./SQ.DM., AND 2.0 G./L. FOR:

1. ● WATTS
2. ▲ GLYCERALDEHYDE
3. □ XYLOSE
4. △ GLUCOSE
5. ● LACTOSE HYDRATE
6. ○ RAFFINOSE HYDRATE
7. ■ DEXTRIN

----0.5 G./L.

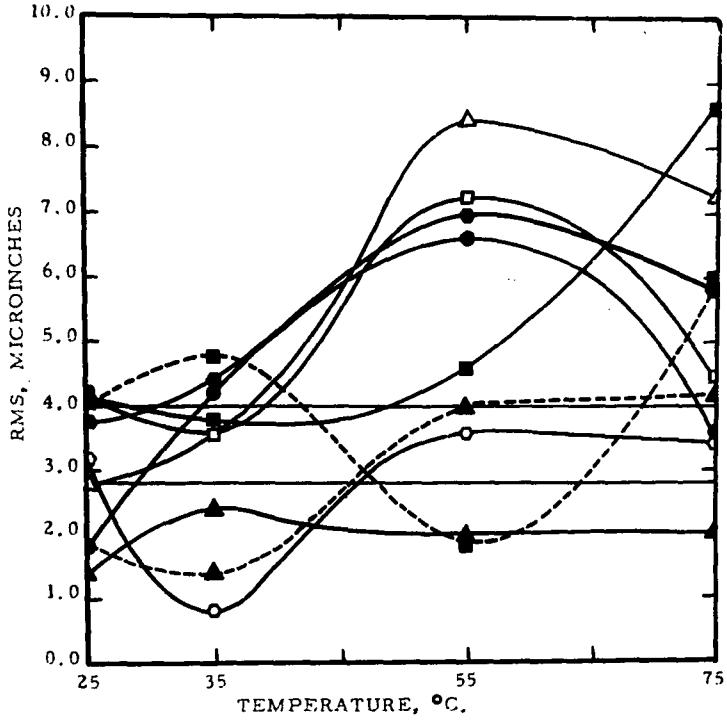


FIGURE 30. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 6.5 AMP./SQ.DM., AND 2.0 G./L. FOR:

1. ● WATTS
2. ▲ GLYCERALDEHYDE
3. □ XYLOSE
4. △ GLUCOSE
5. ● LACTOSE HYDRATE
6. ○ RAFFINOSE HYDRATE
7. ■ DEXTRIN

----0.5 G./L.

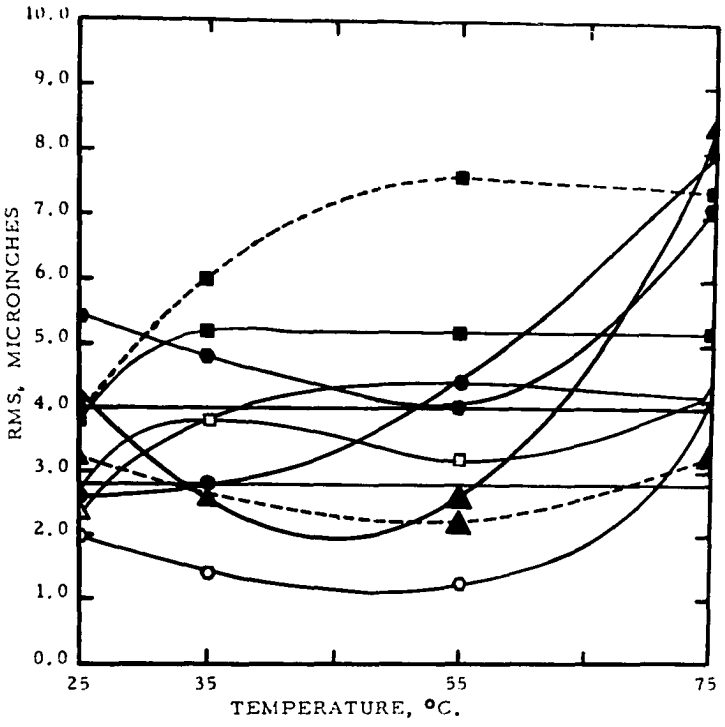


FIGURE 31. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 9.0 AMP./SQ.DM., AND 2.0 G./L. FOR:

1. ● WATTS
2. ▲ GLYCERALDEHYDE
3. □ XYLOSE
4. △ GLUCOSE
5. ● LACTOSE HYDRATE
6. ○ RAFFINOSE HYDRATE
7. ■ DEXTRIN

----0.5 G./L.

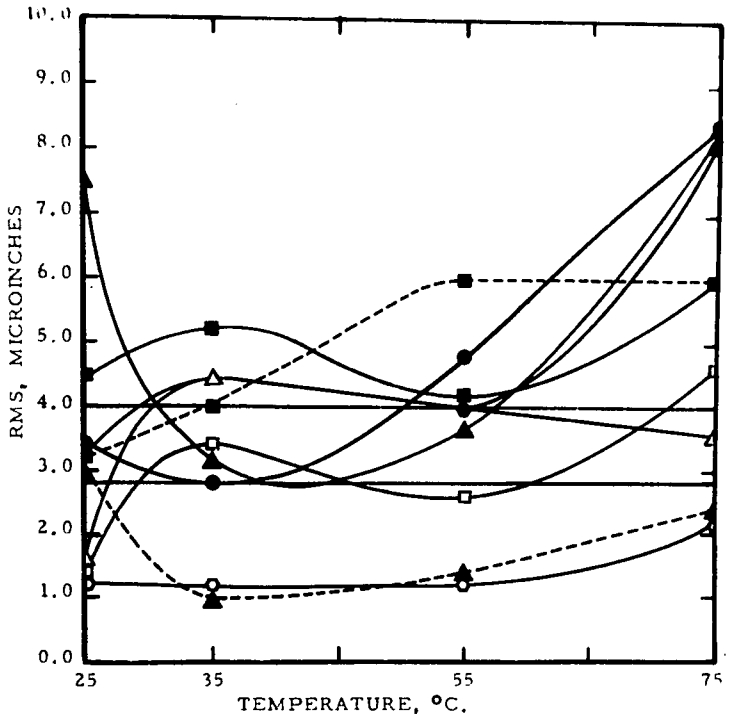


FIGURE 32. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 6.5 AMP./SQ.DM., AND 2.0 G./L. FOR:

1. ● WATTS
2. ▲ GLYCERALDEHYDE
3. □ XYLOSE
4. △ GLUCOSE
5. ● LACTOSE HYDRATE
6. ○ RAFFINOSE HYDRATE
7. ■ DEXTRIN

----0.5 G./L.

Table 73. RMS surface roughness effects of polymers and unsaturated aliphatic compounds.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Methyl Cellulose			Polvinyl Alcohol	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
910	3.8	4.0	1640	9.8	6.0
920	5.6	5.6	1630	3.8	2.4
930	8.6	8.8	1620	4.8	6.0
940	7.6	6.6	1610	4.2	3.4
	[pH 3.8]			[pH 3.8]	
94	3.8	5.0	164	3.4	4.0
93	6.2	5.8	163	7.0	5.2
92	5.0	5.2	162	3.6	4.0
91	>10.0	>10.0	161	5.8	6.0
	Acrylic Acid			1,4-Butynediol	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
4310	4.0	3.2	5310	4.0	2.8
4320	2.2	2.8	5320	3.8	3.8
4330	5.6	4.4	5330	>10.0	8.4
4340	7.6	8.0	5340	8.0	6.0
	[pH 3.8]			[pH 3.8]	
431	3.2	4.0	531	3.4	3.0
432	4.0	3.0	532	3.8	3.6
433	8.0	6.6	533	6.4	6.2
434	>10.0	>10.0	534	>10.0	8.0

Table 73 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	[2.0 g./l., pH 2.2]			[2.0 g./l., pH 2.2]	
4350	6.2	8.0	5350	2.2	2.0
4360	4.6	4.0	5360	2.6	2.8
4370	8.0	7.4	5370	0.8	0.8
4380	6.0	6.0	5380	1.2	1.2
	[pH 3.8]			[pH 3.8]	
435	4.0	3.8	535	2.4	2.4
436	7.4	6.6	536	4.0	3.4
437	>10.0	>10.0	537	>10.0	4.0
438	>10.0	>10.0	538	9.0	5.0

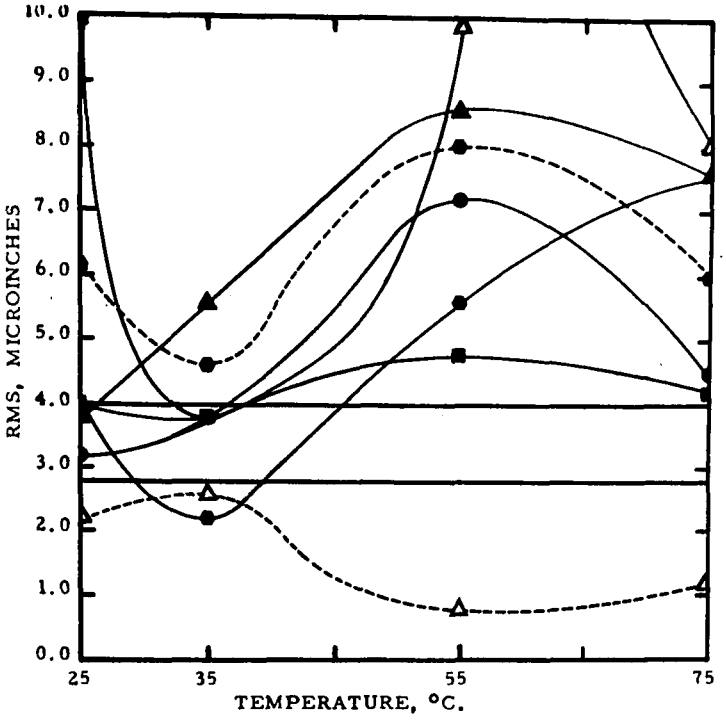


FIGURE 33. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ▲ METHYLCELLULOSE
3. ■ POLYVINYL ALCOHOL
4. ⬢ ACRYLIC ACID
5. △ 1,4-BUTYNEDIOL

----2.0 G./L.

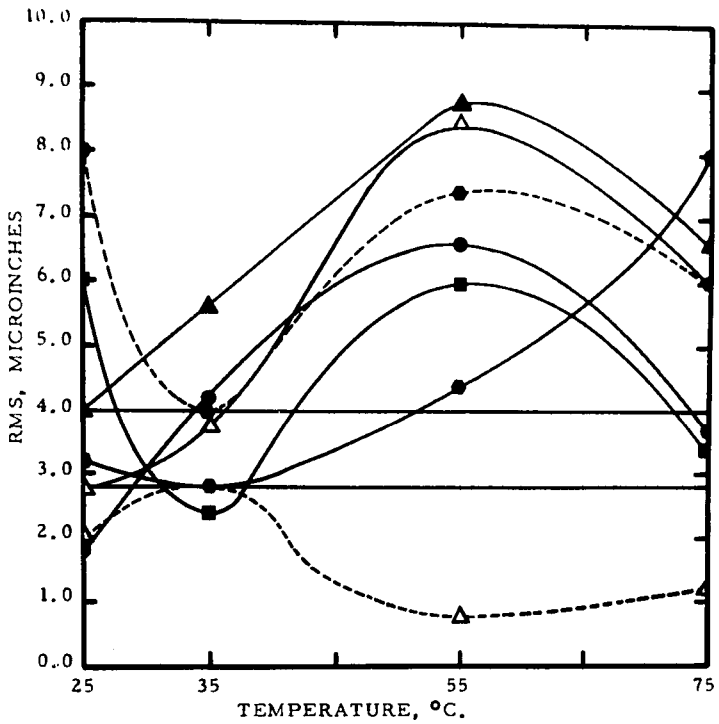


FIGURE 34. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ▲ METHYLCELLULOSE
3. ■ POLYVINYL ALCOHOL
4. ● ACRYLIC ACID
5. △ 1,4-BUTYNEDIOL

----2.0 G./L.

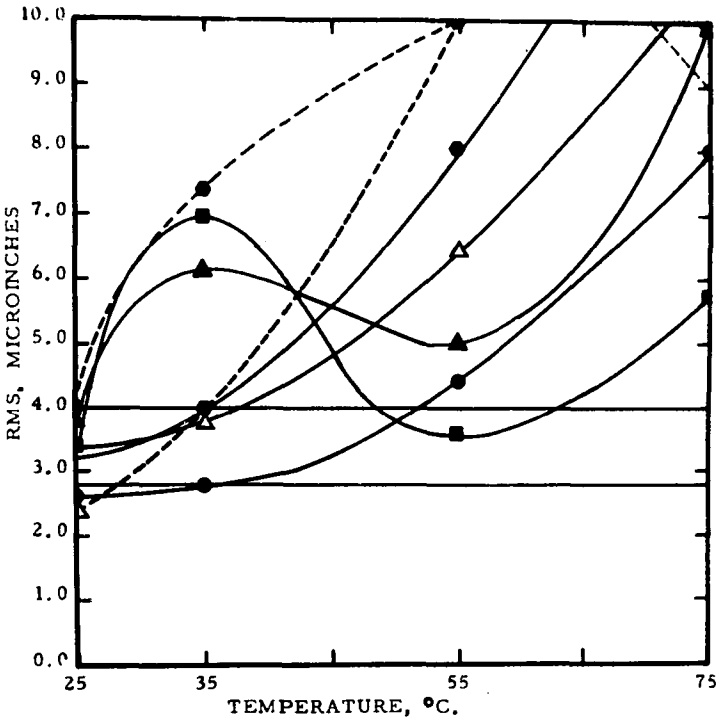


FIGURE 35. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ▲ METHYLCELLULOSE
3. ■ POLYVINYL ALCOHOL
4. ● ACRYLIC ACID
5. △ 1,4-BUTYNEDIOL

----2.0 G./L.

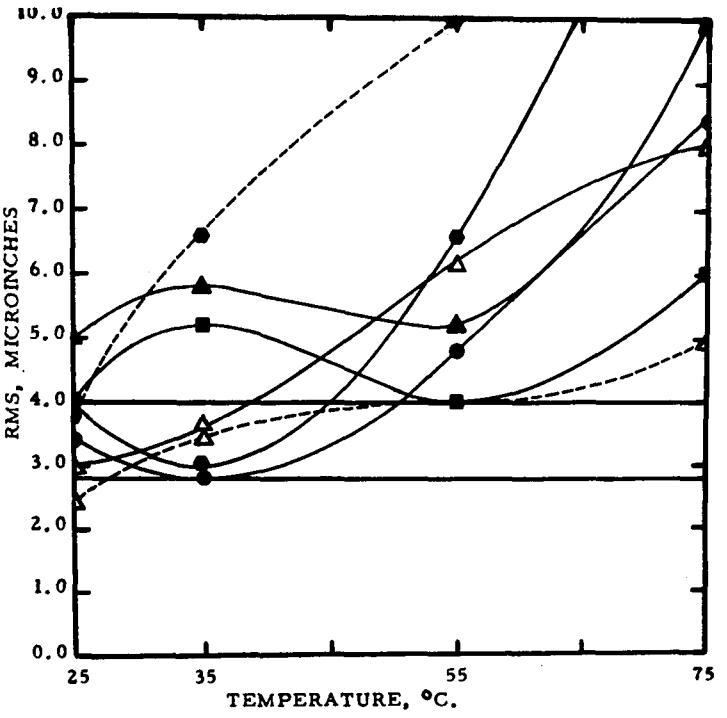


FIGURE 36. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:
1. ● WATTS
2. ▲ METHYLCELLULOSE
3. ■ POLYVINYL ALCOHOL
4. ● ACRYLIC ACID
5. △ 1,4-BUTYNEDIOL
----2.0 G./L.

Table 74. RMS roughness effects of carbonyl compounds.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Camphor			p-Bromoacetophenone	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
1110	2.4	4.0	1210	2.0	1.8
1120	3.6	4.6	1220	5.0	7.4
1130	9.2	8.6	1230	7.0	6.8
1140	9.5	6.6	1240	7.8	6.8
	[pH 3.8]			[pH 3.8]	
114	3.6	3.4	124	5.2	1.8
113	6.0	5.6	123	3.0	2.4
112	6.8	7.0	122	3.2	1.8
111	5.8	6.0	121	9.6	9.8
	Cinnamaldehyde			Acetaldehyde	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
1340	7.0	4.6	2610	2.0	1.6
1330	>10.0	>10.0	2620	1.6	2.0
1320	8.0	3.6	2630	8.4	4.6
1310	5.4	2.0	2640	4.8	7.2
	[pH 3.8]			[pH 3.8]	
134	-	3.8	261	10.0	>10.0
133	2.0	2.0	262	7.0	9.6
132	4.0	4.0	263	8.2	8.0
131	4.8	4.8	264	3.2	6.0

Table 74 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.4 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Chloral			Pyruvic Acid	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
1740	4.8	4.0	1440	3.6	3.2
1730	6.0	4.0	1430	3.8	4.2
1720	8.6	>10.0	1420	4.6	3.6
1710	6.6	5.0	1410	3.2	4.0
	[pH 3.8]			[pH 3.8]	
174	4.5	5.0	144	3.4	2.8
173	7.4	6.0	143	4.4	4.6
172	8.5	8.0	142	4.0	4.0
171	>10.0	>10.0	141	4.0	4.8
	Butyl Chloral			beta-Methyl Umbelliferone	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
4010	2.6	4.0	1540	6.6	6.6
4020	0.8	3.0	1530	5.4	6.6
4030	4.6	3.4	1520	8.0	8.0
4040	6.6	4.8	1510	9.6	8.6
	[pH 3.8]			[pH 3.8]	
401	3.0	4.0	154	-	8.0
402	4.0	2.6	153	7.0	7.0
403	2.4	3.6	152	8.6	9.6
404	3.4	4.0	151	>10.0	9.6

Table 74 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	[2.0 g./1., pH 2.2]				
4050	1.6	1.2			
4060	1.0	1.4			
4070	1.6	1.0			
4080	1.2	2.0			
	[pH 3.8]				
405	3.6	3.0			
406	2.8	3.2			
407	1.8	2.4			
408	3.6	3.8			

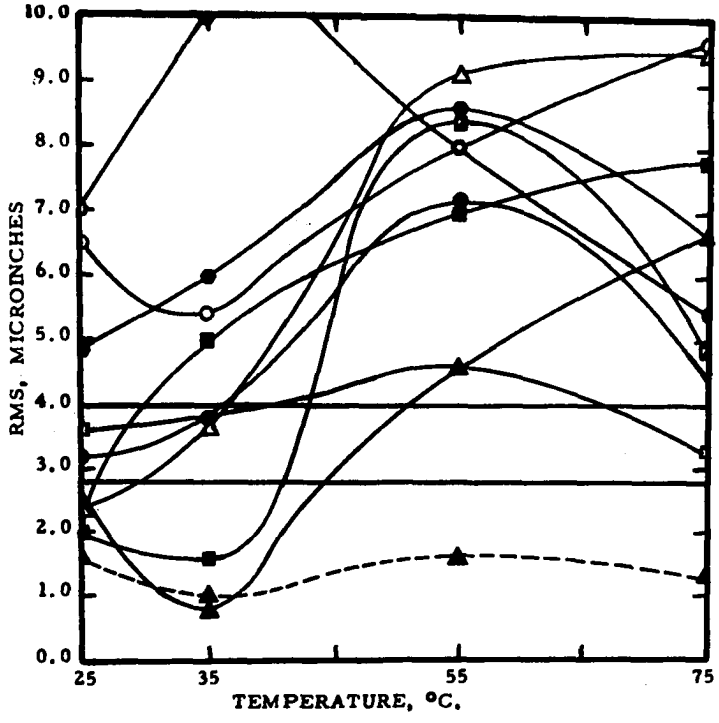


FIGURE 37. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. △ CAMPHOR
3. ■ p-BROMOACETOPHENONE
4. ○ CINNAMALDEHYDE
5. ◪ ACETALDEHYDE
6. ◉ CHLORAL HYDRATE
7. □ PYRUVIC ACID
8. ▲ BUTYL CHLORAL
9. ○ beta-METHYLUMBELLIFERONE

----2.0 G./L.

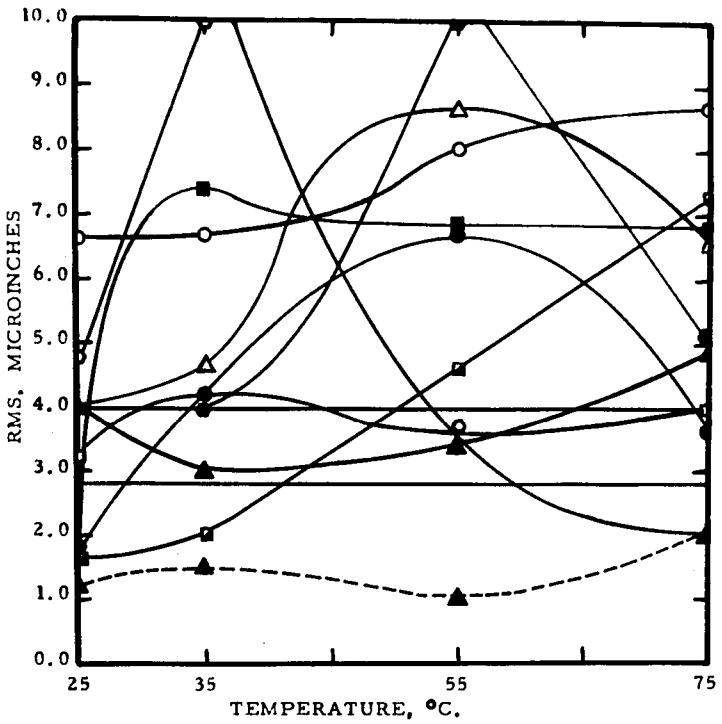


FIGURE 38. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. △ CAMPHOR
3. ■ p-BROMOACETOPHENONE
4. ○ CINNAMALDEHYDE
5. ▣ ACETALDEHYDE
6. ● CHLORAL HYDRATE
7. □ PYRUVIC C ACID
8. ▲ BUTYL CHLORAL
9. ○ beta-METHYLUMBELLIFERONE

----2.0 G./L.

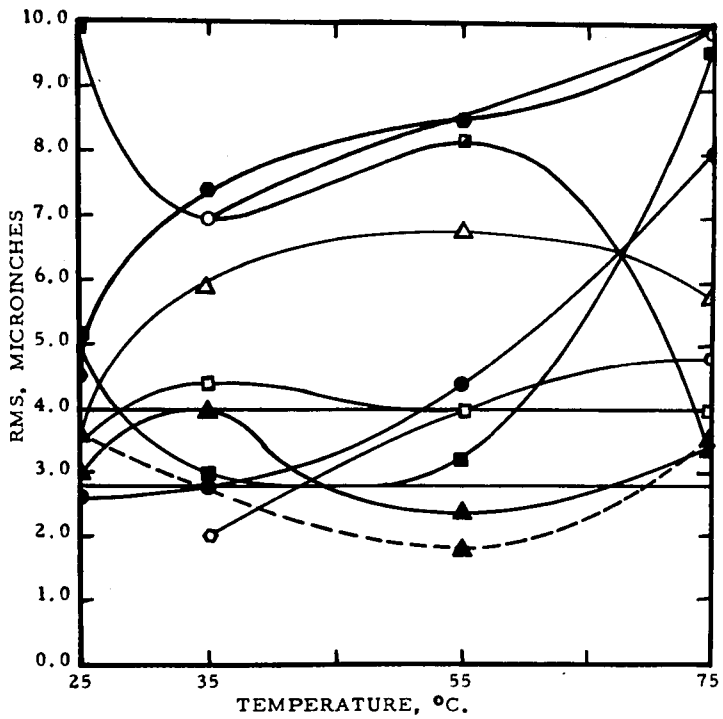


FIGURE 39. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 9.0 AMP./SQ.DM. FOR:

1. ● WATTS
2. △ CAMPHOR
3. ■ p-BROMOACETOPHENONE
4. ○ CINNAMALDEHYDE
5. ▨ ACETALDEHYDE
6. ● CHLORAL HYDRATE
7. □ PYRUVIC ACID
8. ▲ BUTYL CHLORAL
9. ○ beta-METHYLUMBELLIFERONE

----2.0 G./L.

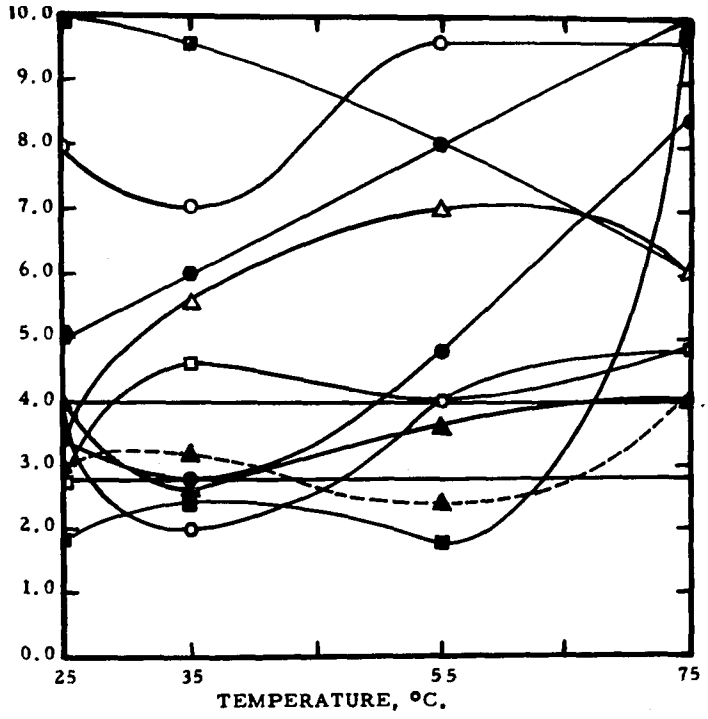


FIGURE 40. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 6.5 AMP./SQ.DM., AND 0.6 G./L. FOR:

1. ● WATTS
2. △ CAMPHOR
3. ■ p-BROMOACETOPHENONE
4. O CINNAMALDEHYDE
5. ◪ ACETALDEHYDE
6. ● CHLORAL HYDRATE
7. □ PYRUVIC ACID
8. ▲ BUTYL CHLORAL
9. O beta-METHYLUMBELLIFERONE

----2.0 G./L.

Table 75. RMS roughness effects of dyes.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Clayton Yellow			Primuline Yellow	
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
3110	4.0	5.4	3210	2.8	4.2
3120	2.2	2.6	3220	5.6	3.2
3130	>10.0	9.5	3230	6.8	6.0
3140	2.6	3.4	3240	3.4	3.0
	[pH 3.8]			[pH 3.8]	
311	2.2	3.6	321	2.6	3.4
312	6.0	5.6	322	5.6	4.2
313	5.8	2.6	323	3.0	4.4
314	3.8	5.0	324	5.0	5.6
	Monastral Blue				
	[0.5 g./l., pH 2.2]				
2810	4.0	4.0			
2820	3.2	3.8			
2830	9.0	8.5			
2840	9.0	>10.0			
	[pH 3.8]				
284	4.0	5.4			
283	9.0	9.0			
282	>10.0	>10.0			
281	>10.0	>10.0			

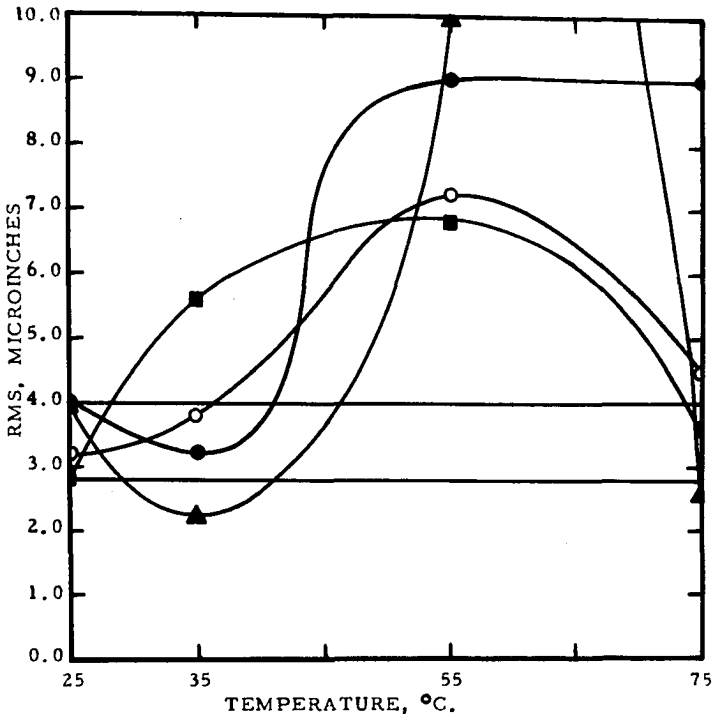


FIGURE 41. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:
1. ○ WATTS
2. ● MONASTRAL BLUE
3. ▲ CLAYTON YELLOW
4. ■ PRIMULINE YELLOW

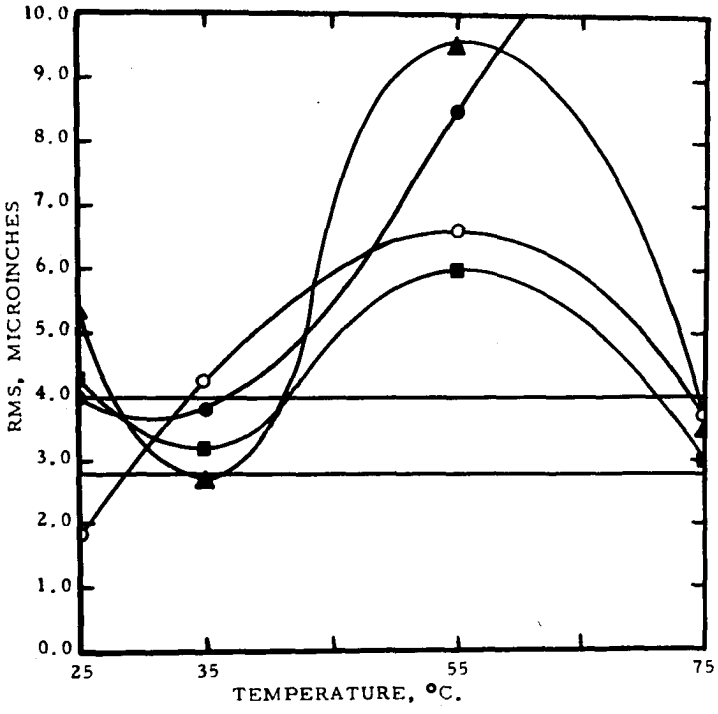


FIGURE 42. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. O WATTS
2. ● MONASTRAL BLUE
3. ▲ CLAYTON YELLOW
4. ■ PRIMULINE YELLOW

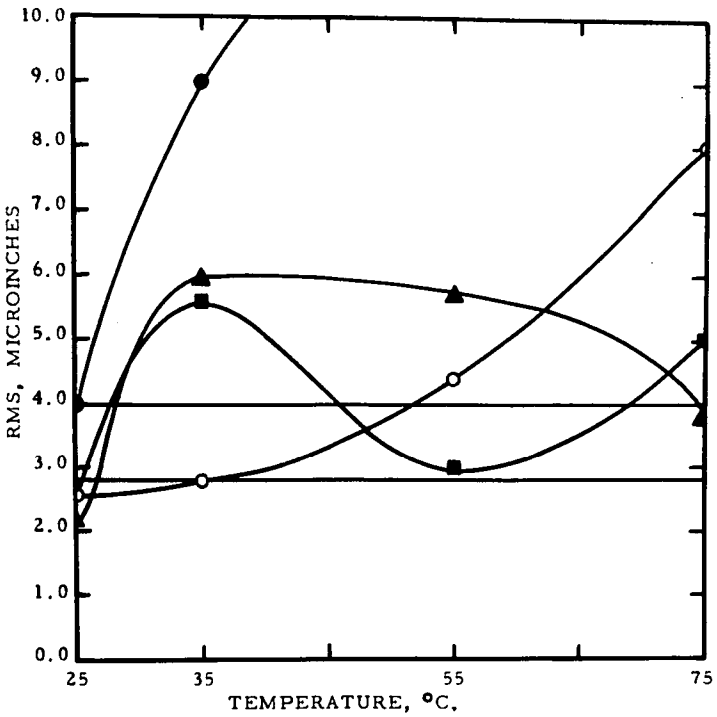


FIGURE 43. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ○ WATTS
2. ● MONASTRAL BLUE
3. ▲ CLAYTON YELLOW
4. ■ PRIMULINE YELLOW

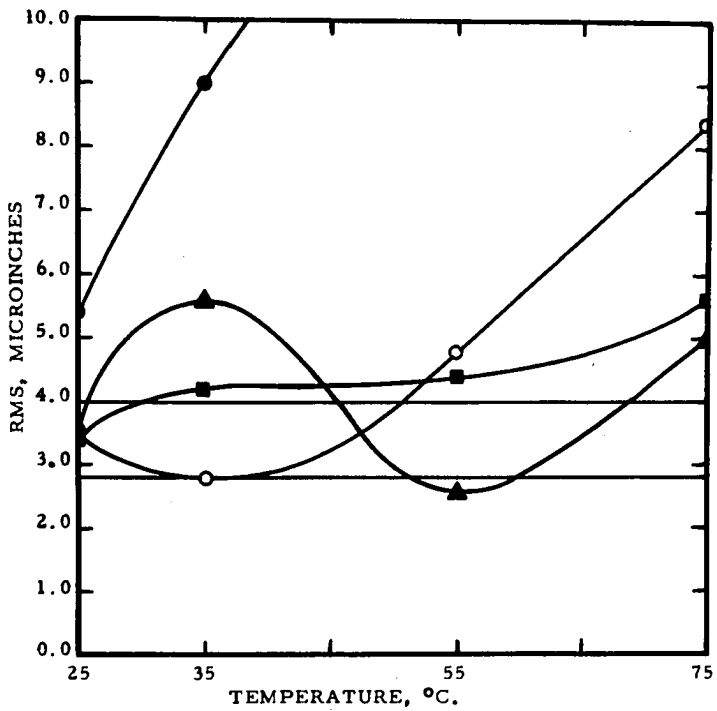


FIGURE 44. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ○WATTS
2. ●MONASTRAL BLUE
3. ▲CLAYTON YELLOW
4. ■PRIMULINE YELLOW

Table 76. RMS roughness effects of phenols.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	4,4-Dihydroxybiphenyl [0.33 g./l., pH 2.2]			3,5,3,'5-Tetranitro-4,4-dihydroxybiphenyl [0.33 g/l., pH 2.2]	
3010	2.8	3.4	2710	2.3	3.2
3020	2.8	3.4	2720	3.8	5.0
3030	6.0	7.6	2730	4.6	4.0
3040	3.6	3.4	2740	3.6	3.0
	[pH 3.8]			[pH 3.8]	
301	2.4	2.2	271	9.0	5.0
302	4.0	4.4	272	-	8.5
303	9.0	7.6	273	6.0	6.0
304	10.0	10.0	274	-	-
	Phenol [0.5 g./l., pH 2.2]			o-Nitrophenol [0.5 g./l., pH 2.2]	
4110	5.0	4.8	4210	3.4	3.8
4120	3.0	3.6	4220	3.2	2.4
4130	9.4	8.0	4230	3.8	3.8
4140	9.6	9.0	4240	3.8	3.2
	[pH 3.8]			[pH 3.8]	
411	3.4	3.2	421	4.0	4.4
412	4.0	5.2	422	4.8	4.0
413	3.8	3.8	423	4.4	4.2
414	>10.0	>10.0	424	3.4	3.8

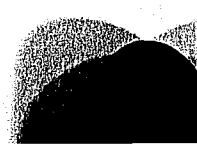


Table 76 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
p-Aminophenol Hydrochloride			o-Aminophenol Hydrochloride		
	[0.5 g./l., pH 2.2]			[0.5 g./l., pH 2.2]	
4810	2.6	3.4	4910	3.6	4.4
4820	5.2	4.6	4920	3.0	2.8
4830	7.0	7.0	4930	3.4	2.8
4840	4.8	5.0	4940	6.4	4.6
	[pH 3.8]			[pH 3.8]	
481	3.6	2.4	491	2.8	3.0
482	3.4	2.8	492	5.2	4.0
483	-	-	493	2.8	2.6
484	-	-	494	6.2	5.2
	[2.0 g./l., pH 2.2]			[2.0 g./l., pH 2.2]	
4850	>10.0	4.4	4950	8.0	6.2
4860	-	-	4960	6.5	5.0
4870	7.6	5.2	4970	4.2	3.4
4880	5.4	6.0	4980	3.8	2.8
	[pH 3.8]			[pH 3.8]	
485	5.4	5.4	495	6.4	5.2
486	-	-	496	6.8	6.0
487	-	-	497	5.2	6.0
488	-	-	498	6.6	5.0

Table 76 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.
	Catechol			Resorcinol	
	[0.5 g./1., pH 2.2]			[0.5 g./1., pH 2.2]	
5010	6.0	5.0	5110	3.4	2.6
5020	3.0	3.6	5120	3.2	2.6
5030	9.0	8.8	5130	9.8	8.6
5040	>10.0	9.6	5140	>10.0	9.5
	[pH 3.8]			[pH 3.8]	
501	4.0	5.4	511	3.0	3.4
502	3.6	3.8	512	4.4	5.0
503	7.0	6.4	513	6.4	6.0
504	6.2	5.0	514	8.0	7.0
	[2.0 g./1., pH 2.2]			[2.0 g./1., pH 2.2]	
5050	5.0	3.4	5150	2.4	2.4
5060	4.8	4.0	5160	6.6	3.8
5070	>10.0	9.0	5170	8.6	7.0
5080	>10.0	>10.0	5180	8.6	7.2
	[pH 3.8]			[pH 3.8]	
505	4.4	4.0	515	4.0	3.6
506	4.0	4.4	516	5.6	3.8
507	6.0	7.0	517	4.2	4.0
508	>10.0	>10.0	518	9.5	7.0

Table 76 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	beta-Naphthol				
	[0.5 g./l., pH 2.2]				
5210	3.0	3.8			
5220	5.0	3.8			
5230	5.0	3.6			
5240	3.6	2.4			
	[pH 3.8]				
521	-	3.2			
522	4.2	2.8			
523	3.2	3.2			
524	4.0	2.6			

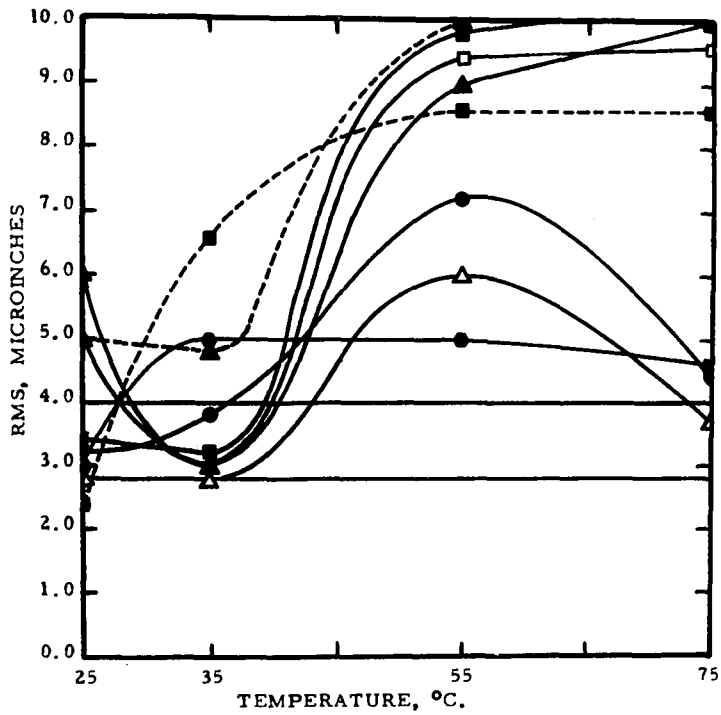


FIGURE 45. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. △ 4,4'-DIHYDROXYBIPHENYL 0.3 G./L.
3. □ PHENOL
4. ▲ CATECHOL
5. ■ RESORCINOL
6. ● beta-NAPHTHOL

----2.0 G./L.

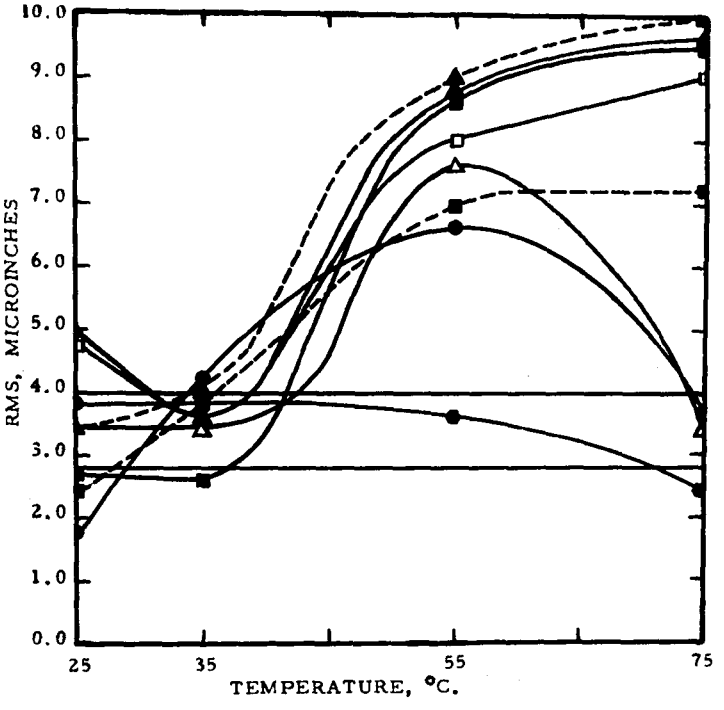


FIGURE 46. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. △ 4,4'-DIHYDROXYBIPHENYL 0.3 G./L.
3. □ PHENOL
4. ▲ CATECHOL
5. ■ RESORCINOL
6. ● beta-NAPHTHOL

----2.0 G./L.

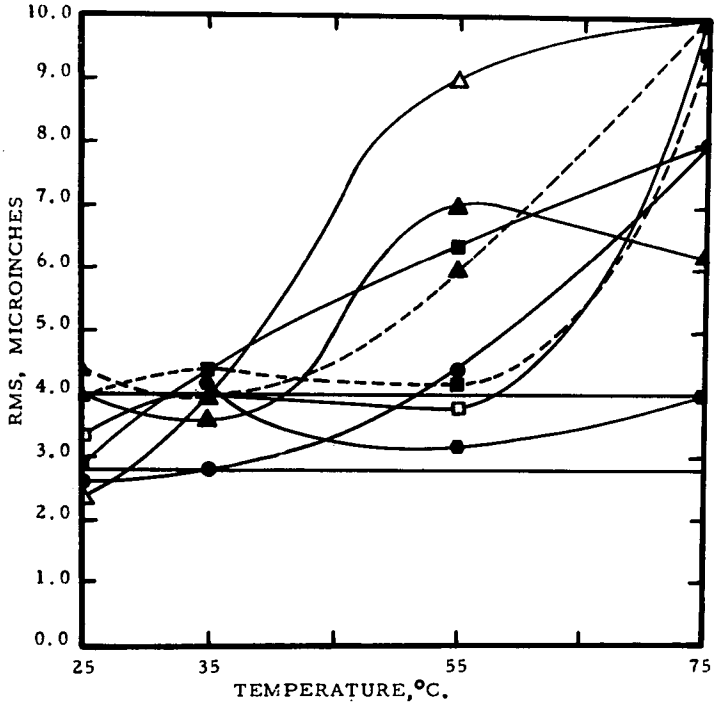


FIGURE 47. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. △ 4,4'-DIHYDROXYBIPHENYL 0.3 G./L.
3. □ PHENOL
4. ▲ CATECHOL
5. ■ RESORCINOL
6. ● beta-NAPHTHOL

----2.0 G./L.

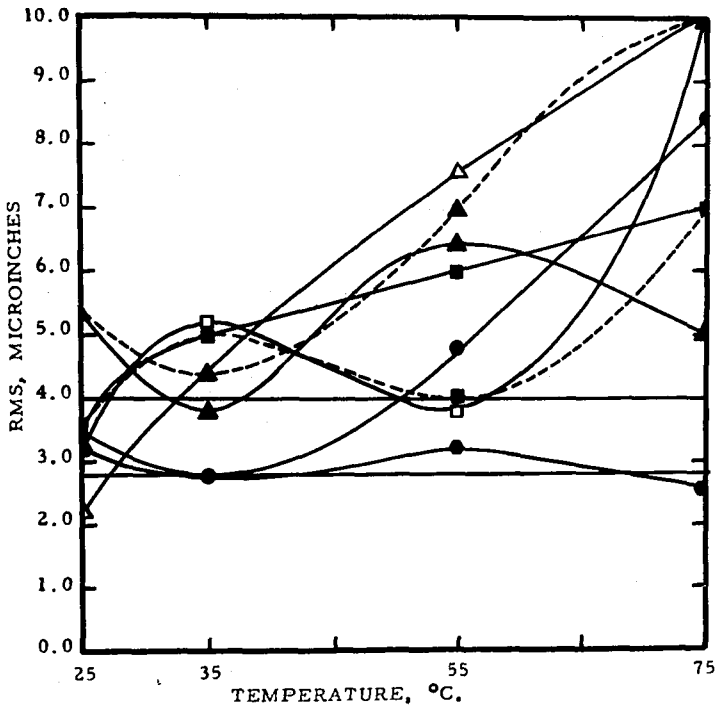


FIGURE 48. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. △ 4,4'-DIHYDROXYBIPHENYL 0.3 G./L.
3. □ PHENOL
4. ▲ CATECHOL
5. ■ RESORCINOL
6. ● beta-NAPHTHOL

----2.0 G./L.

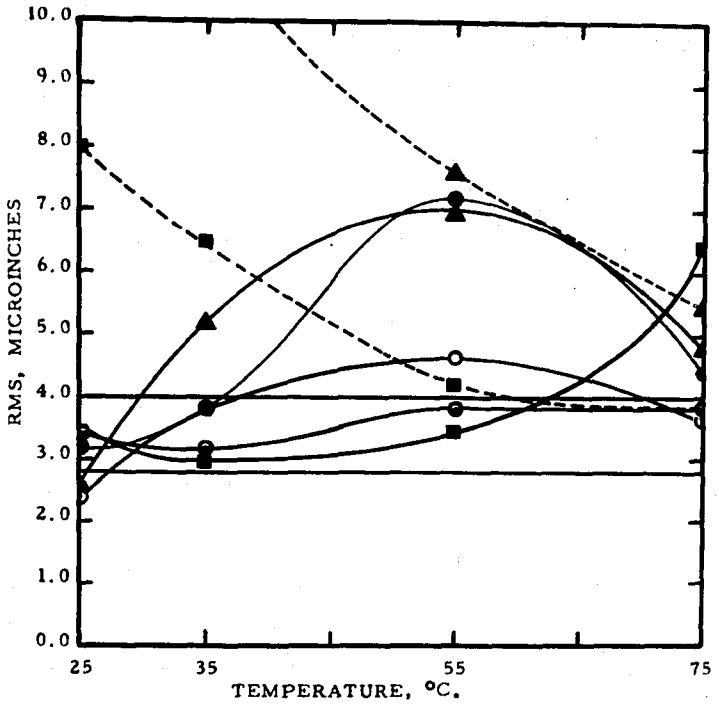


FIGURE 49. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ⊖ o-NITROPHENOL
3. ■ o-AMINOPHENOL HYDROCHLORIDE
4. ▲ p-AMINOPHENOL HYDROCHLORIDE
5. ○ 3,5,3',5'-TETRANITRO-4,4'-DIHYDROXY-BIPHENYL 0.3 G./L.

----2.0 G./L.

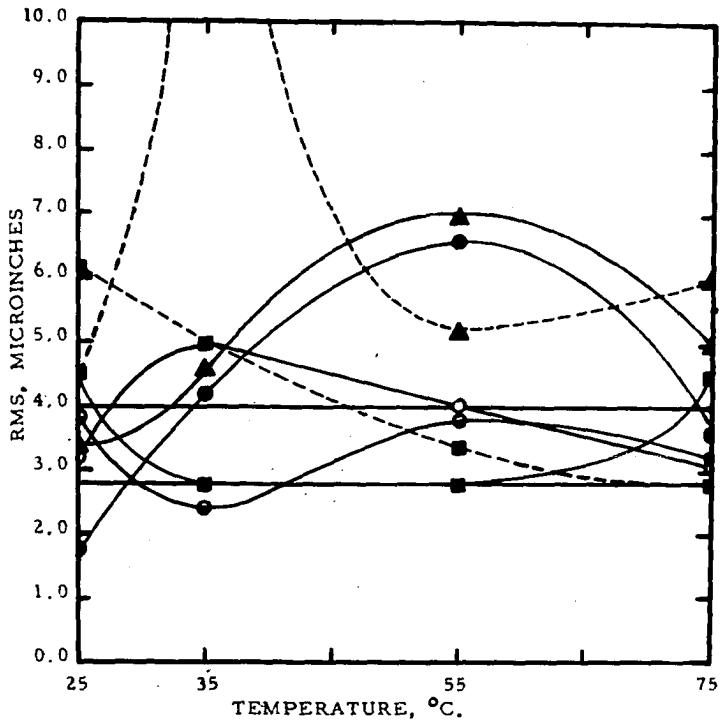


FIGURE 50. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 2.2, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ⊖ o-NITROPHENOL
3. ■ o-AMINOPHENOL HYDROCHLORIDE
4. ▲ p-AMINOPHENOL HYDROCHLORIDE
5. ○ 3,5,3',5'-TETRANITRO-4,4'-DIHYDROXY-BIPHENYL 0.3 G./L.

----2.0 G./L.

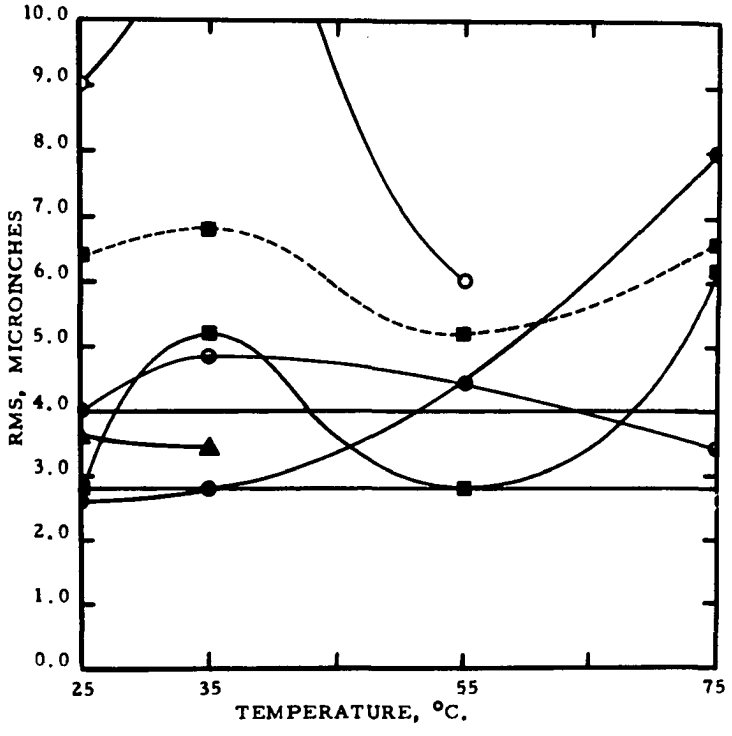


FIGURE 51. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 9.0 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ◐ o-NITROPHENOL
3. ■ o-AMINOPHENOL HYDROCHLORIDE
4. ▲ p-AMINOPHENOL HYDROCHLORIDE
5. ○ 3,5,3',5'-TETRANITRO-4,4'-DIHYDROXY-BIPHENYL 0.3 GM./L.

----2.0 G./L.

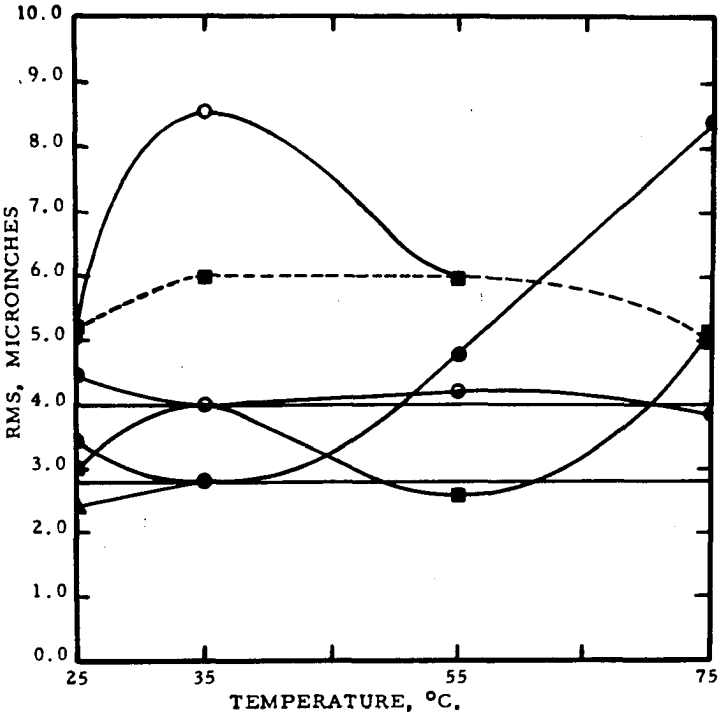


FIGURE 52. SURFACE ROUGHNESS VS. TEMPERATURE AT pH 3.8, 6.5 AMP./SQ.DM., AND 0.5 G./L. FOR:

1. ● WATTS
2. ◒ o-NITROPHENOL
3. ■ o-AMINOPHENOL HYDROCHLORIDE
4. ▲ p-AMINOPHENOL HYDROCHLORIDE
5. ○ 3,5,3',5',TETRANITRO-4,4'-DIHYDROXY-BIPHENYL 0.3 GM./L.

----2.0 G./L.

Table 77. RMS surface roughness effects for 2,7-naphthalene disulfonic acid and increasing concentrations* of glucose.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.	Temp. (° C.)
371-1	2.6	3.4	
371-2	3.2	2.6	
371-3	2.6	2.4	
371-4	3.2	2.2	
371-5	3.0	2.8	
371-6	1.8	1.8	
371-7	3.0	2.6	
371-8	1.6	1.8	
371-9	2.0	2.4	
371-10	1.8	1.9	
371-11	2.0	3.8	25
371-12	2.6	2.8	38
371-13	3.0	2.6	52
371-14	3.0	3.2	60
371-15	3.4	2.6	60

* Refer to Tables 37 to 67 for clarification of additions referred to in remainder of roughness tables.

Table 78. RMS surface roughness effects for 2,7-naphthalene disulfonic acid and increasing concentrations of chloral.

Panel No.	RMS Roughness (microinches)		Temp. (° C.)
	9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	
381-1	3.0	2.9	
381-2	3.8	4.0	
381-3	1.6	5.0	
381-4	2.8	5.0	
381-5	9.0	9.0	
381-6	9.0	9.5	
381-7	4.0	7.0	
381-8	3.0	3.0	
381-9	7.0	7.0	
381-10	3.0	3.0	
381-11	1.9	1.8	28
381-12	>10.0	>10.0	38
381-13	2.2	2.6	52
381-14	2.6	3.2	60
381-15	3.6	2.6	60

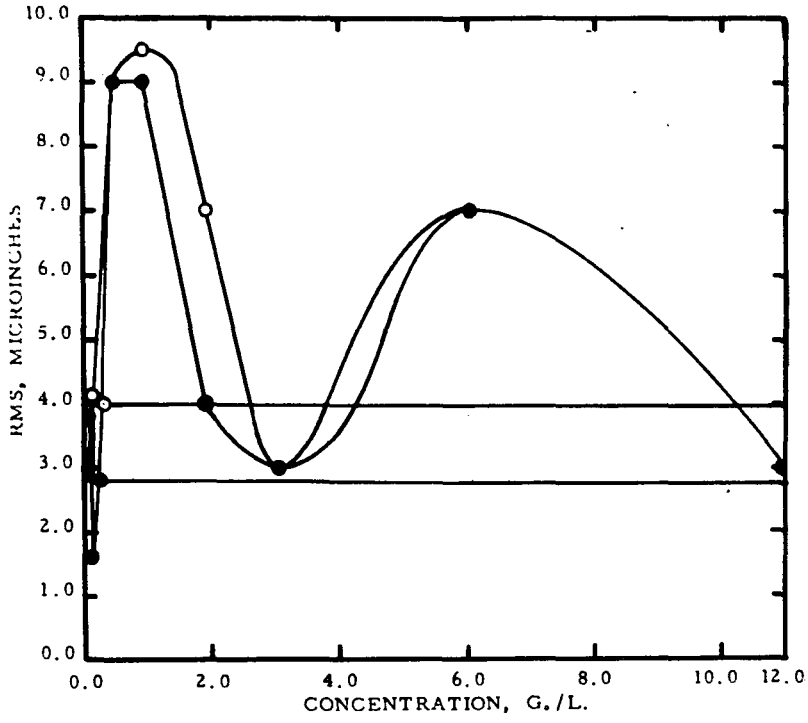


FIGURE 53. SURFACE ROUGHNESS VS. CONCENTRATION OF CHLORAL AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 65 °C. FOR CURRENT DENSITIES:
1. ● 9.0 AMP./SQ.DM.
2. O 6.5 AMP./SQ.DM.

Table 79. RMS surface roughness effects for 2,7-naphthalene disulfonic acid and increasing concentrations of representative polymer and unsaturated aliphatic compounds.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Polymethyl Vinyl Ether Maleic Anhydride			Acrylic Acid	
361-1	2.6	2.4	46-1	3.0	3.0
361-2	2.0	1.7	46-2	2.6	2.6
361-3	2.2	2.2	46-3	3.8	3.6
361-4	2.0	2.0	46-4	3.2	3.0
361-5	2.2	2.2	46-5	4.0	4.0
361-6	2.6	2.4	46-6	3.4	4.0
361-7	7.6	7.8	46-7	2.6	3.2
361-8	4.0	2.7	46-8	4.2	3.8
361-9	4.0	4.0	46-9	3.0	3.8
361-10	8.0	9.0	46-10	4.0	5.0
			46-11	3.6	5.4
Panel No./ Temp. (° C.)			46-12	3.6	2.2
				1,4-Butynediol	
361-11/28	2.6	3.2	531-1	5.0	4.6
361-12/38	2.8	4.0	531-2	6.0	5.0
361-13/52	5.4	3.8	531-3	5.6	5.6
361-14/60	5.0	3.0	531-4	4.8	5.2
361-15/60	2.8	3.2	531-5	5.4	5.0

Table 79 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.
			531-6	5.0	5.0
			531-7	6.2	5.4
			531-8	6.0	5.2
			531-9	4.0	5.0
			531-10	6.0	6.0

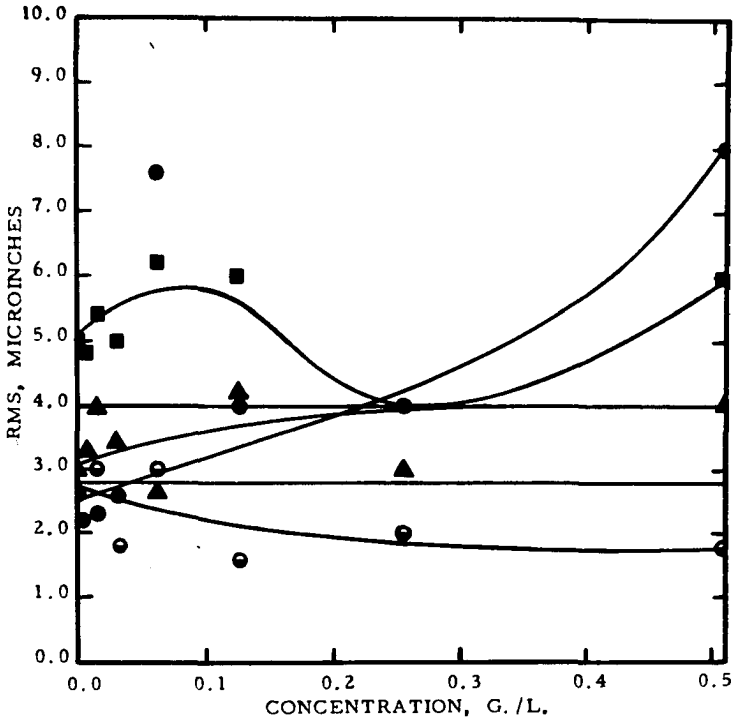


FIGURE 54. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 9.0 AMP./SQ.DM. AND 65 °C. FOR:

1. ⊖ GLUCOSE
2. ● PVM/MA
3. ▲ ACRYLIC ACID
4. ■ 1,4-BUTYNEDIOL

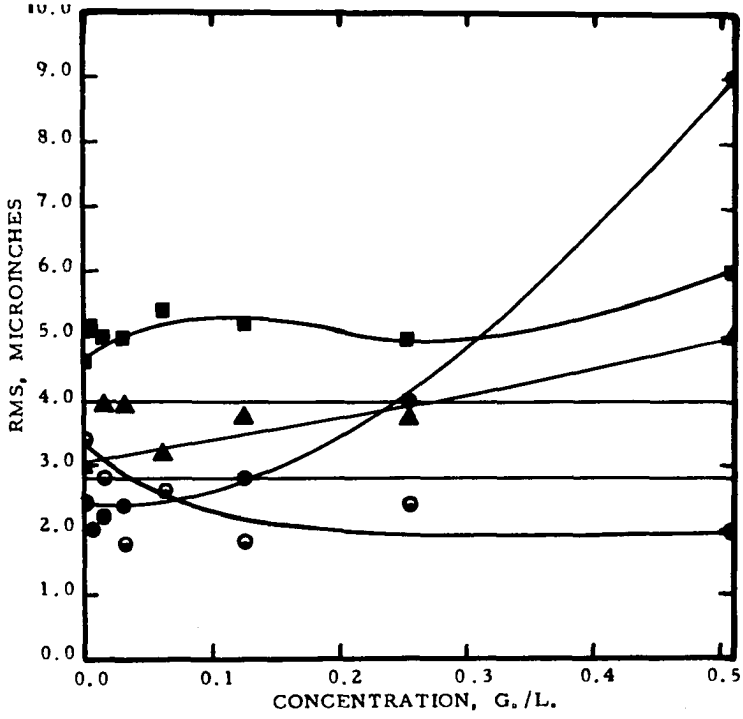


FIGURE 55. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 6.5 AMP./SQ.DM. AND 65 °C. FOR:

1. ⊖ GLUCOSE
2. ● PVM/MA
3. ▲ ACRYLIC ACID
4. ■ 1,4-BUTYNEDIOL

Table 80. RMS surface roughness effects for 2,7-naphthalene disulfonic acid and increasing concentrations of dyes.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Clayton Yellow			Primuline Yellow	
311-1	2.6	3.4	321-1	3.0	4.0
311-2	3.6	4.4	321-2	3.8	6.0
311-3	3.2	2.8	321-3	3.2	3.8
311-4	3.6	3.0	321-4	3.2	2.4
311-5	2.6	3.0	321-5	3.4	3.8
311-6	2.6	4.8	321-6	3.2	3.0
311-7	2.2	1.8	321-7	3.6	3.2
311-8	3.2	4.0	321-8	2.8	3.0
311-9	3.6	3.8	321-9	4.8	3.0
311-10	2.6	2.2	321-10	3.2	3.2
311-11	3.0	3.0	321-11	4.0	4.0
311-13	3.6	2.2	321-13	3.6	4.0
	Methylene Blue			Toluidine Blue	
331-1	3.8	4.2	341-1	2.2	2.0
331-2	4.0	4.2	341-2	2.0	3.4
331-3	3.6	3.8	341-3	2.6	2.2
331-4	3.4	3.2	341-4	2.6	2.4
331-5	3.0	4.0	341-5	2.6	3.2
331-6	2.4	2.8	341-6	1.0	1.8
331-7	2.4	1.8	341-7	2.8	2.2

Table 80 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
331-11	2.6	2.0	341-11	6.0	4.5
331-13	4.0	3.8	341-13	2.0	3.0
	Monastral Blue				
351-2	2.4	3.2			
351-3	4.4	2.2			
351-4	1.6	2.2			
351-5	1.8	2.0			
351-6	2.4	2.4			
351-7	3.6	1.8			
351-8	2.0	2.4			
351-9	2.4	5.0	Temp. (° C.)		
351-10	2.0	2.4			
351-11	3.0	2.4	28		
351-12	3.0	4.0	38		
351-13	1.6	2.0	52		
351-14	1.2	0.8	60		
351-15	2.2	2.4	60		

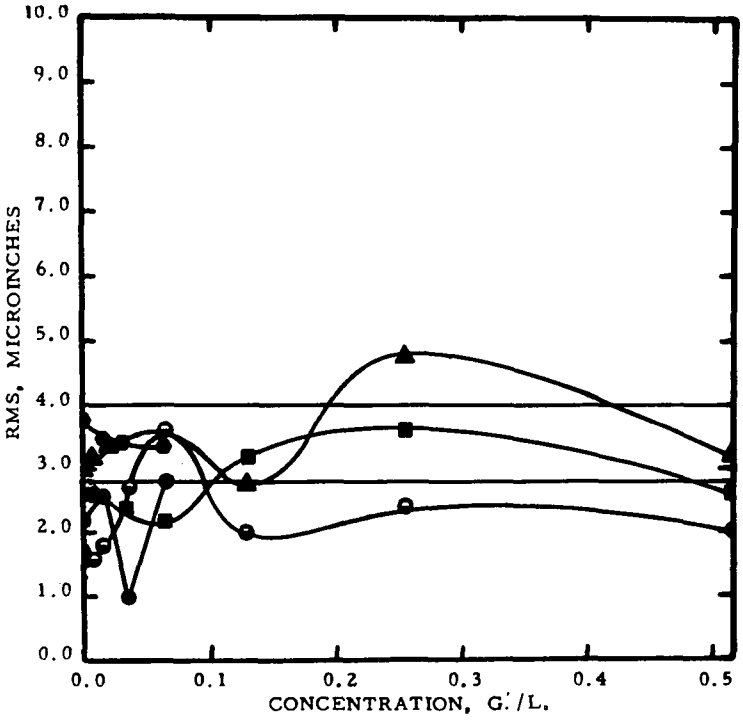


FIGURE 56. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPTHALENE DISULFONIC ACID AT 9.0 AMP./SQ.DM. AND 65 °C. FOR:

1. ○ MONASTRAL BLUE
2. ■ CLAYTON YELLOW
3. ▲ PRIMULINE YELLOW
4. ● TOLUIDINE BLUE
5. ● METHYLENE BLUE

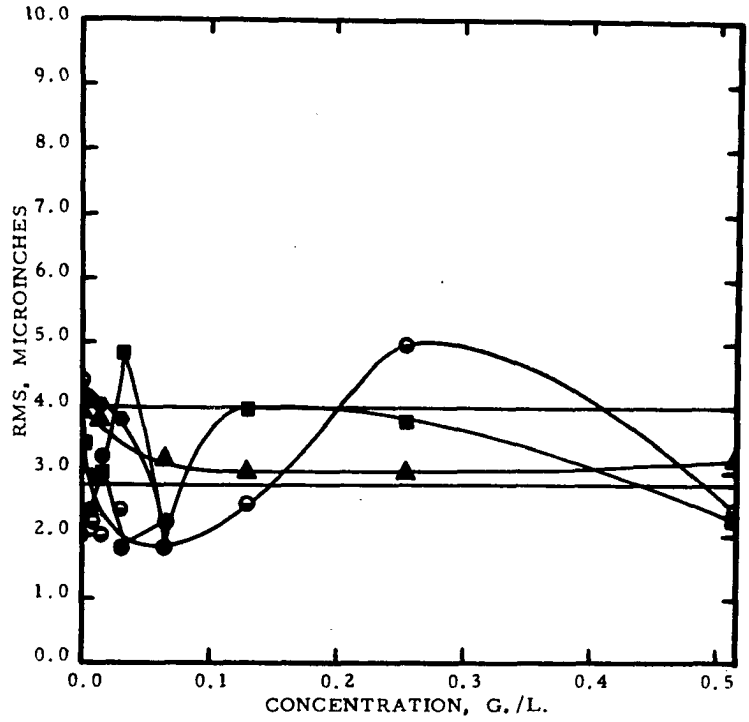


FIGURE 57. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPTHALENE DISULFONIC ACID AT 6.5 AMP./SQ.DM. AND 65 °C. FOR:

1. ○ MONASTRAL BLUE
2. ■ CLAYTON YELLOW
3. ▲ PRIMULINE YELLOW
4. ● TOLUIDINE BLUE
5. ● METHYLENE BLUE

Table 81. RMS surface roughness effects for 2,7-naphthalene disulfonic acid and increasing concentrations of phenols.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	
	4,4-Dihydroxybiphenyl			3,5,3,5-Tetranitro-4,4-dihydroxybiphenyl		
301-1	4.0	3.4	271-1	3.0	3.6	
301-2	2.6	2.8	271-2	2.6	2.4	
301-3	2.8	2.8	271-3	3.0	3.0	
301-4	2.6	3.6	271-4	2.6	2.6	
301-5	2.2	2.6	271-5	2.4	3.8	
301-6	3.4	2.2	271-6	2.6	3.0	
301-7	3.0	3.0	271-7	3.0	2.8	
301-8	4.0	3.0	271-8	2.4	3.2	
301-9	2.0	2.0	271-9	4.0	4.0	
301-10	2.0	3.0	271-10	>10.0	>10.0	
Panel No./ Temp. (° C.)			Panel No./ Temp. (° C.)			
301-12/47	3.6	1.6	271-11	4.0	4.0	(pH3.00)
301-14/24	2.8	2.2	271-12/47	4.0	3.6	
301-15/35	3.0	3.0	271-14/24	>10.0	>10.0	
301-16/55	2.0	2.4	271-15/35	>10.0	>10.0	
301-17/75	5.0	3.8	271-16/55	>10.0	>10.0	
			271-17/75	4.0	5.2	

Table 81 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.
	Phenol			o-Nitrophenol	
411-4	2.2	4.0	421-4	1.8	1.8
411-5	1.8	2.6	421-5	1.9	1.5
411-6	3.0	2.2	421-6	2.8	5.2
411-7	3.2	3.6	421-7	2.2	2.2
411-8	3.2	3.0	421-8	3.8	3.0
411-9	3.0	2.8	421-9	3.8	5.2
411-10	4.0	1.8	421-10	3.6	2.6
411-11	3.6	3.0	421-11	2.8	2.8
411-12	2.4	3.6	421-12	3.6	3.8
	p-Nitrophenol			p-Aminophenol Hydrochloride	
47-1	5.0	4.2	481-1	5.0	5.0
47-2	4.8	5.6	481-2	4.0	3.6
47-3	5.6	5.0	481-3	5.0	5.4
47-4	5.2	5.8	481-4	4.2	4.0
47-5	5.4	4.8	481-5	3.4	3.8
47-6	7.0	7.6	481-6	3.6	5.2
47-7	5.4	5.2	481-7	3.8	4.6
47-8	6.2	5.4	481-8	4.6	4.8
47-9	-	-	481-9	2.4	3.0
			481-10	3.0	2.4

Table 81 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	RMS Roughness (microinches) 6.5 amp./ sq.dm.
			Panel No./ Temp. (° C.)		
			481-11/35	4.4	4.0
			481-12/49	4.4	4.4
			481-13/59	4.4	4.8
o-Aminophenol Hydrochloride			Catechol		
491-1	4.6	5.0	501-1	6.0	5.8
491-2	5.2	4.0	501-2	6.0	5.8
491-3	5.0	4.0	501-3	5.4	4.8
491-4	4.6	4.0	501-4	6.0	5.0
491-5	3.0	3.6	501-5	5.0	5.6
491-6	4.4	3.4	501-6	4.6	4.4
491-7	4.0	4.0	501-7	5.4	5.8
491-8	4.6	4.2	501-8	4.4	4.4
491-9	3.4	3.6	501-9	7.4	7.4
491-10	3.5	3.8	501-10	4.0	4.2
			501-14	5.0	4.0

Table 81 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
Panel No./ Temp. (° C.)			Panel No./ Temp. (° C.)		
491-11/35	4.0	6.0	501-11/35	5.0	5.0
491-12/49	4.0	4.6	501-12/49	5.0	5.0
491-13/59	4.0	4.2	501-13/59	5.0	4.0
	Resorcinol			beta-Naphthol	
511-1	7.0	6.2	521-1	6.0	5.4
511-2	5.6	5.6	521-2	6.0	5.6
511-3	6.0	6.4	521-3	5.4	6.0
511-4	5.8	5.2	521-4	3.8	4.2
511-5	5.8	6.2	521-5	5.2	4.8
511-6	4.6	4.0	521-6	6.8	5.2
511-7	5.6	5.2	521-7	3.0	3.8
511-8	4.8	5.2	521-8	6.0	6.0
511-9	4.8	4.4	521-9	9.0	9.0
511-10	4.6	4.0	521-10	9.0	8.2
511-14	4.0	4.6			

Table 81 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
Panel No./ Temp. (° C.)					
511-11/35	5.0	5.0			
511-12/49	3.2	3.8			
511-13/59	4.0	3.6			

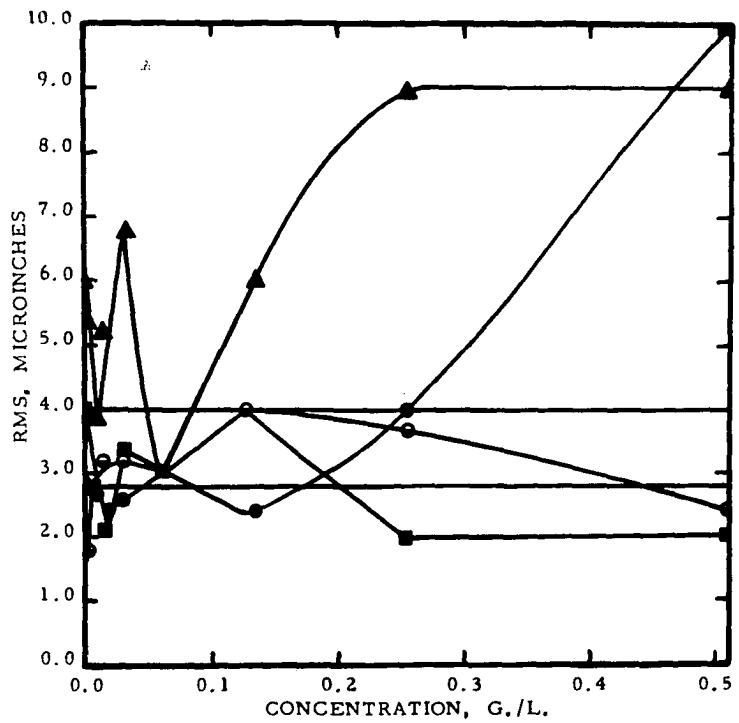
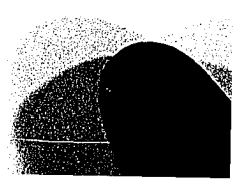


FIGURE 58. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 9.0 AMP./SQ.DM. AND 65 °C. FOR:

1. ■ 4,4'-DIHYDROXYBIPHENYL
2. ● 3,5,3',5'-TETRANITRO-4,4'-DIHYDROXY-BIPHENYL
3. ▲ beta-NAPHTHOL
4. ⊖ PHENOL



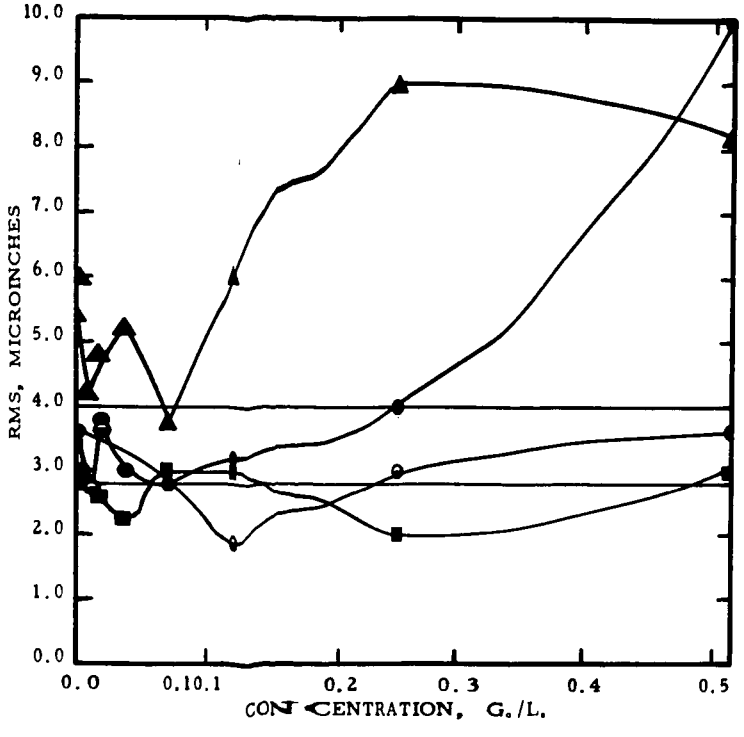


FIGURE 59. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 6.5 AMP./SQ.DM. AND 65 °C. FOR:

1. ■ 4,4'-DIHYDROXYBIPHENYL
2. ● 3,5,3',5'-TETRANITRO-4,4'-DIHYDROXY-BIPHENYL
3. ▲ beta-NAPHTHOL
4. ○ PHENOL

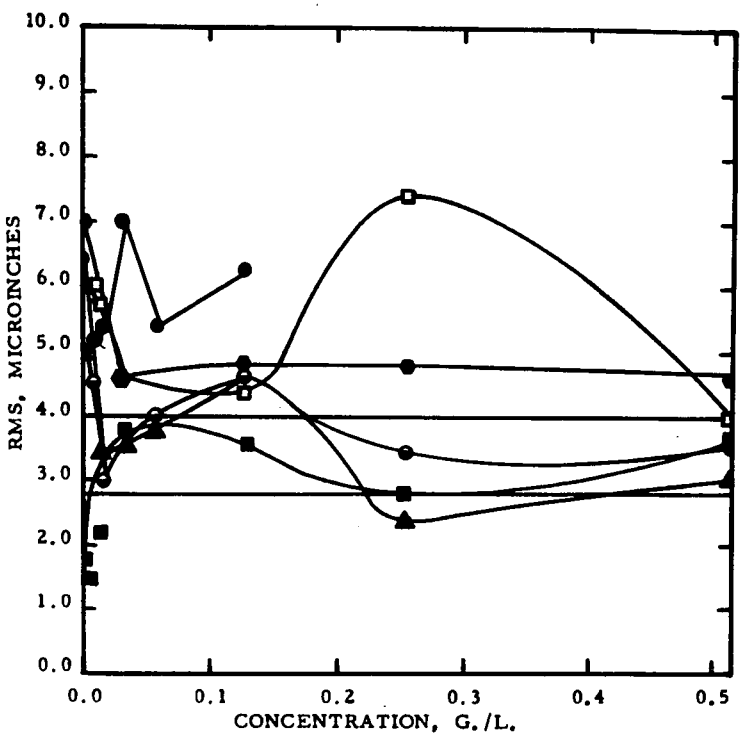


FIGURE 60. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 9.0 AMP./SQ.DM. AND 65 °C. FOR:

1. ■ o-NITROPHENOL
2. ● p-NITROPHENOL
3. ⊖ o-AMINOPHENOL HYDROCHLORIDE
4. ▲ p-AMINOPHENOL HYDROCHLORIDE
5. □ CATECHOL
6. ⬢ RESORCINOL

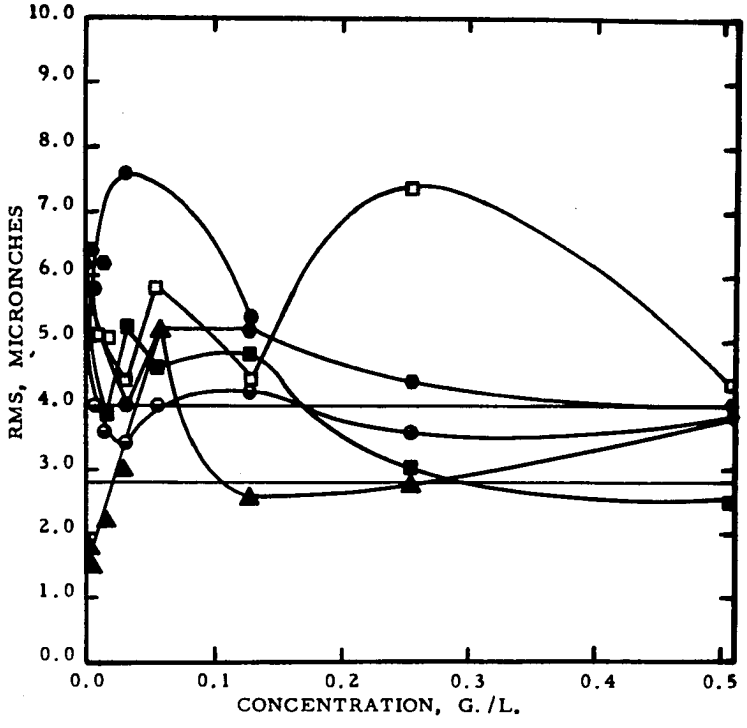


FIGURE 61. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT AND 5.0 G./L. OF 2,7-NAPHTHALENE DISULFONIC ACID AT 6.5 AMP./SQ.DM. AND 65 °C. FOR:

1. ▲ o-NITROPHENOL
2. ● p-NITROPHENOL
3. ⊖ o-AMINOPHENOL HYDROCHLORIDE
4. ■ p-AMINOPHENOL HYDROCHLORIDE
5. □ CATECHOL
6. ⬣ RESORCINOL

Table 82. RMS surface roughness effects for nickel cobalt depositions in the presence of nickel formate and increasing concentrations of carbonyl compound.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Cinnamaldehyde			Chloral with $(NH_4)_2SO_4$	
181	6.4	8.0	191	3.6	5.0
182	5.0	4.6	192	7.0	5.0
183	3.8	4.4	193	>10.0	8.5
			194	7.6	6.0
			195	>10.0	>10.0
			196	8.5	8.0
			197	>10.0	>10.0
			198	>10.0	9.0
	Chloral			Acetaldehyde	
201	4.0	3.2	241	4.6	5.2
202	4.0	3.4	242	1.8	2.8
203	2.8	4.0	243	4.6	3.4
204	4.2	4.0	244	3.6	3.2
205	6.4	6.0	245	5.0	2.4
206	3.8	4.0	246	2.8	3.0
207	3.8	3.2	247	6.6	3.2
208	4.0	4.6	248	5.8	5.0
			249	3.6	3.8

Table 82 (Continued)

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
291	3.6	1.8	298	2.8	2.2
292	5.0	3.8	299	4.6	4.0
293	3.2	2.6	2910	5.6	5.0
294	1.8	3.8	2911	5.0	5.4
295	2.6	6.5	2912	4.0	4.8
296	5.5	4.6	2913	5.4	6.0
297	3.8	5.0	2914	7.2	8.0
			2915	9.0	4.0
			2916	5.0	5.4
			2917	4.4	5.2
			2918	5.0	5.6
	Butyl Chloral				
391	4.2	3.6			
392	2.2	2.8			
393	1.8	4.0			
394	1.6	3.2			
395	1.8	2.0			
396	4.0	3.4			
397	5.4	4.0			
398	3.0	3.6			
399	5.0	3.6			

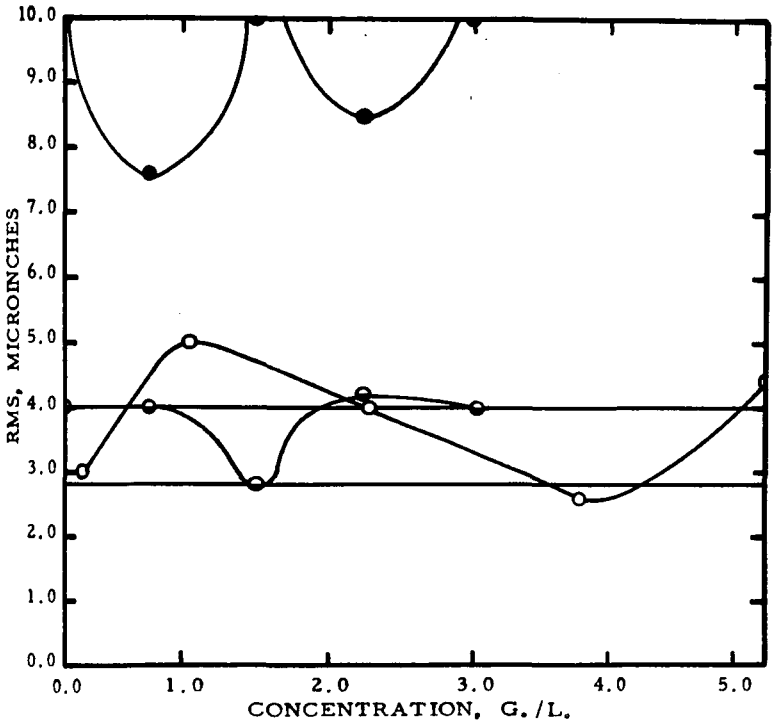


FIGURE 62. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT FOR NICKEL-COBALT DEPOSITION IN THE PRESENCE OF NICKEL FORMATE AT 9.0 AMP./SQ.DM. AND 65 °C. FOR:

1. ● CHLORAL WITH AMMONIUM SULFATE PRESENT
2. ◒ CHLORAL
3. ○ CHLORAL IN PRESENCE OF NICKEL CHLOROACETATE

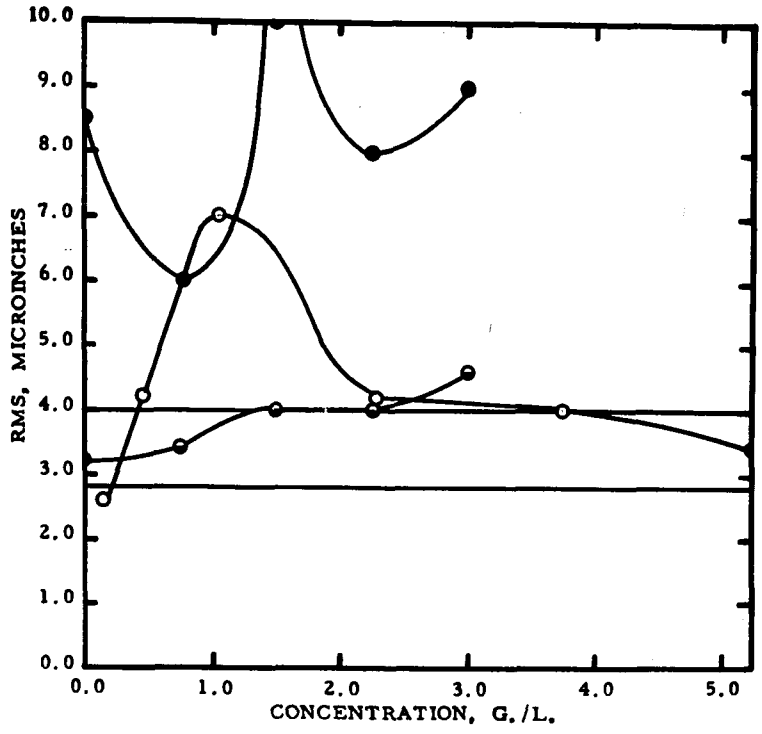


FIGURE 63. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT FOR NICKEL-COBALT DEPOSITION IN THE PRESENCE OF NICKEL FORMATE AT 6.5 AMP./SQ.DM. AND 65°C. FOR:

1. ● CHLORAL WITH AMMONIUM SULFATE PRESENT
2. ◒ CHLORAL
3. ○ CHLORAL IN THE PRESENCE OF NICKEL CHLOROACETATE

Table 83. RMS surface roughness effects for nickel-cobalt depositions with increasing concentrations of chloral in the presence of organic nickel salts.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	Nickel Chloroacetate			Nickel Acrylate	
441	4.2	4.6	451	7.6	2.6
442	6.2	6.6	452	2.2	1.8
443	5.8	6.0	453	4.2	3.6
444	3.0	2.6	454	3.6	3.0
445	3.8	4.2			
446	5.0	7.0			
447	4.0	4.2			
448	2.6	4.0			
449	4.4	3.4			
4410	2.8	2.2			
4411	4.0	3.6			
4412	2.4	2.8			

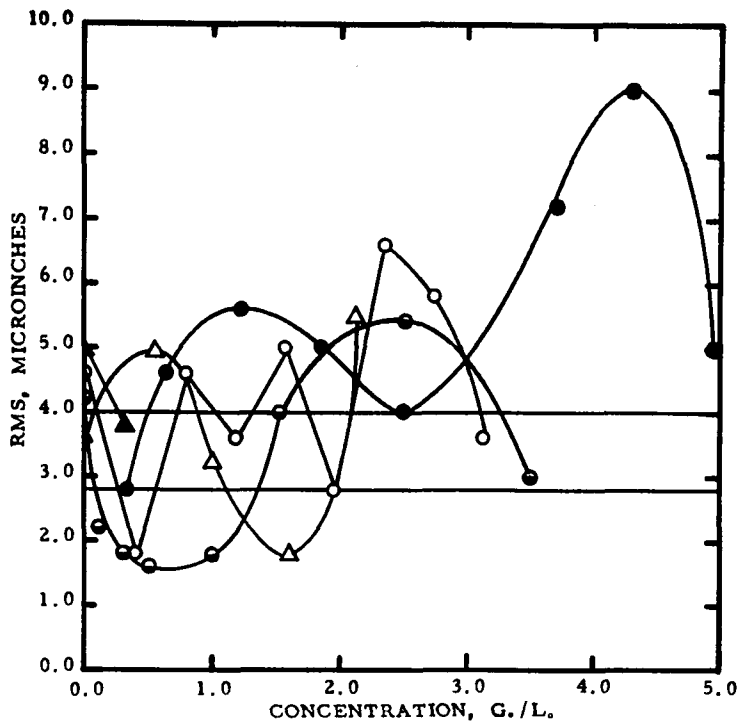


FIGURE 64. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT FOR NICKEL-COBALT DEPOSITION IN THE PRESENCE OF NICKEL FORMATE AT 9.0 AMP./SQ.DM. AND 65°C. FOR:

1. O ACETALDEHYDE
2. Δ ETHYL PYRUVATE
3. ● GLYOXAL
4. ⊖ BUTYL CHLORAL
5. ▲ CINNAMALDEHYDE

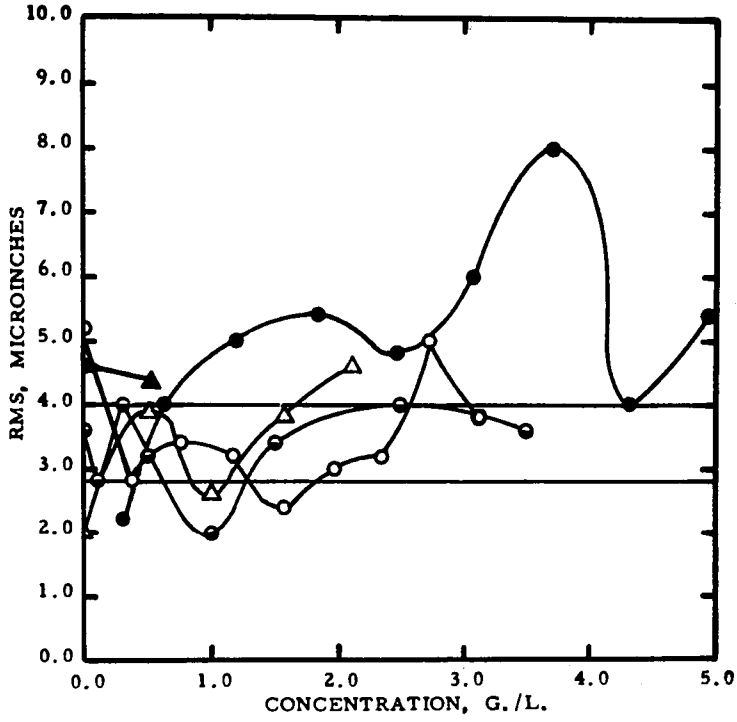


FIGURE 65. SURFACE ROUGHNESS VS. CONCENTRATION OF ADDITION AGENT FOR NICKEL-COBALT DEPOSITION IN THE PRESENCE OF NICKEL FORMATE AT 6.5 AMP./SQ.DM. AND 65 °C. FOR:

1. ○ ACETALDEHYDE
2. △ ETHYL PYRUVATE
3. ● GLYOXAL
4. ⊖ BUTYL CHLORAL
5. ▲ CINNAMALDEHYDE

Table 84. RMS surface roughness effects for nickel-iron depositions with various additions.

Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.	Panel No.	RMS Roughness (microinches) 9.0 amp./ sq.dm.	6.5 amp./ sq.dm.
	$FeSO_4$ and Chloral			$FeSO_4$	
211	5.0	3.6	221	3.6	3.0
212	7.8	4.6	222	5.6	6.5
213	8.0	7.0	223	3.0	2.2
214	4.0	3.8	224	3.8	3.6
215	4.0	4.4	225	8.0	4.0
216	3.6	3.6	226	5.0	2.8
217	3.8	3.2	227	7.0	3.0
218	3.2	4.2	228	4.0	3.2
			229	3.6	5.4
			2210	3.8	2.6
	Nickel Propionate, $FeSO_4$, and Chloral				
251	6.0	6.4			
252	3.2	3.0			
253	4.2	2.0			
254	1.6	2.2			

From the appearance and surface roughness data, it is immediately apparent that these properties are functions of temperature, pH, and current density for nickel deposits obtained from a pure Watts nickel solution. While normal operating conditions are frequently 50° to 65° C. and 1.6 to 5.4 amp./sq. dm. for this solution, it may be generally stated that temperatures less than 35° C., a pH of 3.8, and current densities greater than 6.5 amp./sq. dm. are necessary in order to obtain the greatest modification of the Watts nickel deposit toward the bright appearance range. From the roughness data, the smoothest deposits were obtained in the same general range but were not so pH dependent. As a result of these trends existing in the pure Watts plating solution and since this solution was used as the reference nickel solution for observing the effects of various organic substituents which were added in known concentration prior to electrodeposition, it seemed advisable to compare all effects on the nickel electrodeposits of single organic compounds added to the Watts nickel solution with those effects observed on nickel deposits obtained from the pure solution. Thus, the nickel deposits obtained from the pure Watts nickel solution are frequently referred to as control deposits, the panels as control panels.

When a reducing carbohydrate was added to the Watts plating solution, an immediate widening of the current density range for the modification toward a bright deposit was noted and, further, this widening was directly related to concentration. Xylose, glucose, lactose, hydrate, and raffinose hydrate increased the bright current density range at 25° C. and pH 3.8 and more markedly at 2.0 g./l. than at 0.5 g./l. Increasing the temperature to 35° C. definitely narrowed the bright range so that only glucose and lactose hydrate gave significantly brighter ranges than the comparable control panel. Increased temperatures destroyed any brightening tendency for these sugars as deposits compared favorably with the control panels. At pH 2.2 the same general trend was observed, but the brightening power was considerably diminished.

Dextrin demonstrated somewhat anomolous effects. In the first place, dextrin was the only substance of this group which yielded bright depositing ranges at the low pH. Significantly bright ranges on panels 820 and 870, deposited at 55° C. and pH 2.2 were observed. There was no development or loss of the bright range during the temperature variation which would apparently point to the rather specific nature of this phenomenon. Secondly, when the pH was increased to 3.8, a bright range developed at the low current

density area of the panel and migrated to the high current density area as the temperature increased to 55° C. At 75° C. the bright range disappeared. Finally, when the surface roughness curves were referred to, at pH 2.2, the roughness of metal surfaces plated in the presence of dextrin tended toward a lower value at 35° C. and a concentration of 0.5 g./l. and considerably more roughness at 2.0 g./l. was observed. This was in direct opposition to the trends observed for xylose, glucose, lactose hydrate, raffinose hydrate, and the lower concentration of glyceraldehyde. At pH 3.8, however, the roughness curve of dextrin tended to approach more closely the general trend of increasing roughness with increasing temperature.

While glyceraldehyde demonstrated similar effects to those discussed for xylose, glucose, lactose hydrate and raffinose hydrate, its more powerful brightening propoerties were more apparent at the lower concentration of 0.5 g./l. Again at pH 3.8, a wide bright range rapidly attenuated with increasing temperature. When the pH was lowered to 2.2, the brightening strength was appreciably reduced. When the concentration was raised to 2.0 g./l., the brightening effect was reduced. Roughness increased with concentration, although at pH 2.2 and low temperature greater roughness was noted for the lower concentration of glyceraldehyde.

The inclusion of a nonreducing sugar, raffinose, in this series of additions without significant interruption of the trend of the data is noteworthy. This would tend to indicate that the reducing nature of the carbohydrate could not be singled out as a necessary property for modifying nickel deposits. In addition to the properties discussed, the use of a carbohydrate additive involves at least three basic considerations of functionality. They are (1.) the colloidal aspects, (2.) the role of the carbonyl group, and (3.) the role of the hydroxyl group.

In order to study some of the colloidal aspects, the effects of some water soluble polymers were observed. Methyl cellulose was of particular interest because it not only satisfied the particle concept, but it also could be compared with dextrin on the basis of replacing the hydroxyl group with a methoxyl group. When methyl cellulose was added to a pure Watts nickel solution, deposits made from this medium were not modified toward the bright range. Rather, conversely, the result was to shift the deposit to a duller range than is normally obtained from a pure Watts nickel solution, particularly at the lower temperature. This is contrary to the trend observed in the case of dextrin. Roughness measurements tend to support this trend. In all cases deposits made at temperatures of 55° C. or

less were rougher than the comparable Watts deposit, but above 55° C. the roughness of the Watts deposit and that made in the presence of methyl cellulose became more comparable.

When polyvinyl alcohol was added to a Watts nickel solution and electrodeposits made, a significant modification toward the bright range was demonstrated at 25° C. and pH 3.8 and also at 55° C. and pH 2.2. In the former case, it was a somewhat continuous modification which was spent at both high and low current densities with increase in temperature, while in the latter case the modification approached from the lower current densities at 35° C. and spent at the lower current densities at 75° C. Also, in the former case, roughness measurements show no change compared to the Watts deposit while, in the latter case, the deposit is smoother than the corresponding Watts deposit. The general shape of the roughness curves for methyl cellulose and polyvinyl alcohol were comparable to the pure Watts nickel solution deposit, but the order of magnitude of roughness was generally greater in the case of methyl cellulose, while it was generally less in the case of polyvinyl alcohol.

The most notable polymeric effect was obtained from the addition of the copolymer of methyl vinyl ether and maleic anhydride (PVM/MA) to the pure nickel solution. Bright nickel deposits were demonstrated over the entire temperature range at a pH as low as 2.2.

Insolubility of the copolymer in the nickel solution at a pH greater than 3.0 prevented evaluation above this point, but when the pH exceeded 2.75, a distinct narrowing of the bright range became apparent. The copolymer deposited with the nickel metal. It could be wiped from the wet metal surface and dried in adherent white flecks randomly distributed over the cathode surface. Since PVM/MA is a good sizing agent for paper, a piece of Whatman No. 2 filter paper was placed over the cathode and deposition carried out in the manner previously described. The paper was dried and demonstrated sizing to such a stiffness that bending once shattered the paper. The deposit brightness was somewhat reduced by the presence of the paper. Because the metal surface was visibly covered with polymer, no roughness measurements were carried out on panels where PVM/MA was the only addition to a pure Watts nickel solution.

Because of the influence of PVM/MA on the depositing nickel, the relative effect of molecular weight on the deposit was investigated. Three copolymers of PVM/MA with specific viscosities of 0.4, 2.6, and 3.2 were added in aqueous suspension to a pure Watts nickel solution in increasing concentration. Each copolymer demonstrated a tendency to brighten the deposit in concentrations of 0.5 to 0.6 g./l. However, the strongest tendency for modification was demonstrated in the case of PVM/MA, specific viscosity, 2.6.

Observations with respect to acrylic acid and 1,4-butynediol have been included in this group. Both substances indicated their strongest tendency to brighten the nickel deposit at pH 3.8. The stronger agent at lower concentrations was 1,4-butynediol, but the initial panel from solution 43, Table 10 and the final panels from solution 46, Table 40 tend to illustrate an appreciable brightening property for acrylic acid in higher concentrations. However, as a single addition to the pure Watts nickel solution at concentrations 0.5 to 2.0 g./l., the modifying effect of acrylic acid was limited to the high current density areas and higher pH value. Roughness measurements do not particularly bear this out, since the effect was most apparent at current densities above 9.0 amp./sq. dm.--the highest current density at which surface evaluations were carried out. On the other hand, 1,4-butynediol was a very strong brightener with a wide current density range and, from the viewpoint of concentration, stronger at pH 3.8 than 2.2. In general, surface evaluations paralleled this. The anomality of this trend, found in Figures 33 and 35 may be explained by pitting effects.

For the investigation of the carbonyl group, the importance of its oxidizing tendency was studied. A group of compounds the potentials of which are listed in Table 85 was selected and first added to

Table 85. Oxidation potentials of carbonyl compounds (36).

	E_o, m.v.
Camphor	82
p-Bromoacetophenone	129
Cinnamaldehyde	186
Acetaldehyde	226
Formaldehyde	257-270
Chloral	277
Pyruvic Acid	-
Butyl Chloral	-
Ethyl Pyruvate	297
beta-Methyl umbelliferone	-
Glyoxal	-

the pure Watts nickel solution. Finally, the effect of increasing concentrations of selected carbonyl compounds was observed on an alloy deposit, patterned after the manner of Weisberg and Stoddard (34). This alloy depositing solution, was made up, in general, of the compounds contained in the Watts solution, as well as suitable concentrations of cobalt sulfate and, usually, nickel formate.

The effect of carbonyl compounds added to the Watts nickel solution at pH 2.2 generally followed the trends of the pure Watts nickel solution deposits with some exceptions. First, cinnamaldehyde caused marked general pitting over the entire temperature range. Secondly, butyl chloral markedly brightened the deposit at 2 g./l., while at 0.5 g./l it did not extend the bright range more than any of the other carbonyls. Thirdly, all of the carbonyls tended to extend the modified range beyond the control panel at the lower temperatures. Finally, beta-methylumbelliferone, butyl chloral, pyruvic acid, chloral, and cinnamaldehyde increased burning of the deposit at the high current density edge. In the case of all but cinnamaldehyde the burnt area had a tendency to deposit a green powdery substance instead of the metal. Roughness evaluations showed a mixed trend compared with current density, but generally a rougher deposit than the control panel, unless significant modification occurred as in the case of butyl chloral for pH 2.2 and 3.8.

At pH 3.8 the same general appearance trends were observed. However, the cinnamaldehyde effect was less apparent. A darkening of the lower current density areas by p-bromoacetophenone, acetaldehyde, and pyruvic acid, subtly present in the pH 2.2 panels at 75° C. became much more apparent at pH 3.8. Cinnamaldehyde was added to the list, but the effect disappeared in the case of acetaldehyde and butyl chloral. The marked brightening by butyl chloral was limited at 35° C. However, acetaldehyde and pyruvic acid tended to extend the bright modification in the 25° C. panels and chloral demonstrated marked bright modification as high as 55° C. Finally, the high current density burning at 25° C. became more apparent at pH 3.8 than at pH 2.2.

When nickel-cobalt deposits were made with increasing concentrations of carbonyl compound, in the presence of nickel formate, the optimum ranges of the brightness obtained are listed in Table 86.

Even when the lack of bright range of cinnamaldehyde and ethyl pyruvate are explained by the limit of solubility--for in both cases solubility had been exceeded slightly at the concentration indicated in Table 86--it is difficult to conclude that the oxidation potential is linked with the strength of the carbonyl compound as a brightener. However, where solubility is not a problem, there seems

Table 86

Solution	Carbonyl Compound Added	Amount Added (ml./g.)	Molarity of Carbonyl	Bright Range (amp./sq.dm.)
18	Cinnamaldehyde	0.5/0.55	0.0037	under 5.4
19	Chloral with Ammonium Sulfate	1.5/2.25	0.0149	entire range
20	Chloral	1.5/2.25	0.0149	entire range
24	Acetaldehyde	3.0/2.35	0.0523	under 8.6
29	Ethyl pyruvate	1.5/1.59	0.0138	under 2.6
	Glyoxal	4.0/1.24	0.0207	under 3.2
39	Butyl chloral	2.5 to 3.5	0.0142 0.0199	under 15.1
44	Chloral*	3.5/5.27 to 5.5/8.27	0.0357 0.0561	entire range
45	Chloral**	-	-	-

* In presence of nickel chloroacetate.

** In presence of nickel acrylate.

to exist some limited correlation. Chloral which has almost the same oxidation potential as formaldehyde yields a very wide bright range where the alloy is deposited. Acetaldehyde even in more concentrated solution did not give as wide a bright range. Butyl chloral, the oxidation potential of which is not known, gave approximately equivalent bright range at the same molar concentration. Thus there seems to be some limited correlation between the oxidation potential of the carbonyl and its brightening properties.

Glyoxal was included, though its potential is also unknown, because it exhibits hydrating properties which have been compared favorably with those of the highly halogenated aldehydes such as chloral and butyl chloral. The fact, that it yields such a poor bright range at comparable molar concentrations, seems to eliminate this property of the carbonyl compound from consideration.

The importance of the acid ion species present was considered. As well as nickel formate, equimolar concentrations of nickel chloroacetate and acrylate were added to the alloy plating solutions and the effect of chloral in increasing concentration also observed. The relative acid equilibrium constants of the parent acids are formic acid (46), 2.1×10^{-4}, chloroacetic acid (46), 1.52×10^{-3}, and acrylic acid (47), 5.6×10^{-5}.

From Table 86 it is shown that more chloral is necessary when chloroacetic acid is present than when formic acid is present in the plating solution. When the unsaturated acrylic acid is present, the whole brightening mechanism is completely interrupted and no real optimum range is observed. As chloral concentration was increased in this latter case, the deposition grew steadily more undesirable.

In the case of nickel-cobalt alloy depositions, surface roughness measurements did not point out any significant trends which isolate the brightening carbonyl compounds from the nonbrightening compounds. It is noteworthy that rougher surfaces were obtained from Solution 19 containing small amounts of ammonium sulfate than from Solution 20 which yielded the same optimum limits of chloral concentration but smooter deposits without ammonium sulfate.

The relationship in concentration between the organic acid, which was used to adjust the pH of the solution, and the aldehyde appears to be important. This can be pointed out be referring to Solution 20, Table 59 where a full bright range was achieved on Panel 205. Formic acid was added to the solution to readjust to the proper pH and immediately the bright range of the next panel was notably reduced. Successive additions of chloral returned the bright range

that had been obtained previously. Solution 39 gave a similar phenomenon and is demonstrated in Panels 397, 398, and 399. While controlling the pH of the solutions, attempt was made to minimize this effect by elimination of acid addition during the course of increasing the concentration of the carbonyl compound.

When the alloying constituent is changed from cobalt to iron a more limited bright range is observed for the optimum concentration of chloral noted in nickel-cobalt deposition. Solution 21, Panel 215 will point this out. Addition of tartaric acid immediately interrupted the brightening effect, however, as Panel 216 demonstrated, and caused abnormal stressing in the deposit. Tartaric acid would not control the formation of a copious yellow-orange precipitate which formed in the iron-nickel solutions. When nickel propionate and chloral were added to the iron-nickel plating solution, a modification toward a bright deposit was observed, but stressing and precipitation could not be controlled. It is noteworthy that the solution could not be reduced in pH below 4.4, when nickel propionate was present.

E. Raub and M. Wittum (45) investigated the effects of aliphatic alcohols including polyhydroxyl types and found that these compounds had no real brightening strength even at very high concentrations. Therefore, in order to study some effects of the hydroxyl

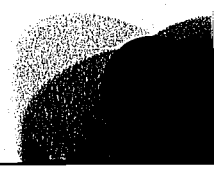
group, it seemed desirable to use a group of isomeric and substituted phenols. The series selected can be subdivided functionally into two types: (1.) rings which contain the hydroxyl group only, and (2.) rings which contain nitro or amino groups as well as the hydroxyl group. The first type includes phenol, 4,4-dihydroxy-biphenyl, beta-naphthol, catechol, and resorcinol. At pH 2.2, the general trend of the Watts control panels carried over to deposits made in the presence of this type with few comparatively minor variations, except for beta-napthol which modified the deposit toward the bright range more notably and caused marked burning and exfoliation of the deposit at the high current density edge up to 55° C. Surface roughness measurements, plotted in Figure 45 and Figure 46 parallel the trends of the Watts panels markedly except for beta-naphthol which yielded smoother deposits.

At pH 3.8, the first type paralleled the Watts panels somewhat less. As well as beta-naphthol, phenol and resorcinol at the higher concentration of 2.0 g./l. exerted modifying effects which extended as high as 55° C. Notable smoothing of the deposits is observed in the surface roughness data by these three compounds.

The second type of phenolic compounds included 3,5,3',5'-tetranitro-4,4'-dihydroxy biphenyl, o-nitrophenol, o-aminophenol

hydrochloride and p-aminophenol hydrochloride. At pH 2.2 all of these phenols modified the deposit toward the bright range. In the case of the nitro group, 3,5,3',5'-tetranitro-4,4'-dihydroxbiphenyl exerted a stronger effect than o-nitro phenol while in the case of the amino group, p-aminophenol hydrochloride exerted a stronger effect than o-aminophenol hydrochloride. This also holds true at pH 3.8. Roughness measurements do not parallel the general brightening effect. For o- and p-aminophenol hydrochloride at pH 2.2., there is inversion of the trends with increased concentration and at pH 3.8 exfoliation by p-aminophenol prevents comparison. For both the aminophenols and the nitrophenols there is an increase in roughness with stronger brightening tendency.

In addition to the factors already discussed, a group of representative dyes were included since their use with anaromatic sulfonic acid in nickel deposition is classical (7,9). The effects of the phthalocyanine dye Monastral Blue, of the thiazole dyes Clayton Yellow and Primuline Yellow, and of the thiazine dyes Methylene Blue and Toluidine Blue, were observed. As single additions to a Watts nickel solution, Monastral Blue was the least effective agent at 0.5 g./l. The thiazole dyes were most effective at pH 3.8--low temperatures with Primuline Yellow appearing to be the stronger of



the two investigated. In general, smoothness of the deposit paralleled these observations. A widening of the modification at 75° C. and pH 2.2 by both thiazole dyes is noteworthy.

Both thiazine dyes markedly inhibited metal deposition at all temperatures and pH values. The dyes selectively deposited and colored the cathode with the characteristic color of each dye. Burning and exfoliation was particularly apparent at high current densities and low temperatures in both cases and extended to 75° C. in the case of Methylene Blue. However, wherever nickel did deposit, a brightness was noted on the metal surface. Surface evaluations would be of no value for these deposits and were not executed.

The effects of the compounds discussed above, or of representatives of each group, in increasing concentration at 65° C. and pH 3.8, in the presence of 5 g./l. of 2,7-napatholene disulfonic acid, were next observed in a Watts nickel solution. Table 87 lists all of the compounds studied under these conditions, together with the first optimum concentration producing the widest bright range of deposition and the comparative molar concentrations of each. Thirteen of the twenty compounds produced a bright range over the full current density range of the cathode. Based on the molar concentration and the bright range produced, the compounds were listed in decreasing

Table 87

		Minimum Optimum Concentration (g./l.)	Molar Concentration	Bright Current Density Range (amp./sq.dm.)
371	Glucose	-	-	above 14.0
381	Chloral	1.90	0.0129	entire range
361	PVM/MA	0.063	-	entire range
46	Acrylic Acid	0.511	0.00709	above 1.6
531	1,4-Butynediol	0.255	0.00296	entire range
351	Monastral blue BG	0.511	-	entire range
311	Clayton yellow	0.063	0.0000906	entire range
321	Primuline yellow	0.063	0.000132	entire range
331	Methylene blue	0.070	0.0000219	entire range
341	Touidine blue	0.007	0.0000229	entire range
301	4,4'-Dihydroxybiphenyl	0.255	0.00137	above 4.3*
271	3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl	0.003	0.0000083	above 3.2
411	Phenol	0.015	0.000159	above 11.8*
421	o-Nitrophenol	0.015	0.000108	entire range
47	p-Nitrophenol	0.063	0.000453	above 9.0
481	p-Aminophenol hydrochloride	0.007	0.0000481	entire range
491	o-Aminophenol hydrochloride	0.015	0.000103	entire range
501	Catechol	0.031	0.000281	above 14.0
511	Resorcinol	0.031	0.000281	above 10.8
521	beta-Naphthol	0.063	0.000437	above 6.5

* Haze bright.

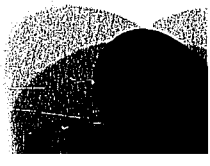
strength as brighteners in Table 88. The position of PVM/MA is somewhat in doubt, since its exact molecular weight is not known.

From the plots of roughness data, all compounds through the dyes listed in Table 88 show minimum points of RMS roughness value at the optimum brightening concentration except acrylic acid, Methylene Blue, and Toluidine Blue. In the case of acrylic acid, the maximum value is observed, but it is very close in magnitude to the surface value of the basis metal so is not very significant. In the case of Methylene Blue and Toluidine Blue the trend is decreasing with a wide bright range continuing so it also is not significantly anomolous. This general trend is also reflected in the cases of the phenols.

Exploratory results have been reported in Tables 68, 69, and 70 for surface treatment or predipping of the cathode followed by deposition, a pure Watts nickel solution. This surface treatment of the cathode, in the case of Table 68, consisted of wrapping the cathode with Whatman No. 2 filter paper or dipping through a lens of cinnamaldehyde floating on the surface of Watts nickel solution, and then plating in a pure Watts nickel solution. In the case of Tables 69 and 70, the cathodes were dipped in Watts nickel solutions of 0.5 g./l. of Clayton Yellow and Methylene Blue, respectively. Table 68 demonstrates some significant modification of the deposit, both by the filter paper and the cinnamaldehyde lens.

Table 88

Methylene Blue
Toluidine Blue
p-Aminophenol hydrochloride
PVM/MA
Clayton Yellow
o-Aminophenol hydrochloride
o-Nitrophenol
Primuline Yellow
Monastral Blue
1,4-Butynediol
Chloral
3,5,3',5'-Tetranitro-4,4'-dihydroxybiphenyl
Acrylic acid
beta-Naphthol
p-Nitrophenol
Resorcinol
Catechol
Glucose
4,4'-Dihydroxybiphenyl
Phenol



Dipping in proven brighteners, however, as shown in Tables 69 and 70, did not significantly modify the deposit under the conditions of the respective experiments until the dipping solution was dried on the cathode in the case of Methylene Blue.

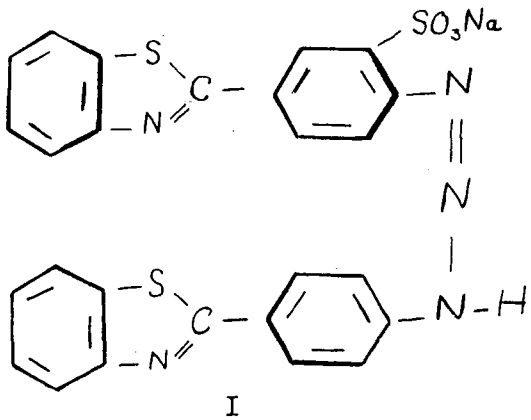
DISCUSSION

The relative strength, as brighteners, of the organic compounds studied (Table 88) provides some interesting comparisons of their properties. It appears that functional groups are important in the brightening of nickel by phenols. Phenol was the least effective of the group while the aminophenols were the strongest. Nitrophenols were intermediate in strength and poly-hydroxphenols were not much better than phenol. These data stress the importance of the particular functional group. The trend observed by comparing the relative effect of 4,4'-dihydroxybiphenyl with phenol and the nitrophenols tended to support this.

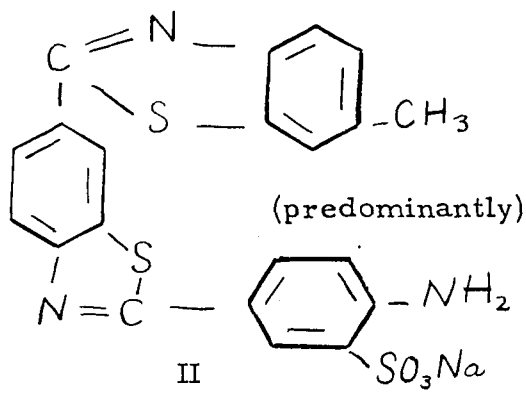
The functionality of the aromatic ring itself is apparently also important. A comparison of phenol, 4,4'-dihydroxybiphenyl and beta-naphthol shows that the naphthyl ring must contribute some factor to the conditions of modifying the nickel deposit. While phenol and 4,4'-dihydroxybiphenyl yielded very similar results, beta-naphthol was appreciably stronger as a brightener. A significant parallelism at this point is the relative double bond character present in the rings. Phenol and 4,4'-dihydroxybiphenyl are derived from the benzene

nucleus, which is reported to have one-half double bond character (37) in the carbon to carbon linkage, when its resonance forms are considered, while the carbon carbon bond in the naphthalene ring has two-thirds double bond character. If we extent this point further and note the position of acrylic acid and 1,4-butynediol in Table 88, there is a trend toward increasing brightening strength with increasing unsaturation of the organic substituent. Thus, it would seem that the degree of unsaturation of an organic compound as a brightener should be considered as an important contribution. If this is true, increasing the number of hydroxyl groups would tend to attenuate the modifying effect of the organic compound. Although these data do not specifically point this out, it has been observed that the hydroxyl group added to the aromatic ring does actually reduce the modifying effects of certain organic aromatic acids (38).

The molecular sturctures for the thiazole dyes (39), Clayton Yellow (I) and Primuline Yellow (II), and thiazine dyes (39), Methylene Blue (III) and Toluidine Blue (IV) are shown.

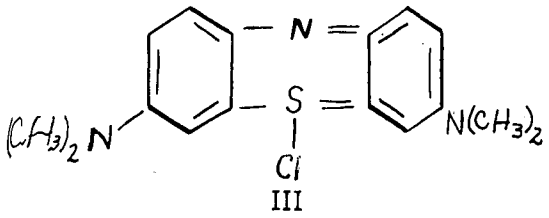


I

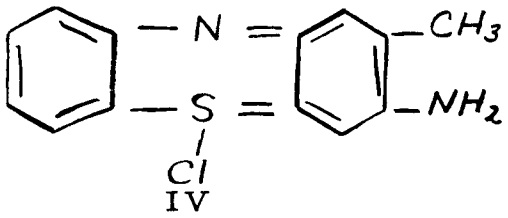


(predominantly)

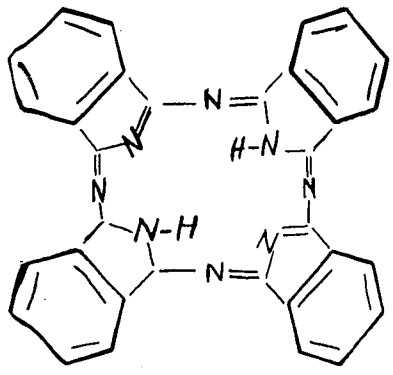
II



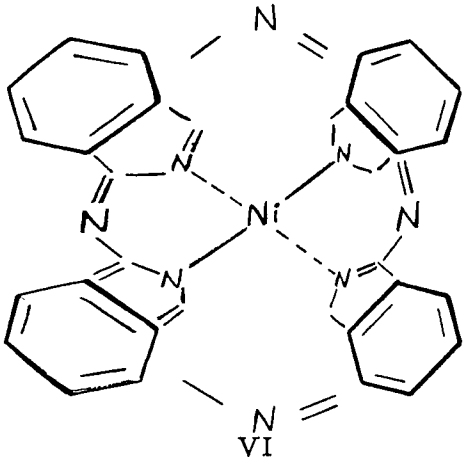
III



IV



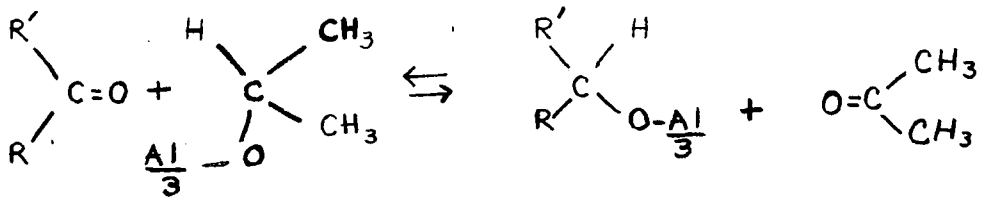
V



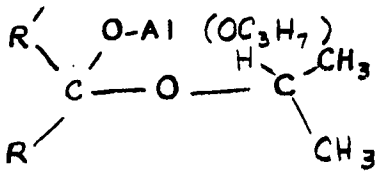
VI

The structure (40) of phohalocyanine (V) and the nickel coordination compound of phthalocyanine (VI) are also shown. These structures are of interest in weighing the applicability of the complex theory of brightening a metal deposit versus the adsorption theory. It is obvious in all of these structures that a coodinating nitrogen atom is available. This is true of all the compounds listed in Table 88 down to 1,4-butynediol except PVM/MA which can actually form a nickel salt and the nitrophenols which are considered later. Thus the compounds with the strongest brightening properties investigated apparently can chemically associate with the organic brightener.

The situation for the carbonyl and the unsaturated hydroxyl compound is somewhat more in doubt. In the case of the carbonyl, the comparison with oxidation potential is discussed and there are indications of some correlation. Reference to the original paper (36) where the oxidation potentials are reported showed that these potentials are obtained from Oppenauer oxidations of reference carbonyl compounds of known potential, which were obtained independently. By polarographic analysis of suitable equilibrium mixtures of a reference carbonyl compound and the carbonyl compound of unknown potential, the oxidation potential was calculated using a form of the Nernst equation. Wilds (41) has represented the course of the reaction, in considering the reverse case, reduction, as follows:*



Although the exact mechanism of the transfer of one valence bond of the aluminum bond and one hydrogen atom is unknown, an intermediate aluminum derivative of a hemiacetal (VII) has been postulated independently be Verley, Meerwin, and Ponndorf.



VII

Whether such an hemiacetal species is stable in aqueous nickel salt solution and present at the cathode layer in a nickel deposition is still not certain. However, the amount of water which is present in the cathode layer, particularly when an organic addition agent is present, is also open to question. Results obtained by dipping the cathode in a lens of cinnamaldehyde and reported in Table 68 might tend to support this. The film adsorbed on the cathode was very insoluble, the cathode wetted with diffulty, and marked modification of the deposit was reported. Thus a possible chemical association between the carbonyl and the nickel species could be considered.

The pi elections of the unsaturated hydroxyl compounds may also be considered in the discussion of a molecular complex theory. Although relatively little definite evidence exists (42), particularly in an aqueous solution state, a pi complex of nickel and the organic hydroxyl compound may exist.

The comparison of nickel acrylate with nickel chloracetate and nickel formate is of interest in the consideration of pi complexes. In alloy deposition with increasing concentrations of chloral, the organic acid augmented the action of chloral except in the case of acrylic acid. Nickel propionate and chloral also somewhat augmented each other in the case of nickel-iron deposition. However, when chloral was added to the nickel solution containing nickel acrylate, burning of the deposit increased from the high current density edge of the panel and a green powdery substance, probably nickel salts, deposited rather than the nickel with additions of chloral. This phenomenon is often explained by assuming a tightly bonded metal ion and insufficient energy--voltage--to discharge the metal ion at the cathode surface. A parallel observation has been noted for the deposition of nickel from highly alkaline media in the presence of stiochiometric amounts of ethylenediamine tetraacetic acid when the potential drop across the cell was 12 volts (43).

Whether a complex molecule completely controls the modifying of a nickel deposit, or whether these properties discussed above are significant for desirable adsorption conditions cannot be decided from the data reported. A nickel complex with the organic addition agent does however seem to help explain a possible mode of transference, in addition to electrophoresis, of the organic species into the cathode layer.

The role of the nitro group provides some further consideration. In the first place, the orthoisomer of nitrophenol had a much stronger effect on the nickel deposit than the paraisomer. This was not the case for the aminophenols, but there was less difference in the strengths of the aminophenol structural isomers. When 3,5,3',5'-tetranitro-4,4'-dihydroxybiphenyl was considered, more than one-half as many moles was required to produce the bright range compared. Finally, the fate of the nitro group is in question. Electrochemical preparation investigations (44) have not reported the products of reduction of mononitrophenols fully in acid and neutral media at a nickel cathode to date. Calculation of the Faradays required to fully reduce nitro group will show that minor amounts of the current passed through each cell could convert the nitro group to an amino group. Thus it seems difficult to attribute the brightening role of the nitrophenol fully to the nitro group, since it could be reduced to the very effective amino group.

SUMMARY

Various groups of organic substances have been added to pure Watts nickel solutions, solutions containing 5 g./l. of 2,7-naphthalene disulfonic acid and nickel-cobalt or nickel-iron alloy depositing solutions. The following conclusions are suggested, based on the interpretation of data with respect to appearance of the deposit and its surface roughness trends.

1. At 25° C. and pH 3.8, the sugars investigated brightened nickel deposits greatest, and of the representative group chosen, glucose was the strongest brightener. Smoothness paralleled this general trend.

2. The reducing properties of sugars are not requisite for their brightening properties.

3. The group of nickel brighteners has been extended to include synthetic polymers.

4. The molecular weight of the polymer, which was reflected by its viscosity properties, is a function of brightening strength.

5. The oxidization potential of acetaldehyde and chloral compare somewhat favorably with formaldehyde. Their effect on a nickel deposit obtained from a Watts nickel solution or a nickel-cobalt alloy-depositing solution is also comparable.

6. The phthalocyanine dye, Monastral Blue has been added to the classical group of dyes which brighten nickel deposits.

7. The functionality of an organic compound is important in determining its brightening strength. However, it appears from the data that isomeric structure tends to increase or decrease brightening strength of a functional group.

8. A group of organic brighteners have been reported in decreasing order of brightening strength.

9. In general, single additions of organic compounds to a Watts nickel solution are not as effective or controlable as specific combinations.

10. The nickel-cobalt alloy-depositing solution has been studied and additions of organic acids have been extended successfully to an organic acid of K_a value, similar to formic acid. Additions of aldehydes also have been extended to carbonyl compounds of oxidation potential similar to formaldehyde.

11. The balance of free organic acid and aldehyde concentration tends to be important in determining the bright current density range of the nickel-cobalt deposit.

12. The hydroxyl group tends to have little apparent brightening strength when insufficient unsaturated carbon-carbon bond character is present.

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