



(19)

Europäisches Patentamt  
European Patent Office  
Office européen des brevets



(11)

EP 0 505 606 B2

(12)

## NEW EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention  
of the opposition decision:  
**26.02.2003 Bulletin 2003/09**

(51) Int Cl.<sup>7</sup>: **C23G 1/08, C23C 22/34**

(45) Mention of the grant of the patent:  
**02.11.1995 Bulletin 1995/44**

(21) Application number: **91113628.1**

(22) Date of filing: **14.08.1991**

**(54) Process for pickling and passivating stainless steel without using nitric acid**

Verfahren zum Beizen und Passivieren von rostfreiem Stahl ohne Verwendung von Salpetersäure

Procédé de décapage et de passivation de l'acier inoxydable sans utilisation de l'acide nitrique

(84) Designated Contracting States:  
**AT BE CH DE DK ES FR GB GR IT LI LU NL SE**

(30) Priority: **29.03.1991 IT MI910879**

(43) Date of publication of application:  
**30.09.1992 Bulletin 1992/40**

(73) Proprietor: **Henkel KGaA  
40589 Düsseldorf (DE)**

(72) Inventor: **Bianchi, Marco  
I-20121 Milan (IT)**

(74) Representative: **Gervasi, Gemma, Dr. et al  
Studio Brevetti e Marchi  
NOTARBARTOLO & GERVASI S.r.l.,  
Corso di Porta Vittoria, 9  
20122 Milano (IT)**

(56) References cited:

<b>EP-A- 0 188 975</b>	<b>WO-A-87/01739</b>
<b>WO-A-91/05079</b>	<b>DE-A- 899 890</b>
<b>DE-B- 2 364 162</b>	<b>FR-A- 2 551 465</b>
<b>FR-A- 2 587 369</b>	<b>GB-A- 2 000 196</b>
<b>JP-A- 2 205 692</b>	<b>JP-A- 60 243 289</b>
<b>US-A- 2 474 526</b>	<b>US-A- 4 059 678</b>

• **PATENT ABSTRACTS OF JAPAN, vol. 11, no. 80 (C-409)(2527), 11 March 1987; & JP-A-61 235 581 (C UYEMURA AND CO LTD) 20 October 1986**

- **PATENT ABSTRACTS OF JAPAN, vol. 6, no. 106 (C-108)(984), 16 June 1982; & JP-A-57 035 686 (KAWASAKI SEITETSU K.K.) 26 February 1982**
- **JP-A-60 243 289 (English translation)**
- **Les Editions de Physique, 1990, pages 868-872:"Les Aciers Inoxydables"**
- **Eric N. Simons:"The Surface Treatment of Steel", Sir Isaac Pitman & Sons**
- **Chemical Abstract, Section 55-Ferrous Metals, Vol. 95, 1981, page 217, item 95:101387y;**
- **Chemical Abstract, Vol.97, 1882, page 224, item 97:59442b;**
- **Chemical Abstract, Vol.103, 1985, page 237, item 103:108550p;**
- **Synthetic Detergents; 6th ed., Davidson & Milwidsky, pages 244-245**
- **M. Zavattoni - Rivista di Chimica n.1-2,Jan.-Feb.1991, pages 16-20**
- **R.C. Weast; Handbook of Chemistry and Physics, ed. 55th, pages D-114, D-115, F-145**
- **R. Pointeau, Nouveau Traité de Chimie Minerale, Tome XIII, pag 1368-1369**
- **L. Domange, Bibl. page 118,123**
- **Fluorine compounds, inorganic, Vol. 10, page 741;**
- **Kirk-Othmer, Enc. of Chem. Tech.,III ed.vol.12, pages 432-433**
- **Ullmann's Enc. of Ind. Chemistry, V.ed., vol. A13, pages 461,464**
- **Willi Machu:"Das Wasserstoffperoxyd und die Perverbindungen", II.ed., 1951, Springer Verl., Seiten 195-202**

**Description****Technical problem**

**[0001]** During the manufacture of hot-rolled steel products or of intermediate products undergoing heat treatment such as annealing, it is well known that the material becomes covered with a layer of oxidation products of varying thickness. Because of the need to obtain a bright surface finish for the final product, these oxide layers have to be totally removed. This is achieved by the well known pickling processes, for which inorganic mineral acids such as hydrochloric, sulphuric, nitric and hydrofluoric acids are used, either alone or in mixtures of varying proportions.

**[0002]** In the stainless steel field, based on a knowledge of currently used industrial processes the pickling process most commonly or indeed almost exclusively used involves the use of a mixture of nitric acid and hydrofluoric acid, the mutual concentrations of which vary according to the type of plant, the type of steel to be pickled, its surface characteristics and the geometry of the article to be treated. The process is without doubt economical and enables excellent results to be obtained. It has however the very serious drawback of creating considerable problems of an ecological nature which are difficult to solve, precisely because of the use of nitric acid. In this respect, nitrogen oxide vapours of general formula  $\text{NO}_x$  are emitted into the atmosphere, these being highly polluting and aggressive towards metals and non-metals with which they come into contact, and in addition high nitrate levels are attained in the wash water and in the spent baths, with the consequent problem of their disposal. The elimination of the  $\text{NO}_x$  vapours in the air and of the nitrates in spent baths creates considerable plant problems (for example at the moment there is no  $\text{NO}_x$  treatment method which is technically free of problems), high running costs and no certainty that the results will satisfy current regulations. Thus in the final analysis the cost in terms of investment is difficult to sustain in most industrial plants.

**[0003]** A pickling system which does not involve the use of nitric acid is therefore of considerable industrial interest and various proposals have been advanced in this respect throughout the world, especially during the last ten years.

**Processes alternative to the use of nitric acid: state of the art**

**[0004]** A search carried out of patents relating to nitric acid-free cycles proposed as an alternative to the traditional stainless steel pickling process based on  $\text{HNO}_3 + \text{HF}$  and of the main technical literature on this subject has brought to light the following:

A) Japanese patent JP 50071524 published on 13.6.75 uses a system consisting of hydrochloric

acid and ferric chloride at a temperature of 70 °C and a treatment time of 20 seconds;

B) the two Japanese patents JP 55018552 published on 8.2.80 and JP 55050468 published on 12.4.80 comprise three stages, namely: 1) an initial descaling in sulphuric or hydrochloric acid, 2) subsequent immersion firstly in a solution of potassium permanganate and inorganic acids (not HF) and secondly in a solution of ferric nitrate, ferric sulphate and peroxydisulphuric acid, and 3) final washing with pressurized water or ultrasound;

C) Swedish patent SE 8001911 published on 12.10.81 describes treatment, for a time of between 1 and 120 minutes (1-20 mins preferred) at a temperature of between 10 and 90°C (30-60°C preferred), in a solution formed from sulphuric acid and hydrogen peroxide;

D) German patent DD 244362 published on 1.4.87 uses at 15-30°C a solution formed from chromic acid, sulphuric acid, hydrofluoric acid and an inhibitor (hexamethylenetetramine); the bath is then neutralized with calcium and barium salts;

E) German patent DE 3937438 published on 30.8.90 is mainly directed towards the wire processing industry and uses a hydrofluoric acid solution containing  $\text{Fe}^{3+}$  added in the form of a fluoride complex; an oxygenated gas and/or fluid medium is then added to the solution to be subjected to an electrolysis process to obtain nascent oxygen able to oxidize the bivalent iron to trivalent;

F) German patent DE 3222532 published on 22.12.83 describes the pickling of austenitic steel pipes or vessels, the internal surfaces of which are treated at 15-30°C with a solution formed from hydrofluoric acid and peroxides (either stabilized hydrogen peroxide or sodium perborate or organic peroxides not further identified), whereas the external surfaces are pickled with pastes formed from hydrofluoric acid, peroxides and fillers (carboxymethylcellulose); the pastes have to be disposed of by neutralization with calcium salts, the peroxides being destroyed either by catalysts or by heating;

G) British patent 2,000,196 of TOKAI Denka Kogyo uses a pickling bath consisting of ferric sulphate and hydrofluoric acid.  $\text{H}_2\text{SO}_4$  and hydrogen peroxide in a 1:1 molar ratio are fed continuously to maintain an adequate ferric ion concentration during the process. The method for controlling the process by continuously measuring the Redox potential of the system is also claimed, this having to be maintained at  $\geq 300$  mV by controlling the feed of  $\text{H}_2\text{SO}_4 + \text{H}_2\text{O}_2$ ;

H) two very similar European patents EP 188975 and EP 236354 (= WO 87/01739) with priority dates 22.1.85 and 19.9.85 respectively, use a pickling solution consisting of hydrofluoric acid (5-50 g/l) and a trivalent ferric ion introduced in the form of fluorinated complexes, into which air or oxygen is con-

tinuously blown; the treatment time is between 30 seconds and 5 minutes and the temperature varies from 10°C to 70°C; it is also recommended to continuously control the Redox potential, which has to be maintained between -200 and + 800 mV for the first patent and between +100 mV and +300 mV for the second patent, adding an oxidant such as potassium permanganate or hydrogen peroxide to raise the potential if necessary. All the tests carried out relate only to pickling steel sheet, without using oxidizing compounds other than atmospheric air.

**[0005]** Finally, there are two further patents relating to the possibility of preventing or reducing to a minimum the formation of NO<sub>x</sub> nitrogen oxides in baths operating with nitric acid, by directly feeding suitable oxidants into the pickling bath. The first, Japanese JP 58110682 of 1.7.83, uses hydrogen peroxide; the other, Swedish (SE 8305648 of 15.4.85, priority date 14.10.83, SE 835648), again uses hydrogen peroxide and/or alternatively urea.

**[0006]** Notwithstanding this proliferation of patents, until to-day the traditional process based on nitric acid and hydrofluoric acid is still widely used throughout the world and none of the aforesaid proposed alternatives have been accepted industrially.

#### Process of the invention

**[0007]** The process according to the present patent as defined in claim 1 has shown brilliant results both in laboratory tests and, in particular, in industrial trials carried out on high-production lines and plants, and is undoubtedly superior to all previous proposals. It incorporates interesting aspects of certain of these proposals, which are rationalized into an overall and exhaustive project to which various aspects of absolutely novel character are added.

**[0008]** The process is based on the use of a pickling bath containing ferric ions, H<sub>2</sub>SO<sub>4</sub>, HF, H<sub>2</sub>O<sub>2</sub> and conventional additives such as wetting agents, emulsifiers, brighteners and anticorrosives, into which a strong air flow is continuously blown. The operating temperature is generally between 30 and 70°C and preferably between 45 and 55°C. The basic characteristics of the process are as follows:

Inorganic mineral acid content of the bath: on preparing the pickling bath a solution is prepared containing at least 150 g/l and preferably about 170 g/l of H<sub>2</sub>SO<sub>4</sub>, and at least 40 g/l and preferably about 50 g/l of HF. These acids have various functions, of which the most important are to maintain the process pH at less than 1 and preferably between 0 and 0.5, to solubilize the oxides originating from the heat treatment, and, in the case of the hydrofluoric acid, to complex the Fe<sup>3+</sup> and Cr<sup>3+</sup> ions to the maximum extent.

**[0009]** As the concentrations of the two acids, and particularly the hydrofluoric acid, tend to fall during the pickling process, they have to be fed periodically on the basis of the bath analysis (free acid and fluoride ion values).

**[0010]** Fe<sup>3+</sup> ion content of the bath: on preparing the bath, an Fe<sup>3+</sup> ion quantity of not less than 15 g/l is introduced into the pickling solution in the form of ferric sulphate. The function of this ion is to replace nitric acid as oxidizing agent in the reaction 2Fe<sup>3+</sup> + Fe → 3Fe<sup>2+</sup>, favoured by the bath pH conditions. During the process the correct conditions for maximizing the ferric rather than ferrous form for the iron dissolved in the bath must be continuously created.

**[0011]** The oxidation of Fe<sup>2+</sup> ions to Fe<sup>3+</sup> ions during the process to maintain the concentration of these latter above the minimum predetermined value is achieved by the combined action of the air blown into the bath and the H<sub>2</sub>O<sub>2</sub> added continuously to the bath in small quantities.

#### Continuous addition of stabilized hydrogen peroxide

**[0012]** For the process to be economical, the quantity of hydrogen peroxide consumed must be as small as possible. For this reason it is important to use hydrogen peroxide containing a known stabilizer effective in preventing or at least substantially retarding peroxide decomposition under the operation conditions (temperature up to 70°C, very acid bath pH, iron up to 100 g/l, presence of Ni and Cr ions). A particularly suitable stabilizer is that marketed by Interox (Laporte-Solvay) under the name Interox S 333 or Interox S 333C. The use of suitably stabilized H<sub>2</sub>O<sub>2</sub> in combination with the use of air blown into the bath as complementary oxidation medium has resulted in a process in which the use of H<sub>2</sub>O<sub>2</sub> is economically convenient, this never having been possible with known processes. The pickling bath is prepared with an H<sub>2</sub>O<sub>2</sub> concentration of between 1 and 20 g/l, and preferably 2-5 g/l.

**[0013]** During pickling, the continuous H<sub>2</sub>O<sub>2</sub> feed is regulated on the basis of the type of steel to be pickled, the surface characteristics of the material (or semi-finished product), and the quantity and quality of scale resulting from rolling or annealing. Generally an H<sub>2</sub>O<sub>2</sub> quantity of between 0.3 and 1 g/l of bath per hour of operation is fed.

#### Continuous air blowing

**[0014]** During pickling, a continuous air flow into the bath is maintained at a rate of at least 3 m<sup>3</sup>/m<sup>3</sup> of bath per hour of operation. This air flow, if fed in at a suitable speed, contributes to good bath agitation, this being an important condition for effective pickling as it continuously disturbs the laminar layer in proximity to the surface to be treated, hence ensuring that this surface is always in direct contact with a fresh pickling solution. To

ensure optimum mechanical agitation and homogenization of the treatment liquid it is advisable to blow the air into the bottom of the tank via perforated feed tubes, or by the use of suitable blowing equipment.

[0015] As already stated, the blown air also oxidises the ferrous ions in combination with the hydrogen peroxide, so resulting in a considerable reduction in the consumption of this latter.

[0016] Control of Redox potential: it is well known that the behaviour of stainless steel in acid mixtures is characterised by polarization curves which present activity, passivity and transpassivity phases for different potentials, so that the bath must be kept under those conditions in which the material does not corrode, ie the process must be operated at a potential falling within the passivity range, which can be predetermined based on the type of steel.

[0017] During operation, as the concentration of the bivalent ferrous ion in the bath increases, the Redox potential of the bath tends to decrease, however the addition of hydrogen peroxide in combination with the oxidising action of the blown air returns it to optimum values, normally well in excess of 300 mV. By constantly controlling the potential it is therefore possible not only to ensure good material pickling but also to ensure that the passivation film forms on it. In this respect, industrial tests have resulted in all cases in bright, shiny and perfectly level surfaces on which no signs of any corrosive attack due for example to pitting or excessive pickling action were visible. In this respect it should be noted that often the traditional pickling process based on nitric acid and hydrofluoric acid results in such defects, and it is by no means rare for the traditional system to result in "burning" of the material (ie intercrystalline corrosion phenomena).

[0018] During those periods in which the pickling bath is not operating (weekend, nights), it is necessary only to provide minimum air blowing to maintain the Redox potential at optimum values, so making it possible to leave the material immersed in the solution for many hours without risk of attack.

#### Miscellaneous additives content of the pickling bath

[0019] In formulating the pickling bath according to the present invention, usual additives for this type of process are used, chosen from non-ionic surfactants acting as wetting agents, emulsifiers, brighteners and acid attack inhibitors. These additives, by mutual synergic action, improve and favour the pickling action. They are used in a total quantity of about 1 g/l of bath.

#### Advantages of the process

[0020] Absence of sludge: the process according to the invention reduces to a minimum or even prevents sludge formation with consequent further cost saving. This advantage is due inter alia to an appropriate HF

concentration during the process and to proper control of the concentration of ferrous ions, which are immediately and adequately oxidized to ferric ions.

[0021] Facility for automatic control: the process can 5 be constantly controlled by automatic equipment which on the basis of analytical measurements (free and total acid, free fluoride ion content, bivalent ferrous ion content, Redox potential) meter the quantities of pickling products and stabilized hydrogen peroxide to be fed to 10 achieve correct operating parameters.

[0022] Process versatility: the process of the invention is easily adaptable to all industrial stainless steel treatment plants, requiring only modest modification. It 15 is also suitable for treating articles and semifinished products of any type, including wire, rod, strip, plate and tubes, the treatment parameters (temperature, time, concentrations) being able to undergo variation without in any way prejudicing results.

[0023] The process is suitable for steel of any type: 20 martensitic, ferritic, austenitic.

[0024] The following examples are given merely to illustrate some applications of the process according to the invention.

#### A) Tests on an industrial plant, processing steel rod

[0025] 70 t of steel rod of average diameter 6 mm, equivalent to about 5000 m<sup>2</sup> of the following materials: 30 AISI 303, AISI 304 L, AISI 304 K, AISI 304 K2, AISI 316 L, AISI 316 R, AISI 316 Ti and AISI 430, were treated in an industrial tank with a useful bath capacity of 5 m<sup>3</sup>.

[0026] The initial pickling bath had the following composition:

35 172 g/l of H<sub>2</sub>SO<sub>4</sub>  
48 g/l of HF  
15 g/l of Fe<sup>3+</sup>  
5 g/l of H<sub>2</sub>O<sub>2</sub>  
2 g/l of H<sub>2</sub>O<sub>2</sub> stabilizer  
40 1 g/l of miscellaneous additives.

[0027] 130 vol. hydrogen peroxide was used. The hydrogen peroxide stabilizer was Interrox S 333 of Laporte Interrox.

[0028] The additives consisted of non-ionic surfactants and acid attack inhibitors of known type for pickling baths.

[0029] The initially measured Redox potential was about 700 mV.

[0030] During the test, which lasted a total of 300 hours, stabilized hydrogen peroxide was added continuously at a rate of 1 g/l per hour of operation. H<sub>2</sub>SO<sub>4</sub> was added at intervals to a total of 340 kg, as were HF to a total of 460 kg and additives of the aforesaid type to a total of 25 kg.

[0031] The bath temperature was maintained between 50 and 60 ° C and the air flow at 30 m<sup>3</sup>/h.

[0032] The treatment time varied between 40 and 75

minutes according to the type of steel treated, with pickling kinetics similar to if not in various cases better than those of the traditional process based on nitric acid and hydrofluoric acid, which was simultaneously compared in a parallel tank.

[0033] The Redox potential, measured periodically, remained between 350 and 450 mV, hence ensuring optimum surface finish of the material treated. On termination of treatment the total iron content was about 100 g/l with an Fe<sup>3+</sup> content of 60 g/l and an Fe<sup>2+</sup> content of 40 g/l.

[0034] In no case and on no material was there any surface pitting or "burning".

[0035] On termination of treatment the formation of precipitate in the bath was found to be totally irrelevant and consisted mainly of graphite. No ferrous sulphate crystallization was found. The bath was found to still possess full pickling efficiency.

#### B) Laboratory tests on tubes

[0036] Laboratory tests were carried out on AISI 304 and AISI 316 tubes under the bath conditions described under point A.

[0037] The ratio of the material quantity used to the test tank capacity was equal to that of normal industrial cycles. The temperature was fixed at 50°C and the treatment time varied from 30 to 60 minutes depending on the type of material.

[0038] The progress of the test and the results obtained were similar to those described under point A, with regard to product consumption, to the behaviour of the Redox potential, to the final surface appearance of the material, to the attack kinetics and to the absence of any pitting phenomena.

#### CONCLUSIONS of the industrial scale trials.

[0039] From the foregoing it is apparent that the new stainless steel pickling and passivation process, characterised by a bath of specific composition, control of the bath during the entire operation, in particular of its Redox potential, and continuous air blowing, represents an optimum solution in terms of the technical result of the treatment, process economy (in particular due to the low H<sub>2</sub>O<sub>2</sub> consumption), and the pollution problem posed by traditional nitric acid processes.

#### Claims

1. A process for pickling and passivating stainless steel consisting of bringing the material to be treated into contact with a bath maintained at a temperature of between 30 and 70°C and preferably between 45 and 55°C, and having the following initial composition of the bath:

- 5 a) H<sub>2</sub>SO<sub>4</sub> at least 150 g/l
- b) Fe<sup>3+</sup> at least 15 g/l
- c) HF at least 40 g/l
- d) H<sub>2</sub>O<sub>2</sub> (containing known stabilizers) 1-20 g/l and preferably 2-5 g/l
- e) additives of the non-ionic surfactant type (emulsifiers, wetting agents, brighteners) and acid attack inhibitor type: about 1 g/l in total;

10 into said bath being continuously fed:

- an air flow of at least 3m<sup>3</sup>/h per m<sup>3</sup> of bath, using a suitable distributor device for diffusing the flow into the liquid mass;
- a quantity of stabilized H<sub>2</sub>O<sub>2</sub> of between 0.3 and 1g/l per hour, controlled on the basis of the redox potential of the bath, which must be maintained at  $\geq 350$  mV;
- and possibly sufficient quantities of ingredient e) to maintain its concentration in the bath at optimum levels;

15 and being periodically fed sufficient quantities of ingredients a) and c) to maintain their concentration in the bath at optimum levels on the basis of the bath analysis, i.e. the free acid and fluoride ion values, and to maintain the bath pH less than 1 and preferably between 0 and 0.5.

20

25

30

35

- 2. A process as claimed in claim 1, wherein the Fe<sup>3+</sup> ions are introduced into the initial bath in the form of ferric sulfate.
- 3. A process as claimed in claim 1, conducted in combination with preliminary partial removal of oxides by a known process.

#### Patentansprüche

40

45

50

55

- 1. Verfahren zum Beizen und Passivieren von rostfreiem Stahl, der mit einem Bad bei einer Temperatur von zwischen 30 und 70°C und vorzugsweise zwischen 45 und 55°C in Kontakt gebracht wird, und der die folgende Anfangszusammensetzung hat:

  - a) H<sub>2</sub>SO<sub>4</sub> zumindest 150 g/l
  - b) Fe<sup>3+</sup> zumindest 15 g/l
  - c) HF zumindest 40 g/l
  - d) H<sub>2</sub>O<sub>2</sub> (umfassend bekannte Stabilisatoren) 1-20 g/l und vorzugsweise 2 bis 5 g/l
  - e) Additive vom Typ des nicht-ionischen oberflächenaktiven Mittels (Emulgatoren, Benetzungsmittel, Aufhellmittel) und vom Typ des Säureangriffsinhibitors: etwa 1 g/l insgesamt;

wobei in das Bad kontinuierlich geführt werden:

- ein Luftfluss von wenigstens 3 m<sup>3</sup>/h pro m<sup>3</sup> Bad, unter Verwendung eines geeigneten Verteilungsgerätes zum Diffundieren des Flusses in die flüssige Masse;
- eine Menge an stabilisiertem H<sub>2</sub>O<sub>2</sub> von zwischen 0,3 und 1 g/l pro Stunde, gesteuert auf der Basis des Redoxpotentials des Bads, das bei  $\geq 350$  mV gehalten werden muss;
- und gegebenenfalls ausreichende Mengen des Bestandteils e), um dessen Konzentration in dem Bad bei optimalen Gehalten und wobei ausreichende Mengen der Bestandteile a) und c) periodisch zugeführt werden, um ihre Konzentration im Bad bei optimalen Gehalten auf der Grundlage der Badanalyse, d.h. der Werte der freien Säure- und Fluoridionen, zu halten und um den Bad-pH bei weniger als 1 und vorzugsweise zwischen 0 und 0,5 zu halten.

2. Verfahren nach Anspruch 1,  
**dadurch gekennzeichnet, dass**  
 die Fe<sup>3+</sup>-Ionen in das Anfangsbad in der Form von Ferrisulphat eingeführt werden.

3. Verfahren nach Anspruch 1,  
 durchgeführt in Kombination mit der vorherigen teilweisen Entfernung von Oxiden durch ein bekanntes Verfahren.

### Revendications

1. Procédé de décapage et de passivation d'acier inoxydable consistant à porter le matériau à traiter au contact d'un bain maintenu à une température comprise entre 30 et 70°C, et de préférence entre 45 et 55°C, et ayant la composition initiale suivante :

- a) H<sub>2</sub>SO<sub>4</sub> au moins 150 g/l
- b) Fe<sup>3+</sup> au moins 15 g/l
- c) HF au moins 40 g/l
- d) H<sub>2</sub>O<sub>2</sub> (contenant des stabilisants connus) 1-20 g/l, et de préférence 2-5 g/l.
- e) additifs du type surfactif non ionique (émulsifiants, agents mouillants, lustrants) et du type inhibiteur d'attaque acide : environ 1 g/l au total ;

en introduisant de manière continue dans le-  
 dit bain :

- un courant d'air d'eau moins 3 m<sup>3</sup>/h par m<sup>3</sup> de bain, en utilisant un dispositif distributeur approprié pour diffuser le courant dans la masse liquide;
- une quantité d'H<sub>2</sub>O<sub>2</sub> stabilisé comprise entre 0,3 et 1 g/l par heure, régulée sur la base du

potentiel redox du bain, qui doit être maintenu à  $\geq 350$  mV;

- et le cas échéant des quantités suffisantes de l'ingrédient e) pour maintenir sa concentration dans le bain à un niveau optimum ; et des quantités suffisantes des ingrédients a) et c) étant périodiquement apportées pour maintenir leur concentration dans le bain à des niveaux optima sur la base de l'analyse du bain, c'est-à-dire les valeurs d'acide libre et d'ion fluorure, et pour maintenir le pH du bain à moins de 1, et de préférence entre 0 et 0,5.

2. Procédé selon la revendication 1, dans lequel les ions Fe<sup>3+</sup> sont introduits dans le bain initial sous forme de sulfate ferrique.
3. Procédé selon la revendication 1, réalisé en combinaison avec l'élimination partielle préalable des oxydes par une procédé connu.

25

30

35

45

50

55