

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization

International Bureau

(43) International Publication Date
19 April 2018 (19.04.2018)



(10) International Publication Number
WO 2018/069934 A2

(51) International Patent Classification:
E21B 43/16 (2006.01)

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

(21) International Application Number:

PCT/IN2017/050461

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

(22) International Filing Date:

10 October 2017 (10.10.2017)

Published:

— *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

201611034721 10 October 2016 (10.10.2016) IN

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(81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every
kind of regional protection available*): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) Title: METHANE PRODUCTION FROM UNDERGROUND COALBED METHANE WELLS

(57) Abstract: The present disclosure reveals processes to promote production of methane gas from underground coalbed methane wells by bio-stimulation with optimized nutrient media. Also disclosed are compositions of the optimized nutrient media used for bio-stimulation of methane gas from underground coalbed methane wells and strategies adopted for achieving increased methane production.



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METHANE PRODUCTION FROM UNDERGROUND COALBED METHANE WELLS

FIELD OF THE INVENTION

5 [001] The present disclosure relates to production of methane from underground coalbed methane wells. Enhanced Gas production is achieved by injecting a nutrient media into the coalbed methane well to enhance the production and recovery of methane.

BACKGROUND OF THE INVENTION

10 [002] Petroleum hydrocarbons are a major source of energy providing 50% of the energy used all over the world. However, with the increasing demand and finite source of fossil fuels, there is an urgent need for alternative source(s) of hydrocarbons. Coalbed methane (CBM) has emerged as a clean non-conventional source of energy to supplement the rising demand of conventional hydrocarbons.

15 The term CBM refers to a type of natural gas, composed mostly of methane, which is generally present in coalbeds. India is the third largest coal producer in the world and commercial production of CBM has good prospects (Ojha et al., International Journal of Chemical Engineering and Application, 2011, 2(4), 256-260).

[003] Coalbed wells are a source of natural gas produced either biologically or
20 thermogenically. Thermogenic methane is produced by thermo-chemical devolatilization of coal, whereas biogenic methane is the result of a series of biochemical reactions by which coal is converted into methane by various types of bacteria under anaerobic conditions. There are three functionally different trophic groups of bacteria required for methanogenesis, which are: (1) hydrolytic
25 fermentive, (2) syntrophic acetogenic and (3) methanogenic bacteria. Hydrolytic fermentive and syntrophic acetogens hydrolyses complex polymers into monomers. These monomers are finally utilized by methanogens to produce methane (Conrad et al., FEMS Microbiology Ecology, 1999, 28(3), 193-202). The methanogenic bacteria generate methane by several pathways. The universal mode of methane
30 production is hydrogen mediated reduction of carbon dioxide. Environment factors

such as pH, salinity, temperature and nutritional factors (inorganic and organic) affect methanogenesis. Though, the process of biogenic methane production is poorly understood and is a highly complex process, such processes are pervasive in methanogens.

5 **[004]** Furthermore, a methanogenic-generating consortium extracted from coal is observed to grow on low-volatile bituminous coal as the sole carbon source. A microbial consortium was successfully applied to bioassay methane generating potential in 18 coal samples (Jones et al., Applied and Environmental Microbiology, 2008, 76(21), 7013-7022). Subbituminous coal from a non-
10 productive well in south Texas was stimulated to produce methane in microcosms when the native population is supplemented with nutrients (bio stimulation) or when nutrients and a consortium of bacteria and methanogens enriched wetlands sediments are added (bio augmentation). In a recent study, microbial methane production from bituminous coal waste, lignite and bituminous coal material under
15 diverse conditions was shown.

[005] Physical intercession includes drilling and fracturing techniques which increases methane recovery from coal (US Patent No. 3,934,649). Other improved methods involve the application of external factors directly into the coalbeds. These include, for example, the injection of gases such as cryogenic liquid nitrogen
20 (US Patent No. 5,464,01) and CO₂ (U.S. Patent No. 5,402,847, U.S. Patent No. 8247009, U.S. Publication No. 5332036 A); and the injection of hot fluids such as water or steam (U.S. Patent No. 5,072,990). Microbial production of methane and carbon dioxide from lignite, bituminous coal and waste coal material (A.Opara et al., International Journal of Coal Geology, 2012, 96-97, 1-8). Various methods are
25 intended to increase the permeability of the coal bed seams either physically (U.S. Patent No. 5,014,788) or chemically (U.S. Patent No. 5,865,248).

[006] In the Jharia coalfield in India, which is considered to be the most prospective area, the methane content is estimated to be between 7.3 and 23.8 m³
30 per ton of coal within the depth range of 150 and 1200 m. Analysis indicates every 100m increase in depth is associated with a 1.3m³ increase in methane content. Yet, efficient methane production is limited largely due to lack of reservoir

permeability, and techniques to efficiently and maximally extract the resident methane.

SUMMARY OF THE INVENTION

5 [007] In an aspect of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6
10 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the methane gas from the underground coalbed methane well as per industry practices, wherein the production of the methane gas from the underground coalbed methane well is more than production of methane gas otherwise obtained from an underground coalbed methane well not injected with said nutrient media while
15 producing gas as per standard industry practices for the underground coalbed methane well.

[008] In an aspect of the present disclosure, there is provided a nutrient media comprising: (i) formation water obtained from an underground coalbed methane well; (ii) at least one reducing agent; (iii) K_2HPO_4 ; (iv) KH_2PO_4 ; (v) NaCl; (vi)
20 NH_4Cl ; (vii) yeast extract; (viii) $NaHCO_3$; (ix) $MgCl_2 \cdot 6H_2O$; and (x) sodium acetate.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

[009] The following drawings form part of the present specification and are included to further illustrate aspects of the present disclosure. The disclosure may
25 be better understood by reference to the drawings in combination with the detailed description of the specific embodiments presented herein. The drawings / results are result of laboratory incubation studies where the sample bottles were initially contained with the liquid inoculated mix with Nitrogen gas in head-space and after incubation, the head-space gas was sampled and analyzed based on which the gas

production (Methane / CO₂) figures as a result of microbial incubation are reported.

5 [0010] Figure 1A-C depicts the percent gas production by methanogens from coal as substrate using MBP nutrient media in the presence of peptone, yeast extract or ammonium chloride respectively at various concentrations, in accordance with an embodiment of the present disclosure.

[0011] Figure 2A-C depicts the percent gas production by methanogens from coal as a substrate using MSP nutrient media in the presence of ammonium chloride, yeast extract, and sodium carbonate respectively at various concentrations, in accordance with an embodiment of the present disclosure.

10 [0012] Figure 3A-C depicts the percent gas production by methanogens from coal as a substrate using MPB nutrient media with variable nitrogen sources (ammonium chloride, corn steep liquor (CSL), and urea respectively) at various concentrations, in accordance with an embodiment of the present disclosure.

15 [0013] Figure 4 depicts the percent gas production by methanogens from coal as substrate using MBP nutrient media, in accordance with an embodiment of the present disclosure.

[0014] Figure 5 depicts the percent gas production by methanogens using coal as substrate using optimized MPB nutrient media, in accordance with an embodiment of the present disclosure.

20 [0015] Figure 6 depicts field study observations after bio-stimulation in underground coalbed well, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

25 [0016] Those skilled in the art will be aware that the present disclosure is subject to variations and modifications other than those specifically described. It is to be understood that the present disclosure includes all such variations and modifications. The disclosure also includes all such steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively, and any and all combinations of any or more of such steps or features.

30

Definitions

[0017] For convenience, before further description of the present disclosure, certain terms employed in the specification, and examples are collected here. These definitions should be read in the light of the remainder of the disclosure and
5 understood as by a person of skill in the art. The terms used herein have the meanings recognized and known to those of skill in the art, however, for convenience and completeness, particular terms and their meanings are set forth below.

[0018] The articles “a”, “an” and “the” are used to refer to one or to more than
10 one (i.e., to at least one) of the grammatical object of the article.

[0019] The terms “comprise” and “comprising” are used in the inclusive, open sense, meaning that additional elements may be included. It is not intended to be construed as “consists of only”.

[0020] Throughout this specification, unless the context requires otherwise the
15 word “comprise”, and variations such as “comprises” and “comprising”, will be understood to imply the inclusion of a stated element or step or group of element or steps but not the exclusion of any other element or step or group of element or steps.

[0021] The term “including” is used to mean “including but not limited to”.
20 “Including” and “including but not limited to” are used interchangeably

[0022] The term “coalbed methane/CBM well” refers to a well drilled and completed into a water bearing coal seam/s which have natural fractures or artificial fractures created through hydro-fracturing and having installed artificial lift facilities for dewatering the coal seams and also for obtaining the gas
25 production, all as per the standard industry practices.

[0023] “Bio-stimulation” for the purposes of the document refers to injecting underground coalbed methane well, an optimized specific nutrient medium for facilitating the growth of bacteria and hence, promoting the generation of methane gas.

[0024] “Pre-bio-stimulation” refers to the condition prior to the injecting of an
30 optimized specific nutrient medium into an underground coalbed methane well.

[0025] “Post bio-stimulation” refers to the condition post injecting an optimized specific nutrient medium into an underground coalbed methane well.

[0026] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art
5 to which this disclosure belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the disclosure, the preferred methods, and materials are now described. All publications mentioned herein are incorporated herein by reference.

[0027] The present disclosure is not to be limited in scope by the specific
10 embodiments described herein, which are intended for the purposes of exemplification only. Functionally-equivalent products, compositions, and methods are clearly within the scope of the disclosure, as described herein.

[0028] The present document reveals processes for achieving enhanced production of methane gas from underground coalbed wells. Also, it discloses nutrient media
15 which is used for injecting into the underground coalbed wells for enhancing the production of methane gas. Various parameters assessed during production of methane gas has been discussed in the embodiments.

[0029] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well,
20 comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the methane gas from the underground coalbed methane well as per industry practices,
25 wherein the production of the methane gas from the underground coalbed methane well is more than production of methane gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well.

[0030] In an embodiment of the present disclosure, there is provided a process for
30 promoting production of methane gas from underground coalbed methane well,

comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) formation water obtained from an underground coalbed methane well; (ii) at least one reducing agent; (iii) K_2HPO_4 ; (iv) KH_2PO_4 ; (v) NaCl; (vi) NH_4Cl ; (vii) yeast extract; (viii) $NaHCO_3$; (ix) $MgCl_2 \cdot 6H_2O$; and (x) sodium acetate.

[0031] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) formation water obtained from an underground coalbed methane well; (ii) at least one reducing agent; (iii) K_2HPO_4 ; (iv) KH_2PO_4 ; (v) NaCl; (vi) NH_4Cl ; (vii) yeast extract; (viii) $NaHCO_3$; (ix) $MgCl_2 \cdot 6H_2O$; and (x) sodium acetate, and wherein the formation water comprises: (1) 18 – 26% by weight of chloride; (2) 1.60 – 2% by weight of fluoride; (3) 7.40 – 8.9% by weight of sulphate; and (4) 3 - 3.5% by weight of iron.

[0032] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; 5 (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well 10 not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) formation water obtained from an underground coalbed methane well; (ii) at least one reducing agent; (iii) K_2HPO_4 ; (iv) KH_2PO_4 ; (v) NaCl; (vi) NH_4Cl ; (vii) yeast extract; (viii) $NaHCO_3$; (ix) $MgCl_2 \cdot 6H_2O$; and (x) 15 sodium acetate, and wherein the formation water comprises: (1) 30 - 250 mg/L chloride; (2) 0.5 - 2 mg/L fluoride; (3) 5 - 9 mg/L sulphate; and (4) 2 - 14 mg/L iron.

[0033] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient 20 media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the methane gas from the underground coalbed methane well as per industry practices, 25 wherein the production of the methane gas from the underground coalbed methane well is more than production of methane gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) 0.1 - 0.6 % by weight 30 of K_2HPO_4 ; (ii) 0.1 - 0.3 % by weight of KH_2PO_4 ; (iii) 0.9 - 1.5 gm/L NaCl; (iv) 0.9 - 1.5 % by weight of NH_4Cl ; (v) 1.0 - 2.0 % by weight of yeast extract; (vi)

0.9 – 1.5 % by weight of NaHCO_3 ; (vii) 0.1 – 0.3 % by weight of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; (viii) 0.9 – 1.2 % by weight of sodium acetate; (ix) 0.4 – 1.2 % by weight of L-Cysteine hydrochloride; and (x) formation water to make up to 100% of the nutrient media, and wherein the formation water comprises: (1) 18-26% by weight of chloride; (2) 1.60-2% by weight of fluoride; (3) 7.40-8.9% mg/L sulphate; and (4) 3-3.5% by weight of iron.

[0034] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C ; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) 0.1 – 0.6 % by weight of K_2HPO_4 ; (ii) 0.1 – 0.3 % by weight of KH_2PO_4 ; (iii) 0.9 – 1.5 gm/L NaCl ; (iv) 0.9 – 1.5 % by weight of NH_4Cl ; (v) 1.0 – 2.0 % by weight of yeast extract; (vi) 0.9 – 1.5 % by weight of NaHCO_3 ; (vii) 0.1 – 0.3 % by weight of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; (viii) 0.9 – 1.2 % by weight of sodium acetate; (ix) 0.4 – 1.2 % by weight of L- Cysteine hydrochloride; and (x) formation water to make up to 100% of the nutrient media, and wherein the formation water comprises: (1) 30 - 250 mg/L chloride; (2) 0.5 – 2 mg/L fluoride; (3) 5 - 9 mg/L sulphate; and (4) 2 - 14 mg/L iron.

[0035] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C ; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the

gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) 0.2 – 0.5 % by weight of K_2HPO_4 ; (ii) 0.1 – 0.2 % by weight of KH_2PO_4 ; (iii) 0.9 – 1 % by weight of NaCl; (iv) 0.9 – 1 % by weight of NH_4Cl ; (v) 1.0 – 1.5 % by weight of yeast extract; (vi) 0.9 – 1 % by weight of $NaHCO_3$; (vii) 0.1 – 0.2 % by weight of $MgCl_2 \cdot 6H_2O$; (viii) 0.9 – 1 % by weight of sodium acetate; (ix) 0.5 – 1.2 % by weight of L- Cysteine hydrochloride; and (x) formation water to make up to desired volume, wherein the formation water comprises: (1) 50 - 60 mg/L chloride; (2) 0.8 - 1 mg/L fluoride; (3) 5.5 – 7.5 mg/L sulphate; and (4) 3.2 – 3.5 mg/L iron.

[0036] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) 0.2 – 0.5 % by weight of K_2HPO_4 ; (ii) 0.1 – 0.2 % by weight of KH_2PO_4 ; (iii) 0.9 – 1 % by weight of NaCl; (iv) 0.9 – 1 % by weight of NH_4Cl ; (v) 1.0 – 1.5 % by weight of yeast extract; (vi) 0.9 – 1 % by weight of $NaHCO_3$; (vii) 0.1 – 0.2 % by weight of $MgCl_2 \cdot 6H_2O$; (viii) 0.9 – 1 % by weight of sodium acetate; (ix) 0.5 – 1.2 % by weight of L- Cysteine hydrochloride; and (x) formation water to make up to desired volume, wherein the formation water

comprises: (1) 18-26% by weight of chloride; (2) 1.60-2% by weight of fluoride; (3) 7.40-8.9% mg/L sulphate; and (4) 3-3.5% by weight of iron.

[0037] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the nutrient media comprises: (i) 0.4 % by weight of K_2HPO_4 ; (ii) 0.2 % by weight of KH_2PO_4 ; (iii) 1 % by weight of NaCl; (iv) 1 % by weight of NH_4Cl ; (v) 1 % by weight of yeast extract; (vi) 1 % by weight of $NaHCO_3$; (vii) 0.2 % by weight of $MgCl_2 \cdot 6H_2O$; (viii) 1 % by weight of sodium acetate; (ix) 0.5 % by weight of L-Cysteine hydrochloride; and (x) formation water to make up to desired volume, wherein said formation water comprises: (1) 5.9 mg/L chloride; (2) 0.82 mg/L fluoride; (3) 5.5 mg/L sulphate; and (4) 3.3 mg/L iron.

[0038] In an embodiment of the present disclosure, there is provided a process for promoting production of methane gas from underground coalbed methane well, comprising: (a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C; (b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks; (c) unsealing the underground coalbed methane well; and (d) extracting the gas from the underground coalbed methane well as per industry practices, wherein the production of the gas from the underground coalbed methane well is more than production of gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing the gas as per standard industry practices for the underground coalbed methane well, and wherein the

nutrient media comprises: (i) formation water obtained from an underground coalbed methane well; (ii) at least one reducing agent; (iii) K_2HPO_4 ; (iv) KH_2PO_4 ; (v) $NaCl$; (vi) NH_4Cl ; (vii) yeast extract; (viii) $NaHCO_3$; (ix) $MgCl_2 \cdot 6H_2O$; and (x) sodium acetate, and wherein the reducing agent is L-cysteine hydrochloride.

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[0039] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the gas also comprises carbon dioxide (CO_2) having lighter carbon isotopic composition as compared to CO_2 in gas which is produced without injecting the nutrient media in the underground coalbed methane well.

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[0040] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the methane gas comprises at least 95% methane.

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[0041] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the gas comprises at least 97.5% methane.

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[0042] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the gas bears no significant change in its methane composition and / or heating value compared to methane gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media.

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[0043] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the underground coalbed methane well has an improved fluid flow after injection of the nutrient media.

[0044] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the underground coalbed methane well has a temperature in the range of $25^\circ C$ to $70^\circ C$.

30

[0045] In an embodiment of the present there is provided a process for promoting production of methane gas from underground coalbed methane well as described

herein, wherein the underground coalbed methane well has a temperature in the range of 40°C to 70°C.

[0046] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the underground coalbed methane well has a temperature
5 in the range of 40°C to 50°C.

[0047] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the underground coalbed methane well has a temperature
10 of 41.5°C.

[0048] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the coalbed methane well comprises carbonaceous coal. In another embodiment, the coal is primarily sub-bituminous, bituminous or
15 mixture thereof.

[0049] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, the process further comprising carrying out characterization and analysis of formation water from coalbed methane well for pH, conductivity, heavy
20 metals and toxic ions, volatile fatty acids, methane gas analysis including carbon isotope studies before and after injecting the nutrient media.

[0050] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the nutrient media pH is in the range of 6– 8.

[0051] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the nutrient media pH is in the range of 7– 7.5.
25

[0052] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the nutrient media pH is in the range of 7– 8.
30

[0053] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as described herein, wherein the nutrient media pH is 7.8.

[0054] In an embodiment of the present disclosure there is provided a nutrient media comprising: (i) formation water obtained from an underground coalbed methane well; (ii) at least one reducing agent; (iii) K_2HPO_4 ; (iv) KH_2PO_4 ; (v) NaCl; (vi) NH_4Cl ; (vii) yeast extract; (viii) $NaHCO_3$; (ix) $MgCl_2 \cdot 6H_2O$; and (x) sodium acetate.

[0055] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water comprises: (i) 18 – 26% by weight of chloride; (ii) 1.60 – 2% by weight of fluoride; (iii) 7.40 – 8.9% by weight of sulphate; and (iv) 3 - 3.5% by weight of iron.

[0056] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water comprises: (i) 20 – 24% by weight of chloride; (ii) 1.70 – 1.90% by weight of fluoride; (iii) 7.50 – 8.5% by weight of sulphate; and (iv) 3.1 - 3.4% by weight of iron.

[0057] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water comprises: (i) 30 - 250 mg/L chloride; (ii) 0.5 – 2 mg/L fluoride; (iii) 5 - 9 mg/L sulphate; and (iv) 2 - 14 mg/L iron.

[0058] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water comprises: (i) 50 - 60 mg/L chloride; (ii) 0.8 - 1 mg/L fluoride; (iii) 5.5 – 7.5 mg/L sulphate; and (iv) 3.2 – 3.5 mg/L iron.

[0059] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water comprises: (i) 5.9 mg/L chloride; (ii) 0.82 mg/L fluoride; (iii) 5.5 mg/L sulphate; and (iv) 3.3 mg/L iron.

[0060] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the reducing agent is L-cysteine hydrochloride.

[0061] In an embodiment of the present disclosure there is provided a nutrient media comprising: (a) 0.1 – 0.6 % by weight of K_2HPO_4 ; (b) 0.1 – 0.3 % by weight

of KH_2PO_4 ; (c) 0.9 – 1.5 gm/L NaCl; (d) 0.9 – 1.5 % by weight of NH_4Cl ; (e) 1.0 – 2.0 % by weight of yeast extract; (f) 0.9 – 1.5 % by weight of NaHCO_3 ; (g) 0.1 – 0.3 % by weight of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; (h) 0.9 – 1.2 % by weight of sodium acetate; (i) 0.4 – 1.2 % by weight of L- Cysteine hydrochloride; and (j) formation water to
5 make up to 100% of the nutrient media, wherein the formation water comprises: (i) 18-26% by weight of chloride; (ii) 1.60-2% by weight of fluoride; (iii) 7.40-8.9% mg/L sulphate; and (iv) 3-3.5% by weight of iron.

[0062] In an embodiment of the present disclosure there is provided a nutrient media comprising: (a) 0.1 – 0.6 % by weight of K_2HPO_4 ; (b) 0.1 – 0.3 % by weight
10 of KH_2PO_4 ; (c) 0.9 – 1.5 gm/L NaCl; (d) 0.9 – 1.5 % by weight of NH_4Cl ; (e) 1.0 – 2.0 % by weight of yeast extract; (f) 0.9 – 1.5 % by weight of NaHCO_3 ; (g) 0.1 – 0.3 % by weight of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; (h) 0.9 – 1.2 % by weight of sodium acetate; (i) 0.4 – 1.2 % by weight of L- Cysteine hydrochloride; and (j) formation water to make up to 100% of the nutrient media, wherein the formation water comprises: (i)
15 30 - 250 mg/L chloride; (ii) 0.5 – 2 mg/L fluoride; (iii) 5 - 9 mg/L sulphate; and (iv) 2 - 14 mg/L iron.

[0063] In an embodiment of the present disclosure there is provided a nutrient media comprising: (a) 0.2 – 0.5 % by weight of K_2HPO_4 ; (b) 0.1 – 0.2 % by weight
20 of KH_2PO_4 ; (c) 0.9 – 1 % by weight of NaCl; (d) 0.9 – 1 % by weight of NH_4Cl ; (e) 1.0 – 1.5 % by weight of yeast extract; (f) 0.9 – 1 % by weight of NaHCO_3 ; (g) 0.1 – 0.2 % by weight of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; (h) 0.9 – 1 % by weight of sodium acetate; (i) 0.5 – 1.2 % by weight of L- Cysteine hydrochloride; and (j) formation water to make up to desired volume, wherein the formation water comprises: (i) 18-26% by
25 weight of chloride; (ii) 1.60-2% by weight of fluoride; (iii) 7.40-8.9% mg/L sulphate; and (iv) 3-3.5% by weight of iron.

[0064] In an embodiment of the present disclosure there is provided a nutrient media comprising: (a) 0.2 – 0.5 % by weight of K_2HPO_4 ; (b) 0.1 – 0.2 % by weight
30 of KH_2PO_4 ; (c) 0.9 – 1 % by weight of NaCl; (d) 0.9 – 1 % by weight of NH_4Cl ; (e) 1.0 – 1.5 % by weight of yeast extract; (f) 0.9 – 1 % by weight of NaHCO_3 ; (g) 0.1 – 0.2 % by weight of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; (h) 0.9 – 1 % by weight of sodium acetate; (i) 0.5 – 1.2 % by weight of L- Cysteine hydrochloride; and (j) formation water to

make up to desired volume, wherein the formation water comprises: (i) 50 - 60 mg/L chloride; (ii) 0.8 - 1 mg/L fluoride; (iii) 5.5 – 7.5 mg/L sulphate; and (iv) 3.2 – 3.5 mg/L iron. In an embodiment of the present disclosure there is provided a nutrient media comprising: (a) 0.4 % by weight of K_2HPO_4 ; (b) 0.2 % by weight of KH_2PO_4 ; (c) 1 % by weight of NaCl; (d) 1 % by weight of NH_4Cl ; (e) 1 % by weight of yeast extract; (f) 1 % by weight of $NaHCO_3$; (g) 0.2 % by weight of $MgCl_2 \cdot 6H_2O$; (h) 1 % by weight of sodium acetate; (i) 0.5 % by weight of L-Cysteine hydrochloride; and (j) formation water to make up to desired volume, wherein said formation water comprises: (i) 5.9 mg/L chloride; (ii) 0.82 mg/L fluoride; (iii) 5.5 mg/L sulphate; and (iv) 3.3 mg/L iron.

[0065] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the nutrient media is suitable for growth of methanogenic bacteria.

[0066] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the nutrient media pH is in the range of 6– 8.

[0067] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the nutrient media pH is in the range of 7 – 7.5.

[0068] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the nutrient media pH is 7.

[0069] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water pH is in the range of 7-8.

[0070] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water pH is 7.8.

[0071] In an embodiment of the present disclosure there is provided a nutrient media as described herein, wherein the formation water volatile fatty acid concentration is increased. In another embodiment, the formation water volatile fatty acid concentration is in the range of 50 – 700mg/L.

[0072] In an embodiment of the present disclosure there is provided a process for promoting production of methane gas from underground coalbed methane well as

described herein, wherein the nutrient media volume injected into coalbed methane well is in the range of 100 KL to 500 KL.

[0073] Although the subject matter has been described with reference to specific embodiments, this description is not meant to be construed in a limiting sense.

5 Various modifications of the disclosed embodiments, as well as alternate embodiments of the subject matter, will become apparent to persons skilled in the art upon reference to the description of the subject matter. It is therefore contemplated that such modifications can be made without departing from the spirit or scope of the present subject matter as defined.

10 [0074] The embodiments will be followed by certain examples explicitly showing the process for obtaining enhanced production of methane gas from underground coalbed wells. Strategies for optimization of nutrient media has been discussed in different working examples. The production of methane has been shown to increase significantly after bio-stimulation. The field studies performed with
15 underground coalbed well over different time points depict that bio-stimulation with optimized nutrient media leads to enhanced production of methane gas.

EXAMPLES

[0075] The disclosure will now be illustrated with working examples, which is intended to illustrate the working of disclosure and not intended to take
20 restrictively to imply any limitations on the scope of the present disclosure. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this disclosure belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice of the disclosed methods and
25 compositions, the exemplary methods, devices and materials are described herein. It is to be understood that this disclosure is not limited to particular methods, and experimental conditions described, as such methods and conditions may vary.

Example 1

Sample collection

[0076] In first phase of sampling, four formation water samples were collected from different wells of OJ# 1, OJ# 3, OJ# 4, OB# 11 and ON# 11.

[0077] In second phase of sampling, one formation water sample was collected each from OJ# 1 and OJ# 3 wells.

- 5 [0078] In third phase of sampling two formation water samples were collected from OJ# 1 well.

Table 1 below depicts the characteristics of different coalbed methane wells from which formation water samples were collected.

Table1.

Well Id	Depth (m)	Bottom hole temp (°C)	Nature of sample collected
OJ# 1	670	41.5	Formation water & Gas
OJ# 3	1191	58.88	Formation water & Gas
OJ# 4	1251	61.11	Formation water & Gas
OB# 11	982	61.11	Formation water & Gas
ON# 4	996	61.66	Formation water & Gas

10

Example 2

Physio-chemical analysis of formation water samples

- [0079] The various samples as shown in Table 1 above were collected in 1000 ml sterilized wheaton serum bottles. Physio-chemical analysis was carried out as per
- 15 API (Active Pharmaceutical Ingredient) standards and APHA guidelines as shown in Table 2.

Table 2.

Heavy metals	Method followed for detection
Arsenic(As)	IS3025PT 37:1988
Cadmium(Cd)	APHA3100(B)
Chromium(Cr)	APHA3500(B)
Copper(Cu)	APHA3111(B)
Zinc(Zn)	APHA3100(B)
Silver(Ag)	APHA3113(B)
Nickel(Ni)	APHA3111(B)
Total Iron(Fe)	APHA3100(B)

Table 3.

Well Numbers	pH	Salinity (psu)	Conductivity (mS/cm)	TDS (mg/L)	VFAs (mg/L)
OJ # 1	7.8	1.23	3.3	1648	100
OJ # 3	7.20	1.69	2.40	1280	610.63
OJ # 4	7.55	1.40	2.63	1384	485.46
OB # 11	7.12	0.23	1.70	235	434.67
ON # 4	7.30	0.19	2.69	200	404.35

- 15 **[0080]** Physio-chemical analysis of formation water from the various samples is shown in Table 3. All the samples showed hydrogen ion concentration in the range of 7.8 - 7.55. Maximum hydrogen ion concentration was recorded in OJ# 4. Highest salinity was found in OJ# 3 followed by OJ# 4. However minimum salinity was found in ON# 4 (0.19 psu) followed by OB# 11 (0.23 psu). Conductivity of formation water sample was done by conductivity meter and found that OJ# 1 showed highest conductivity i.e 3.3 mS/cm. Total dissolved solids was estimated in all the formation waters and it was in the range of 200 - 1648 mg/L. Formation water samples were also analyzed for volatile fatty acid analysis by gas
- 20

chromatography (Table 3). The maximum total volatile fatty acid (VFA) was found in OJ# 3.

Table 4

Heavy metals	OJ# 1	OJ# 3	OJ# 4	OB# 11	ON# 4
Arsenic	ND (<0.01)	ND (<0.01)	ND (<0.01)	ND (<0.01)	ND (<0.01)
Cadmium	ND (<0.04)	ND (<0.04)	ND (<0.04)	ND (<0.04)	ND (<0.04)
Chromium	ND (<0.01)	ND (<0.01)	ND (<0.01)	ND (<0.01)	ND (<0.01)
Copper	ND (<0.02)	ND (<0.02)	ND (<0.02)	ND (<0.02)	ND (<0.02)
Zinc	ND (<0.05)	ND (<0.05)	ND (<0.05)	ND (<0.05)	ND (<0.05)
Silver	ND (<0.05)	ND (<0.05)	ND (<0.05)	ND (<0.05)	ND (<0.05)
Nickel	ND (<0.03)	ND (<0.03)	ND (<0.03)	ND (<0.03)	ND (<0.03)
Iron mg/L	3.3	0.3	8.4	5	13.36

5

[0081] In APHA method detection limits of the arsenic, cadmium, chromium, copper, zinc, silver, nickel and iron are 0.01, 0.04, 0.01, 0.02, 0.05, 0.05, 0.03 and 0.02 mg/L respectively. Except iron no other heavy metal as shown in Table 4 were detected in collected formation water samples.

10 Table 5

CHNS (%)	OJ#1	OJ#3	OJ#4	OB#11	ON#4
Carbon (%)	0.011	0.014	0.040	0.05	0.018
Hydrogen (%)	0.014	0.010	0.018	0.016	0.012

Nitrogen (%)	0.0010	0.009	0.034	0.032	0.020
Sulphur (%)	0.0013	0.015	0.016	0.014	0.010

[0082] Carbon, hydrogen, nitrogen, and sulphur (CHNS) analysis was done using IS: 1350/APHA guidelines (Table 5). Carbon was detected in the range of 0.011 - 0.05 %. Hydrogen was detected in the range 0.010 – 0.016 %. Concentration of nitrogen ranged from 0.001 - 0.034 % in all the samples. Sulphur was detected in the range of 0.010 - 0.016 %.

Table 6

Toxic Ions	Methods	OJ# 1	OJ# 3	OJ# 4	OB# 11	ON# 4
Chloride mg/L	IS3025	59	50.36	252	30.22	70.5
Fluoride mg/L	APHA 4500	0.82	1.64	1.91	0.97	2
Sulphate mg/L	IS 3025	5.50	7.6	8.4	6.6	8

Table 6 depicts the toxic ion analysis in formation water samples from CBM wells wherein water comprises 30 - 250 mg/L of chloride, 0.5 – 2 mg/L of fluoride and 5 - 9 of mg/L sulphate.

Example 3

Compositional analysis of coal

[0083] The detailed analysis of coal in terms of ash content, moisture, volatile matter and fixed carbon along with specific carbon, hydrogen, nitrogen, sulfur and oxygen (CHNSO) profile was determined as per the guidelines of ASTM standards (Table 7). Table 7 below depicts the ultimate and proximate analysis of coal from different CBM wells.

Table 7

Test	Method	OJ# 1	OJ# 3	OJ# 4
Proximate Analysis				
Ash (%)	ASTM D3174-97	20.14	13.98	30.57
Moisture (%)	ASTM D3173-87	0.28	0.37	0.15
Volatile Matter (%)	ASTMD3175-89	26.98	18.60	27.43
Fixed Carbon (%)	ASTMD3172-89	52.60	67.05	41.85
Ultimate analysis				
Carbon (%)	ASTM3178-89 (1997)	53.89	56.40	51.16
Hydrogen (%)	ASTM3178-89 (1997)	4.55	4.67	4.07
Nitrogen (%)	ASTM3179-89 (1997)	1.64	1.91	1.35
Sulfur (%)	ASTM3177-89 (1997)	0.78	0.70	0.55
Oxygen (%)	ASTM3176-89 (1997)	18.72	21.97	12.15

15 Example 4

Gas Compositional analysis

[0084] Gas composition was analyzed for the presence of methane, carbon-dioxide, and nitrogen. They were quantified by calibrated gas chromatography model GC-7890A, Agilent Ltd. USA) equipped with a molecular sieve packed stainless steel column (2 m X 2 mm id NUCON, INDIA) and a thermal conductivity detector (TCD) as described by Rathi et al., 2015 (Rathi, Rohit, et al. International Journal of Coal Geology 147 (2015): 25-34). Argon was used as a carrier gas, at a flow rate of 1.0 ml/min using a thermal conductivity detector. The operating temperatures of the injector, oven and detector were 100⁰C, 50⁰C and 150⁰C respectively (Rathi et al., 2015). Table 8 below depicts a compositional analysis of gas from coalbed methane well wherein methane, carbon dioxide and nitrogen were 97.50%, 1.10%, and 1.34% respectively.

Table 8

Sample	Composition of Gas		
	Methane (%)	Carbon dioxide (%)	Nitrogen (%)
OJ# 1	97.56	1.10	1.34

Example 5

Optimization of nutrient media

To optimize the nutrient media that can be introduced into coalbed methane well to enhance the production of methane, formation water samples were collected from CBM wells and added in two different methanogen specific media i.e. MPB and MSP for *Methanosprillum* sp., containing coal as a substrate and incubated at the bottom hole temperature (i.e 60 °C) for 20 days. The MPB medium contains K₂HPO₄ 0.4 gm/L; KH₂PO₄ 0.2 gm/L; NaCl 1.0 gm/L; NH₄CL 1.0 gm/L; yeast extract 0.5 gm/L; casein peptone 0.5g; MgCl₂.6H₂O 0.2 gm/L; resazurine 0.001 gm/L; L-cysteine HCL 0.5 gm/L. The composition of MSP medium is: KH₂PO₄ 0.5 gm/L; NaCl 1.0 gm/L; NH₄CL 0.4 gm/L; Yeast extract 0.5 gm/L; MgCl₂.7H₂O 0.2 gm/L; resazurine 0.001 gm/L, L-cysteine HCL 0.5 gm/L; NaHCO₃, 0.2 gm/L. The pH of media was adjusted to 7 and 100 µl of resazurine was added as an oxygen indicator and made up to 1000 ml, then boiled for 10 min and cooled under a nitrogen purge to remove dissolved oxygen. Cysteine hydrochloride was added as it acts as a reducing agent to remove dissolved oxygen. A volume of 250 ml of medium was dispensed into 500 ml serum bottles flushed with O₂-free N₂. The serum bottles were sealed with butyl rubber stoppers and crimped with aluminum seals. Prior to addition, the sealed pressurized bottles were sterilized in an autoclave at 121 °C for 15 min. Then 250 ml of media (MPB) was added with 5 ml of the formation water, with 1% coal using aseptic, strict anaerobic techniques and kept in an incubator at 60 °C for 20 days. The incubated culture was tested for methane and carbon dioxide production by taking 0.5 ml of headspace gas samples from the anaerobic serum bottles using gas-tight syringe. Further in 10 liters scale up studies methane production was 43.98% along with 7.78% of CO₂ was observed as shown in Figure 5.

Example 6

Formulation of a nutrient media for enhanced methane production

[0085] To improve the biogenic methane production from coalbed methane well, three ingredients yeast extract, peptone and ammonium chloride of MPB medium

were evaluated at 0%, 0.1%, 0.5%, 1% and 2% w/v respectively. Similarly, enhanced methane generation efficiency was also evaluated by optimizing three components (yeast extract, ammonium chloride and sodium bi-carbonate) of MSP medium. For yeast extract, concentration at 0.03 %, 0.05% and 0.1% w/v were considered. For ammonium chloride concentration at 0.02% - 0.2% w/v was tested. While, sodium bi-carbonate concentration at 0 – 0.2% (w/v) was evaluated. Serum bottle of 130-mL contained 0.5 % w/v coal, 45 mL of different mediums and 5 mL of formation water. The bottles were kept at 55 °C for 20 days.

[0086] In this experiment, it was found that with the increase in concentration of ammonium chloride in MPB medium, methane production was increased up to 43% at 0.1% after 20 days at 55°C (Figure 1). After 0.1% by weight of NH₄Cl concentration, inhibitory effect for methanogenesis was observed. However, increasing yeast extract and peptone concentration in MPB medium showed enhanced methane production up to 55% after 20 days. But this increase in methane concentration was also associated with the increase in CO₂ concentration up to 19 %.

[0087] Similarly, in MSP medium, it was found that increasing concentration of ammonium chloride and yeast extract showed increased methane generation after 20 days at 55°C. Maximum methane of 34.7% and 40.71% were observed at 0.2 % w/v by weight of ammonium chloride and 0.1% w/v by weight of yeast extract concentration in MSP medium (Figure 23). However, with the increasing concentration of sodium bi-carbonate up to 0.02% w/v showed enhanced methane (37%) generation after 20 days at 55°C. Above, 0.02% w/v by weight of sodium bicarbonate concentration in MSP medium has shown decrease in methane generation.

Example 7

Effect of different nitrogen sources on methane production

[0088] The effect of different nitrogen sources (ammonium chloride, urea and corn steep liquor) on culture from coalbed methane well was evaluated in terms of methane production at a range of concentration (0.5 - 2% w/v) in 130 ml anaerobic serum bottles containing 45 ml modified MSP medium. The 5 ml of formation

water was added into above media bottles and kept at 55 °C for 20 days for incubation. Methane generated in the headspace of the experimental bottles was quantified by gas chromatography. Ammonium chloride is a promising nitrogen source for microbial methane generation from coal. Maximum methane generation was observed 42.47% along with 7.18% CO₂ when supplemented with additional 0.1% by weight of ammonium chloride in MPB medium (Figure 3).

Example 8

Methane production from formation water collected from OJ# 1 at optimum nutrient recipe

[0089] Methane production by formation water was carried out with the optimized nutrient recipe containing (a) 0.4 gm/L K₂HPO₄; (b) 0.2 gm/L KH₂PO₄; (c) 1 gm/L NaCl; (d) 1 gm/L NH₄Cl; (e) 1 gm/L yeast extract; (f) 1 gm/L NaHCO₃; (g) 0.2 gm/L MgCl₂.6H₂O; (h) 1 gm/L sodium acetate; (i) 0.5 gm/L L- Cysteine hydrochloride; and (j) formation water to make up to desired volume. 0.5 gm coal was added in 45 ml anaerobic modified MPB medium at temperature 55°C. Methane and carbon-dioxide production was periodically analyzed after every 10 days interval for the period of 30 days. Maximum accumulated methane observed was 44.6 % on the 30th day (Figure 4). As shown in Figure 4, there is an increase in methane production between 20 to 30 days.

Example 9

Compatibility studies

[0090] The compatibility of nutrient recipe with the freshly collected formation water from CBM well was performed. In this experiment, optimized nutrient medium (MPB) with 1% w/v coal is prepared by using commercial grade chemicals in formation water and incubated for 20 days at 55 °C. In this experiment, no precipitation was observed with commercial/Lab grade chemicals in formation water and tube well water. Similar pattern of methane generation was found in tube well water with commercial grade chemical whereas methane generation was slightly reduced in formation water. Table 9 below depicts the percentage production of methane and carbon dioxide in formation as well as tube well water with optimized nutrient media.

Table 9.

S.No.	MPB Medium Conditions	Formation water		Tube well water	
		CH ₄ (%)	CO ₂ (%)	CH ₄ (%)	CO ₂ (%)
1.	Heat+Sparge+Autoclave	54.37	2.8	50.86	3.17
2.	Sparge+Autoclave	53.48	4.36	50.52	3.02
3.	Heat+Sparge+without Autoclave	36.45	2.02	34.17	4.43
4.	Sparge+without Autoclave	34.51	4.83	34.01	4.07

Example 10

Injection of nutrient media into coalbed methane well

5 [0091] The OJ# 1 CBM well was equipped with a sucker rod pump (SRP) and tubing was installed. At the surface, suitable facilities were provided to energize pump, to separate liquid from gas conveyed through pipe two separate outlets were present for gas and liquid. Base line production data of liquid and gas was generated for about one month for well OJ# 1 using the installed water and gas flow meter (Rockwin flow meter. Data was generated in a detail reporting format

10 (DPR) as shown in Table 10.

Table 10.

Well No.	OJ# 1
Perforation/fracture Interval	559.65-570.75 m (Object I) 491.5-499.5, 502.5-504, 506.5-508 m (Object II)
Mode of lift	SRP
Initial Reservoir Pressure	47.73 Kg/cm ²
Flowing Reservoir Pressure	12Kg/cm ² (Before injection)
Bottom hole temperature	≈ 41.5° C

Liquid production rate	1.8 m ³ /d (Tested on 17.01.2016)
Gas production Rate	528 SCM/day
Injectivity	500-600 L/min
Permeability	26.19md (Post fracture permeability)
Porosity	0.5% (average)

[0092] Optimized nutrient medium of 200m³ can be pumped through annulus of CBM well with the rate ~ 20m³/ hour while keeping tubing outlet valve closed and ensuring that pressure in stuffing box of SRP installed is less than its rating of 2000 psi. Composition of optimized nutrient media comprises (a) 0.4 gm/L K₂HPO₄; (b) 0.2 gm/L KH₂PO₄; (c) 1 gm/L NaCl; (d) 1 gm/L NH₄Cl; (e) 1 gm/L yeast extract; (f) 1 gm/L NaHCO₃; (g) 0.2 gm/L MgCl₂.6H₂O; (h) 1 gm/L sodium acetate; (i) 0.5 gm/L L- Cysteine hydrochloride; and (j) formation water to make up to desired volume. Based on the actual initial injection rates and pressure, further nutrient preparation and its pumping can be synchronized.

[0093] After injection, the well remained closed for a specific time period. During incubation period, pressure in the casing and tubing was monitored. A significant increase in casing pressure was observed after the injection of nutrient media.

Example 11

15 Production of methane and Field study after Bio-stimulation

[0094] Production of methane was analyzed at different time points. First stage analysis was done after 4-6 weeks of sealing the well after injection of specific nutrient media as described in previous section. At the time of opening the well, pressure in the casing was measured. In case casing was pressurized, valve is opened to flow gas. Gas sample was collected and measured for compositional analysis as shown in Table 11. Sucker rod pumping started, commences dewatering and liquid flow was also measured. The pH 7.8, conductivity 7.4 mS/cm and redox – 257 mV of co-produced water was recorded. Table 11 below depicts a Compositional analysis of gas from CBM well after injecting media wherein methane, carbon dioxide and nitrogen are 97.65%, 0.53%, and 1.82% respectively.

Table 11

S.N.	Sample	Composition of Gas		
		Methane (%)	Carbon dioxide (%)	Nitrogen (%)
1.	OJ# 1	97.65	0.53	1.82

[0095] Before injecting the nutrient media, the flow rate of methane is quite less, for example 528 standard cubic meter/day. Stabilized and enhanced production of methane can reach flow rates in order of 528 – 2800 scm/day after injecting nutrient media.

10 [0096] Field study was performed for the well OJ#1 over a period of 10 months of bio-stimulation with the optimized specific nutrient medium (as described in Example 8) starting from October 2016 to August 2017. Figure 6 depicts the standard cubic meters (scm) of gas produced per day (scmd) along with water production, gas pressure and SRP operational hours over the time-period.

15 Significant increase in gas production was observed as a result of bio-stimulation, the production was increased from 528 scmd (pre-bio-stimulation) to around 2800 scmd (May-June 2017) after bio-stimulation. The total gas production after bio-stimulation reached to 0.53 million metric standard cubic meters (mmscm) which is considered as a significant improvement in yield as compared to the declining trend
 20 of production from the well before job was taken up.

[0097] The production of methane gas was also analyzed after around 4 months and 10 months of sealing the well after injecting the optimized nutrient media as described in Example 8 (bio-stimulation). Table 12 depicts the parameters of the well along with date of sample collection after bio-stimulation.

25 Table 12:

Sl. No.	Well	Depth (m) /Object	Date/ Time of collection	Gas Isotopic Composition	
				$\delta^{13}C_1$	$\delta^{13}CO_2$
1.	OJ#1	491.5-571/I&II (pre bio-stimulation job)	5.5.2016	-37.6	0.2

2.	OJ#1	491.5-570.75/I&II (post bio-stimulation job)	29.09.2016	-41.2	-14.3
3.	OJ#1	491.5-570.75/I&II (post bio-stimulation job)	07.03.2017	-41.9	-9.9

[0098] Table 12 also depicts the isotopic composition of the gas. It can be appreciated that after around 10 months of bio-stimulation and sealing of the well, the CO₂ produced along with methane is lighter in carbon isotopic composition in comparison to the CO₂ produced before bio-stimulation. This observation proves that bio-stimulation with optimized media assists in producing methane gas of enhanced quality as compared to the gas produced under normal conditions without any bio-stimulation.

Example 12

10 Analysis of Microbe consortia and gas composition

[0099] The analysis of gas composition and the presence of microbes in the samples after specific time interval of bio-stimulation was performed in well OJ#1. The composition and the time point of gas collection has been depicted along with other parameters in Table 13. The presence of microbes was also studied before and after bio-stimulation with the optimized specific nutrient media as described in Example 8. The difference in microbial composition in pre-bio-stimulation job and post bio-stimulation job has been depicted in Table 14 below.

Table 13:

Parameters	Pre-job Activity	Post job activity
pH	7.8	7.5
Conductivity ms/cm	3.3	7.4
TDS mg/L	1648	2041
Carbon (%)	0.0126	0.0067
Hydrogen (%)	0.0015	<0.001
Nitrogen (%)	0.002	0.0074
Sulfur (%)	0.001	<0.001
Chloride mg/L	48.44	700
Fluoride mg/L	0.66	0.22
Sulphate mg/L	1.07	13

Total Iron mg/L	2	5.19
Gas Composition	7/3/2016	14/06/2016
CH₄	97.56	97.63
CO₂	1.13	0.53
H₂S	Not detected	Not detected

Table 14:

Microbial Composition	Pre-job activity	Post job activity
<i>Methanobacteriaceae archaeon</i>	9%	15%
<i>Methanosarcina sp.</i>	46%	71%
<i>Methanothermobacter thermautotrophicus strain</i>	11%	5%
<i>Methanolinea tarda strain</i>	18%	5%
<i>Methanobacterium flexile</i>	1%	Not detected
<i>Methanosaeta thermophila</i>	3%	Not detected
<i>Methanobrevibacter sp.</i>	1%	Not detected
<i>Methanobacterium sp.</i>	2%	Not detected
<i>Methanomethylovorans sp.</i>	2%	Not detected
<i>Clostridium sartagoforme</i>	3%	Not detected
<i>Thermacetogenium phaeum strain</i>	2%	Not detected
<i>Methanospirillum sp.</i>	2%	2%
<i>Methanofollis sp.</i>	Not detected	2%

[00100] Referring to Table 13 it can be appreciated that the effect of bio-stimulation is observed after a period of around 3 months. The level of CO₂ has significantly reduced from 1.13% to 0.53%.

[00101] Referring to Table 14 it can be appreciated that after the stimulation with appropriate nutrient media as described in Example 8, the microbe consortia in the well has adapted accordingly to yield maximum production of methane gas. The presence of *Methanosarcina sp.* is increased from 46% to 71% after a time-period of 3 months after bio-stimulation. Similarly, the presence of

Methanobacteriaceae archaeon is also increased from 9% to 15% in the time-period.

[00102] In summary, Examples 1 - 4 provides the parameters that can help in in-situ stimulation of microbial enhanced methane generation. For the successful
5 in-situ implementation of the process, suitability of the reservoir condition must be understood as the environmental conditions prevalent might affect rates of methane generation. Further, examples 5 - 9 provides the optimized nutrient media that can be introduced into the coalbed methane well to enhance the biogenic production of methane. To enhance methane gas production on a very large scale, a process is
10 described in examples 10-11 and an optimized nutrient media is injected into the well, sealed for a sufficient period of time to allow the microorganisms to produce methane. It further focusses on in-depth analysis of a field study performed after bio-stimulation of the underground well OJ#1 over a period of 10 months. Example 12 studies the difference in microbe consortia in the well following bio-stimulation
15 with the nutrient media. The example also discusses the gas composition after a period of around 3 months of bio-stimulation. However, it is to be noted that no external cultures of micro-organism were added in the CBM well for the production of methane, only nutrient media was optimized and added which facilitated the growth of micro-organism already present in the well.

[00103] The demand for methane gas will continue to increase in the future, therefore a need for new methods to increase the production of methane gas from CBM wells. Previous inventions in this area involve the removal of pure and diluted methane through hydraulic fracturing boreholes drilled into CBM wells in order to recover methane.

25 Advantages of the present disclosure:

[00104] Prior to this invention, no process for enhanced methane production has been reported by injecting specific nutrient media into CBM wells. The present disclosure thus provides a process for enhancing methane production in a very short period of time. The instant disclosure also provides the composition of
30 optimized nutrient media that can be introduced into the coalbed methane well to enhance the biogenic production of methane. Nevertheless, results from this study

increase our understanding of factors and provide insight for developing a strategy to improve the future productivity of methane from CBM wells. In addition, to this there is large amount of fluid production from coalbed methane well which is relatively high as compared to conventional oil / gas wells.

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I/WE CLAIM:

- 1) A process for promoting production of methane gas from underground coalbed methane well, comprising:
- 5 a) injecting into the underground coalbed methane well a nutrient media, wherein the underground coalbed methane well temperature is up to 70°C;
- b) sealing the underground coalbed methane well of step (a) for a period of 4-6 weeks;
- c) unsealing the underground coalbed methane well; and
- 10 d) extracting the methane gas from the underground coalbed methane well as per industry practices,
- wherein the production of the methane gas from the underground coalbed methane well is more than production of methane gas otherwise obtained from an underground coalbed methane well not injected with the nutrient media while producing methane gas as per standard industry practices for the
- 15 underground coalbed well.
- 2) The process as claimed in claim 1, wherein the methane gas comprises at least 95% methane.
- 3) The process as claimed in claim 1, wherein the methane gas comprises carbon dioxide (CO₂) having lighter carbon isotopic composition as compared to CO₂
- 20 in gas which is produced without injecting the nutrient media in the underground coalbed well.
- 4) The process as claimed in claim 1, wherein the methane gas produced bears no significant change in methane composition and / or heating value compared to methane gas otherwise obtained from an underground coalbed methane well
- 25 not injected with the nutrient media.
- 5) The process as claimed in claim 1, wherein the nutrient media is injected under pressure in the underground coalbed methane well.
- 6) The process as claimed in claim 1, wherein the underground coalbed methane well casing has an increased head build up pressure after injecting the nutrient
- 30 media.

- 7) The process as claimed in claim 1, wherein the underground coalbed methane well has an improved fluid flow after injection of the nutrient media.
- 8) The process as claimed in claim 1, wherein the underground coalbed methane well has a temperature in the range of 25°C to 70°C.
- 5 9) A nutrient media comprising:
- a) formation water obtained from an underground coalbed methane well;
 - b) at least one reducing agent;
 - c) K_2HPO_4 ;
 - d) KH_2PO_4 ;
 - 10 e) NaCl;
 - f) NH_4Cl ;
 - g) yeast extract;
 - h) $NaHCO_3$;
 - i) $MgCl_2 \cdot 6H_2O$; and
 - 15 j) sodium acetate.
- 10) The nutrient media as claimed in claim 9, wherein the nutrient media is suitable for growth of methanogenic bacteria.
- 11) The nutrient media as claimed in claim 9, wherein the nutrient media has a pH in the range of 6– 8.
- 20 12) The nutrient media as claimed in claim 9, wherein the nutrient media has a pH in the range of 7 – 7.5.
- 13) The nutrient media as claimed in claim 9, wherein the formation water has a pH in the range of 7-8.
- 14) The nutrient media as claimed in claim 9, wherein the formation water
- 25 comprises:
- a) 18 – 26% by weight of chloride;
 - b) 1.60 – 2% by weight of fluoride;
 - c) 7.40 – 8.9% by weight of sulphate; and
 - d) 3 - 3.5% by weight of iron.
- 30 15) The nutrient media as claimed in claim 9, wherein the at least one reducing agent is L-cysteine.

- 16) A nutrient media comprising:
- a) 0.1 – 0.6 % by weight of K_2HPO_4 ;
 - b) 0.1 – 0.3% by weight of KH_2PO_4 ;
 - c) 0.9 – 1.5% by weight of NaCl;
 - 5 d) 0.9 – 1.5% by weight of NH_4Cl ;
 - e) 1– 2% by weight of yeast extract;
 - f) 0.9 – 1.5% by weight of $NaHCO_3$;
 - g) 0.1 – 0.3% by weight of $MgCl_2 \cdot 6H_2O$;
 - h) 0.9 – 1.2% by weight of sodium acetate;
 - 10 i) 0.4 – 1.2% by weight of L-cysteine; and
 - j) formation water to make up to 100%, wherein said formation water comprises:
 - i) 18 – 26% by weight of chloride;
 - ii) 1.60 – 2 % by weight of fluoride;
 - 15 iii) 7.40 – 8.9 % by weight of sulphate; and
 - iv) 3 - 3.5 % by weight of iron.

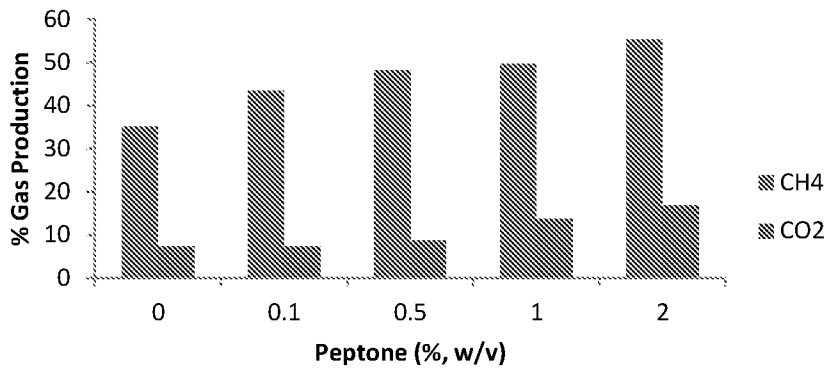


Figure 1A

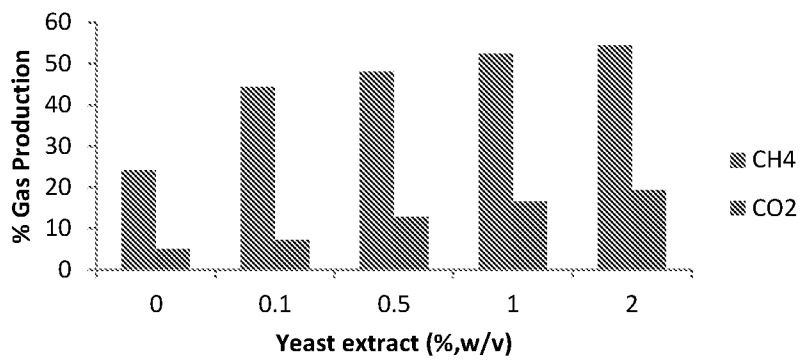


Figure 1B

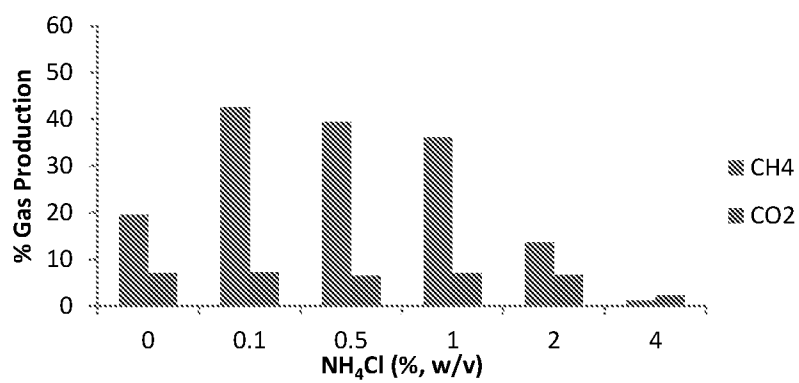


Figure 1C

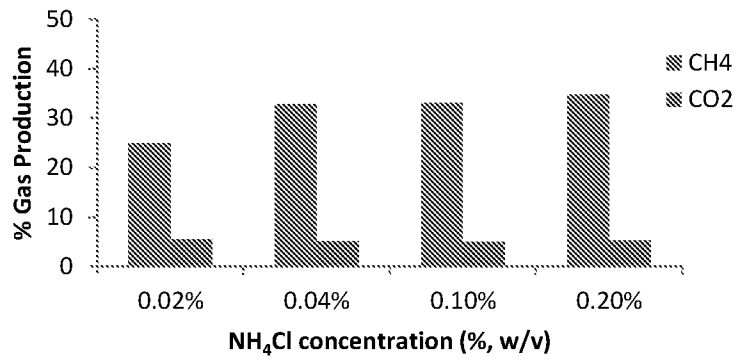


Figure 2A

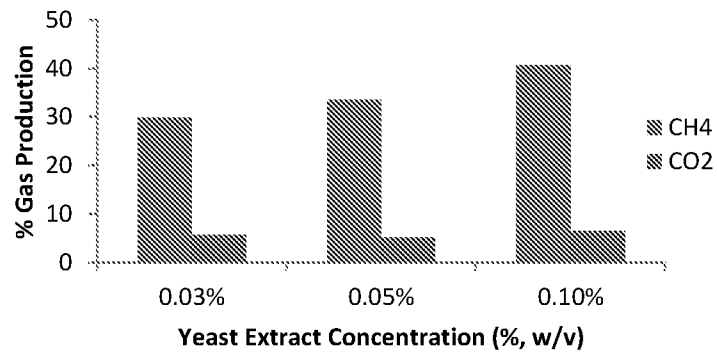


Figure 2B

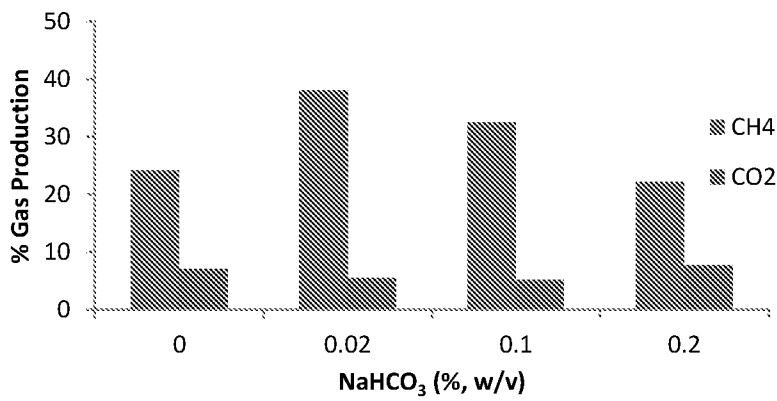


Figure 2C

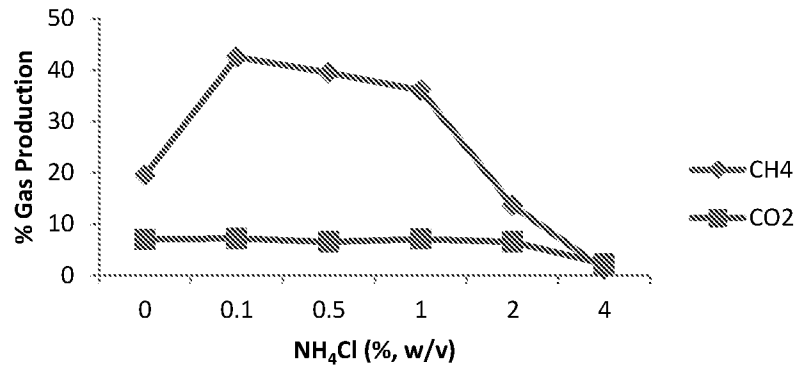


Figure 3A

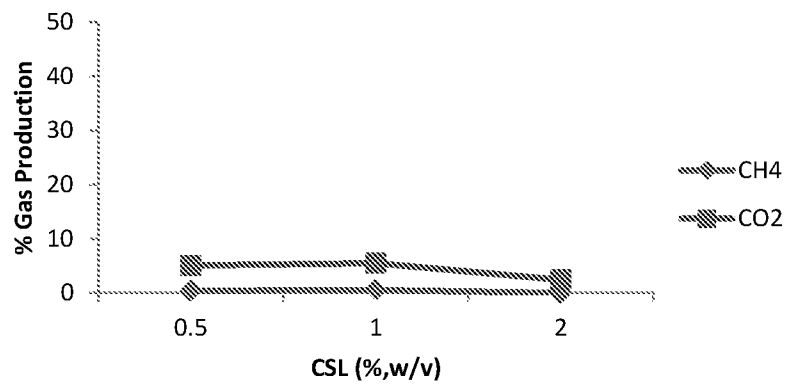


Figure 3B

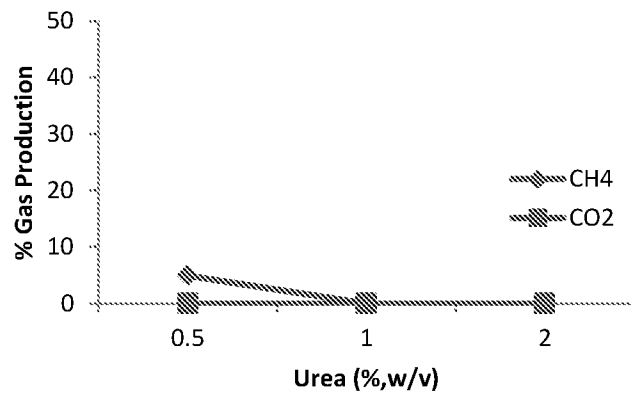


Figure 3C

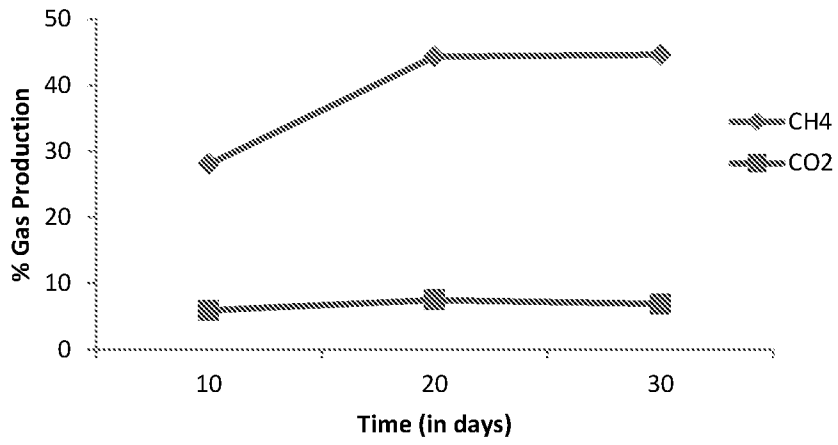


Figure 4

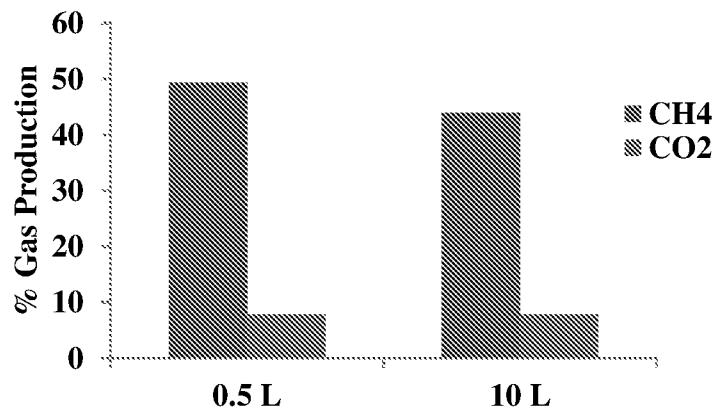


Figure 5

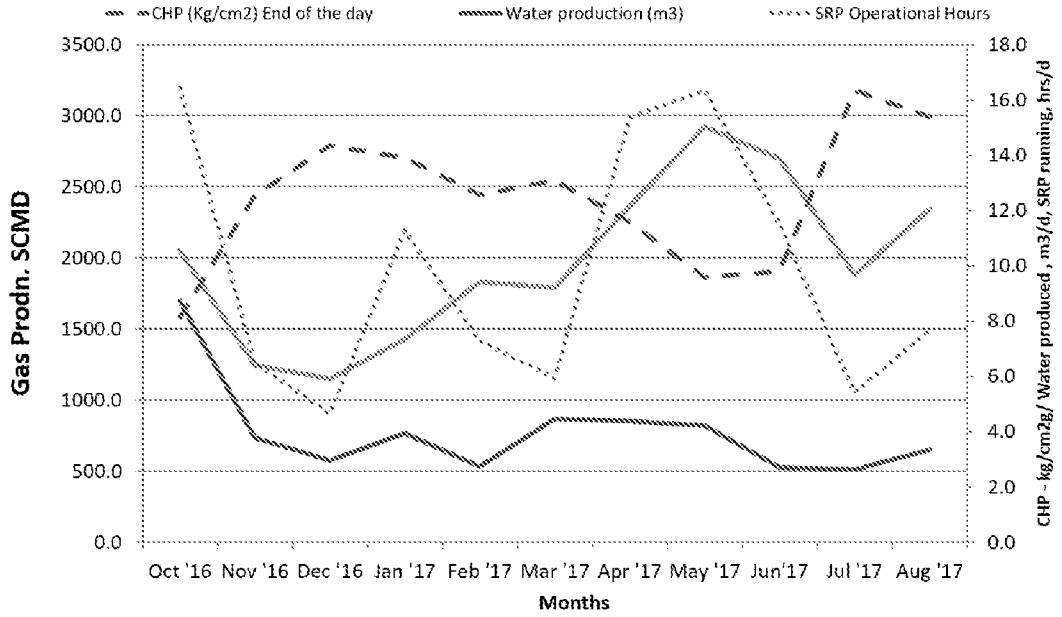


Figure 6