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Hardy et al.

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[54] **DOWNHOLE CONTROL VALVE FOR CATALYTIC WELLBORE HEATERS**

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[51] **Int. Cl.** **E21b 43/24**

[58] **Field of Search** ..... 166/53, 59, 64, 65 R, 166/65 M, 66, 72, 251, 302; 236/15 B, 69; 431/80

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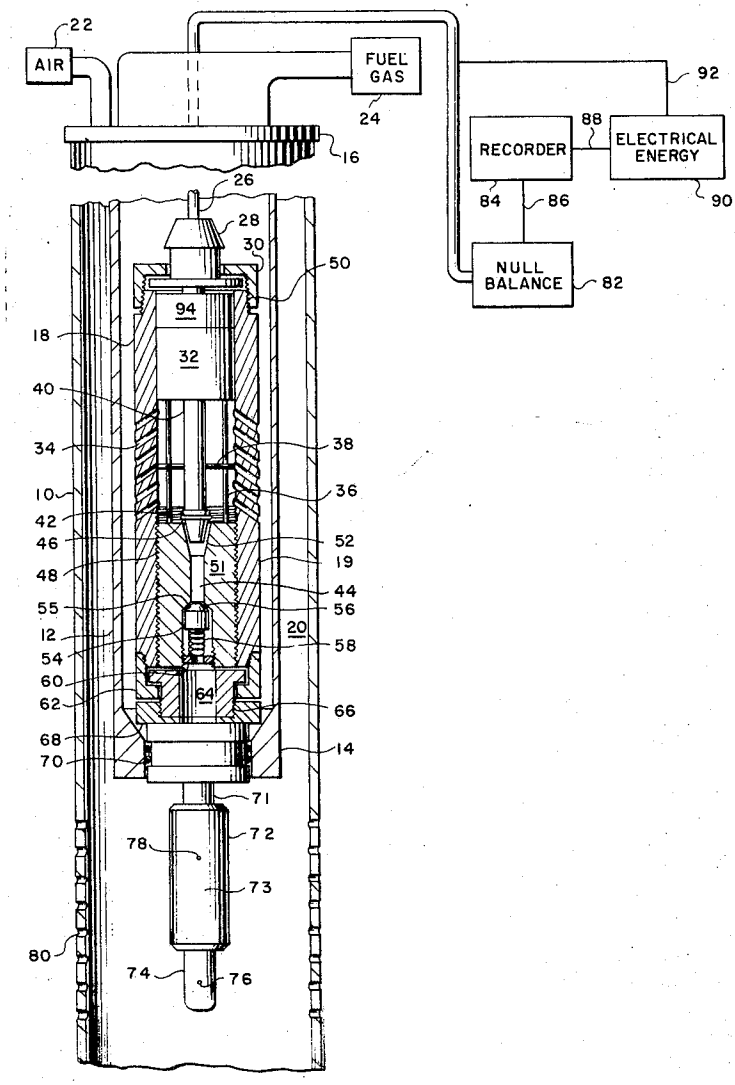
[57] **ABSTRACT**

A downhole control valve is positioned in well pipe above a catalytic wellbore heater and is used to control fuel being fed to the heater.

23 Claims, 2 Drawing Figures



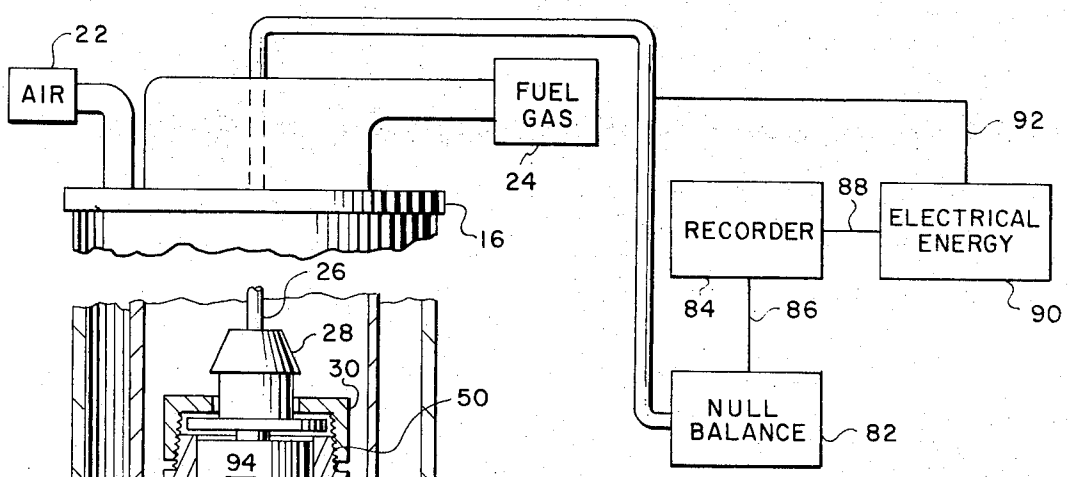
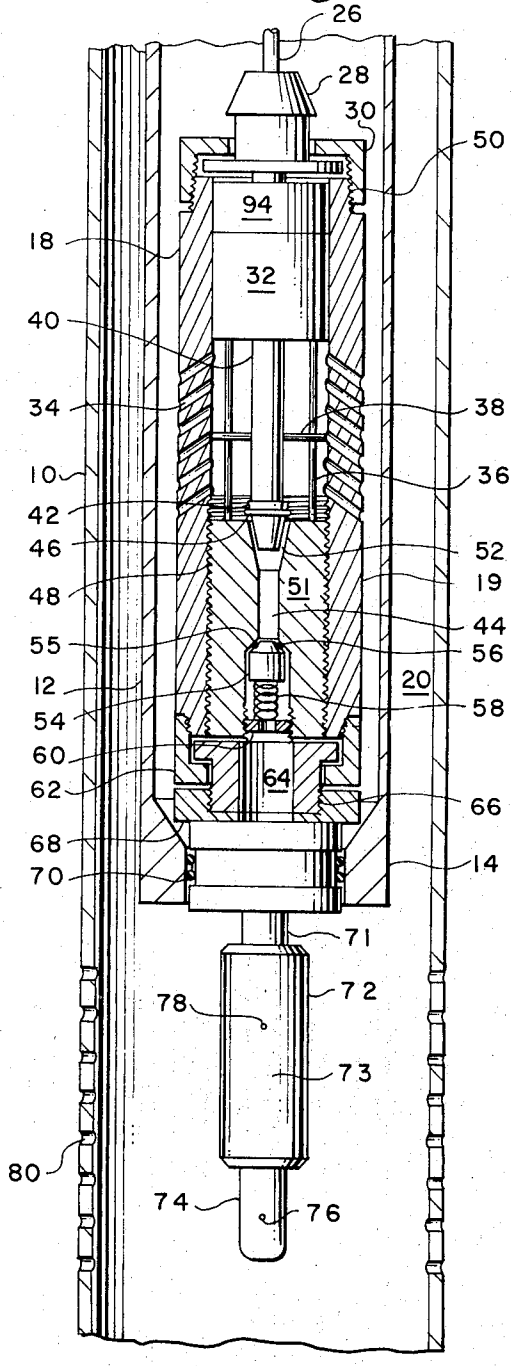


FIG. 1



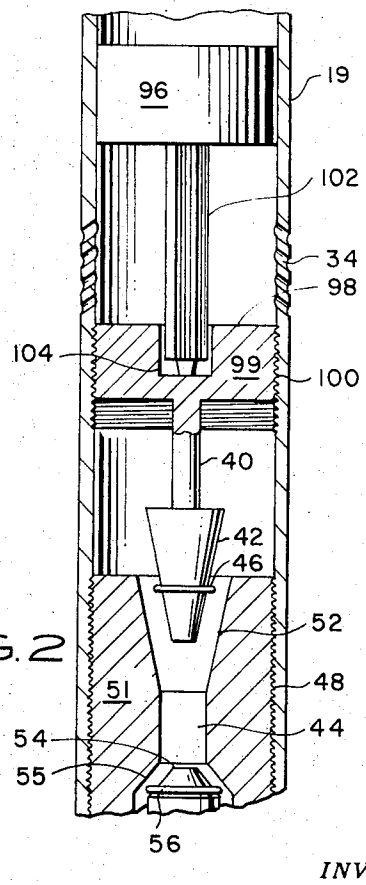


FIG. 2

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DOWNHOLE CONTROL VALVE FOR CATALYTIC WELLBORE HEATERS

BACKGROUND OF THE INVENTION

This invention relates to a fuel control device for use with a catalytic wellbore heater as disclosed in Ser. No. 92,836, entitled "METHOD AND APPARATUS FOR CATALYTICALLY HEATING WELLBORES" or catalytic ignitors for conventional wellbore heaters such as described in Ser. No. 889,060, entitled "METHOD AND APPARATUS FOR IGNITING WELLHEATERS."

Wellbores are heated for various purposes including wellbore clean-out, sand consolidation and in situ combustion. Heat may be supplied by downhole electrical heaters, gas burners, catalytic reactors, etc.

Heretofore, the use of electrical heaters was limited to shallow wells due to the problems related to supplying electrical power at depths in excess of three thousand feet. High voltages are required for operation of the electrical heater and when the electrical cable exceeds a length of three thousand feet, for example, electrical resistance reduces voltage to a point below that required for operation of the heater. Electrical heaters also have a tendency to short out due to hot spots developed through poor heat exchange caused by coke formation on the surface of the heater. The temperature in the coke layer builds up until it exceeds the melting point of the heating elements, causing the electrical heater to fail. In addition, electrical energy is not always available in remote areas, necessitating use of large generators which are expensive to acquire, locate and maintain.

Gas fuel burners unlike electrical heaters can be used at depths below three thousand feet. In such burners the combustion temperatures of natural gas can approximate 4000 F. Heat shields are used to prevent damage to tubing and casing. However, at higher temperatures damage to the heat shield and well pipe may occur, especially when the flame stands off from the nozzle and extends below the heat shield. The formation adjacent the damaged casing also may suffer irreparable heat damage.

Catalytic heaters operate at temperatures sufficiently low to prevent wellbore damage. They also can be used at any depth that the electrical or gas burner systems can be used. One present type of catalytic heater relies totally or partially on radiation of heat generated by catalytic reaction. Such a system is usually totally enclosed or partially opened to allow passage of gases taking part in the catalytic reaction. This system requires separate conduits to supply the fuel mixture to the catalytic material and therefore is fairly expensive to use. Also, there is poor heat exchange because of the necessity of radiating through an enclosed system, or relying on the flow of the reaction gases passing through the catalyst which are limited to fairly low rates to insure efficient reaction of such gases.

Another catalytic system utilizes a catalytic material completely open to the wellbore where a fuel gas is flowed down the tubing and passes through the catalytic material and air passes down the annulus and into contact with the exterior of the catalytic material causing catalytic reaction. An excess of air is flowed down the annulus to carry the heat of the reaction into the formation. This system has proved highly efficient in that the heated reaction is efficiently carried into the

formation. With the above described system, heat is not lost by radiation through well pipe nor is the heat transferred, limited to the flow rate of reaction gas passing through the catalytic material. In the utilization of this system, it has been discovered that changes in gas or air flow may cause extremely high temperatures which damage the catalytic heater and its operability. Changes in flow rate of the fuel gas and/or air may result from various causes. One such cause is the freeze up of the air line, resulting in a rich mixture reaching the catalytic surface because of a lack of air. As the mixture enriches at the catalytic surface, the flame temperature of the fuel gas may be reached and act in the manner of a cutting torch on the catalytic heater. Another cause of change in flow rate may be the breakdown of the formation permeability caused by such things as the melting of paraffin or the breakdown of heavy hydrocarbons. When the formation's resistance to flow breaks down, the effect is to suck the fuel gas in the rubing out through the catalyst and thereby cause a rich mixture at the catalyst surface. This rich mixture may cause a highly intense flame or an explosion which will cause damage to the heater and possibly damage to the well pipe. Because of the cost of the catalytic heaters and the time required to retrieve and replace damaged heaters, substantial economy can be had by obviating this problem. It is therefore an object of the present invention to provide an improved catalytic heater.

SUMMARY OF THE INVENTION

With these and other objects in view, the present invention contemplates use of a downhole catalytic heater having means for controlling the flow rate of gas being supplied to the catalytic surface. This control is interposed in well pipe above the catalytic material.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational view partly in cross section of a catalytic heater having a flow control, with surface equipment schematically represented.

FIG. 2 is a cross section of an alternative embodiment of a portion of the flow control shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 1 of the drawings, there is depicted a catalytic heater located in a wellbore, connected with surface equipment for supplying a fuel mixture to the catalytic heater and a fuel flow control to regulate the amount of fuel reaching the catalytic surface area.

The catalytic heater **18** has a flow control section **19** and a catalytic section **72.** The catalytic section is shown extending below tubing **12** and adjacent perforations **80** and casing **10.** The catalytic section **72** has been described in detail in Ser. No. 92,836, entitled METHOD AND APPARATUS FOR CATALYTICALLY HEATING WELLBORES. For the purposes of this drawing there is shown an oxidation catalyst on a suitable support which is formed on a cylindrical pipe member **71** which has perforations therein to allow communication between the interior of the pipe and the catalytic material. Positioned on the catalytic surface **73** is thermocouple **78.** Extending below the catalytic surface **73** is temperature pill holder **74** containing pills which melt at different temperatures so that the

highest temperature attained by the heater can be determined. On the exterior of temperature pill holder **74** is lower thermocouple **76.** The thermocouples **76** and **78** transmit an electromotive force signal to a surface recorder **84** by way of thermocouple cable **26.** The thermocouple cable **26** is armored in order that it can be used to lower the catalytic heater **18** into the wellbore. The thermocouple cable **26** is attached to the heater **18** by cablehead **28.** This cablehead **28** is locked into the upper portion of control section **19** by connector **30** which is threadedly attached to the catalytic heater at **50** and has an annular flange portion which extends over a mating annular flange formed on the cablehead **28.**

The flow control section **19** has a rectifier **94** for converting alternating to direct current and a solenoid **32** located at the upper end of the section which solenoid is connected with a cylindrical valve stem **40** having a sealing surface **42** with an O-ring **46** thereon. The solenoid **32** is of a conventional design and may be energized through an electrical line contained in thermocouple cable **26** and connected through rectifier **94.** The solenoid **32** has a spring located therein connected with the valve stem **40** in such a manner that the spring operates to keep the sealing surface **42** spaced from a valve seat **52.** Valve seat **52** is an annular sealing surface describing an inverted truncated cone. The sealing surface **42** connects the flow passage **44** which extends through the remainder of the flow control section **19** to connect with the interior of the cylindrical pipe member **71** extending through catalytic section **72.** A portion of the flow passage **44** is configured to provide a check valve seat **55** for check valve **54** as well as the valve seat **52** located at the upper end of the flow passage **44.** Check valve **54** is a valve stem mounted on a spring **58.** The spring **58** is adjusted to provide a resistance of approximately 1 pound per square inch. The spring **58** is mounted on annular lock ring **60** which is threadedly engaged with the wall of flow passage **44.** The annular lock ring **60** consists of an annular threaded ring for seating the spring **58** and having a bore therethrough for allowing passage of gas. O-ring **56** is mounted on the check valve **54** and is arranged to provide a seal when in contact with check valve seat **55.** The valve seat **52** for engaging the solenoid operated valve stem **40,** check valve seat **55,** and a portion of flow passage **44** are all part of removable valve seat housing **51** which threadedly engages the interior wall surface of the flow control section **19.**

In order to keep the valve stem **40** properly aligned with valve seat **52,** there is guide **38** extending between the wall of the flow control section **19,** which guide is shown in the area adjacent upwardly directed flow channels **34.** Also shown extending through the portion of the flow control section **19** housing the valve stem **40,** are thermocouple lines **36** which are recessed in a groove in the wall of the flow control section **19.**

Located below the flow control section **19** is alignment plug **64** which is held in place by threaded connector **62.** The alignment plug **64** has the flow passage **44** and thermocouple conduits for thermocouple lines **36** passing therethrough. The plug **64** is locked into place such that it is aligned with the thermocouple line **36.**

"No-go" flange **68** is threadedly attached to and positioned below alignment plug **64** with such threaded connection shown at **66.** The no-go flange **68** has an O-ring section **70,** for engaging a seating nipple **14** located on the lower end of tubing **12.**

Air compressor **22** is located at the surface and supplies air to the annular space **20** between the tubing **12** and the casing **10.** The air compressor is of sufficient capacity to supply air at a pressure in excess of the formation pressure. A fuel gas supply **24** also located at the surface, provides a fuel gas to the interior of the tubing **12.** Thermocouple cable **26** extends to the surface and connects with null balance **82** which is connected by electrical line **86** to a strip chart recorder **84** used to continuously record the temperature adjacent the catalytic section **72** and the temperature pill holder **74.** Null balance **82** is arranged to activate a control system if the temperature exceeds the threshold value which has been preset in the null balance. The null balance **82** is connected through strip chart recorder **84** with electrical energy source **90** by way of electrical line **88.** The control signal emanating from null balance **82** acts to close a switch (not shown) so that electrical energy from electrical energy source **90** can pass through electrical line **92** and through the electrical line in armored thermocouple cable **26** and finally to solenoid **32** through rectifier **94.**

In the operation of the apparatus described in FIG. **1,** the catalytic ignitor **18** is lowered into the interior of the tubing **12** by thermocouple cable **26.** No-go flange **68** acts to seat the catalytic heater **18** so that the catalytic section **72** extends below the tubing **12.** The O-ring seal section **70** acts to seal the interior tubing **12** from the exterior of the tubing. Air supplied by air compressor **22** is pumped into the annular space **20** which flows by catalytic section **72** and out perforations **80.** A fuel gas from fuel gas source **24** is pumped into the tubing whereupon reaching the flow control section **19** the gas enters upwardly directed flow channels **34.** A filter may be placed either on the exterior or the interior of the flow channels **34** to prevent foreign particles from adhering to the valve seat **52.**

After the fuel gas enters the interior of flow control section **19** it enters flow channel **44** which extends down to and through the catalytic section **72.** Upon reaching the catalytic section **72** the fuel gas passes through the catalytic surface by way of slots in the cylindrical pipe member **71** passing through the catalytic section **72.**

Given the proper conditions the fuel gas and air now present at the catalytic surface will react and supply heat to be carried into the formation through the perforations **80** by excess air entering the annular space **20** from air compressor **22.** Hydrogen may be used to attain a spontaneous reaction and raise the temperature adjacent the catalyst above that needed to react natural gas and air. This procedure is described in detail in Ser. No. 92,836. In order for the fuel gas to pass through the flow control section **19,** it must exert sufficient force to overcome spring **58** which acts to operate check valve **54.** This check valve **54** may be configured so as to operate both when insufficient and excessive pressure is being supplied to the catalytic section **72.**

The temperature adjacent the catalytic section **72** is continuously monitored by thermocouples **76** and **78.** These thermocouples transmit an electromotive force signal which is carried by the armored thermocouple cable **26** to the null balance **82** which connects with strip chart recorder **84** where it is recorded. If the temperature indicated by thermocouples **76** and **78** ex-

ceeds predetermined threshold values, the null balance **82** transmits a control voltage through line **88** to activate a switch to connect electrical source **90** with solenoid **32** by way of electrical line **92,** thermocouple cable **26** and rectifier **94.**

Upon activation of solenoid **32,** the core of the solenoid forces valve stem **40** downward so that the sealing surface portion **42** of the valve stem will engage the valve seat **52.** O-ring **46** also engages the valve seat **52** to insure a tight seal. When the temperature located adjacent the catalytic section **72** subsides to a point below the threshold value required to activate the control signal in the null balance, the electrical energy will be terminated and the spring in the solenoid will act to retract the core and attached valve stem **44** to open the valve.

In the interest of safety it may be desirable to require manual action to terminate the electrical energy being supplied to the solenoid **32.** This procedure will allow time for rectifying any problems which may have caused the temperature to be excessively high.

Referring next to FIG. **2,** there is shown a portion of a flow control section similar to the one described at **19** in FIG. **1.** Reversible motor **96** is mounted in the upper portion of flow control section **19** and is a direct current electric motor wired in a manner so that the motor shaft can be driven in both a counterclockwise and a clockwise direction. The motor shaft is hexagonally shaped at its lower end and engages a hexagonally shaped recess in drive section **99** of a valve stem **40** which is located on the upper end of such valve stem **40.** The drive section **99** of the valve stem **40** is threadedly engaged with the wall of flow control section **19** at **100.** The valve stem **40** terminates at its lower end with a generally cylindrical sealing surface **42** which has a shallow taper narrowing toward its lower end and also has an O-ring **46** attached thereto.

Positioned adjacent the sealing surface **42** is valve seat **52** which is tapered to conform with the taper of the sealing surface **42.** Flow channel **44** extends below the valve seat **52** and is a cylindrical bore through valve housing **51.** The lower portion of the flow channel **44** has been configured to provide a check valve seat **55.** This check valve seat **55** is a circular sealing surface and conformed to engage check valve **54** which has an O-ring section **56.** As in FIG. **1,** the removable valve seat housing **51** is threadedly engaged with the outer wall of the flow control section **19.**

Flow channels **34** are located in the wall of the flow control section **19** at a point adjacent the motor shaft **102.** These ports **34** are upwardly directed so as to reduce the amount of debris that would enter the interior of the flow control section **19.** Filters also may be used adjacent the ports **34** so that debris does not enter the flow control section **19** and impede closure of the valves.

The apparatus shown in FIG. **2** operates much in the same manner as the flow control section does in FIG. **1.** The check valve **54** operates in same fashion as it did in FIG. **1.** Air passes down the annulus between the tubing and casing and contacts the surface of the catalyst. Fuel gas flows down the tubing and enters the flow control section **19** through the ports **34.** Thermocouple information is conveyed to the surface in the same manner as was described in FIG. **1** and the surface equipment used in FIG. **1** operates essentially in the same manner to operate the valve in FIG. **2.** The null balance shown at **82** in FIG. **1** would have to be adapted to provide a control signal for temperatures below a minimum temperature setting and a different control signal for temperatures above a maximum temperature setting.

If a two wire system is connected with the electric motor **96,** the control signal produced by the null balance would activate a switch to impress voltage across the electric motor **96** in a manner to drive the motor shaft **102** in either a clockwise or counterclockwise direction. Thus, if the drive section **99** is threadedly engaged with the wall of the flow control section **19** in a manner that the valve stem **40** descends when the motor shaft **102** is rotated clockwise, then for temperatures in excess of the upper threshold temperature the signal from the null balance would act to operate the motor in a clockwise direction. Conversely, if the temperature is below the lower threshold temperature, the control signal from the null balance would act on the electrical energy source to impress voltage across the electric motor **96** so as to drive the motor shaft **92** in a counterclockwise direction, thereby moving the sealing surface **42** away from the valve seat **52.** Thus, there is a spline drive connection between the motor shaft and the valve stem resulting in upward or downward movement of the valve stem depending on the direction of rotation of the motor shaft.

A single control wire system can also be utilized to operate the motor **96** by frequency control to change polarity of the motor.

The configuration shown in FIG. **2** has the advantage that fuel is generally supplied to the catalytic section continuously because of the gradual closure of the valve. This will help to prevent having to initiate anew the catalytic reaction each time the temperature exceeds the upper threshold temperature of the null balance.

It is contemplated that various configurations of valves and means of opening and closing such valves may be utilized to prevent excessive flows through a catalytic heater. Thus, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects, and therefore the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. In a catalytic wellbore heater system having a catalytic surface communicating with the interior of well pipe, the improvement comprising: downhole valve means in the well pipe adjacent the catalytic surface for regulating the flow rate of one component of a fuel mixture to the catalytic surface; means for continuously monitoring the temperature adjacent the catalytic surface; and downhole means operably connected to the valve means for controlling the valve means in response to the temperature monitoring means.

2. The apparatus of claim **1** wherein the valve means comprises a valve stem, a valve seat sized to engage the valve stem, and a motor connected with the valve stem for moving the valve stem toward and away from the valve seat.

3. The apparatus of claim **2** including electrical energy means, responsive to the temperature monitoring means, for energizing the motor.

4. The apparatus of claim **1** wherein the controller means comprises means for comparing the sensed tem-

perature adjacent the catalytic section with a preselected temperature range, said comparer means adapted to provide a control signal when the sensed temperature is outside the preselected temperature range, and means reponsive to the control signal for controlling the supply of electrical energy to the valve means.

5. The apparatus of claim **4** wherein the valve means includes a housing containing a valve stem, a valve seat, and an electrically operated motor connected with the valve stem in a manner such that the valve stem can be moved toward and away from the valve seat, and wherein the motor is also connected with the electrical energy means.

6. The apparatus of claim **5** wherein the connection between the motor and the valve stem is a spline drive connection and wherein the motor is reversible to allow both clockwise and counterclockwise movement of the motor shaft and connected valve stem.

7. The apparatus of claim **6** wherein a portion of the valve stem adjacent the spline drive connection is threadedly engaged with the housing.

8. The apparatus of claim **1** wherein the valve means includes a housing containing a valve stem, a valve seat, and a solenoid connected with the valve stem.

9. The apparatus of claim **8** wherein the means for controlling the valve means includes electrical energy means interruptably connected with the solenoid and which is responsive to the temperature monitoring means.

10. The apparatus of claim **9** wherein the temperature monitoring means comprises thermocouples located adjacent the catalytic heater, which are electrically connected with a surface recorder.

11. The apparatus of claim **10** including a null balance connected with the thermocouples and adapted to transmit a control signal to the valve control means upon receiving temperature readings outside a predetermined temperature range.

12. The apparatus of claim **11** wherein the valve control means is responsive to the control signal, transmitted by the null balance and includes a switch means, interposed between the electrical energy means and the solenoid, for controlling the flow of electrical energy from the electrical energy means to the solenoid.

13. The apparatus of claim **1** including a check valve means, positioned below the valve means, for preventing backflow through the catalytic surface.

14. In a downhole catalytic wellbore heater system having a catalytic surface extending below well pipe and utilizing a fuel mixture passed from the surface, the improvement comprising: a temperature responsive downhole valve means having a valve seat and valve stem positioned in the well pipe above and adjacent to the downhole catalytic surface, and wherein said downhole valve means is adapted to regulate the amount of one component of a fuel mixture passing through the valve seat and into contact with the catalytic surface.

15. The apparatus of claim **14** including means for continuously determining the temperature adjacent the catalytic surface, including means for determining when such temperature is outside a predetermined temperature range, and which is adapted to initiate a control signal upon the occurrence of the temperature falling outside that predetermined range, and means operably connected to the valve means and responsive to the control signal for activating the temperature responsive valve means.

16. The apparatus of claim **15** wherein the valve activating means includes an electric motor connected with the valve stem.

17. The apparatus of claim **16** wherein the valve activating means includes a source of electrical energy located at the surface, an electric line connecting the energy source with the electric motor, and switch means positioned on the electric line and responsive to the control signal generated by the temperature limit means.

18. The apparatus of claim **20** wherein the regulating means comprises a valve stem, a valve seat located adjacent the valve stem, and a motor coupled with the valve stem and wherein a portion of the valve stem is threadably engaged with the housing such that rotation of the valve stem about its longitudinal axis will cause the valve stem to move in a vertical direction.

19. The apparatus of claim **18** wherein the motor is adapted to run in a forward and a reverse direction and wherein the motor is attached to the valve stem in a manner to allow rotation of the valve stem.

20. Apparatus for supplying heat to a wellbore having well pipe therein comprising: a catalytic material having flow channels therethrough attached at the lower end of the well pipe; means for flowing one component of a fuel mixture down the well pipe and through the catalytic material; means for flowing the remaining component of the fuel mixture down the wellbore between the wellbore and the well pipe and past the catalytic material; and, flow control means positioned in the well pipe directly above the catalytic material which comprises a housing, a restricted flow channel in said housing, and means in said housing for regulating flow through the restricted flow channel.

21. The apparatus of claim **20** including electrically responsive means for controlling movement of the flow regulating means; electrical energy means electrically connected with the flow regulating means; means for continuously determining the temperature adjacent the catalytic material; means for comparing such temperature with a predetermined range; and means responsive to the comparer means for controlling the electrical energy means so that the flow regulating means is responsive to the temperature adjacent the catalytic material.

22. The apparatus of claim **21** wherein the temperature determining means includes thermocouples positioned on the catalytic material and in the wellbore below the catalytic material; wherein the restricted flow channel includes a valve seat and the flow regulating means includes a valve stem; wherein the flow regulating means includes an electric motor connected with the valve stem; wherein the temperature comparer includes a null balance; and wherein the controller means includes a switch means responsive to the null balance, and which switch means acts to control the current being supplied the electric motor.

23. The apparatus of claim **22** wherein the electric motor has the capability to run in both a forward and reverse direction and is attached to the valve stem in a manner to rotate the valve stem in clockwise and counterclockwise directions and wherein a portion of the valve stem is threadedly engaged with the interior wall of said flow control means housing, such that rotation of the valve stem will move the valve stem in a vertical direction.

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