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(72) Benson, Sidney W., US

(72) Hisham, Mohamed W. M., US

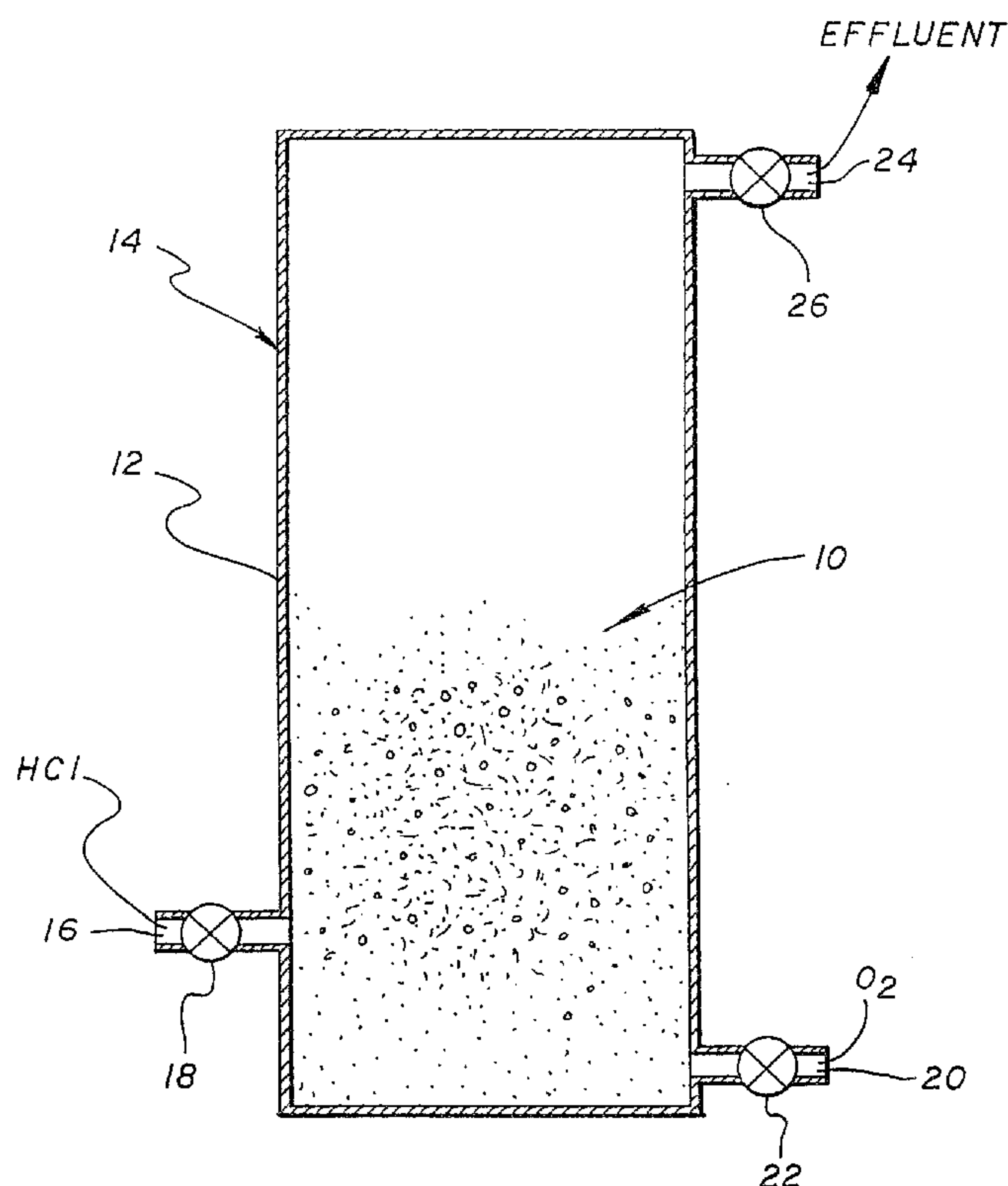
(73) UNIVERSITY OF SOUTHERN CALIFORNIA, US

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(30) 1989/11/02 (430,805) US

(54) **PRODUCTION EFFICACE DE CHLORE A PARTIR DE
CHLORURE D'HYDROGENE**

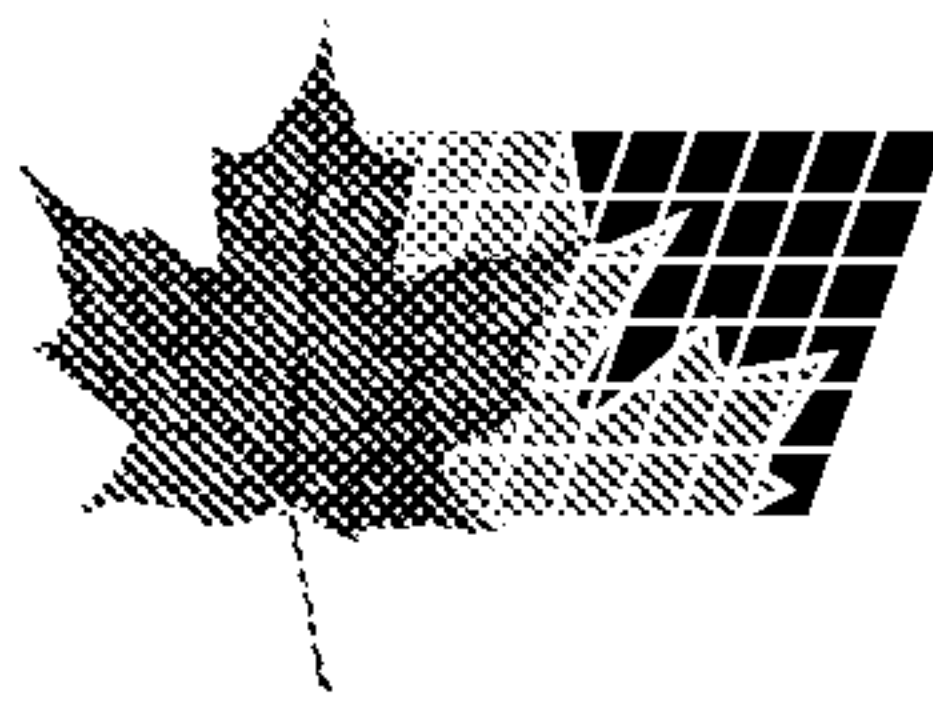
(54) **EFFICIENT PRODUCTION OF CHLORINE FROM HYDROGEN
CHLORIDE**



(57) Procédé pour la production à fort rendement de Cl_2 à partir de HCl gazeux, au moyen d'un catalyseur (1) comprenant un oxyde métallique de transition, un chlorure métallique alcalin et, accessoirement, un chlorure de terre rare trivalent, qui agit de manière productive à des températures modérées et sans que le

(57) A process for the efficient production of Cl_2 from gaseous HCl , using a catalyst (1) containing a transition metal oxide, an alkali metal chloride, and, optionally, a trivalent rare earth chloride, operates efficiently at moderate temperatures and without volatilization of the catalyst (10). The process comprises two steps: 1) a





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catalyseur (10) s'évapore. Le procédé comprend deux phases: 1) une phase de chloruration dans laquelle le HCl est mis en contact avec le catalyseur (1) à une température élevée, transformant l'oxyde métallique de transition en un chlorure métallique de transition avec élimination d'eau; et (2) une phase d'oxydation dans laquelle le chlorure métallique de transition produit dans la première phase est mis en contact avec une source d'oxygène à une température d'un moins environ 300 °C mais cependant inférieure à 400 °C et suffisamment élevée pour que le Cl₂ se dégage et que le chlorure métallique de transition se retransforme en oxyde métallique de transition. La température de la phase d'oxydation est supérieure à celle de la phase de chloruration. Préférentiellement, l'oxyde métallique de transition est du MnO₂, dans ce cas le MnO₂ se transforme en MnCl₂ lors de la première phase avec l'émission du Cl₂. L'oxyde métallique de transition peut également être du Co₂O₃, Co₃O₄, Cr₂O₃, NiO, Ni₂O₃, Mo₂O₃ ou du CuO.

chloridizing step in which the HCl is contacted with the catalyst (1) at an elevated temperature, converting the transition metal oxide to a transition metal chloride with elimination of water; and 2) an oxidizing step in which the transition metal chloride produced in the first step is contacted with a source of oxygen at a temperature at least about 300° C but less than 400 °C and sufficiently high that Cl₂ is evolved and the transition metal chloride is reconverted to a transitional metal oxide. The temperature of the oxidizing step is increased over that of the chloridizing step. Preferably, the transition metal oxide is MnO₂, in which case the MnO₂ is converted to MnCl₂ in the first step with the release of Cl₂. The transition metal oxide can also be Co₂O₃, Co₃O₄, Cr₂O₃, NiO, Ni₂O₃, Mo₂O₃, or CuO.





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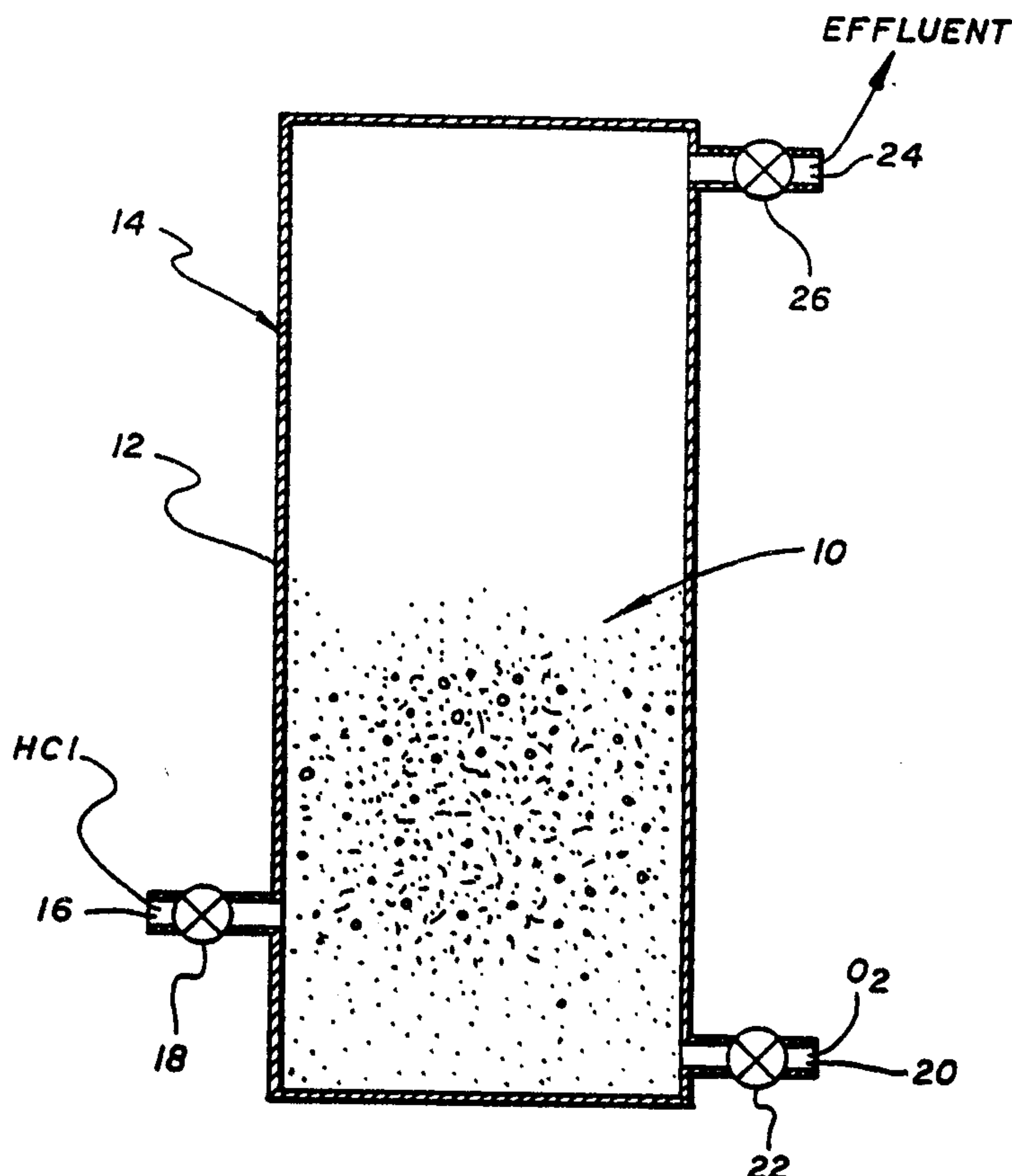
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(21) International Application Number: PCT/US90/06184 (22) International Filing Date: 26 October 1990 (26.10.90) (30) Priority data: 430,805 2 November 1989 (02.11.89) US (71) Applicant: UNIVERSITY OF SOUTHERN CALIFORNIA [US/US]; University Park, Los Angeles, CA 90089 (US). (72) Inventors: BENSON, Sidney, W. ; 1110 N. Bundy Drive, Los Angeles, CA 90049 (US). HISHAM, Mohamed, W., M. ; 2145A Bedell Road, Grand Island, NY 14072 (US).		(74) Agents: SULLIVAN, Daniel, F. et al.; Poms, Smith, Lande & Rose, 2121 Avenue of the Stars, Suite 1400, Los Angeles, CA 90067 (US). (81) Designated States: AT (European patent), AU, BE (European patent), BR, CA, CH (European patent), DE, DE (European patent), DK (European patent), ES, ES (European patent), FR (European patent), GB, GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), NL, NL (European patent), SE (European patent), SU. Published <i>With international search report.</i>	

(54) Title: EFFICIENT PRODUCTION OF CHLORINE FROM HYDROGEN CHLORIDE

(57) Abstract

A process for the efficient production of Cl_2 from gaseous HCl , using a catalyst (1) containing a transition metal oxide, an alkali metal chloride, and, optionally, a trivalent rare earth chloride, operates efficiently at moderate temperatures and without volatilization of the catalyst (10). The process comprises two steps: 1) a chloridizing step in which the HCl is contacted with the catalyst (1) at an elevated temperature, converting the transition metal oxide to a transition metal chloride with elimination of water; and 2) an oxidizing step in which the transition metal chloride produced in the first step is contacted with a source of oxygen at a temperature at least about 300°C but less than 400°C and sufficiently high that Cl_2 is evolved and the transition metal chloride is reconverted to a transitional metal oxide. The temperature of the oxidizing step is increased over that of the chloridizing step. Preferably, the transition metal oxide is MnO_2 , in which case the MnO_2 is converted to MnCl_2 in the first step with the release of Cl_2 . The transition metal oxide can also be Co_2O_3 , Co_3O_4 , Cr_2O_3 , NiO , Ni_2O_3 , Mo_2O_3 , or CuO .



EFFICIENT PRODUCTION OF CHLORINE FROM HYDROGEN CHLORIDE

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BACKGROUND

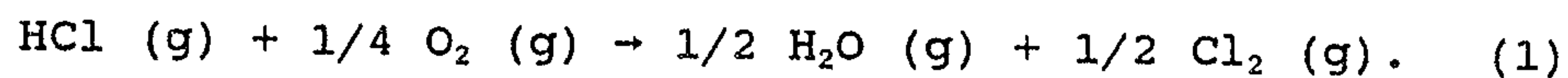
10 This application relates to improved processes for the chemical production of chlorine from gaseous HCl. The gaseous HCl can be part of a complex mixture.

15 In recent years, increasing amounts of HCl are being obtained as a by-product of several manufacturing processes such as the industrial production of chlorinated hydrocarbons. At the same time industrial demand for gaseous chlorine has also greatly increased. As a result there is a great need for more efficient chemical processes for producing chlorine from hydrogen chloride, especially processes capable of large-scale industrial application.

20

In 1868, Deacon developed a process by which chlorine is produced by direct oxidation of gaseous HCl with O₂ in the presence of a CuCl₂ catalyst. This process is described by the overall chemical equation

25



30

Reaction (1) in the presence of a CuCl₂ catalyst is a fast overall exothermic process which is expected to reach equilibrium under normal industrial operating conditions of 700°K to 750°K.

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A number of engineering problems are associated with the Deacon process. The temperatures of the process reduce the equilibrium constant for the conversion, resulting in incomplete conversion of the HCl and thereby reducing yield. This is especially a problem when the Deacon process is carried out at a single temperature in a single vessel. Furthermore, at elevated temperatures above 675°K, the catalyst's activity rapidly decreases, mainly because of volatilization of the CuCl.

Since the early 1900's various efforts have been made to improve the Deacon Process. Several modifications of the catalyst's composition have been suggested, such as addition of less volatile rare earth metals in the form of chlorides or oxides, and addition of various copper salts, which are promoted by chlorides or oxides of a number of metals such as V, Be, Mg, Bi, and Sb. Several researchers have proposed the addition of NaCl and KCl, which form double salts with the CuCl. These double salts are less volatile than the CuCl itself. Cr₂O₃ and V₂O₅ have also been shown to be efficient catalysts for the process. However, few, if any, of these modifications have been shown to improve efficiency of the process under actual industrial operation conditions.

Particular modifications of the Deacon process are described in U.S. Patent No. 2,206,399 to Grosvenor et al., U.S. Patent No. 2,577,808 to Pye et al., and J. Th. Quant, J. van Dam, W.F. Engel, and F. Wattimena, "The Shell Chlorine Process," The Chemical Engineer, 224-232 (1963).

U.S. Patent No. 2,206,399 to Grosvenor et al. discloses the chlorination and oxidation of a variety of chlorine-carrying multivalent metals, including chromium, cobalt, copper, manganese, nickel, magnesium, and iron. The metal is preferably iron.

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U.S. Patent No. 2,577,808 to Pye et al. discloses the use of iron as a chlorine carrier in a fluidized bed reaction where a granular contact mass including ferric oxide falls by gravity through a heating or cooling zone, and then through a chloridizing zone which has a temperature of 300°C at the top and 500°C at the bottom. Thereafter, the chlorine carrier, now in the form of ferric chloride, falls into an oxidizing zone which has a temperature of 500°C at the top and 550°C at the bottom to oxidize the particles to ferric oxide. These particles are then returned to the top, cooled, and recycled.

The *Chemical Engineer* article by J. Th. Quant et al. describes a variation of the Deacon process using a Cu catalyst adsorbed on a porous carrier containing alkali metal chlorides and/or lanthanide chlorides, the so-called "Shell catalyst." The reaction is optimally carried out in a fluidized bed.

A number of other processes have been proposed for the recovery of Cl_2 from waste HCl . These processes include:

(1) The Kel-Chlor Process. This process involves the reaction of HCl with nitrosylsulfuric acid (HNSO_3) contained in a stream of H_2SO_4 to produce nitrosyl chloride (NOCl) with eventual production of Cl_2 by oxidation of NOCl .

(2) Direct Electrolysis of Hydrochloric Acid.

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(3) Direct Oxidation with an Inorganic Oxidizing Agent. Such oxidizing agents include nitrogen dioxide, sulfur trioxide, or a nitric/sulfuric acid mixture. The reaction is carried out in the liquid phase.

(4) Weldon Process. This process is based on the oxidation of aqueous hydrochloric acid with manganese dioxide, with subsequent reconversion of manganous chloride by air blowing in the presence of lime.

None of these processes can be characterized as completely successful. Direct electrolysis of HCl is only exploitable where power costs are low and the recovered co-product, hydrogen, can be made to bear an appropriate share of the manufacturing costs. In the present industrial environment of high and unpredictably fluctuating energy costs, such a process has little use. The processes involving direct oxidation with an inorganic oxidizing agent are very corrosive and give relatively low yields of chlorine. The various two-stage processes, including the Weldon process and variations of the Deacon process, attain far lower conversions under normal industrial operating conditions than are claimed to occur theoretically. Also, catalytic activity decline and loss due to catalyst volatilization still remain severe problems and major components of the final product cost. The Kel-Chlor process is very costly in plant design, safety features, and energy requirements.

Accordingly, there is a need for an efficient process for the preparation of chlorine from HCl that gives a nearly quantitative conversion of HCl to chlorine, operates under conditions in which the catalyst does not volatilize and in which the activity of the catalyst remains

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stable, and operates at relatively moderate temperatures to prevent corrosion and minimize the extrinsic energy input required.

SUMMARY OF THE INVENTION

5 We have developed an improved process for producing Cl_2 from HCl that remedies defects of previous processes for the production of Cl_2 . This improved process functionally separates the Deacon process into two steps: Step 1, a chloridizing step; and Step 2, an oxidizing step. A process
10 according to the present invention is operable at moderate temperatures and uses a catalyst that does not volatilize and has a relatively long lifetime under the actual reaction conditions of the process. It gives a high yield of Cl_2 and efficient conversion of the HCl to Cl_2 , and can be practiced
15 using a simple apparatus. It requires only limited input of extrinsic energy, making it economical to operate.

 In accordance with the present invention, there is provided a process for producing Cl_2 from HCl , comprising the steps of: (a) contacting in a stationary bed and at a
20 chloridizing temperature of between about 25°C and about 250°C a gas containing HCl with a catalyst comprising: (i) a transition metal oxide selected from the group consisting of MnO_2 , Co_2O_3 , Co_3O_4 , Cr_2O_3 , Ni_2O_3 , NiO , Mo_2O_3 , CuO , and combination thereof; and (ii) an alkali metal chloride selected
25 from the group consisting of LiCl , NaCl , KCl , and combinations thereof, in the ration of about 1 mole of alkali metal chloride per mole of transition metal oxide, the catalyst being supported on an inert support; the chloridizing temperature being sufficiently high that the transition metal oxide is
30 converted to a transition metal chloride by the HCl with elimination of water; and (b) contacting in said stationary bed the transition metal chloride generated in step (a) with a

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source of oxygen at an oxidizing temperature greater than the chloridizing temperature, the oxidizing temperature being sufficiently high, at least 300°C that Cl₂ is evolved and the transition metal chloride in the catalyst is reconverted to the
5 transition metal oxide for reuse in step (a).

There is further provided a process comprising the steps of:

(1) contacting at an elevated temperature a gas containing HCl with a catalyst comprising:

10 (a) a transition metal oxide selected from the group consisting of MnO₂, CO₂O₃, CO₃O₄, Cr₂O₃, NiO, Ni₂O₃, Mo₂O₃, CuO, and combinations thereof;

- 5 (b) An alkali metal chloride selected from the group consisting of LiCl, NaCl, KCl, and combinations thereof; and
- 10 (c) optimally, a promoter selected from the group consisting of LaCl₃, PrCl₃, and Pr₂O₃, and combinations thereof, the elevated temperature being sufficiently high, in the range of from about 100°C to about 300°C, that the transition metal oxide is converted to transition metal chloride by the HCl with elimination of water; and
- 15 (2) contacting the transition metal chloride generated in step (1) with a source of oxygen at a temperature increased over the temperature of step (1), the temperature being sufficient high, at least about 300°C up to about 400°C, that Cl₂ is evolved and the transition metal chloride in the catalyst is reconverted to the transition metal oxide for reuse in step (a).
- 20
- 25

30 The components are present in the catalyst in a ratio of about 1 mole of alkali metal chloride and up to about 0.2 mole of promoter, if present, per mole of transition metal oxide.

35 Preferably, the elevated temperature in the first step of the reaction is in the range of from about 100°C to about 250°C.

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In a preferred version of the invention, the transition metal oxide is MnO_2 , Co_2O_3 , or Co_3O_4 , or a combination thereof, most preferably MnO_2 . In this version, described for convenience with MnO_2 , the MnO_2 is converted to
5 MnCl_2 by the HCl and water and Cl_2 are evolved in the first step, which preferably occurs at a temperature of from about 100°C to about 250°C . Preferably, the MnCl_2 is contacted with the source of oxygen in the second step at a temperature of from about 350°C to about 375°C . In this version of the
10 invention, Cl_2 is evolved in both steps of the reaction.

In another version of the invention, the transition metal oxide is Cr_2O_3 , NiO , Ni_2O_3 , or Mo_2O_3 , or a combination thereof. In this version, two changes are made from the preferred version. In the first set, the HCl is preferably
15 contacted with the catalyst containing the transition metal oxide at a temperature of from about 100°C to about 225°C . In the second step, the resulting transition metal chloride is preferably contacted with the source of oxygen at a temperature of from about 310°C to about 375°C .

20 In a third version of the invention, the transition metal oxide is CuO . In this version of the invention, the temperature range in the first set is from about 100°C to about 300°C . The temperature range in the second step is from about 310°C to about 375°C , preferably from about 310°C to about
25 330°C , to prevent volatilization of the copper-containing catalyst.

The catalyst is preferably supported on an inert support. The weight of the catalyst preferably comprises about 10 to about 20 percent of the total weight of the catalyst and
30 the inert support. The inert support is

preferably gamma-alumina, pumice, silica, or molecular sieve material.

5 The source of oxygen for these processes can be O_2 ; the O_2 can be diluted with N_2 . The source of oxygen can be preheated to provide at least some of the necessary heat for the evolution of Cl_2 and the reconversion of the transition metal chloride in the catalyst to the transition metal oxide.

10

The first step of the process can occur in a first reaction zone and the second step in a second reaction zone. In this embodiment, the process comprises the additional step of recycling reconverted transition metal oxide from the second reaction zone to the first reaction zone.

15

The catalysts for the process of the present invention can be contained in a fluidized bed or a stationary bed. When the process occurs in two separate reaction zones, the catalyst can be contained in a fluidized bed in both reaction zones. In particular, the catalyst can be contained in a first fluidized bed in the first reaction zone and a second fluidized bed in the second reaction zone.

20
25

DRAWING

These and other features, aspects, and advantages of the present invention will become better understood from the accompanying description, appended claims, and accompanying drawing where:

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The single figure is a schematic diagram of a single-state reaction vessel usable for the process of the present invention.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

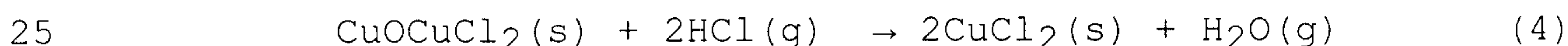
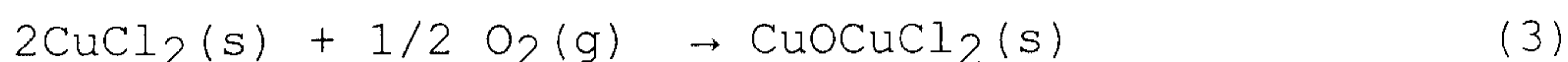
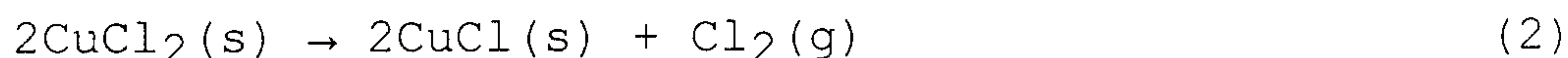
An improvement in the Deacon process that we have developed meets the needs of high yield, stability of catalyst activity, and operability at moderate temperatures. This
 5 improvement avoids the use of excessively complex apparatus and can be performed using either a stationary or a fluidized bed.

This improvement functionally separates the Deacon process into two steps: Step 1, a chloridizing step; and Step 2, an oxidizing step. This functional separation can be
 10 performed either by physically moving the catalyst from one reaction vessel to another, or by cycling the temperature between the optima for each step in a single vessel. In the first of these alternatives, each step of the process is actually performed in a separate reaction vessel whose
 15 temperature is controlled independently.

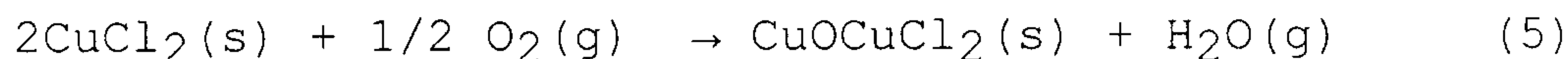
By separating the two steps, we avoid the equilibrium limit on the reaction, we avoid having the corrosive mixture of HCl and H₂O present in the same process stream.

A. Thermodynamic Considerations

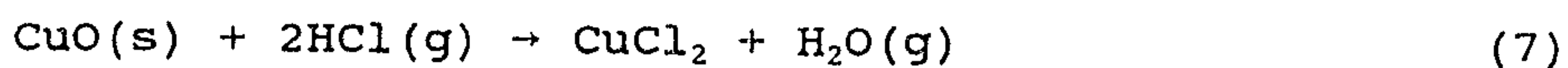
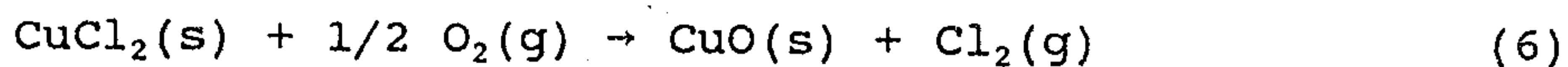
20 There is general agreement at the reaction mechanism of the Deacon process with a Cu catalyst is described by the following overall mechanistic scheme:



Adding equations (2) and (3),



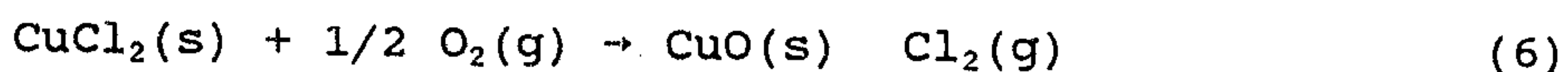
Equations (4) and (5) can be reformulated as follows:



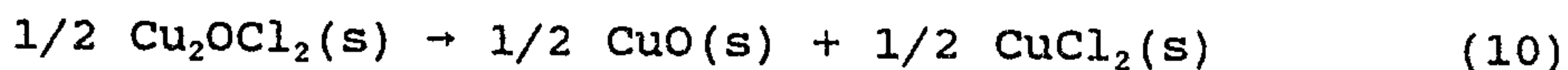
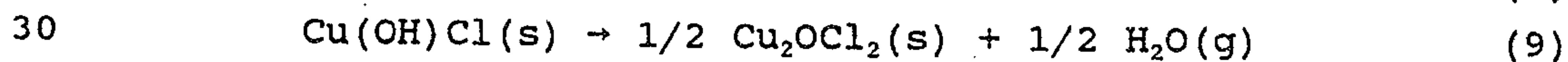
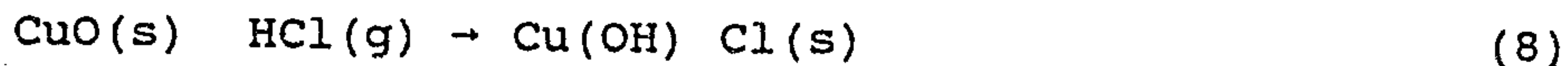
5 In 1962, Allen, in J.A. Allen, J. App. Chem.
 (London) 12, 406 (1962), suggested that for a metal to be an
 effective Deacon process catalyst the free energy changes
 associated with reactions (6) and (7) must be small
 (approximately zero). Only a limited number of metals
10 satisfies this criterion, and with the exception of Mg, all
 of these metals have been found to be effective Deacon
 process catalysts.

 We have recently developed a theoretical
15 technique for accurate estimating of the thermodynamic
 properties of metal-oxy and chloro-hydroxy intermediate
 compounds. As a result, it is now possible to study in
 detail the thermochemistry of the Deacon process. Based on
 our knowledge of the thermochemical properties of these
20 intermediate reactive species and after testing
 thermochemically the validity of a number of alternative
 mechanistic routes we have proposed the following reaction
 mechanism for the Deacon process, using a Cu catalyst:

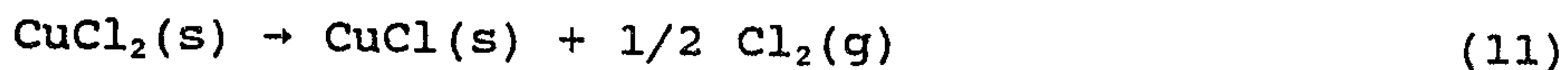
25 CuO formation:



 HCl absorption steps:



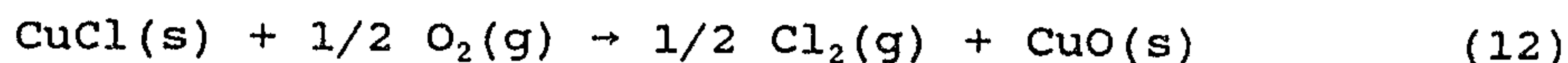
 Valency change:



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Catalyst regeneration:



5 Since the reaction mechanism of the Deacon
process consists of both exothermic and endothermic steps,
one expects an optimal temperature range for the process,
which has been found experimentally. The observation,
furthermore, that the true catalyst for the process is a
mixture of the oxide and chloride forms of Cu, the oxide
10 form being necessary for HCl adsorption and the chloride
form participating in the Cl₂ release step, opens new avenues
for further engineering optimization in terms of feed
composition, pressure and temperature cycling, and adaptive
control.

15

B. Choice of Catalyst

With the thermodynamic factors taken into account, the
optimal catalyst in the Deacon process is a variation of the
so-called "Shell Catalyst." This catalyst comprises a
20 transition metal oxide, an alkali metal chloride and,
optimally, a trivalent rare earth metal chloride or rare
earth metal oxide. The trivalent rare earth metal chloride
or oxide serves as a promoter and is subsequently referred
to by this term.

25

The transition metal oxide is one of MnO₂, Co₂O₃,
Co₃O₄, Cr₂O₃, Mo₂O₃, CuO, NiO, or Ni₂O₃, or mixtures and
combinations thereof.

30

The alkali metal chloride is preferably LiCl,
NaCl, or KCl. Most preferably, it is NaCl or KCl. A
mixture of any of these alkali metal chlorides can also be
used. The promoter is preferably LaCl₃ or PrCl₃, but other
similar rare earth chlorides, such as NdCl₃, or a mixture of
35 NdCl₃ and PrCl₃, as well as trivalent rare earth metal

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oxides, such as Pr_2O_3 , can also be used as the promoter. The alkali metal chloride is typically present in the catalyst at a ratio of about 1 mole of alkali metal chloride per mole of transition metal oxide. The promoter, if present, is at a ratio of up to 0.2 mole per mole of transition metal oxide.

The catalyst is typically supported on an inert support. The inert support is preferably gamma-alumina, pumice, silica or molecular sieve material. The weight of the catalyst is preferably about 10 percent to about 20 percent of the total weight of the catalyst and the inert support taken together. Typically, the catalyst is incorporated in high-surface-area material, with a surface area of 100-500 m^2/g .

C. Reaction with Catalyst Using MnO_2

The reaction with a catalyst using MnO_2 is exceptional in that Cl_2 is released in both steps of the reaction: step 1, the chloridizing step; and step 2, the oxidizing step.

In step 1, the chloridizing step, the catalyst is contacted with a gas containing HCl at a temperature of from about 25°C to about 250°C , preferably from about 100°C to about 250°C , more preferably no higher than 225°C . As a result of this contact, the MnO_2 is converted into MnCl_2 , being reduced from a (+4) oxidation state to a (+2) oxidation state. The exit stream of the reaction contains steam and Cl_2 according to the equation



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The steam and Cl_2 can be easily separated from each other or condensed together and subsequently separated as needed. This step is exothermic, with a H of -6 kcal/mole.

5 In step 2, the oxidizing step, the chloridized catalyst is then contacted with a source of oxygen at a temperature of at least 300°C but less than about 400°C but sufficiently high that Cl_2 is evolved and the MnCl_2 is reconverted to the original catalytic MnO_2 for reuse in the
10 first step. The temperature of step 2 is increased over that of step 1. The temperature is preferably from about 350°C to about 375°C at this step. This step is also exothermic with a H of -8 kcal, and takes place according to the equation

15



The source of oxygen in this step can be O_2 gas, pure or diluted with N_2 , or air.

20

Preferably the source of oxygen is preheated to provide at least some of the necessary heat not provided by the reaction itself for the evolution of Cl_2 and the reversion of MnCl_2 to MnO_2 . Additional heat is required
25 because of the considerable rise in temperature in going from the first step to the second step. Any O_2 not consumed can be recycled.

30

Typically, the pressure of the reaction is close to about 1 atmosphere, but there is no theoretical limit on the pressure, and use of a supra-atmospheric pressure, such as about 10 atmospheres, might be beneficial for the production of chlorine.

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D. Reaction Using Catalysts Containing Other Metal Oxides

The reaction using catalyst containing metal oxides other than MnO_2 proceeds similarly in two steps, except that in the first chloridizing step, no Cl_2 is released, only H_2O as steam or water vapor. In the second oxidizing step Cl_2 is released.

The temperature limits in the first step are preferably from about 100°C to about 225°C if a catalyst containing metal oxides other than CuO is used. If a catalyst containing CuO is used, the optimum temperature for the first step can range from about 100°C to about 300°C .

If the catalyst does not contain CuO , the temperature of the second step is at least about 300°C but less than about 400°C , sufficiently high that Cl_2 is evolved and the metal chloride is reconverted to a metal oxide for reuse in the first step. The temperature of the second step is increased over that of the first step. More preferably, the temperature in the second step is to be from about 310°C to about 375°C . If the catalyst does contain CuO , the temperature of the second step should be from about 310°C to 375°C . If the catalyst does contain CuO , the temperature of the second step should be from about 310°C to 375°C , more preferably from about 310°C to about 330°C . The maximum temperature should be limited when the catalyst contains CuO to avoid volatilization of the catalyst.

E. Apparatus for Performing the Reaction

The reaction can be carried out in a simple reaction vessel as shown in Figure 1.

Figure 1 shows a reaction vessel suitable for carrying out the two-step process using a catalyst containing MnO_2 . The catalyst 10 is contained in the body 12 of the reaction vessel 14. A first inlet 16, controlled by valve 18 admits the HCl -containing gas for the performance of the first, chloridizing, step. A second inlet 10, controlled by valve 22, admits the source of oxygen, such as O_2 gas, for the performance of the second, oxidizing step. An outlet 24, controlled by valve 26, allows escape of the effluent gas in each step for further processing. The vessel is surrounded by a temperature control mechanism (not shown) that can supply or remove heat as needed to keep the temperature within the required limits.

Alternatively, the reaction can be carried out in a fixed bed or fluidized bed reactor.

In another, preferred, alternative, the reaction can be carried out in an apparatus in which the first, chloridizing, step occurs in a first reaction zone and the second, oxidizing, step occurs in a second reaction zone. In this alternative, the reaction further comprises the step of recycling reconverted transition metal catalyst from the second reaction zone to the first reaction zone. When two reaction zones are used, a separate fluidized bed can be used to contain the catalyst in each reaction zone.

This invention will be better understood from the following Examples.

30

Examples 1-4

Reaction of Metal Oxide Catalysts with HCl and O_2

A quartz tube of 15 mm I.D. was packed with glass wool and about 10-12 g of alumina- or silica-supported metal oxide catalyst. The metal oxide content varied between 10

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and 20 weight percent of the total weight of the catalyst, including the support. the tube was located in an electrically heated furnace whose temperature was adjustable.

5

In experiments with HCl, a diluent (Ar or N₂, about 20% by volume) was used and the gas mixture was circulated over the catalyst. Water was condensed in a trap cooled in dry ice. The amount of HCl adsorbed could be accurately ($\pm 1\%$) measured from the pressure drop. All experiments were done between 100°C and 200°C initial temperature. Rates of adsorption were too fast to measure and no other products besides water and Cl₂ were ever observed.

15

In experiments with O₂, the HCl-saturated catalyst was preheated to the desired temperature, usually about 350°C, and O₂ circulated over the catalyst until no further Cl₂ was deposited in the dry ice trap. Measurements of Cl₂ were done by titration and O₂ consumption was measured by pressure drop. No products other than Cl₂ were ever found in the oxygen experiments.

25

The following metal oxides were tested:

Example 1 - CuO

With CuO, HCl was completely absorbed at 150°C. At 315°C, some Cl₂ was observed using O₂. Much faster reaction occurred at 330-375°C. At 475°C, Cl₂ evolution with O₂ was rapid but some CuCl catalyst evaporated outside the oven region.

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Example 2 - NiO

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With NiO at 190°C, HCl absorption was rapid and complete. Above 380°C, Cl₂ was quickly evolved using O₂.

5

Example 3 - MnO₂

At 100-250°C, HCl was completely absorbed and both H₂O and Cl₂, both condensed, were liberated. The resulting MnCl₂ evolved Cl₂ slowly from 350° to 400° and then rapidly at about 400°C.

10

Example 4 - V₂O₅

At 190°C, absorption was complete with only H₂O liberation. On heating the catalyst above 250°C, both Cl₂ and a volatile chloride, probably VO₂Cl or VOCl₃, were evolved.

15

All catalysts tested could be reused through a number of cycles of the experiment with the same results.

20

Based on the above findings and current knowledge of the chemistry of the process, we divided metal oxides into four categories:

25

(1) alkali metal oxides and alkaline earth metal oxides such as Na₂O, CaO, or MgO, whose chlorides do not react with O₂ below 900°C, and metal oxides such as Al₂O₃ that do not react above 100°C with HCl to form chlorides;

30

(2) CuO, Fe₂O₃ and V₂O₅, whose chlorides become volatile at temperatures where the reaction of O₂ with the chlorides is rapid;

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(3) MnO_2 and Co_2O_3 or Co_2O_4 , which produce Cl_2 together with H_2O when adsorbing HCl above 100°C ; and

5 (4) Cr_2O_3 and NiO , which adsorb HCl completely between 100°C and 200°C and whose chlorides react rapidly above 450°C without forming volatile intermediates.

10 Oxides from classes (1) and (2), except for CuO , are not suitable for commercial processes. Oxides from classes (3) and (4) are suitable for such processes. All of them can be benefitted by mixtures with other oxides from these same categories and/or from mixtures with alkali metal
15 halides which tend to lower the melting points of the chlorides formed in the reaction with HCl and then facilitate the rate of the later reaction with O_2 .

A process according to the present invention has
20 many advantages. Such a process is commercially useful for the preparation of chlorine from HCl and operates more efficiently than currently used processes by functionally separating the Deacon process into two steps: a chloridizing step and an oxidizing step. The process gives
25 a nearly quantitative conversion of HCl to chlorine and operates under conditions in which the catalyst does not volatilize, and under which the activity of the catalyst remains stable. The process also requires only limited input of extrinsic energy and operates at relatively
30 moderate temperatures and without corrosion of its surroundings.

Although the present invention has been described
in considerable detail with regard to certain preferred
35 versions thereof, other versions are possible. Therefore,

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the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

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CLAIMS:

1. A process for producing Cl_2 from HCl , comprising the steps of:

(a) contacting in a stationary bed and at a chloridizing temperature of between about 25°C and about 250°C a gas containing HCl with a catalyst comprising:

(i) a transition metal oxide selected from the group consisting of MnO_2 , Co_2O_3 , Co_3O_4 , Cr_2O_3 , Ni_2O_3 , NiO , Mo_2O_3 , CuO , and combination thereof; and

(ii) an alkali metal chloride selected from the group consisting of LiCl , NaCl , KCl , and combinations thereof, in the ratio of about 1 mole of alkali metal chloride per mole of transition metal oxide, the catalyst being supported on an inert support; the chloridizing temperature being sufficiently high that the transition metal oxide is converted to a transition metal chloride by the HCl with elimination of water; and

(b) contacting in said stationary bed the transition metal chloride generated in step (a) with a source of oxygen at an oxidizing temperature greater than the chloridizing temperature, the oxidizing temperature being sufficiently high, at least 300°C that Cl_2 is evolved and the transition metal chloride in the catalyst is reconverted to the transition metal oxide for reuse in step (a).

2. The process of claim 1 wherein the catalyst further comprises a promoter selected from the group consisting of LaCl_3 , PrCl_3 , Pr_2O_3 , and combinations thereof, in the ratio of up to about 0.2 mole of promoter per mole of transition metal oxide.

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3. The process of claim 1 wherein the chloridizing temperature in step (a) is in the range of about 100°C to about 250°C.

4. A process for producing Cl₂ from HCl, comprising the
5 steps of:

(a) contacting in a stationary bed at a chloridizing temperature of between about 25°C and about 250°C a gas containing HCl with a catalyst comprising:

(i) a transition metal oxide selected from the
10 group of MnO₂, CO₂O₃, CO₃O₄, and combinations thereof; and

(ii) an alkali metal chloride selected from the group consisting of LiCl, NaCl, KCl, and combinations thereof, in the ratio of about 1 mole of alkali metal chloride per mole of transition metal oxide, the catalyst being supported on an
15 inert support;

the chloridizing temperature being sufficiently high that the transition metal oxide is converted to a transition metal chloride by the HCl and Cl₂ is evolved from the HCl with elimination of water; and

20 (b) contacting in said stationary bed the transition metal chloride generated in step (a) with a source of oxygen at an oxidizing temperature greater than the elevated temperature, the oxidizing temperature being sufficiently high, at least about 300°C, that Cl₂ is evolved and the transition metal
25 chloride in the catalyst is reconverted to the transition metal oxide for reuse in step (a).

5. The process of claim 4 wherein the catalyst further comprises a promoter selected from the group consisting of LaCl₃, PrCl₃, Pr₂O₃, and combinations thereof, in the ratio of
30 up to about 0.2 mole of promoter per mole of transition metal oxide.

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6. A process for producing Cl_2 from HCl , comprising the steps of:

(a) contacting in a stationary bed at a chloridizing temperature of between about 100°C and about 250°C a gas

5 containing HCl with a catalyst comprising:

(i) MnO_2 ; and

(ii) an alkali metal chloride selected from the group consisting of LiCl , NaCl , KCl , and combinations thereof, in the ratio of about 1 mole of alkali metal chloride per mole
10 of MnO_2 , the catalyst being supported on an inert support;

(b) contacting in said stationary bed the MnCl_2 generated in step (a) with a source of oxygen at an oxidizing temperature greater than the chloridizing temperature, the oxidizing temperature being sufficiently high, at least 300°C ,
15 that the Cl_2 is evolved and the MnCl_2 in the catalyst is reconverted to catalytic MnO_2 for reuse in step (a).

7. The process of claim 6 wherein the catalyst further comprises a promoter selected from the group consisting of LaCl_3 , PrCl_3 , Pr_2O_3 , and combinations thereof, in the ratio of
20 up to about 0.2 mole of promoter per mole of MnO_2 .

8. A process for producing Cl_2 from HCl , comprising the steps of:

(a) contacting in a stationary bed at a chloridizing temperature of between about 25°C and about 250°C a gas

25 containing HCl with a catalyst comprising:

(i) a transition metal oxide selected from the group consisting of Cr_2O_3 , Ni_2O_3 , NiO , Mo_2O_3 , and combination thereof; and

(ii) an alkali metal chloride selected from the
30 group consisting of LiCl , NaCl , KCl , and combinations thereof, in the ratio of about 1 mole of alkali metal chloride per mole

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of transition metal oxide, the catalyst being supported on an inert support;

the chloridizing temperature being sufficiently high that the transition metal oxide is converted to a transition metal chloride by the HCl with elimination of water; and

(b) contacting in said stationary bed the transition metal chloride generated in step (a) with a source of oxygen at an oxidizing temperature greater than the chloridizing temperature, the oxidizing temperature being sufficiently high, at least about 300°C, that Cl₂ is evolved and the transition metal chloride in the catalyst is reconverted to the transition metal oxide for reuse in step (a).

9. The process of claim 8 wherein the catalyst further comprises a promoter selected from the group consisting of LaCl₃, PrCl₃, Pr₂O₃, and combinations thereof, in the ratio of up to about 0.2 mole of promoter per mole of transition metal oxide.

10. A process for producing Cl₂ from HCl, comprising the steps of:

(a) contacting in a stationary bed at a chloridizing temperature of between 25°C and about 250°C a gas containing HCl with a catalyst comprising:

(i) CuO; and

(ii) an alkali metal chloride selected from the group consisting of LiCl, NaCl, KCl, and combinations thereof, in the ratio of about 1 mole of alkali metal chloride per mole of CuO, the catalyst being supported on an inert support;

the chloridizing temperature being sufficiently high that the CuO is converted to CuCl₂ by the HCl with elimination of water; and

(b) contacting in said stationary bed the CuCl₂ generated in step (a) with a source of oxygen at an oxidizing

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temperature, the oxidizing temperature being sufficiently high, from about 310°C to about 375°C, that Cl₂ is evolved and the CuCl₂ in the catalyst is reconverted to CuO for reuse in step (a).

5 11. The process of claim 10 wherein the catalyst further comprises a promoter selected from the group consisting of LaCl₃, PrCl₃, Pr₂O₃, and combinations thereof, in the ratio of up to about 0.2 mole of promoter per mole of CuO.

12. The process of claim 10 wherein the chloridizing
10 temperature in step (a) is in the range of about 100°C to about 250°C.

13. The process of claim 1 wherein the insert support is selected from the group consisting of gamma-alumina, pumice, silica, and molecular sieve material.

15 14. The process of claim 13 wherein the weight of the catalyst comprises about 10 to about 20 percent of the total weight of the catalyst and the inert support.

15. The process of claim 1 wherein the weight of the catalyst comprises about 10 to about 20 percent of the total
20 weight of the catalyst and the inert support.

16. The process of claim 1 wherein the source of oxygen is preheated to provide at least some of the necessary heat for the evolution of Cl₂, and the reconversion of the metal chloride in the catalyst to the metal oxide.

25 17. The process of claim 1 wherein the O₂ is diluted with N₂.

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18. The process of claim 6 wherein the MnCl_2 generated in step (a) is contacted with the source of oxygen at a temperature of from about 350°C to about 375°C .

19. The process of claim 8 wherein the transition metal chloride generated in step (a) is contacted with the source of oxygen at a temperature of from about 310°C to about 375°C .

20. The process of claim 10 wherein the CuCl_2 generated in step (a) is contacted with the source of oxygen at a temperature of from about 310°C to about 330°C .

21. The process of claim 4 wherein the weight of the catalyst comprises about 10 to about 20 percent of the total weight of the catalyst and the inert support.

22. The process of claim 6 wherein the weight of the catalyst comprises about 10 to about 20 percent of the total weight of the catalyst and the inert support.

23. The process of claim 8 wherein the weight of the catalyst comprises about 10 to about 20 percent of the total weight of the catalyst and the inert support.

24. The process of claim 10 wherein the weight of the catalyst comprises about 10 to about 20 percent of the total weight of the catalyst and the inert support.

25. The process of claim 4 wherein the source of oxygen is preheated to provide at least some of the necessary heat for the evolution of Cl_2 and the reconversion of the metal chloride in the catalyst to the metal oxide.

26. The process of claim 6 wherein the source of oxygen is preheated to provide at least some of the necessary heat for the evolution of Cl_2 and the reconversion of the metal chloride in the catalyst to the metal oxide.

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27. The process of claim 8 wherein the source of oxygen is preheated to provide at least some of the necessary heat for the evolution of Cl_2 and the reconversion of the metal chloride in the catalyst to the metal oxide.

5 28. The process of claim 10 wherein the source of oxygen is preheated to provide at least some of the necessary heat for the evolution of Cl_2 and the reconversion of the metal chloride in the catalyst to the metal oxide.

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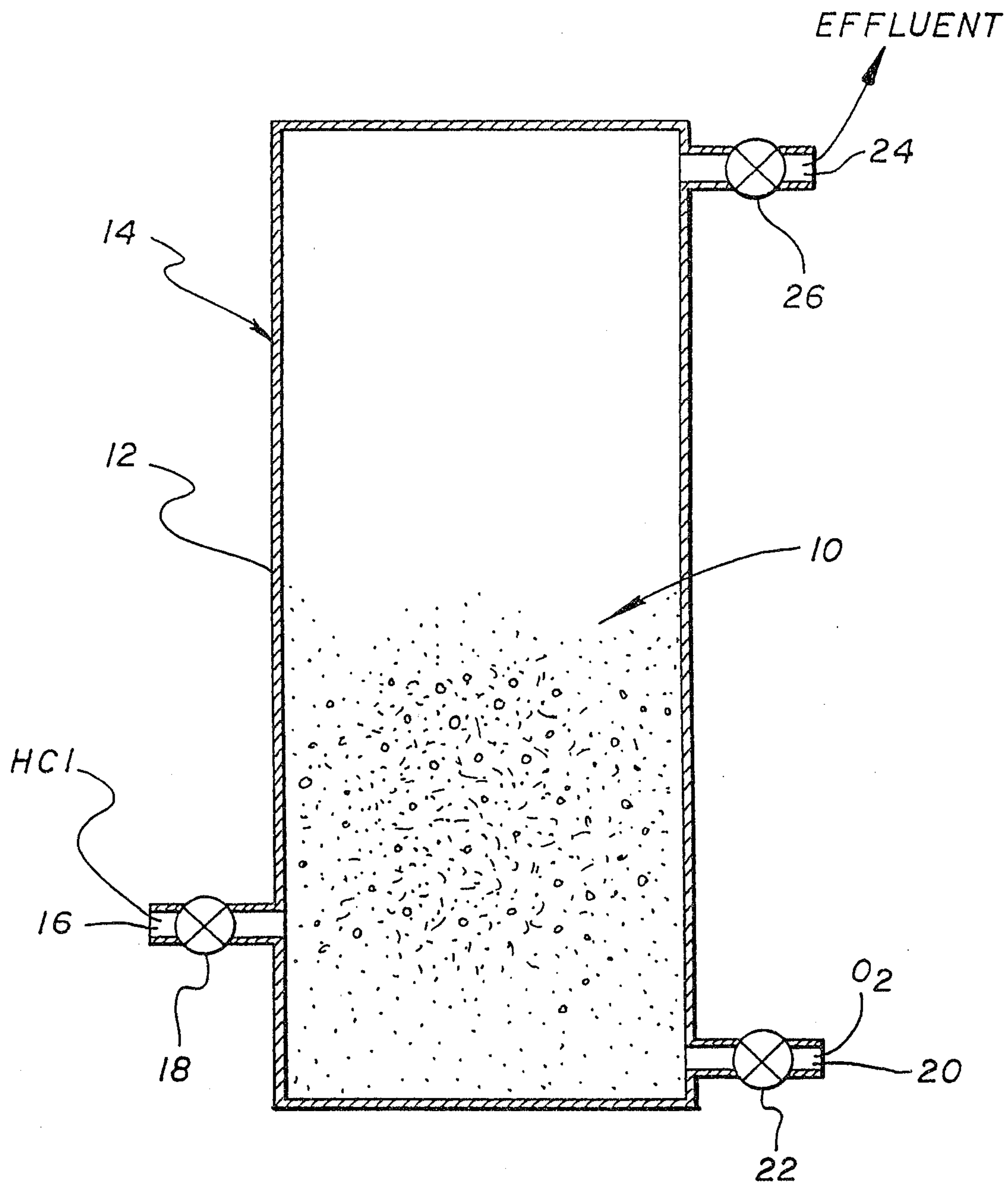


FIG. 1

