With respect to its properties, nickel deposited from my bath is equally as ductile and adherent as ordinary gray nickel deposited from a Watt bath and much more so than "bright nickel." My nickel plate, furthermore, exhibits excellent adherence when deposited directly to a thickness up to 0.001 inch and over upon plain carbon steels, either low carbon or heat treated high carbon steel, or upon low alloy steels. For instance, if a sheet of plain carbon steel plated directly with nickel from my bath be held edge- wise against an emery wheel, there is no separation of the plate whatsoever, whereas, if similarly tested, a "bright nickel" plate would show some separation from the steel. Furthermore, the "bright nickel" plate could easily be stripped entirely from the steel by manually completing the separation started by the emery wheel.

My nickel plate adheres to steel more firmly than does a composite plate of copper and "bright nickel," with the copper deposited from a copper cyanide plating solution. I also find that my nickel plate is at least as firmly adherent to steel as is a composite plate of gray nickel and fulminate of mercury, such as is described in the Hogaboom Patent No. 1,991,747.

With respect to hardness, nickel plate deposited by my method is of the same order of hardness as ordinary gray nickel and considerably softer than "bright nickel." In accordance with the method of my present invention, a nickel plating bath containing sodium formate is maintained under oxidizing conditions by means of the use of a supplemental inert anode, such as lead or platinum. The action of the supplemental inert anode is to generate chlorine by electrolytic action upon the chloride present in the bath, and the chlorine so generated maintains the bath in an oxidized condition. When in such condition, the generated chlorine gas serves to prevent pitting, so that no additional pitting agent need be added to the bath. Furthermore, the addition of wetting agents is not only unnecessary, but would render the bath ineffectual for the production of a lustrous nickel electrodeposition. Consequently, the nickel deposited is polished, with consequent saving in labor and material cost. Also, while the relatively small cost of buffing my nickel plate far outweighs the slight added cost of buffing.
deposition of nickel from a nickel plating bath that is maintained under oxidized conditions and that contains sodium formate as one of its essential ingredients.

It is a further important object of this invention to provide a sodium formate nickel plating bath for use with a lead anode to maintain oxidized conditions within the bath, whereby relatively lustrous, image reflecting electrodeposits of nickel may be obtained directly without the addition to the bath of anti-pit or wetting agents, brightening agents or so-called promoter metals.

It is a further important object of this invention to provide a relatively inexpensive and efficient method for the plating of relatively lustrous, image reflecting deposits of nickel that require very little buffing and that have such excellent adherence to a ferrous foundation metal that the nickel may be plated directly over a ferrous foundation metal to form an adherent undercoating for a subsequent deposit of chromate.

Other and further important objects of this invention will become apparent from the following description and appended claims.

The following illustrates the preferred range of bath compositions and conditions for use with the method of my invention:

**Nickel sulfate, hydrated** 240-300 grams per liter

**Nickel chloride (NiCl₂·6H₂O)** do 35-50

**Sodium formate** do 25-40

**Boric acid** do 25-40

**pH** 3.5-4.0

**Temperature** degrees Fahrenheit 135-145

**Current density** amperes per sq. ft. 40-50

In the foregoing bath the concentrations of nickel sulfate, nickel chloride and boric acid are not critical but may be varied within the usual ranges known to those skilled in the art. In fact, the boric acid may be omitted entirely and good results still obtained, although boric acid is an aid in the obtaining of smooth plates of more or less uniform quality, as measured by surface lustre, on objects of irregular shape. Likewise, the concentration of sodium formate may be varied from as little as 1 gram per liter up to its saturation point of around 50 to 60 grams per liter. I prefer to add sodium formate, as such, to the bath, but the sodium formate may, instead, be formed in the bath by the addition thereto of its constituent radicals in reacting proportions, as by the addition of formic acid and caustic soda, or by any suitable method. Other metal formates, such as nickel formate, or ammonium formate, are not the full equivalent of sodium formate.

In general, the hydrogen ion concentration of the nickel plating bath may be varied between the pH values of 5.5 and 2.5 and the temperatures within the range of 90° to 190° F., the higher temperatures being used with the numerically lower pH values and vice versa. With proper control of the pH of the bath, the bath may be operated at a temperature as low as room temperature. Nickel carbonate, sulfite acid, formic acid may be conveniently used for the adjustment of the pH value of the bath.

In order to obtain best results, the cathode rod should be agitated. An agitation equivalent to 30 cycles of strokes per minute with a minimum travel of 2½ inches has been found to give very satisfactory results. More rapid agitation gives a brighter plate. Other equivalent means of agitation may be employed, such as circulation of the electrolyte over the cathode.

In the operation of a bath such as that just described, it is important that a supplementary anode, such as a lead anode, be employed in addition to production of the lead anodes. By passing a suitable proportion of the total current through a supplementary anode, such as a lead anode, a certain amount of chlorine is generated as a result of the electrolysis of the nickel chloride in the bath, with the consequence that the bath is maintained in an oxidized condition. The amount of current that is passed through the lead anode should be controlled so as to effect the generation of the proper amount of chlorine to maintain the bath in an oxidized condition, but without the generation of too little or too much chlorine, since either causes the nickel deposit to become gray. It has been found satisfactory to pass 0.1% of the total current through the supplementary lead anodes.

The use of a supplementary anode, such as a lead anode, renders it unnecessary to add to the bath an anti-pit agent, such as hydrogen peroxide, or a wetting agent, such as lauryl sulfate or the like. In fact, the addition of an organic wetting agent to the oxidized type of bath of this invention tends to render the bath inoperative for the production of a bright, lustrous nickel electrodospo, so that wetting of the nickel electrodeposi, as such wetting of the nickel electrodeposi, as such wetting of the bath may be avoided. It is also unnecessary to include in the bath composition addition agents such as are generally employed in "bright nickel" plating baths. The expense attendant upon the use of organic wetting agents, brightening agents, promoter metals and the like is therefore entirely eliminated from the cost of operation of the nickel plating bath of my invention.

In place of auxiliary lead anodes as such, the same results may be obtained through the use of a lead lined tank. In any event, the proportion of current passing through the lead anode or lead lining of the tank should be so controlled as to generate sufficient chlorine to maintain the bath in an oxidized condition without causing the nickel to plate out as a gray nickel.

Where a lead anode or lead lining is employed, some lead will be dissolved into the plating bath and will plate out with the nickel. In general, the amount of lead so dissolved will be between 0.05 and 0.5 g./l. with about 0.1 to 0.2 g./l. on the average. From such a bath, the nickel electrodeposi will be found to contain an average of around 0.5% of lead. The sodium formate in the bath acts as a carrier for the lead. Instead of relying upon the electrolytic action of the lead anodes to build up a dissolved lead content in the bath, the lead may be introduced into the bath in the form of additions thereto of a lead salt, such as lead carbonate, acetate, citrate, formate or the like.

I am aware that numerous details of the process may be varied through a wide range without departing from the principles of this invention, and I, therefore, do not propose limiting the patent granted hereon otherwise than necessitated by the prior art.

I claim as my invention:

1. The method of obtaining directly a soft, ductile nickel plate of image reflective ability that may be readily buffed to produce a mirror-like surface, which comprises electrolyzing a solution having a pH between 5.5 and 2.5 and containing, as essential active ingredients, nickel
2,812,617

2. The method of electrodeposition a ductile, adherent, lustrous nickel which comprises passing an electric current from nickel and lead anodes to the work to be plated as a cathode through a solution having a pH between 2.5 and 5.5 and having active ingredients consisting essentially of nickel plating salts consisting of a mixture of nickel chloride and nickel sulphate, between 0.05 and 0.5 g./l. of lead, and sodium formate as a carrier for maintaining said lead in solution.

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