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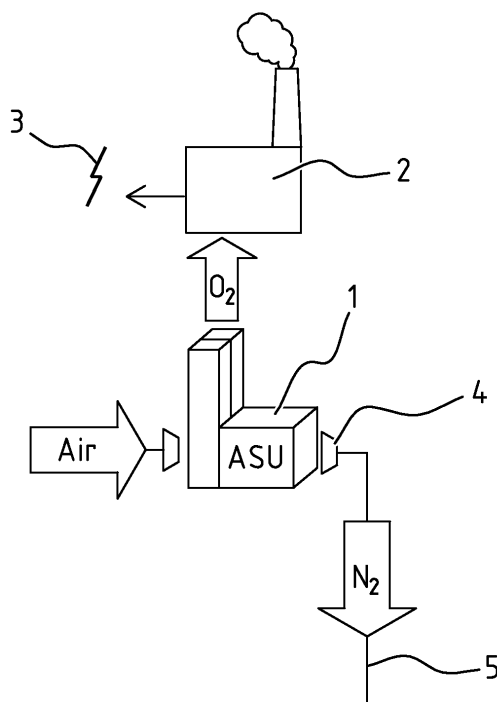
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(54) **Method and system for inhibiting contact of a corrosive displacement gas with corrosion prone natural gas production facilities**

(57) Natural gas production from an underground natural gas containing formation(20) is enhanced by initially injecting into the formation(20) a non-corrosive Nitrogen ( $N_2$ ) containing displacement gas followed by injecting into the formation a corrosive  $CO_2$  containing displacement gas such that the non corrosive displacement gas provides a barrier that inhibits the corrosive displacement gas to reach corrosion prone natural gas production facilities.

Subsequent injection of non-corrosive and corrosive displacement gases reduces the cost of displacement gas injection, inhibits corrosion of natural gas production facilities, and reduces  $CO_2$  emission into the atmosphere.



**FIG. 1**

## Description

### BACKGROUND OF THE INVENTION

**[0001]** The invention relates to a method and system for inhibiting contact of a corrosive displacement gas with corrosion prone natural gas production facilities.

**[0002]** US patent 4,765,407 discloses a method for enhancing production of gas condensates from a gas condensate reservoir by injecting a mixture of carbon dioxide and nitrogen obtained from a Claus plant into the reservoir.

**[0003]** A disadvantage of this known injection technology is that a mixture of carbon dioxide and nitrogen is corrosive and will induce corrosion of corrosion prone fluid injection and production facilities.

**[0004]** International patent application WO 2012021282 discloses a method for enhancing recovery of hydrocarbons trapped in a hydrate containing formation by intermittently injecting slugs of a carbon dioxide containing releasing agent and of a nitrogen containing reagent into the formation.

**[0005]** Canadian patent application CA 2568358 discloses a method for fracturing a hydrate or shale oil containing formation by injecting liquid nitrogen into the formation.

**[0006]** A limitation of the known nitrogen displacement gas technologies is that they are either configured to enhance production from gas condensate, hydrate and/or shale oil containing formations or from tight reservoirs by fracturing and that they are not configured inject a large volume of displacement gas into a formation to enhance natural gas production from the formation. A further limitation of the know nitrogen displacement gas injection technologies is that generation of displacement gas in Air Separation Units or other available displacement gas generation devices is expensive.

**[0007]** There is a need for a cost efficient method and system for generating displacement gas to enhance natural gas production from a natural gas containing formation, wherein a corrosive displacement gas may be used, whilst contact of the corrosive displacement gas with corrosion prone natural gas production facilities is inhibited.

**[0008]** There is a further need to reduce emissions of Carbon Dioxide into the atmosphere since Carbon Dioxide is a potential greenhouse gas that may contribute to global warming.

**[0009]** There is also a need to inject a large volume of displacement gas into an underground natural gas containing formation in order to enhance natural gas production, to preserve reservoir pressure and to inhibit subsidence of the overburden.

### SUMMARY OF THE INVENTION

**[0010]** In accordance with the invention there is provided a method for enhancing natural gas production from an underground natural gas containing formation,

the method comprising injecting into the formation a non corrosive displacement gas comprising Nitrogen followed by injecting into the formation a corrosive displacement gas comprising Carbon Dioxide.

**[0011]** Subsequent injection of non-corrosive and corrosive displacement gases allows injection of a large volume of displacement gas at low cost thereby providing a cost effective method for enhancing natural gas production, preserving reservoir pressure and inhibiting subsidence of the overburden.

**[0012]** The non corrosive displacement gas may be injected into the reservoir formation as a slug which provides in the formation a barrier that inhibits mixing of the corrosive displacement gas with the natural gas and inhibits the corrosive displacement gas to reach corrosion prone natural gas production facilities.

**[0013]** After injecting the slug of non-corrosive displacement gas a slug of water may be injected into the formation before injecting the corrosive displacement gas into the formation to provide an additional barrier that inhibits the corrosive displacement gas to reach corrosion prone natural gas production facilities.

**[0014]** The Nitrogen may be generated in an Air Separation Unit(ASU) of a power or other industrial plant in which a mixture of fuel oxygen enriched air generated by the ASU is combusted to generate electrical energy and the Carbon Dioxide may be obtained from flue gases of the plant.

**[0015]** In accordance with the invention there is also provided a system for enhancing natural gas production from an underground natural gas containing formation, the system comprising:

- an injection well assembly configured to subsequently inject a non corrosive displacement gas comprising Nitrogen and a corrosive displacement gas comprising Carbon Dioxide into the formation during a period of at least several months;
- a production well assembly configured to produce natural gas during at least part of said period; and
- a power plant in which fuel is combusted with oxygen enriched air obtained from an Air Separation Unit(ASU) which is configured to generate the Nitrogen for use in the non corrosive displacement gas;
- flue gas separation means connected to a flue gas exhaust assembly of the power plant for separating the Carbon Dioxide from flue gases of the power plant.

**[0016]** The use of Nitrogen and Carbon dioxide generated as by-products of a power plant operated with oxygen enriched air significantly reduces capital and operating cost of the non corrosive and corrosive displacement gas injection into a gas containing formation.

**[0017]** These and other features, embodiments and advantages of the method and/or system according to the invention are described in the accompanying claims, abstract and the following detailed description of non-

limiting embodiments depicted in the accompanying drawings, in which description reference numerals are used which refer to corresponding reference numerals that are depicted in the drawings.

**[0018]** Similar reference numerals in different figures denote the same or similar objects.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0019]**

Figure 1 shows how Nitrogen for use in the method according to the invention is separated from oxygen in an Air Separation Unit(ASU);

Figure 2A schematically shows how production of Natural Gas is enhanced by one embodiment of the Nitrogen Assisted Depletion Drive (NADD)method according to the invention;

Figure 2B schematically shows how production of Natural Gas is enhanced by another embodiment of the Nitrogen Assisted Depletion Drive (NADD) in combination with the Nitrogen Enhanced Residual Gas (NERG) method according to the invention;

Figure 2C schematically shows how production of Natural Gas is enhanced by a yet another embodiment of the combination of the Nitrogen Assisted Depletion Drive (NADD) and the Nitrogen Enhanced Residual Gas (NERG) method according to the invention;

Figure 2D schematically shows how production of Natural Gas is enhanced by a further embodiment of the Nitrogen Enhanced Residual Gas (NERG) method according to the invention; and

Figure 3 schematically shows how production of Natural Gas is enhanced in a tight gas reservoir by yet a further embodiment of either the Nitrogen Assisted Depletion Drive (NADD) or the Nitrogen Enhanced Residual Gas (NERG) method according to the invention.

#### DETAILED DESCRIPTION OF THE DEPICTED EMBODIMENTS

**[0020]**

Figure 1 shows how Nitrogen ( $N_2$ ) is separated from oxygen ( $O_2$ ) in an Air Separation Unit (ASU)(1) of a power plant (2) that generates electrical energy (3) by combusting fuel using Oxygen( $O_2$ ) or an Oxygen enriched air mixture. The generated Nitrogen ( $N_2$ ) is subsequently pumped by a compressor (4) into a nitrogen supply conduit (5) that is connected to one or more Nitrogen injections wells 22, 31A-D as shown in Figures 2A-D and 3.

Figures 2A-2D schematically show how Nitrogen ( $N_2$ ) that may be generated by the ASU (1) shown in Figure 1 is injected into an underground gas reservoir 20 to perform a Nitrogen Assisted Depletion

Drive (NADD) or the Nitrogen Enhanced Residual Gas (NERG) method according to the invention.

**[0021]** The underground gas reservoir 20 is located in a permeable gas bearing formation layer, also known as the reservoir formation, which is located underneath an impermeable gas cap layer 21 and the Nitrogen ( $N_2$ ) is injected via a Nitrogen injection well 22 into a part of the reservoir formation 20 at a distance to the production well at 20A of the reservoir formation 20 whilst natural gas (comprising  $CH_4$  and other constituents) is produced via a natural gas production well 23.

**[0022]** In the embodiment shown in Figure 2A the reservoir formation 20 only comprises a minor fraction of water which is dispersed in the pores of the reservoir formation 20, so that there is no mobile water accumulation in this part of the reservoir formation 20.

**[0023]** In the embodiment shown in Figure 2B there is significant accumulation of water ( $H_2O$ ) in the pores of near the lower edge 20A of the reservoir formation 20, so that there is a water layer 24 having a upper water level 25 within the pores of the reservoir formation 20, but which water layer may comprise a substantial amount of natural gas that is trapped as a discontinuous phase, i.e. as small bubbles, in the water.

**[0024]** In the embodiment shown in Figure 2B the Nitrogen ( $N_2$ ) is injected into the water layer 24 to stimulate migration of natural gas ( $CH_4$ ) from the water layer 24 and to enhance flux of natural gas ( $CH_4$ ) through the reservoir formation 20 to the natural gas production well 23.

**[0025]** Figure 2C schematically shows how natural gas ( $CH_4$ ) has been partly separated from the pores near the lower edge 20A of the reservoir formation 20 and pore water reaches the production well 23 leaving trapped or residual gas bubbles behind.

**[0026]** Figure 2D schematically shows an embodiment where the pores of substantially the entire reservoir formation 20 are filled with a water-gas mixture comprising pore water and natural gas ( $CH_4$ ), which mixture is stimulated to flow into the production well 23 by injecting Nitrogen into the injection well 22 near the lower edge of the reservoir formation 20.

**[0027]** Figure 3 schematically shows how production of Natural Gas ( $CH_4$ ) from a tight gas reservoir or residual gas formation 30 is enhanced by yet another embodiment of the Nitrogen Assisted Depletion Drive (NADD) or Nitrogen Enhanced Residual Gas (NERG) process according to the invention wherein Nitrogen is injected into possibly several Nitrogen injection wells 31A-D and natural gas ( $CH_4$ ) is produced via possibly several production wells 32A-D traversing the tight gas formation 30.

#### **Claims**

1. A method for enhancing natural gas production from an underground natural gas containing formation,

the method comprising injecting into the formation a non-corrosive displacement gas comprising Nitrogen followed by injecting into the formation a corrosive displacement gas comprising Carbon Dioxide.

2. The method of claim 1, wherein the non-corrosive displacement gas is injected into the formation as a slug which provides in the formation a barrier that inhibits mixing of the corrosive displacement gas with the natural gas and inhibits the corrosive displacement gas to reach corrosion prone natural gas production facilities. 5
3. The method of claim 2, wherein after injecting the slug of the non corrosive displacement gas a slug of water is injected into the formation before injecting the corrosive displacement gas into the formation. 10
4. The method of any one of claims 1-3, wherein the Nitrogen is generated in an Air Separation Unit(ASU) of a power or other industrial plant in which a mixture of fuel oxygen enriched air generated by the ASU is combusted to generate electrical energy and the Carbon Dioxide is obtained from flue gases of the plant. 15
5. The method of any one of claims 1-4, wherein the non corrosive and corrosive displacement gases are each injected into the formation during a period of at least one month, during at least part of which period the natural gas is produced from the formation. 20
6. The method of any one of claims 1-5, wherein the non corrosive and corrosive displacement gases are injected into the formation at a pressure below a fracturing pressure of the formation. 25
7. The method of any one of claims 1, 2 and 4-6, wherein the formation comprises residual natural gas trapped in pore water below a Free Water Level (FWL) and the non corrosive and corrosive displacement gases are injected into the pore water below the Free Water Level (FWL) in the formation. 30
8. The method of claim 6 or 7, wherein the formation is a tilted permeable formation layer with an upper and a lower edge and the non corrosive and corrosive displacement gases are injected into the formation in the vicinity of the lower edge of the tilted permeable underground formation layer. 35
9. The method of any one of claim 1-8, wherein the formation does not contain a substantial amount of associated natural gas formed by natural gas associated to crude oil production, natural gas in a gas cap above an oil reservoir, crude oil and/or condensates. 40

10. A system for enhancing natural gas production from an underground natural gas containing formation, the system comprising:

- an injection well assembly configured to subsequently inject a non corrosive displacement gas comprising Nitrogen and a corrosive displacement gas comprising Carbon Dioxide into the formation during a period of at least one month;
- a production well assembly configured to produce natural gas during at least part of said period; and
- a power plant in which fuel is combusted with oxygen enriched air obtained from an Air Separation Unit(ASU) which is configured to generate the Nitrogen for use in the non corrosive displacement gas;
- flue gas separation means connected to a flue gas exhaust assembly of the power plant for separating the Carbon Dioxide from flue gases of the power plant.

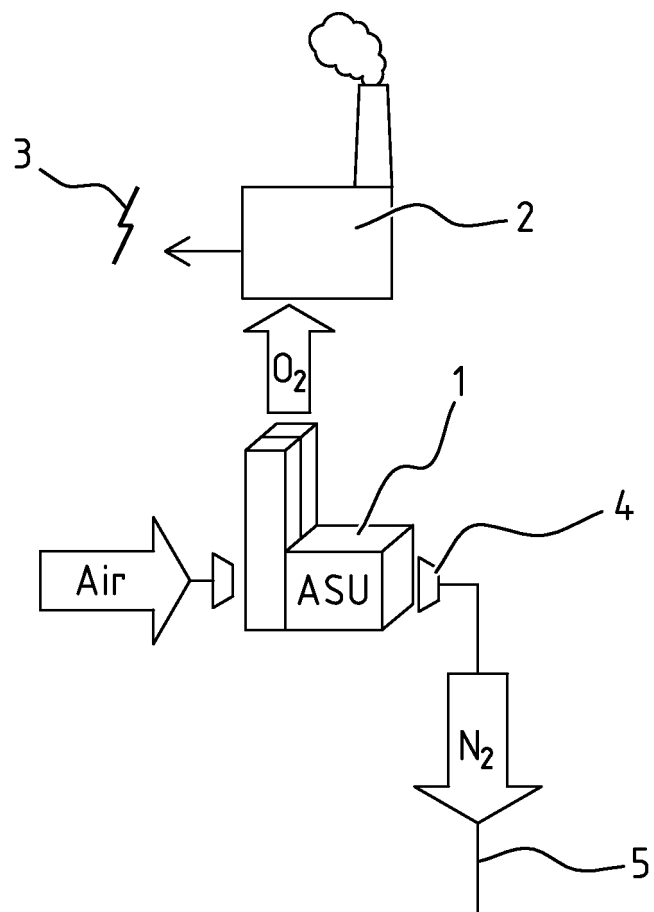
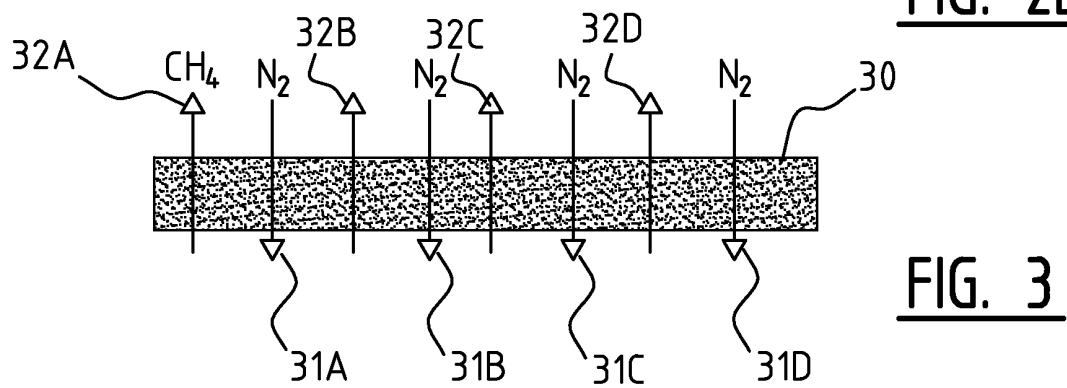
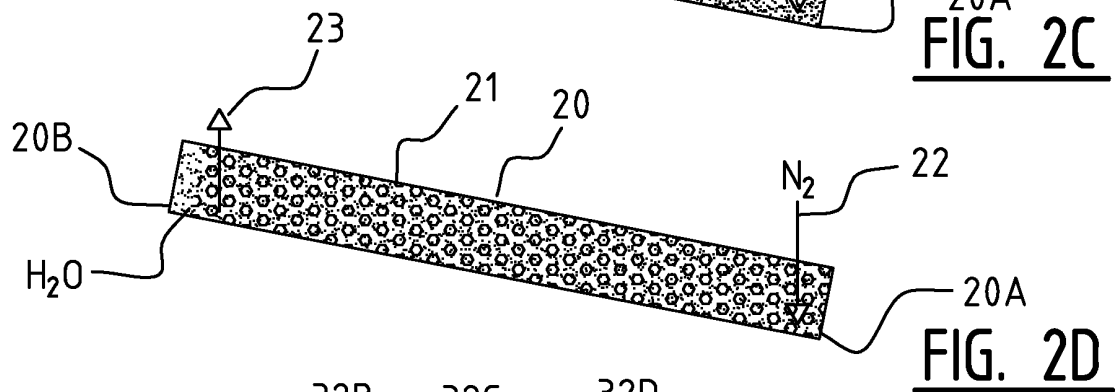
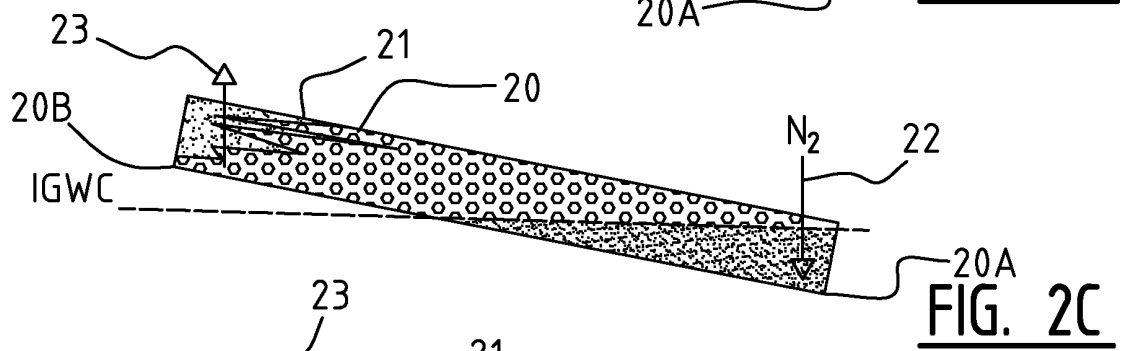
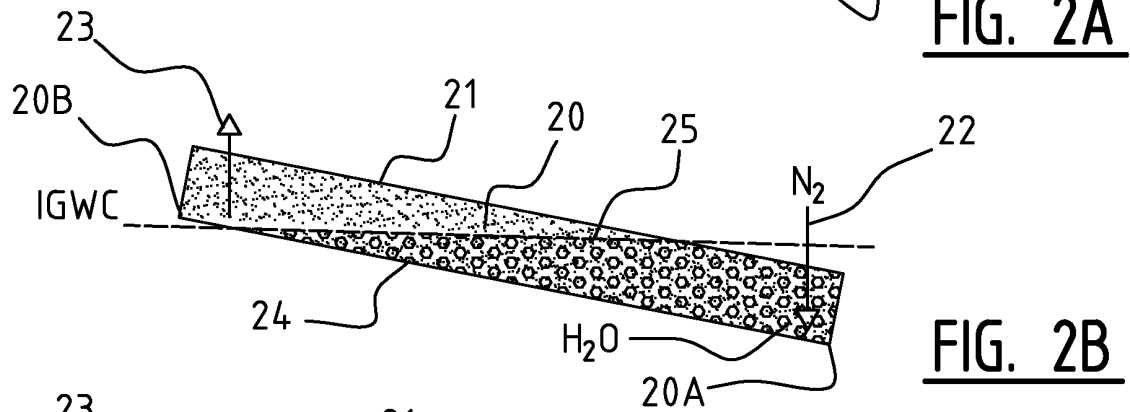
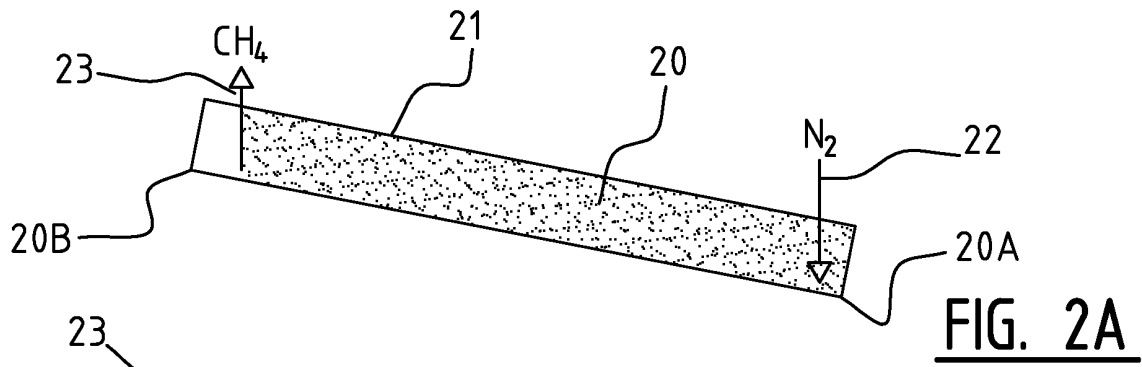


FIG. 1





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Application Number  
EP 12 19 4473

| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                    |                                                  |                                         |
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