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(54) **COAL BED PRETREATMENT FOR ENHANCED CARBON DIOXIDE SEQUESTRATION**

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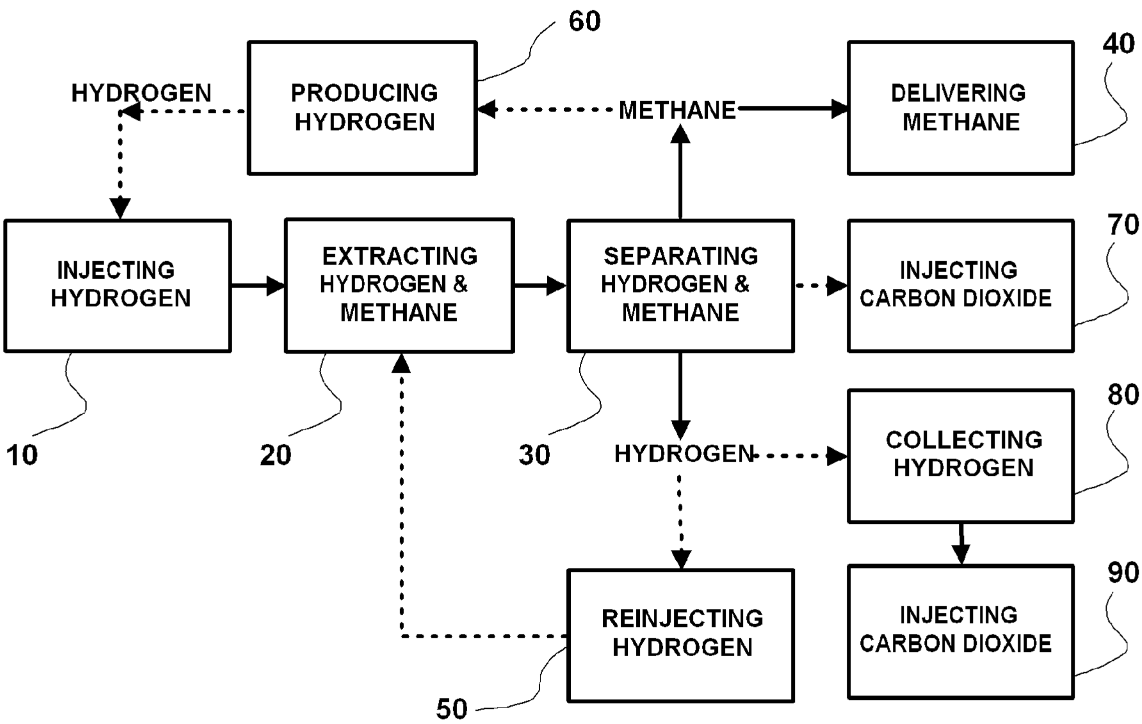
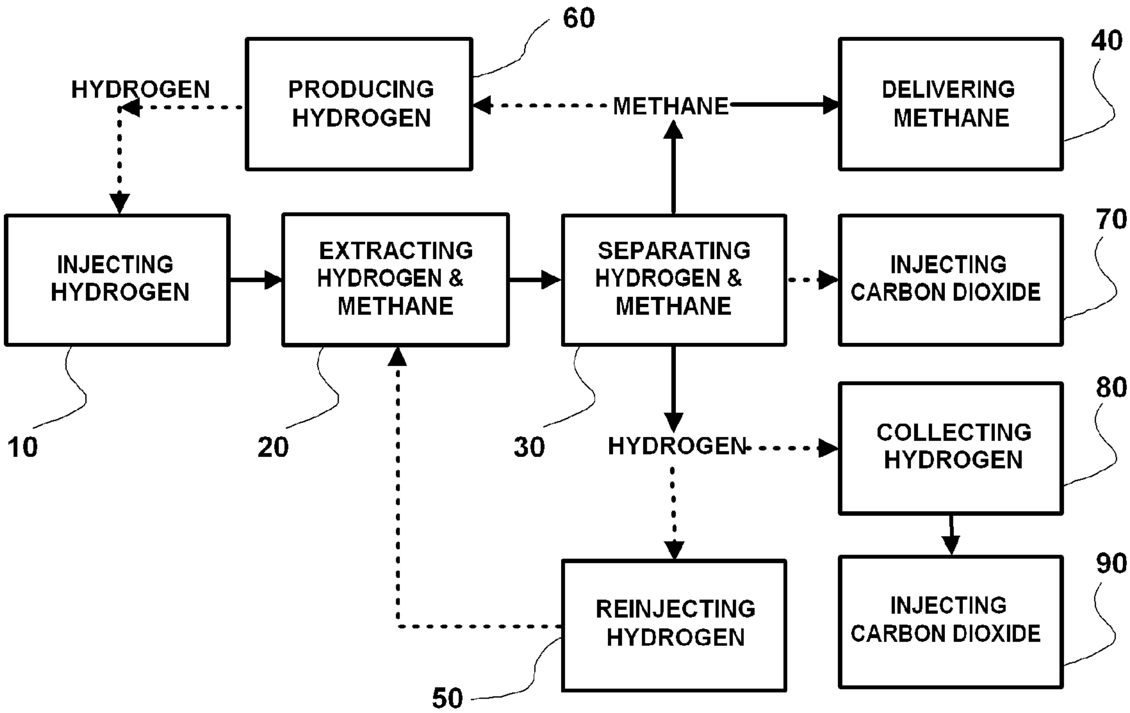
(57) **ABSTRACT**

A method is claimed for enabling storage of greater volumes of carbon dioxide for sequestration while simultaneously enhancing methane recovery from the coal bed. The process is implemented by injecting hydrogen into a coal bed, such as a depleted underground coal deposit, at a temperature below about 800 degrees Centigrade (**10**); extracting the hydrogen together with methane from the deposit (**20**); separating the hydrogen from the methane (**30**); delivering the methane as a product of the process (**40**); reinjecting the separated hydrogen into the deposit to continue the process until sequestration of carbon dioxide is desired (**50**); optionally producing hydrogen from methane (**60**) and optionally injecting carbon dioxide for sequestration (**70**).




60
HYDROGEN
PRODUCING HYDROGEN
METHANE
DELIVERING METHANE
40
INJECTING HYDROGEN
EXTRACTING HYDROGEN & METHANE
SEPARATING HYDROGEN & METHANE
INJECTING CARBON DIOXIDE
70
10
20
30
HYDROGEN
COLLECTING HYDROGEN
80
REINJECTING HYDROGEN
INJECTING CARBON DIOXIDE
90
50

COAL BED PRETREATMENT FOR ENHANCED CARBON DIOXIDE SEQUESTRATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Pursuant to 35 U.S.C. section 119(e), the present invention claims the benefit of the filing date of United States provisional application No. 60/597,447 filed 02 Dec. 2005, the text of which is hereby incorporated by reference herein.

FIELD OF INVENTION

[0002] In the field of carbon dioxide sequestration, a coal bed pretreatment process using hydrogen for increasing the storage potential of an underground coal deposit and enhancing production of methane.

DESCRIPTION OF PRIOR ART

[0003] Methods for adjusting the porosity and permeability of an underground coal bed have been practiced using the injection of fluids. However, none propose the use of hydrogen alone as a fluid displacing methane from the pores of an underground coal bed to enhance the carbon dioxide storage capability of the coal bed.

[0004] Enhanced coal bedded methane recovery is currently under development using carbon dioxide injection prior to carbon dioxide sequestration in the coal bed. For enhanced coal bedded methane recovery, the carbon dioxide is injected into depleted coal bedded methane coal beds, which are usually located deep underground in otherwise unminable coal seams. The injected carbon dioxide displaces methane naturally present in the coal bed, and releases it for recovery.

[0005] The yield of methane can be about 1 mole of methane for 2 moles of injected carbon dioxide, which is very significant for sequestering carbon dioxide. However, this yield quickly drops off because the carbon dioxide tends to swell the coal and tends to block the passage of the methane out of the coal deposit.

[0006] Coal permeability and porosity is significantly diminished by the injection of carbon dioxide. The theory is that carbon dioxide is a large molecule, which gets adsorbed on the surface of the coal in the pores. This adsorption then blocks the methane from getting out of the coal once the pressurized and easily displaced molecules of methane are released, and pumped out of the coal seam.

[0007] The present invention is a coal bed pretreatment process that increases the potential of the coal bed to store carbon dioxide and recover more methane from the coal bed than can be recovered using carbon dioxide.

[0008] As is the case in the known process of carbon dioxide sequestration, the present invention preferably uses an injection well and a production well. Hydrogen is injected into one well and flushed through the coal bed to exit from a production well along with methane. The difference is that hydrogen and not carbon dioxide is used first to flush out methane trapped in the coal bed. In the process of the invention, methane is separated from the hydrogen and methane exiting the production well, and then sold. The main effect of using the method of the invention is that more methane is harvested and the coal bed has greater storage potential for carbon dioxide sequestration. When the hydrogen pretreatment process is completed, the hydrogen is captured and used again at another location.

[0009] Hydrogen in combination with water has been proposed to extract oil from depleted wells. For example, U.S. Pat. No. 4,241,790 to Magnie on Dec. 30, 1980 teaches recovery of crude oil utilizing hydrogen. The '790 patent teaches injection of hydrogen into an underground petroleum reservoir that is devoid of natural gas. Hydrogen is diffused into the crude oil within the reservoir, changing the physical properties of the oil. After the crude oil is saturated with hydrogen, the pressure is lowered in the reservoir. Hydrogen then migrates from the tight portions of the reservoir, sweeping petroleum into the more permeable portions. A water sweep then displaces the oil to production wells. The present invention is different in that it uses hydrogen to displace methane a gaseous energy resource.

[0010] Unlike the '790 disclosure, a coal bed is not devoid of methane. It is the adsorbed and intersticial methane in the coal bed that can be displaced with the hydrogen and recovered. Methane displacement creates greater space within the coal bed for carbon dioxide storage. In the present invention, hydrogen is used in a coal bed and not in an oil reservoir to diffuse with oil. The physical mechanisms are completely different from those in the '790 patent and serve a different function. Also, the method of the present invention does not use hydrogen in combination with water as taught in the '790 disclosure.

[0011] Prior art also describes using hydrogen and steam in an oil deposit to extract petroleum. U.S. Pat. No. 4,597,441 to Ware, et al. on Jul. 1, 1986 is an example of such prior art. The '411 patent teaches a method of recovering petroleum from underground formations penetrated by a production well, superheated steam and then hot hydrogen are injected by way of the well into a preheated formation zone next to the well. The hydrogen is injected under sufficient pressure to cause hydrogenation of the petroleum in the heated zone. The '411 patent does not teach the use of hydrogen to displace methane and is confined to an oil well to produce oil by a chemical process, namely hydrogenation. The present invention does not involve the use of steam or heating of the coal bed. A significant element of the '411 patent is thus omitted in the present invention. The present invention is further distinguished because it not functional through hydrogenation of oil, nor by extension to the hydrogenation of coal.

[0012] The use of hydrogen as a coal bed pretreatment in the present invention will maximize recovery of methane from a coal bedded methane deposit. Enhanced methane recovery is achieved by avoiding the coal bed swelling, blockage and interference of methane extraction from a coal bed found to occur when using carbon dioxide alone.

[0013] Another important fact relative to gas recovery from coal bed is that, from a processing point of view, injection of any gas, whether carbon dioxide or hydrogen in a coal seam, will mix with the displaced methane. When gas is extracted, it is necessary to separate the methane from the injected gas in order to produce a methane product and to recycle the displacing gas. This separation process consumes energy and generally, the larger the difference in the molecular weight of the gases being separated, the lower the energy consumption. The energy performance can thus be indicated by the molecular weight ratio of the gases being separated.

[0014] The molecular weight ratio of methane to hydrogen (MW ratio 16/2) is 8. This compares to a molecular weight ratio of methane to carbon dioxide (MW ratio 16/44) of 0.36. So, the ratio for methane to hydrogen is about 22 times that of methane to carbon dioxide. The much larger molecular weight ratio of methane to hydrogen means that it takes much less energy to separate the methane from hydrogen than it takes to separate methane from carbon dioxide. In fact, hydrogen can be readily separated from the methane by membrane diffusion. The present invention, therefore, improves on the energy efficiency of enhanced coal bedded methane extraction over that obtainable with carbon dioxide.

[0015] While hydrogen is a more expensive gas than carbon dioxide, hydrogen can be recycled. The actual cost will be limited to the loss of hydrogen in the resource deposit and in recycling.

[0016] The loss of hydrogen is expected to be minimal. Coal bedded methane wells are closed systems, otherwise the methane would have leaked away over the centuries. However, the process optionally makes up for any loss of hydrogen by reforming some of the methane produced, so that there is no diminishment in the volume of the hydrogen working fluid.

[0017] For a gas tight well, hydrogen consumption is expected to be minimal, since it is all recycled. When methane extraction is completed, hydrogen filling the depleted well under pressure is pumped out to recover the hydrogen. This is advantageous because with the evacuated coal bed at lower pressure, the capacity to store carbon dioxide is enhanced.

[0018] The invention will, therefore, enhance coal bedded methane recovery by employing a recycling working fluid, hydrogen, that does not require the purchase of hydrogen from market sources. More methane removed from the coal bed means that the coal bed will store that much more carbon dioxide.

[0019] Water can be an environmental pollution problem in coal bedded methane recovery, but may not be a significant effluent in some sites. Water present in a coal seam is usually pumped out with the methane and some of the enhanced methane recovery working fluid. In traditional enhanced methane recovery process using carbon dioxide, the problem is that carbon dioxide is relatively soluble in the water especially under pressure and it forms carbonic acid. This presents two sources of pollution, one from the carbonic acid and the other from the release of carbon dioxide back to the environment.

[0020] In contrast, the present invention's use of hydrogen as the enhanced methane recovery working fluid avoids this environmental pollution problem. Hydrogen is much less soluble and less corrosive than aqueous carbon dioxide. This means that the hydrogen can be more easily separated from water than carbon dioxide and its ease of separation from water are significant advantages to using hydrogen instead of carbon dioxide for enhanced coal bedded methane production.

[0021] The invention, therefore, avoids the potential environmental pollution associated with the dissolution of carbon dioxide in water and the re-release of dissolved carbon dioxide to the environment in the enhanced coal bedded methane recovery process. The invention also minimizes energy consumption in separating the working fluid from the methane.

[0022] Hydrogen is a less adherent gas on coal surfaces than either carbon dioxide or methane. One gram of charcoal at 15 degrees Centigrade can adsorb 48 cubic centimeters of carbon dioxide, 16.2 cubic centimeters of methane and only 4.7 cubic centimeters of hydrogen, which is indicative of the relative adsorptive capacity of a coal carbon structure.

[0023] Hydrogen can also reduce the partial pressure of methane in the coal seam, which is an additional driving force for liberating methane from the surfaces of the coal.

[0024] Hydrogen has been proposed as a means to chemically react with the carbon in a coal seam to form methane. U.S. Patent Publication 2006/021,940 by Steinberg for a pumped carbon mining process represents this prior art. The present invention is distinguished from the pumped carbon mining process in that hydrogen is pumped into the coal seam or oil field at a temperature below that at which significant quantities of carbon in the coal will be extracted from the coal seam by chemical combination with the hydrogen.

[0025] The pumped carbon mining process disclosed in the '940 application removes carbon from the coal seam, creating a much larger storage space than exists in the coal bed. In the present invention, minimal quantities of carbon may be removed, but is fundamentally different because the present invention operates at much lower temperatures and is primarily directed at displacing and removing adsorbed and intersticial methane in the coal bed.

[0026] Accordingly, the present invention will maximize carbon dioxide sequestration potential of an underground coal bed by recovery of greater quantities of methane than is possible using carbon dioxide for this purpose. The present invention improves on the prior art by avoiding the coal bed swelling, blockage and interference of methane extraction from a coal bed by carbon dioxide. The present invention improves the energy efficiency of enhanced coal bedded methane extraction over that obtained with carbon dioxide. The present invention enhances coal bedded methane recovery by using a recycling working fluid, hydrogen, that does not require the purchase of hydrogen from market sources to continue the process. The present invention permits a maximization of carbon dioxide storage capacity of a coal seam. The present invention avoids potential environmental pollution associated with the dissolution of carbon dioxide in water and the re-release of dissolved carbon dioxide to the environment in the known enhanced methane recovery process using carbon dioxide. The present invention minimizes energy consumption in separating the working fluid from the methane. The present invention provides a pretreatment process for an underground coal bed to enable storage of greater volumes of carbon dioxide for sequestration while simultaneously enhancing methane recovery from the coal bed.

BRIEF SUMMARY OF THE INVENTION

[0027] A process enables storage of greater volumes of carbon dioxide for sequestration while simultaneously enhancing methane recovery from the coal bed. The process is implemented by injecting hydrogen into a coal bed, such as a depleted underground coal deposit, at a temperature below about 800 degrees Centigrade; extracting the hydrogen together with methane from the deposit, separating the hydrogen from the methane; delivering the methane as a product of the process; reinjecting the separated hydrogen into the deposit to continue the process until sequestration of carbon dioxide is desired; optionally producing hydrogen from methane and optionally injecting carbon dioxide for sequestration (**70**).

BRIEF DESCRIPTION OF THE DRAWING

[0028] The drawing is a flow diagram of the preferred embodiments of the process.

DETAILED DESCRIPTION OF THE INVENTION

[0029] In the following description, reference is made to the accompanying drawing, which forms a part hereof and which illustrates several embodiments of the present invention. The drawing and the preferred embodiments of the process are presented with the understanding that the present invention is susceptible of embodiments in many different forms and, therefore, other embodiments may be utilized and operational changes may be made without departing from the scope of the present invention.

[0030] The process employs hydrogen for pretreating an underground coal bed to enhance: (1) the potential for carbon dioxide sequestration by removing adsorbed methane and methane trapped within pores of the coal bed, and (2) methane production.

[0031] There are five fundamental steps to the base process. 1. injecting hydrogen into an underground coal bed, wherein the hydrogen is at a temperature below about 800 degrees Centigrade; 2. extracting hydrogen and methane from the coal bed; 3. separating the hydrogen from the methane; 4. delivering the methane as a product of the process; and 5. reinjecting the separated hydrogen into the deposit to continue the process until the deposit is no longer productive or until sequestration of carbon dioxide is desired.

[0032] The first step is injecting hydrogen into the underground coal bed, wherein the hydrogen is at a temperature below about 800 degrees Centigrade (**10**). For the typical embodiments, the coal bed is an underground coal deposit that has already undergone coal bedded methane removal, which typically leaves a significant amount of methane that is adsorbed on the surface of coal and trapped within minute pores of the coal bed.

[0033] Hydrogen is injected at a temperature below that in which significant hydrogasification of the resource occurs, that is namely about 800 degrees Centigrade. Hydrogen is preferably at any convenient temperature and no special temperature below the maximum temperature is required. Hydrogen temperature in a preferred embodiment is typically at ambient temperature, since the hydrogen at any convenient temperature will displace bound or adsorbed methane and will penetrate into the pores of the coal bed displacing and releasing the methane found in these pores. Penetration into the pores is facilitated by the low molecular weight and small molecular size of hydrogen. The upper limit on hydrogen temperature is specified because a chemical reaction forming new methane, called hydrogasification, predominates above about 800 degrees Centigrade. The subject invention is principally directed at methane displacement and not formation of new methane from the chemical combination of hydrogen with the carbon in the coal. The pressure required for hydrogen injection is that needed to circulate the hydrogen through the underground coal deposit.

[0034] Typically, at least one borehole will be utilized for injecting hydrogen. There is no limit on the number of boreholes that may be used to inject the hydrogen into the deposit.

[0035] The second step in the process is extracting hydrogen and methane from the coal bed (**20**). The methane released from the hydrogen injection of the first step mixes with the hydrogen to create a gaseous product, which is what is extracted from the coal bed. Extraction is typically accomplished either by simply allowing the production gas to flow to the surface, or by pumping the gas mixture to the surface through the same borehole. The hydrogen and methane mixture is the "production gas," but, as with any such process, probably includes contaminant gases and unwanted particulate matter.

[0036] In one embodiment, the step for extracting is performed using one borehole and this is typically the same borehole used for injection. In alternate embodiments more than one borehole is used for extraction, whether or not these are the same boreholes as used for injecting the hydrogen. For example, in some coal bedded methane deposits, a single injection borehole is fluidly connected to numerous surrounding extraction boreholes and these boreholes may be used in substantially the same manner for the present invention.

[0037] If the production gas contains contaminant gases, such as carbon dioxide gas, the production gas may be cleaned using well-known processes, such as pressure swing adsorption, membrane diffusion, solvent absorption-stripping, or cryogenic treatment. Particulate contaminates would typically be removed by filtration, but other methods are well known in the art.

[0038] The third step is separating the hydrogen from the methane in the production gas (**30**). Processes to separate gasses are well known in the art. For example, hydrogen can be readily separated from the methane by membrane diffusion. Separation of the hydrogen from the energy commodities is necessary to enable the recycling of the hydrogen back into the deposit to continue the process and to enable production of one or more energy products from the process.

[0039] The fourth step is delivering the methane as a product of the process (**40**). Once separated from the production gas, the methane is a valuable energy commodity that may be sold or used for other purposes.

[0040] The fifth step in the basic process is reinjecting the separated hydrogen into the deposit to continue the process until the deposit is no longer productive or until sequestration of carbon dioxide is desired (**50**). This step in the process is intended to continue the methane recovery process until it is determined that the process is not producing sufficient quantities of methane to merit continuation. However, the process may be stopped at any time either to halt operations or to begin injecting carbon dioxide for sequestration.

[**0041**] Once the methane production operation is stopped, the deposit may be used for sequestration of carbon dioxide. An embodiment of the invention therefore includes a step of injecting carbon dioxide for sequestration (**70**). Of course, the process might be used only to provide for enhanced methane recovery and not for carbon dioxide sequestration. However, while perhaps low in cost, simple recovery of methane is less than optimal use of this process. If such an operation were to be desired, it would be far more efficient and cost effective based on the total resources available to process the deposit with hot, pressurized hydrogen using the pumped carbon mining process. While having a larger front end cost, the pumped carbon mining process would yield far more methane than with the present invention. However, even though the present invention would be far less efficient based on the total resource available, it could still be operated principally as a means for enhanced methane recovery.

[**0042**] In an optimized process, an additional step may be needed to produce hydrogen from the methane to replenish hydrogen lost either in the deposit or in processing. Thus, in this embodiment, the process further includes a step of producing hydrogen from a portion of any separated methane to replenish lost hydrogen in the process (**60**). Typically, such step would involve steam reforming methane produced from the deposit. Steam reforming methods are well known in the art.

[**0043**] At the end of the methane recovery process, an embodiment of the process includes a step of collecting the separated hydrogen for resale or reuse (**80**). This is an optional step considering that one may simply decide to sell the hydrogen with the methane or burn off or discharge the hydrogen. Considering its cost, however, it should be economically attractive to capture and sell the hydrogen separately.

[**0044**] In an embodiment of the invention where the hydrogen is collected at the end of the commodity recovery process, a step is included for injecting carbon dioxide (**90**) for sequestration.

[**0045**] The disclosure herein is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiments illustrated. Thus, the scope of the invention is determined by the appended claims and their legal equivalents rather than by the examples given.

What is claimed is:

1. A process for pretreating an underground coal bed to enhance the potential for carbon dioxide sequestration and to enhance methane production comprising the steps of,

injecting hydrogen into an underground coal bed, wherein the hydrogen is at a temperature below about 800 degrees Centigrade;

extracting hydrogen and methane from the coal bed;

separating the hydrogen from the methane;

delivering the methane as a product of the process; and

reinjecting the separated hydrogen into the deposit to continue the process until the deposit is no longer productive or until sequestration of carbon dioxide is desired.

2. The process of claim 1 further comprising the step of cleaning the extracted methane and hydrogen to remove contaminants.

3. The process of claim 1 further comprising the step of injecting carbon dioxide for sequestration after the last step.

4. The process of claim 1 further comprising the step of producing hydrogen from a portion of the methane to replenish lost hydrogen in the process.

5. The process of claim 1 further comprising the step of collecting the separated hydrogen for resale or reuse after the last step.

6. The process of claim 1 wherein both the step of injecting and the step of extracting are performed using at least one borehole into the deposit.

7. The process of claim 1 wherein the step of injecting is performed using at least one borehole into the deposit and the step of extracting is performed using at least one borehole different than any borehole used for injecting the hydrogen.

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