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(54) **WATER HEATER APPARATUS WITH DIFFERENTIAL CONTROL**

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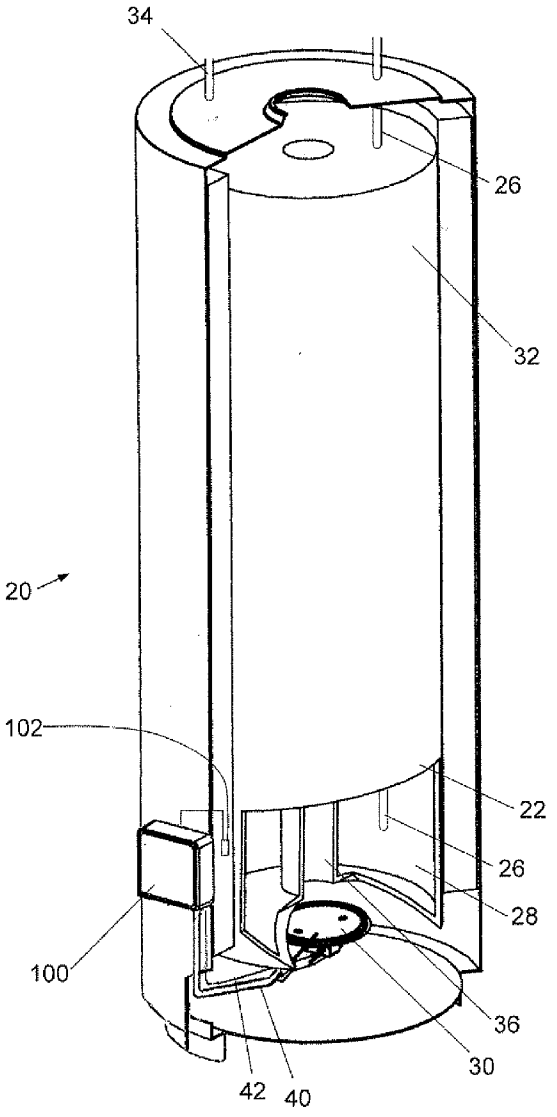
(57) **ABSTRACT**

An apparatus for a water heater is configured to control heating operation of a water heater to maintain a desired water temperature. The various embodiments comprise a sensor that provides an output indicative of the sensed temperature of water in a water heater, and a controller in communication with the sensor. The controller is operable to initiate a present call for heat where the sensed temperature is a predetermined amount below a set-point temperature. The controller is also configured to determine whether a prior call for heat occurred within a predetermined elapsed time period preceding the present call for heat, and to respond thereto by delaying the start of heating operation in the present call for heat until one of a predetermined time period or a predetermined sensed temperature change has occurred.



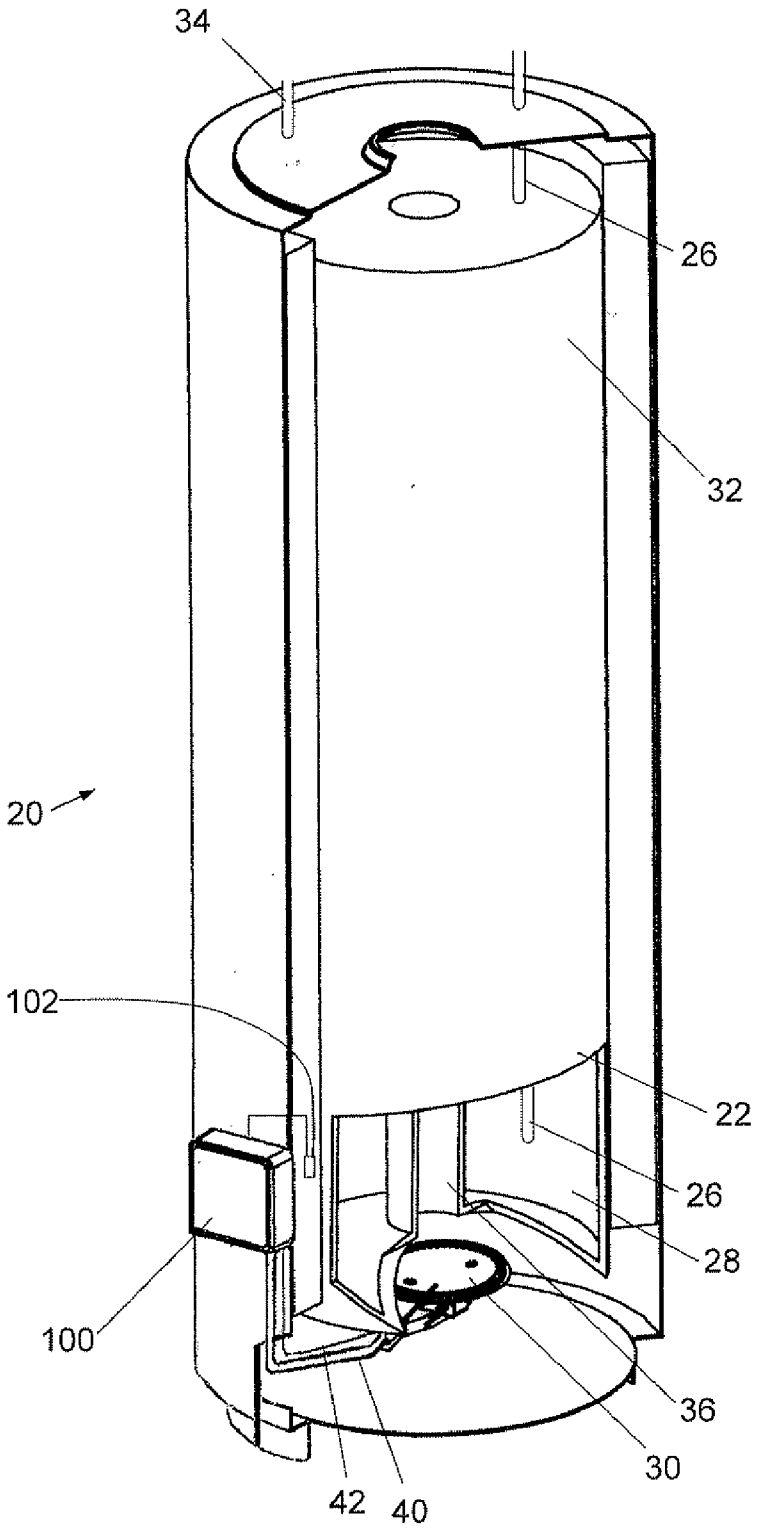


FIG. 1

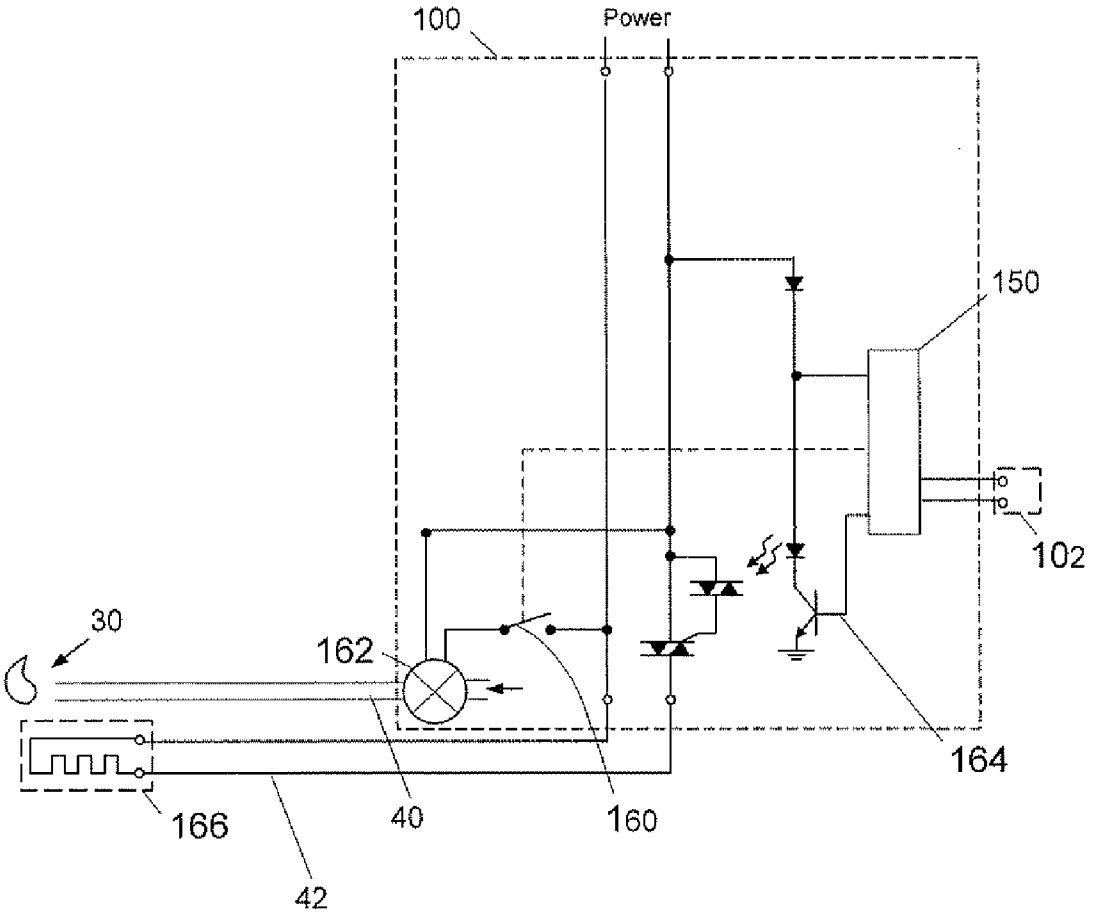


FIG. 2

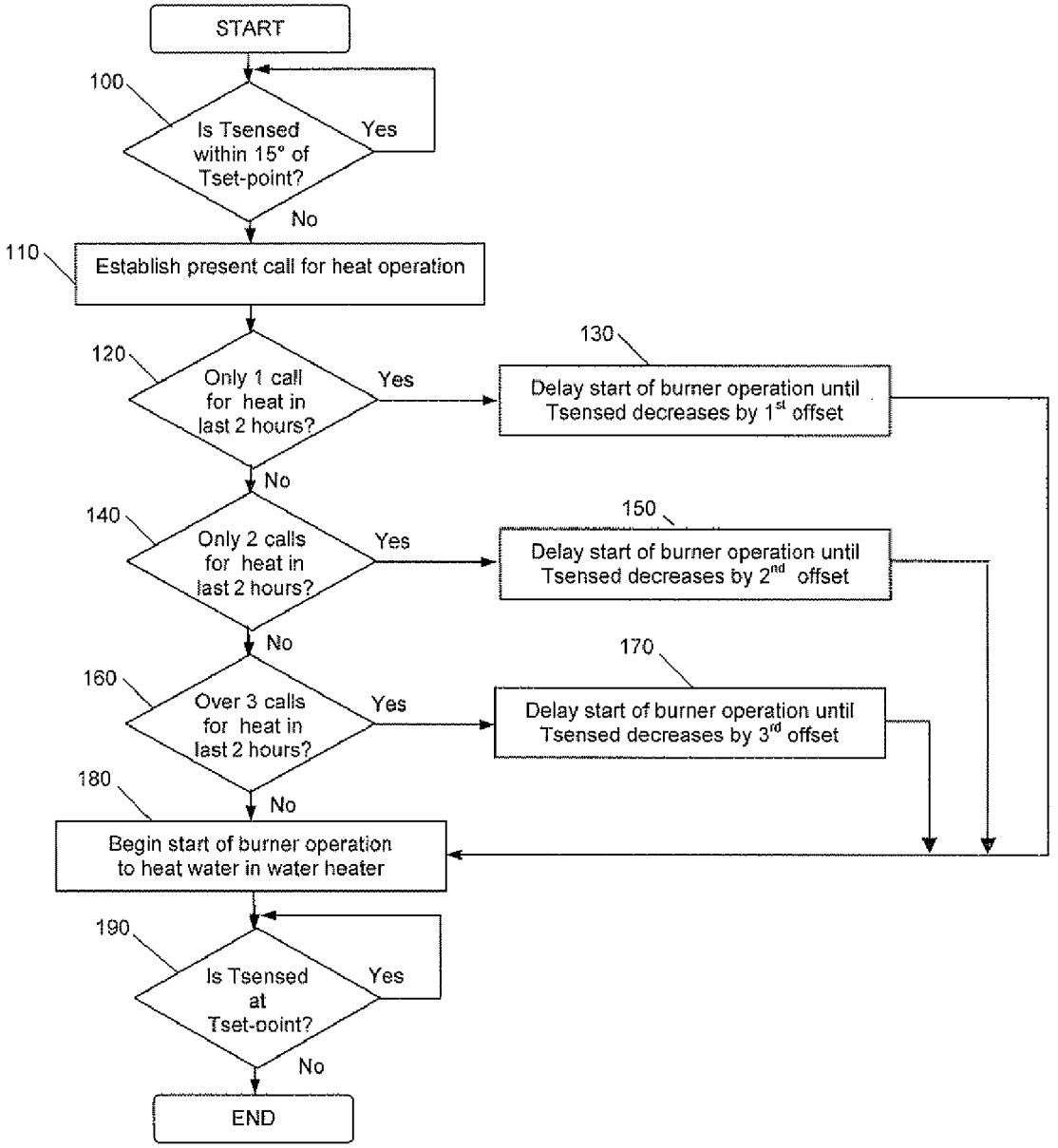

START
100
Is Tsensed within 15° of Tset-point?
Yes
No
110
Establish present call for heat operation
120
Only 1 call for heat in last 2 hours?
Yes
130
Delay start of burner operation until Tsensed decreases by 1st offset
No
140
Only 2 calls for heat in last 2 hours?
Yes
150
Delay start of burner operation until Tsensed decreases by 2nd offset
No
160
Over 3 calls for heat in last 2 hours?
Yes
170
Delay start of burner operation until Tsensed decreases by 3rd offset
No
180
Begin start of burner operation to heat water in water heater
190
Is Tsensed at Tset-point?
Yes
No
END

FIG. 3

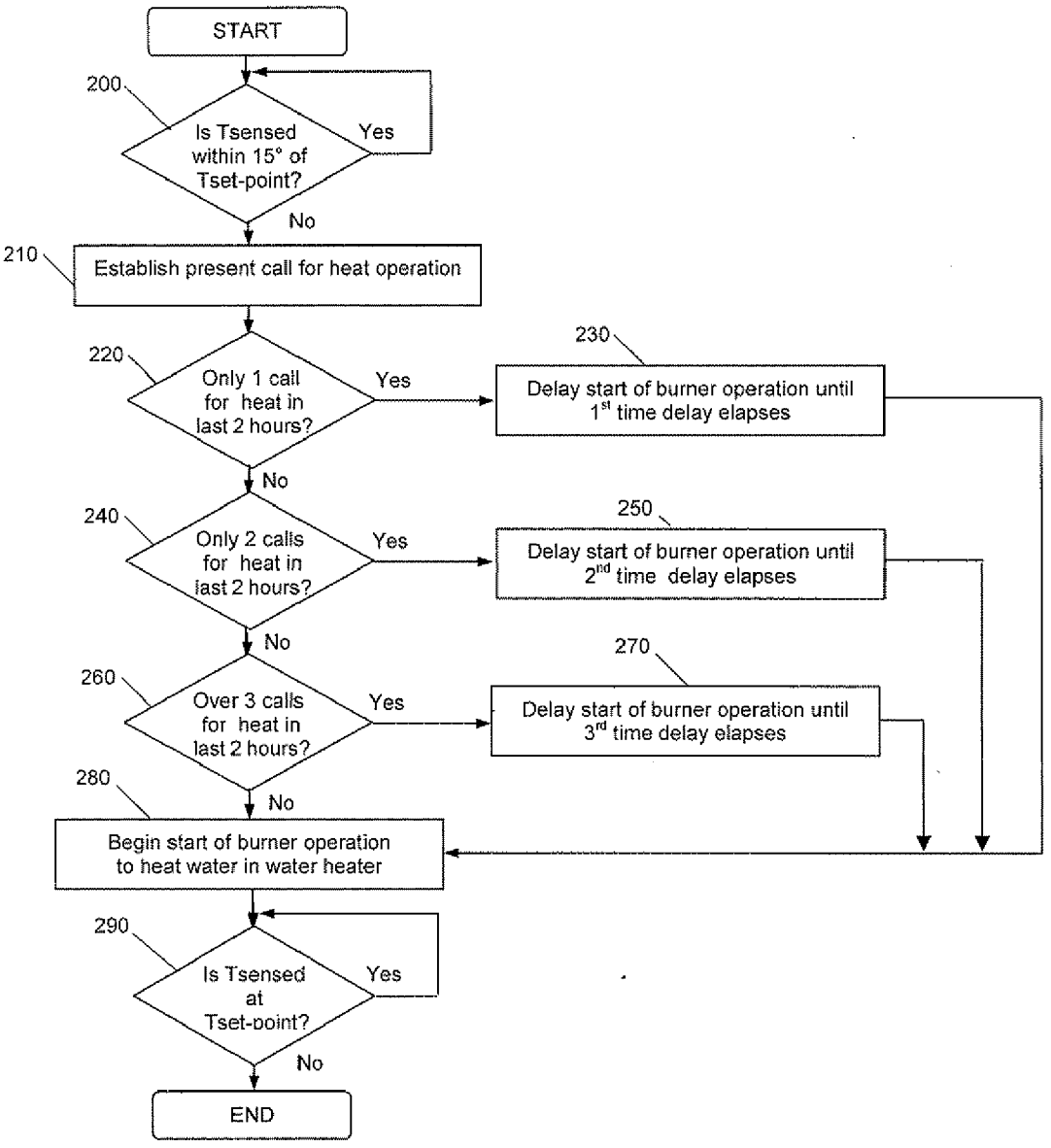

START
200
Is Tsensed within 15° of Tset-point?
Yes
No
210
Establish present call for heat operation
220
Only 1 call for heat in last 2 hours?
Yes
230
Delay start of burner operation until 1st time delay elapses
No
240
Only 2 calls for heat in last 2 hours?
Yes
250
Delay start of burner operation until 2nd time delay elapses
No
260
Over 3 calls for heat in last 2 hours?
Yes
270
Delay start of burner operation until 3rd time delay elapses
No
280
Begin start of burner operation to heat water in water heater
290
Is Tsensed at Tset-point?
Yes
No
END

FIG. 4

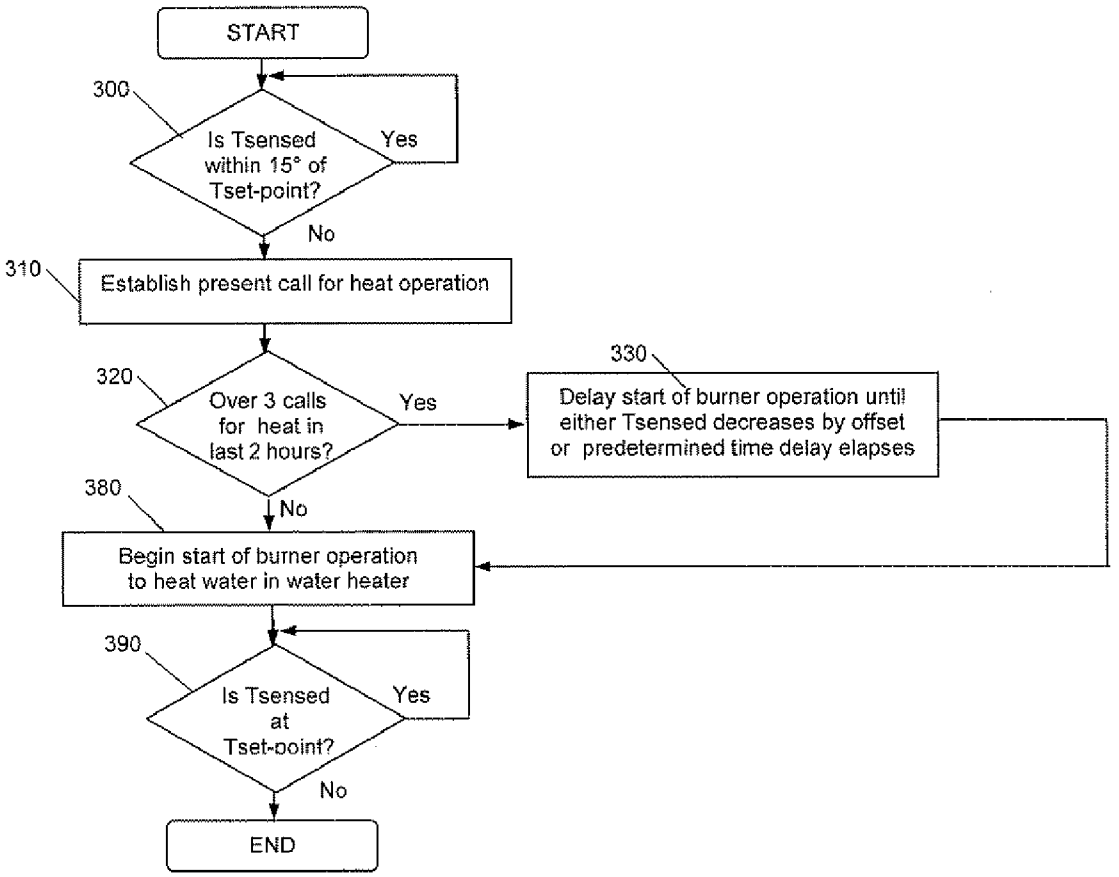

START
300
Is Tsensed within 15° of Tset-point?
Yes
No
310
Establish present call for heat operation
320
Over 3 calls for heat in last 2 hours?
Yes
330
Delay start of burner operation until either Tsensed decreases by offset or predetermined time delay elapses
No
380
Begin start of burner operation to heat water in water heater
390
Is Tsensed at Tset-point?
Yes
No
END

FIG. 5

WATER HEATER APPARATUS WITH DIFFERENTIAL CONTROL

FIELD

[0001] The present disclosure relates to the control of a hot water heater, and more particularly to apparatus for controlling heating operation of the heater to maintain a more consistent temperature.

BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] In a typical water heater, cold water is introduced into the bottom of a hot water heater tank where it is detected by a sensor that triggers a call for heat. When a water heater is subjected to repeated short draws of hot water in which water draw stops shortly after a call for heat is initiated, the water temperature in the tank can stratify and lead to water that is much hotter than the desired temperature setting. Stacking can be reduced by a large temperature differential setting, such as 20° Fahrenheit, so that the water temperature must drop 20° below the water temperature setting before a call for heat is initiated. However, over a few hours of inactivity, the water in the tank will cool off and any hot water draw before a call for heat is initiated will result in complaints that the water is too cold. For example, where a hot water heater is set to 120 degrees F., and the differential is set to 20 degrees F., water in the tank may cool to 101 degrees F. overnight such that any draw of hot water in the morning would be too cold. Thus, large differential settings result in cold water complaints in the morning. A narrower differential setting decreases energy efficiency, because the water heater turns on more often as the water temperature drops over time. Thus, there is a need for control of a water heater that reduces stacking effects yet maintains a comfortable hot water temperature.

SUMMARY

[0004] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features. Various embodiments of an apparatus are disclosed that are configured to control heating operation of a fuel-fired water heater. The various embodiments include an apparatus configured to control heating operation of a water heater to maintain a desired water temperature. The various embodiments comprise a sensor that provides an output indicative of the sensed temperature of water in a water heater, and a controller in communication with the sensor. The controller is operable to initiate a present call for heat where the sensed temperature is a predetermined amount below a set-point temperature. The controller is also configured to determine whether a prior call for heat occurred within a predetermined elapsed time period preceding the present call for heat, and to respond thereto by delaying the start of heating operation in the present call for heat until one of a predetermined time period or a predetermined sensed temperature change has occurred.

[0005] In some embodiments, the controller is configured to delay the start of heating operation until the sensed temperature decreases by a predetermined sensed temperature change, which may be dependent on the number of prior calls for heat within the predetermined elapsed time period. In such embodiments, the controller may be configured to delay heating operation until a first predetermined sensed temperature change occurs where a single prior call for heat occurred within the predetermined elapsed time period. The controller may also be configured to delay heating operation until a second predetermined sensed temperature change occurs where two prior calls for heat occurred within the predetermined elapsed time period, or to delay heating operation until a third predetermined sensed temperature change occurs where at least three prior calls for heat occurred within the predetermined elapsed time period.

[0006] In other embodiments, the controller is configured to delay heating operation until a first predetermined time period has occurred where a single prior call for heat occurred within the predetermined elapsed time period. The controller may also be configured to delay heating operation until a second predetermined time period has occurred where two prior calls for heat occurred within a predetermined elapsed time period, or to delay heating operation until a third predetermined time period has occurred where at least three prior calls for heat occurred within a predetermined elapsed time period, which is a given time period immediately preceding the present call for heat.

[0007] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0008] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0009] FIG. **1** is a cut-away illustration of a water heater having one embodiment of an apparatus for controlling operation of the water heater according to the principles of the present disclosure;

[0010] FIG. **2** is a schematic of one embodiment of an apparatus for controlling operation of a water heater according to the principles of the present disclosure;

[0011] FIG. **3** is a flowchart illustrating the operation of a first embodiment of an apparatus for controlling a water heater; and

[0012] FIG. **4** is a flowchart illustrating the operation of a second embodiment of an apparatus for controlling a water heater; and

[0013] FIG. **5** is a flowchart illustrating the operation of a third embodiment of an apparatus for controlling a water heater.

[0014] Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

[0015] Example embodiments will now be described more fully with reference to the accompanying drawings.

[0016] In the various embodiments, an apparatus is provided that is configured to control heating operation of a water heater to maintain a desired water temperature. The various embodiments comprise a sensor that provides an output indicative of the sensed temperature of water in a water heater, and a controller in communication with the sensor. The controller is operable to initiate a present call for heat

where the sensed temperature is a predetermined amount below a set-point temperature. The controller is also configured to determine whether a prior call for heat occurred within a predetermined elapsed time period preceding the present call for heat, and to respond thereto by delaying the start of heating operation in the present call for heat until one of a predetermined time period or a predetermined sensed temperature change has occurred.

[0017] In some embodiments, the controller is configured to delay the start of heating operation until the sensed temperature decreases by a predetermined sensed temperature change that is dependent on the number of prior calls for heat within the predetermined elapsed time period. In such embodiments, the controller may be configured to delay heating operation until a first predetermined sensed temperature change occurs where a single prior call for heat occurred within the predetermined elapsed time period. The controller may also be configured to delay heating operation until a second predetermined sensed temperature change occurs where two prior calls for heat occurred within the predetermined elapsed time period, or to delay heating operation until a third predetermined sensed temperature change occurs where at least three prior calls for heat occurred within the predetermined elapsed time period.

[0018] In other embodiments, the controller is configured to delay heating operation until a first predetermined time period has occurred where a single prior call for heat occurred within the predetermined elapsed time period. The controller may also be configured to delay heating operation until a second predetermined time period has occurred where two prior calls for heat occurred within a predetermined elapsed time period, or to delay heating operation until a third predetermined time period has occurred where at least three prior calls for heat occurred within a predetermined elapsed time period. The predetermined elapsed time period may be a time period immediately preceding the present call for heat, and may be between about 30 minutes to about 120 minutes.

[0019] Referring to FIG. **1**, an apparatus **100** is provided for controlling heating operation of a water heater **20** to maintain a desired temperature of water in the water heater. The water heater **20** has a storage tank **22** that stores heated water and receives cold water via a cold water inlet **26**. Cold water entering a bottom portion **28** of the tank **22** is heated by a fuel-fired burner **30** beneath the tank. Water that is heated leaves the tank **22** via a hot water outlet pipe **34**. Combustion gases from the burner **30** leave the water heater **20** via a flue **36**. The apparatus **100** provides for control of gas flow via a gas supply line **40** to the burner **30**.

[0020] The apparatus **100** includes a sensor **102** that provides an output or value that is indicative of the sensed temperature of the water inside of the tank **22**. For example, the sensor **102** may be a tank surface-mounted temperature sensor such as a thermistor, or the like. However, other embodiments can alternatively use a temperature probe or other sensor suitable for enabling sensing the water temperature in the tank. The sensor **102** may be positioned at the bottom portion **28** of the tank **22** near the cold water inlet pipe **26**, where cold water entering the tank **22** affects the output of sensor **102**.

[0021] The water heater **20** includes an apparatus **100** positioned, for example, adjacent the tank **22**. The sensor **102** is in communication with the apparatus **100**, and provides an output or value that is indicative of the water temperature in the tank **22**. A second sensor (not shown) may be disposed at an upper portion of the water heater **20**, to provide an output or value that is indicative of the sensed temperature of the water in the upper portion **32** of the tank **22**.

[0022] Referring to FIG. **2**, a schematic is shown of the apparatus **100** having a controller **150** that is in communication with sensor **102**. The controller **150** may be a microprocessor, for controlling at least one gas valve actuator **160** for operating a gas valve **162** to supply gas via supply line **40** to the burner **30**, and may further operate an igniter actuator **164** for actuating an igniter **166** via connection **42**. The controller **150** monitors the sensor **102** and the sensed temperature of the water in the tank, and controls the actuators to establish operation of the burner **30** where the sensed temperature is a predetermined amount below a set-point temperature, as explained below.

[0023] The water in the tank **22** may lose heat over time, for example, such that the sensed temperature of the water drops a given amount below a set-point temperature of the controller **150**. When the controller **150** determines that the sensed temperature of the water is a predetermined "differential" amount below a set-point temperature, the controller **150** establishes a call for heat to raise the water temperature back to the set point temperature. As long as the sensed temperature of the water remains below the desired set-point temperature value, the call for heat will continue and the burner will continue to raise the water temperature. The call for heat is terminated when the sensed temperature of the water detected by sensor **102** reaches a desired set-point temperature value, which may be between about 120 and 150 degrees Fahrenheit. If, for example, the controller **150** has a 120 degree Fahrenheit set-point temperature and a 15 degree Fahrenheit temperature differential setting, the controller **150** would initiate a call for heat when the sensed temperature from sensor **102** drops 15 degrees Fahrenheit below the 120 degree Fahrenheit set-point temperature. Thus, the controller **150** is operable to initiate a call for heat where water temperature drops and a difference between set-point temperature and the sensed temperature of the water exceeds a predetermined temperature differential setting.

[0024] A decrease in water temperature may also occur, for example, when hot water that is being drawn out of the tank **22** through outlet pipe **34** is replaced by cold water entering inlet pipe **26**, which causes the temperature of the water in the lower portion **28** of the tank **22** to drop substantially below the set-point temperature (such as a 10 or 15 degree drop). The controller **150** may determine, for example, that a rapid drop in temperature has occurred, such as when hot water is being drawn from the tank **22** and cold water is entering the bottom of the tank through cold water inlet **28**. Cold water entering the tank **22** significantly reduces the temperature of the water in the lower portion **28** of the tank **22**, while water in the upper portion **32** of the tank **22** still remains hot. When hot water is drawn from the tank **22** for more than a given time, the cold water entering the lower portion **28** creates a temperature difference between the upper and lower portions of the tank. The cold water entering the lower portion **28** of the tank **22** thus affects the output of the sensor **102**, and the controller **150** initiates a call for heat when the difference between the set-point temperature and the sensed temperature exceeds the predetermined temperature differential setting. If, however, hot water is drawn via outlet pipe **34** from the tank **22** for a brief interim just long enough to affect the output of the sensor **102** and cause the controller **150** to initiate a call for heat, the burner **30** would heat the water in the lower portion

28 which by convection would increase the temperature of hot water in the upper portion **32**. When hot water is successively drawn for brief interim periods to establish intermittent calls for heat, the repeated operation of the burner could cause temperature stratification in the tank **22** and potentially result in hot water in the upper portion of the tank exceeding the set-point temperature.

[0025] To address this issue, the controller **150** of the first embodiment is further configured to delay the start of heating operation for a given delay time period where the controller **150** identifies a prior call for heat within a predetermined elapsed time period preceding the present call for heat. The controller **150** is configured to delay heating operation until a predetermined sensed temperature change occurs (the sensed temperature drops by 5 degrees, for example) when only a single prior call for heat has occurred within a predetermined elapsed time period preceding the present call for heat (such as a two hour period, for example). The controller **150** may also be configured to delay the start of heating operation until the sensed temperature decreases by a predetermined sensed temperature change that is dependent on the number of prior calls for heat within the predetermined elapsed time period, as explained below.

[0026] Referring to FIG. **3**, a flow chart is shown illustrating the operation of the controller of the first embodiment. The controller **150** of the apparatus **100** is configured to determine at step **100** whether the sensed temperature (Tsensed) is within a differential setting of 15 degrees of the set point temperature (Tset-point). The controller **150** is operable to initiate a present call for heat at step **110** where the sensed temperature is a predetermined amount (e.g., 15 degrees for example) below the set-point temperature. At step **120**, the controller is configured to determine whether a single prior call for heat occurred within a predetermined elapsed time period (e.g., 2 hours, for example) preceding the present call for heat, and to respond thereto by delaying the start of heating operation in the present call for heat until a predetermined sensed temperature change (or temperature offset) has occurred at step **130**. Once the sensed temperature has decreased by the predetermined sensed temperature change or temperature offset, the controller **150** is configured to start burner operation at step **180** and continue operation at step **190** until the set point temperature is reached. At step **140**, the controller is further configured to determine whether two prior calls for heat occurred within a predetermined elapsed time period (e.g., 2 hours, for example), and to delay the start of heating operation until the sensed temperature decreases by a second predetermined sensed temperature change (or temperature offset) at step **150**. At step **160**, the controller is further configured to determine whether three or more prior calls for heat occurred within a predetermined elapsed time period (e.g., 2 hours, for example), and to delay the start of heating operation until the sensed temperature decreases by a third predetermined sensed temperature change (or temperature offset) at step **170**. Thus, the controller **150** is configured delay the start of heating operation until the sensed temperature decreases by a predetermined sensed temperature change that is dependent on the number of prior calls for heat within the predetermined elapsed time period.

[0027] In a second embodiment, an apparatus is provided for controlling heating operation of a water heater based on sensed temperature, as explained below. The apparatus includes a sensor such as sensor **102** in FIG. **1** that provides a value indicative of the sensed temperature of water, and also includes a controller similar to apparatus **100** in FIG. **1**. The controller of the second embodiment initiates a call for heat when a difference between a set-point temperature and the sensed temperature exceeds a temperature differential setting. The controller of the second embodiment is also configured to delay the start of heating operation until a predetermined time period has occurred or elasped.

[0028] Referring to FIG. **4**, a flow chart is shown illustrating the operation of the controller of the second embodiment. The second embodiment of a controller is configured to determine at step **200** whether the sensed temperature (Tsensed) is within a differential setting of 15 degrees of the set point temperature (Tset-point), and is operable to initiate a present call for heat at step **210** where the sensed temperature is a predetermined amount (e.g., 15 degrees for example) below the set-point temperature. At step **220**, the controller is configured to determine whether a single prior call for heat occurred within a predetermined elapsed time period (e.g., 2 hours, for example), and to respond thereto by delaying the start of heating operation in the present call for heat until a first predetermined time delay period has occurred or elasped at step **230**. Once the first predetermined time delay period has occurred or elasped, the controller is configured to start burner operation at step **280** and continue operation at step **290** until the set point temperature is reached. At step **240**, the controller is further configured to determine whether two prior calls for heat occurred within a predetermined elapsed time period (e.g., 2 hours, for example), and to delay the start of heating operation until a second predetermined time delay period has occurred or elasped at step **250**. At step **260**, the controller is further configured to determine whether three or more prior calls for heat occurred within a predetermined elapsed time period (e.g., 2 hours, for example), and to delay the start of heating operation until a third predetermined time delay period has occurred or elasped at step **270**. Thus, the controller of the second embodiment is configured delay the start of heating operation by a predetermined time delay period that is dependent on the number of prior calls for heat within the predetermined elapsed time period.

[0029] Referring to FIG. **5**, a flow chart is shown illustrating the operation of the controller of a third embodiment. The third embodiment of a controller is configured to determine at step **300** whether the sensed temperature (Tsensed.) is within a differential setting of 15 degrees of the set point temperature (Tset-point), and is operable to initiate a present call for heat at step **310** where the sensed temperature is a predetermined amount (e.g., 15 degrees for example) below the set-point temperature. At step **320**, the controller is configured to determine whether at least 4 calls for heat, or over three calls for heat, occurred within a predetermined elapsed time period (e.g., 2 hours, for example). At step **330**, the third embodiment of a controller is configured to respond thereto by delaying the start of heating operation in the present call for heat until either the sensed temperature decreases by a predetermined sensed temperature change (e.g., 8° F. temperature offset), or a first predetermined time delay period has occurred or elasped (e.g., 10 minutes). Once the first predetermined time delay or temperature change has occurred or elasped, the controller is configured to start burner operation at step **380** and continue operation at step **390** until the set point temperature is reached. Thus, the controller of the third embodiment is configured delay the start of heating operation

by a predetermined time delay period that is dependent on the number of prior calls for heat within the predetermined elapsed time period.

[0030] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

[0031] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0032] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0033] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

What is claimed is:

1. An apparatus for controlling heating operation of a water heater to maintain a desired water temperature, comprising:

a sensor that provides an output indicative of the sensed temperature of water in a water heater;

a controller in communication with the sensor, the controller being operable to initiate a present call for heat where the sensed temperature is a predetermined amount below a set-point temperature, wherein the controller is configured to determine whether a prior call for heat occurred within a predetermined elapsed time period preceding the present call for heat, and to respond thereto by delaying the start of heating operation in the present call for heat until one of a predetermined time period or a predetermined sensed temperature change has occurred.

2. The apparatus of claim **1** wherein the controller is configured to delay the start of heating operation until the sensed temperature decreases by a predetermined sensed temperature change that is dependent on the number of prior calls for heat within the predetermined elapsed time period.

3. The apparatus of claim **1** wherein the controller is configured to delay heating operation until a first predetermined sensed temperature change occurs where a single prior call for heat occurred within the predetermined elapsed time period.

4. The apparatus of claim **1** wherein the controller is configured to delay heating operation until a second predetermined sensed temperature change occurs where two prior calls for heat occurred within the predetermined elapsed time period.

5. The apparatus of claim **1** wherein the controller is configured to delay heating operation until a third predetermined sensed temperature change occurs where at least three prior calls for heat occurred within the predetermined elapsed time period.

6. The apparatus of claim **1** wherein the controller is configured to delay heating operation until a first predetermined time period has occurred where a single prior call for heat occurred within the predetermined elapsed time period.

7. The apparatus of claim **1** wherein the controller is configured to delay heating operation until a second predetermined time period has occurred where two prior calls for heat occurred within a predetermined elapsed time period.

8. The apparatus of claim **1** wherein the controller is configured to delay heating operation until a third predetermined time period has occurred where at least three prior calls for heat occurred within a predetermined elapsed time period.

9. The apparatus of claim **1** wherein the predetermined elapsed time period is a time period immediately preceding the present call for heat, of between about 30 minutes to about 120 minutes.

10. An apparatus for controlling heating operation of a water heater to maintain a desired water temperature, comprising:

a sensor that provides a value indicative of the sensed temperature of water in a water heater;

a controller that initiates a call for heat when a difference between a set-point temperature and the sensed temperature exceeds a temperature differential setting, the controller being configured to delay the start of heating operation for a given delay time period where the controller identifies a prior call for heat within a predetermined elapsed time period preceding the present call for heat.

11. The apparatus of claim **10** wherein the controller is configured to delay heating operation until a first delay time period has occurred where a single prior call for heat occurred within the predetermined elapsed time period.

12. The apparatus of claim **11** wherein the controller is further configured to delay heating operation until a second delay time period has occurred where two prior calls for heat occurred within a predetermined elapsed time period.

13. The apparatus of claim **12** wherein the controller is further configured to delay heating operation until a third delay time period has occurred where at least three prior calls for heat occurred within a predetermined elapsed time period.

14. The apparatus of claim **11** wherein the first delay time period is at least 10 seconds.

15. The apparatus of claim **13** wherein the first delay time period is at least 10 seconds, the second delay time period is at least 10 seconds greater than the first delay time period, and the third delay time period is at least 10 seconds greater than the second delay time period.

16. An apparatus for controlling heating operation of a water heater to maintain a desired water temperature, comprising:

a sensor that provides a value indicative of the sensed temperature of water in a water heater;

a controller that initiates a call for heat when a difference between a set-point temperature and the sensed temperature exceeds a temperature differential setting, the controller being configured to delay the start of heating operation until the sensed temperature decreases by a predetermined amount where the controller identifies a prior call for heat within a predetermined elapsed time period preceding the present call for heat.

17. The apparatus of claim **16** wherein the controller is configured to delay heating operation until the sensed temperature decreases by a first predetermined amount where only a single prior call for heat occurred within the predetermined elapsed time period.

18. The apparatus of claim **17** wherein the controller is configured to delay heating operation until the sensed temperature decreases by a second predetermined amount where two prior calls for heat occurred within the predetermined elapsed time period.

19. The apparatus of claim **18** wherein the controller is configured to delay heating operation until the sensed temperature decreases by a third predetermined amount where at least three prior calls for heat occurred within the predetermined elapsed time period.

20. The apparatus of claim **19** wherein the first predetermined amount is an offset temperature decrease of at least 5 degrees Fahrenheit, and the second predetermined amount is an offset temperature decrease that is at least degrees Fahrenheit lower than the first predetermined amount, and the third predetermined amount is an offset temperature decrease that is at least 5 degrees Fahrenheit lower than the second predetermined amount.

21. An apparatus for controlling heating operation of a water heater to maintain a desired water temperature, comprising:

a sensor that provides an output indicative of the sensed temperature of water in a water heater;

a controller in communication with the sensor, the controller being operable to initiate a present call for heat where the sensed temperature is a predetermined amount below a set-point temperature, wherein the controller is configured to determine whether more than 3 prior calls for heat occurred within a predetermined elapsed time period preceding the present call for heat, and to respond thereto by delaying the start of heating operation in the present call for heat until the first occurrence of either a predetermined time of at least 10 minutes or the sensed temperature decreases by at least 8 degrees Fahrenheit.

* * * * *