

DESCRIPTION

TITLE OF THE INVENTION:

SHOCK WAVE GENERATION SYSTEM

5 Field

[0001] The present disclosure relates to a shock wave generation system for generating a detonation-induced shock wave.

Background

[0002] For example, in refuse incinerators, integrated coal gasification combined cycle power plants (IGCC), and boilers for power generation, dust in flue gas adheres to the inner wall surface of a furnace, the outer surface of a heating tube, and the like. The dust adhering to the inner wall surface of the furnace, the outer surface of the heating tube, and the like reduces the heat transfer rate to deteriorate heat recovery efficiency, or creates resistance to the flue gas flow to reduce the performance of the furnace. It is therefore necessary to periodically remove the dust adhering to the inner wall of the furnace and the outer surface of the heating tube by a dust removing device.

[0003] The dust removing device has a shock wave generation system. The shock wave generation system burns fuel to generate detonation-induced shock waves in which the propagation speed of flame exceeds the speed of sound. The dust removing device removes dust by the shock waves generated by the shock wave generation system. Such conventional shock wave generation systems are described in the following patent literatures.

Citation List

Patent Literature

25 [0004] Patent Literature 1: Japanese Patent Application Laid-open No. S60-205120
Patent Literature 2: Japanese Patent Application Laid-open No. 2002-106826

Summary

Technical Problem

[0005] Conventional shock wave generation systems generate detonation-induced shock waves by igniting a mixture of fuel and oxidizer to burn the mixture. In some form of combustion, not a detonation wave but a deflagration wave is generated. In this case, for example, the dust fails to be properly removed. In addition, the mixture may

spontaneously ignite before the mixture is ignited, causing a backfire. The shock wave generation system therefore needs to determine whether detonation occurs properly.

[0006] The present disclosure is made to solve the aforementioned problem, and an object of the present disclosure is to provide a shock wave generation system capable of
5 determining a combustion state of fuel.

Solution to Problem

[0007] In order to achieve the above object, a shock wave generation system according to the present disclosure includes: a combustion device having a gas passage through which combustion gas flows from a base end to a front end, the front end having an
10 opening; a combustible gas supply device configured to supply a combustible gas from the base end to inside of the combustion device; an ignition device configured to ignite the combustible gas supplied to the combustion device; a flame occurrence timing detection sensor configured to detect timing of occurrence of flame caused by combustion of the combustible gas; and a determination device configured to determine
15 spontaneous ignition of the combustible gas before ignition by the ignition device, based on a detection result from the flame occurrence timing detection sensor.

Advantageous Effects of Invention

[0008] The shock wave generation system according to the present disclosure can determine a combustion state of fuel.

20 Brief Description of Drawings

[0009] FIG. 1 is a schematic configuration diagram illustrating a shock wave generation system according to a first embodiment.

FIG. 2 is a cross-sectional view of an attachment structure of an optical sensor.

FIG. 3 is a cross-sectional view of a modification of the attachment structure of
25 the optical sensor.

FIG. 4 is a time chart to illustrate a method of detecting detonation, deflagration, and backfire.

FIG. 5 is a flowchart illustrating a method of determining a fuel combustion state by the shock wave generation system.

30 FIG. 6 is a schematic diagram to illustrate the intensity of detonation in a shock wave generation system according to a second embodiment.

FIG. 7 is a schematic configuration diagram representing a shock wave

generation system according to a third embodiment.

FIG. 8 is a time chart to illustrate a method of detecting detonation, deflagration, and backfire.

Description of Embodiments

5 [0010] Preferred embodiments of the present disclosure will be described in detail below with reference to the drawings. The present disclosure is not limited by the embodiments, and if there are more than one embodiment, a configuration having a combination of the embodiments may be embraced. The components in the
10 embodiments include those that can be easily conceived by those skilled in the art, those that are substantially identical, and those that are equivalent.

[0011] [First Embodiment]

<Shock Wave Generation System>

FIG. 1 is a schematic configuration diagram illustrating a shock wave generation system according to a first embodiment.

15 [0012] As illustrated in FIG. 1, a shock wave generation system 10 according to the first embodiment is applied to a dust removing device that removes dust adhering to an inner wall surface of a furnace, an outer surface of a heating tube, and the like in a refuse incinerator, an integrated coal gasification combined cycle power plant, a boiler for power generation (hereinafter referred to as boiler), and the like. The furnace has a
20 wall surrounding a combustion field of the boiler. The dust removing device can remove dust adhering to the inner wall surface of the wall continuous to the top and bottom of the furnace. The dust removing device supplies a combustible gas into the furnace through piping communicatively connected to the inside of the furnace and ignites the combustible gas to generate a detonation-induced shock wave S. In other
25 words, when the combustible gas burns, a detonation wave, which is a combination of flame and a shock wave, propagates, and when the combustible gas runs out, the detonation wave propagates as a shock wave. The dust removing device blows off and removes the adhering dust when the detonation-induced shock wave S acts on the inner wall surface of the furnace and the outer surface of the heating tube.

30 [0013] The shock wave generation system 10 is provided in the dust removing device and generates a shock wave S by detonation caused by fuel combustion when the dust removing device is activated while the boiler is stopped.

[0014] The shock wave generation system 10 includes a combustion device 11, a combustible gas supply device 12, an ignition device 13, a flame occurrence timing detection sensor 14, a control device (determination device) 15, and an alarming device 16.

5 [0015] The combustion device 11 has a gas passage 21 through which combustion gas flows from a base end to a front end. The combustion device 11 has a detonator 22 and a combustor 23. The gas passage 21 includes a first passage 24 inside the detonator 22 and a second passage 25 inside the combustor 23.

[0016] The detonator 22 has a cylindrical shape and is closed at a base end 22a and
10 open at a front end 22b. The first passage 24 having a predetermined length is provided in the inside of the detonator 22. The detonator 22 has the base end 22a connected to the combustible gas supply device 12. The combustor 23 has a cylindrical shape, and has a base end 23a coupled to and communicatively connected to the front end 22b of the detonator 22, and a front end 23b open with an opening 23c. The gas passage 21 of
15 the detonator 22 and the second passage 25 of the combustor 23 are concentric.

However, the gas passage 21 of the detonator 22 and the second passage 25 of the combustor 23 may have different shapes rather than being concentric. The second passage 25 having a predetermined length is provided in the inside of the combustor 23. The second passage 25 of the combustor 23 is larger in diameter than the first passage
20 24 of the detonator 22. In the combustor 23, the second passage 25 has the same diameter from the base end 23a to the front end 22b, but the front end 22b may have a larger diameter than the base end 23a. The combustor 23 has the opening 23c at the front end 23b communicatively connected to an interior space 103 defined by a furnace wall 102 of a furnace 101.

25 [0017] The combustible gas supply device 12 has a fuel supply unit 31 and an oxidizer supply unit 41. The fuel supply unit 31 supplies fuel F. The oxidizer supply unit 41 supplies oxygen or air as oxidizer A. The combustible gas supply device 12 supplies a mixture of fuel F supplied by the fuel supply unit 31 and oxidizer A supplied by the oxidizer supply unit 41 as combustible gas M from the base end to the inside of the
30 combustion device 11.

[0018] The fuel supply unit 31 has a fuel supply channel 32, a fuel cylinder 33, a pressure reducing valve 34, a mass flow controller 35, a safety device 36, a fuel supply

valve 37, and a check valve 38. The fuel supply channel 32 is coupled to the fuel cylinder 33 at the upstream end and has the pressure reducing valve 34, the mass flow controller 35, the safety device 36, the fuel supply valve 37, and the check valve 38 toward the downstream side. The fuel cylinder 33 stores fuel F. The pressure reducing valve 34 reduces the pressure of fuel F in the fuel cylinder 33 and adjusts the pressure of fuel F to be supplied. The mass flow controller 35 measures the mass flow rate of fuel F, compares the measured mass flow rate of fuel F with a preset setting value of fuel F, and adjusts the degree of opening of a flow control valve so that the mass flow rate of fuel F becomes the setting value. The safety device 36 prevents backfires. The fuel supply valve 37 is an open/close valve that supplies fuel F when open and stops the supply of fuel F when closed. The check valve 38 prevents backflow of fuel F and combustible gas M to the upstream side.

[0019] The oxidizer supply unit 41 has an oxidizer supply channel 42, an oxidizer cylinder 43, a pressure reducing valve 44, a mass flow controller 45, a safety device 46, an oxidizer supply valve 47, and a check valve 48. The oxidizer supply channel 42 is coupled to the oxidizer cylinder 43 at the upstream end and has the pressure reducing valve 44, the mass flow controller 45, the safety device 46, the oxidizer supply valve 47, and the check valve 48 toward the downstream side. The oxidizer cylinder 43 stores oxidizer A. The pressure reducing valve 44 reduces the pressure of oxidizer A in the oxidizer cylinder 43 and adjusts the pressure of oxidizer A to be supplied. The mass flow controller 45 measures the mass flow rate of oxidizer A, compares the measured mass flow rate of oxidizer A with a preset setting value of oxidizer A, and adjusts the degree of opening of a flow control valve so that the mass flow rate of oxidizer A becomes the setting value. The safety device 46 prevents backfires. The oxidizer supply valve 47 is an open/close valve that supplies oxidizer A when open and stops the supply of oxidizer A when closed. The check valve 48 prevents backflow of oxidizer A and combustible gas M to the upstream side.

[0020] The downstream ends of the fuel supply channel 32 and the oxidizer supply channel 42 are coupled to the upstream end of a combustible gas supply channel 52 via a cross junction 51, and the downstream end of the combustible gas supply channel 52 is connected to the base end 22a of the detonator 22. A purge gas channel 53 is coupled to a blower 54 at the upstream end and coupled to the cross junction 51 at the

downstream end. The purge gas channel 53 has a purge gas supply valve 55. The cross junction 51 communicatively connects the fuel supply channel 32, the oxidizer supply channel 42, the combustible gas supply channel 52, and the purge gas channel 53. The blower 54 supplies purge gas (e.g., air or inert gas) P to the combustible gas supply channel 52. The purge gas supply valve 55 is an open/close valve that supplies purge gas P when open and stops the supply of purge gas P when closed.

[0021] The ignition device 13 ignites combustible gas M supplied to the detonator 22 in the combustion device 11. The ignition device 13 is provided at the base end 22a of the detonator 22.

[0022] The flame occurrence timing detection sensor 14 detects the timing of occurrence of flame C caused by combustion of combustible gas M. The flame occurrence timing detection sensor 14 is provided at the base end 23a of the combustor 23 in the combustion device 11. The flame occurrence timing detection sensor 14 is disposed to face toward the opening 23c from the base end 23a of the combustor 23 and has a sensor area 14a at a predetermined angle.

[0023] The flame occurrence timing detection sensor 14 is preferably an optical sensor that detects light emission from flame C generated by the combustor 23. The optical sensor is preferably a UV light detection sensor. Flame emits electromagnetic radiation with infrared (IR), visible, and ultraviolet (UV) wavelengths. However, since infrared and visible light rays are also emitted from sources other than flame C, a UV light detection sensor, which is insensitive to infrared and visible light rays, is used to detect ultraviolet light rays to detect a signal purely from flame C. In particular, ultraviolet light rays with short wavelengths (e.g., wavelengths of 100 nm to 315 nm that are absorbed by atmosphere and hardly reach the ground as a component of sunlight, especially the solar blind region of 100 nm to 280 nm that hardly reaches the ground) are selectively detected to prevent false detection of solar ambient light.

[0024] However, the optical sensor is not limited to a UV light detection sensor. For example, a photodiode or a phototube may be applied as the optical sensor.

[0025] The control device 15 is connected to the ignition device 13, the flame occurrence timing detection sensor 14, the mass flow controller 35, the fuel supply valve 37, the mass flow controller 45, the oxidizer supply valve 47, and the purge gas supply valve 55.

[0026] The control device 15 can control the timing of ignition of combustible gas M by the ignition device 13. The control device 15 receives a detection result from the flame occurrence timing detection sensor 14. The control device 15 can control the regulation of the mass flow controller 35 and the mass flow controller 45. The control
 5 device 15 can control the opening and closing of the fuel supply valve 37, the oxidizer supply valve 47, and the purge gas supply valve 55.

[0027] The control device 15 also functions as a determination device. In other words, the control device 15 determines spontaneous ignition of combustible gas M before ignition by the ignition device 13, based on a detection result from the flame occurrence
 10 timing detection sensor 14. The control device 15 also determines detonation and deflagration based on a propagation speed of flame C detected by the flame occurrence timing detection sensor 14.

[0028] When determining spontaneous ignition of combustible gas M, the control device 15 controls the combustible gas supply device 12 to stop the supply of
 15 combustible gas M to the combustion device 11. In other words, the control device 15 closes the fuel supply valve 37 and the oxidizer supply valve 47. When determining spontaneous ignition of combustible gas M, the control device 15 supplies purge gas P to the inside of the combustion device 11. In other words, the control device 15 closes the fuel supply valve 37 and the oxidizer supply valve 47, and then opens the purge gas
 20 supply valve 55.

[0029] The control device 15 is connected to the alarming device 16. The control device 15 can control the activation of the alarming device 16. When determining spontaneous ignition or deflagration of combustible gas M, the control device 15 activates the alarming device 16.

25 [0030] Here, the control device 15 is a controller and implemented by, for example, a central processing unit (CPU) or a micro processing unit (MPU) executing various computer programs stored in a memory using a RAM as a work area.

[0031] <Attachment Structure of Optical Sensor>

FIG. 2 is a cross-sectional view of an attachment structure of the optical sensor.

30 [0032] As illustrated in FIG. 2, the combustor 23 has an optical window 62 in a wall 61 at the base end 23a. The optical sensor serving as the flame occurrence timing detection sensor 14 is disposed outside the wall 61 in the combustor 23 so as to cover the optical

window 62. The flame occurrence timing detection sensor 14 has the sensor area 14a at a predetermined angle through the optical window 62. The flame occurrence timing detection sensor 14 detects light emission from flame C through the optical window 62. The optical window 62 may have transmittivity and have filtering performance to
 5 extract only light of specific wavelengths (e.g., ultraviolet light rays). The optical window 62 may have a mechanism that blows purge gas to the inner surface to ensure visibility and cooling.

[0033] The attachment structure of the optical sensor is not limited to that described above. FIG. 3 is a cross-sectional view of a modification of the attachment structure of
 10 the optical sensor.

[0034] As illustrated in FIG. 3, the combustor 23 has an optical window 62 in a wall 61 at the base end 23a. The optical sensor serving as the flame occurrence timing detection sensor 14 is disposed at a predetermined location away from the combustor 23. An optical fiber 63 is provided between the flame occurrence timing detection sensor 14
 15 and the optical window 62. The optical fiber 63 has one end connected to the flame occurrence timing detection sensor 14 and the other end attached by an attachment member 64 on the outside of the wall 61 in the combustor 23 so as to face the optical window 62. The flame occurrence timing detection sensor 14 has the sensor area 14a at a predetermined angle through the optical fiber 63 and the optical window 62. The
 20 flame occurrence timing detection sensor 14 detects light emission from flame C through the optical window 62 via the optical fiber 63.

[0035] <Method of Detecting Detonation, Deflagration, and Backfire>

FIG. 4 is a time chart to illustrate a method of detecting detonation, deflagration, and backfire.

25 [0036] As illustrated in FIG. 1 and FIG. 4, the combustible gas supply device 12 supplies and fills the detonator 22 with combustible gas M, which is a mixture of fuel and oxidizer, through the fuel supply unit 31 and the oxidizer supply unit 41. Then, at time t₂, the ignition device 13 is activated and ignites the combustible gas M in the detonator 22. The combustible gas M is then ignited while flowing through the first
 30 passage 24 of the detonator 22, and burns such that flame C spreads from the base end 22a to the front end 22b. When the flame C from the detonator 22 reaches the combustor 23, combustion takes place such that the flame C spreads from the base end

23a to the front end 23b through the second passage 25, thereby generating a detonation-induced shock wave S.

[0037] The control device 15 determines detonation, deflagration, and backfire (spontaneous ignition) based on the timing of occurrence (propagation speed) of flame C detected by the flame occurrence timing detection sensor 14. The flame occurrence timing detection sensor 14 is an optical sensor and detects flame C (e.g., ultraviolet light rays). The flame occurrence timing detection sensor 14 turns pulse ON when flame C occurs, and turns pulse OFF when flame C is extinct. The control device 15 thus calculates a pulse length τ_d , which is a time length during which flame C occurs from the time of flame occurrence (pulse ON) to the time of flame extinction (pulse OFF) detected by the flame occurrence timing detection sensor 14. The pulse length τ_d is inversely proportional to the propagation speed of flame C. The control device 15 determines a combustion state of fuel (combustible gas M) based on the pulse length τ_d (the propagation speed of flame C) which is a period of time of occurrence of flame C.

[0038] When fuel burns, the fuel detonates or deflagrates depending on the propagation speed of flame C. When the propagation speed of flame C is the speed of sound or less, deflagration occurs, and when the propagation speed of flame C exceeds the speed of sound, detonation occurs to produce a shock wave S. When detonation occurs, a shock wave S is generated. Here, a threshold τ_t is set between detonation and deflagration, according to the propagation speed of flame C. The threshold τ_t between detonation and deflagration according to the propagation speed is, for example, a pulse length according to a propagation speed of 1000 m/s. In other words, detonation is when the calculated pulse length τ_d is the threshold τ_t or less, and deflagration is when the pulse length τ_d (the propagation speed of flame C) exceeds the threshold τ_t . In general, since the propagation speed of a detonation-induced shock wave S (the propagation speed of flame C) is 1000 m/s or more, the pulse length τ_d is short.

[0039] Therefore, the control device 15 determines detonation when the pulse length τ_d is the threshold τ_t or less, and determines deflagration when the pulse length τ_d (the propagation speed of flame C) exceeds the threshold τ_t . In other words, when the pulse turns ON at time t_3 and turns OFF at time t_4 , the control device 15 determines detonation because the pulse length τ_d is the threshold τ_t or less. On the other hand, when the pulse turns ON at time t_3 and OFF at time t_6 , the control device 15 determines

deflagration because the pulse length τ_d exceeds the threshold τ_t .

[0040] In operation of the boiler, the combustible gas M filled in the combustor 23 may spontaneously ignite due to heat from flue gas rising through the interior space 103 of the furnace 101. The control device 15 determines a backfire due to spontaneous
 5 ignition, based on the timing of occurrence of flame C detected by the flame occurrence timing detection sensor 14. In other words, at time t_2 , the ignition device 13 is activated and the combustible gas M in the detonator 22 is ignited, and then the combustible gas M ignites and a detonation-induced shock wave S is generated. However, if the combustible gas M filled in the combustor 23 spontaneously ignites, the flame
 10 occurrence timing detection sensor 14 detects flame C before the ignition device 13 is activated. When the ignition device 13 is activated at time t_2 to ignite the combustible gas M, if a backfire (spontaneous ignition) occurs, the pulse turns ON at time t_1 , which is T_a before time t_2 , and the pulse turns OFF at time t_5 . The control device 15 determines a backfire if the pulse turns ON at time t_1 before time t_2 at which the
 15 ignition device 13 is activated.

[0041] When the control device 15 determines detonation, the combustion device 11 has normal combustion, so the control device 15 activates the combustion device 11, the combustible gas supply device 12, and the ignition device 13 under similar control at the next operating timing as well.

[0042] On the other hand, when the control device 15 determines deflagration, the combustion device 11 has abnormal combustion, so the control device 15 activates the combustion device 11, the combustible gas supply device 12, and the ignition device 13 under different control at the next operating timing. In other words, the control device 15, for example, adjusts a mixture ratio of fuel and oxidizer in the combustible gas M
 25 generated by the combustible gas supply device 12.

[0043] When the control device 15 determines a backfire, the combustion device 11 has abnormal combustion, so the control device 15 stops the supply of combustible gas M to the combustion device 11 by the combustible gas supply device 12. Purge gas P is then supplied to the combustion device 11 to suppress the progress of the backfire.

30 [0044] <Method of Determining Fuel Combustion State>

FIG. 5 is a flowchart illustrating a method of determining a fuel combustion state by the shock wave generation system.

[0045] As illustrated in FIG. 1 and Fig. 5, at step S11, the control device 15 closes the purge gas supply valve 55 to stop the supply of purge gas P to the combustion device 11. At step S12, the control device 15 opens the fuel supply valve 37 to start the supply of fuel F and opens the oxidizer supply valve 47 to start the supply of oxidizer A. The combustible gas M, which is a mixture of fuel F and oxidizer A, is then supplied to the detonator 22 of the combustion device 11.

[0046] At step S13, the control device 15 determines whether the flame occurrence timing detection sensor 14 detects a pulse (ON) produced with flame occurrence. If the control device 15 determines that the flame occurrence timing detection sensor 14 detects a pulse (ON) (Yes), at step S14, the control device 15 determines that a backfire occurs, and at step S15, the control device 15 determines that the combustion device 11 has abnormal combustion. In other words, the control device 15 determines that the combustion is abnormal combustion with a backfire, because the flame occurrence timing detection sensor 14 detects flame C occurring in the combustor 23 although the ignition device 13 is not yet activated. Then, at step S16, the alarming device 16 is activated. At step S17, the supply of combustible gas M to the combustion device 11 is stopped, and at step S18, purge gas P is supplied to the combustion device 11.

[0047] On the other hand, at step S13, if the control device 15 determines that the flame occurrence timing detection sensor 14 does not detect a pulse (ON) (No), the process moves to step S19. At step S19, the control device 15 determines whether a predetermined elapsed time set in advance has passed since the combustible gas M is supplied to the detonator 22. As used herein the elapsed time is the time taken for a predetermined amount of combustible gas M to be filled in the detonator 22 and the combustor 23 in the combustion device 11. If the control device 15 determines that the predetermined elapsed time has not passed (NO), the process returns to step S13.

[0048] On the other hand, if the control device 15 determines that the predetermined elapsed time has passed (Yes), at step S20, the control device 15 closes the fuel supply valve 37 to stop the supply of fuel F and also closes the oxidizer supply valve 47 to stop the supply of oxidizer A. The supply of combustible gas M to the detonator 22 of the combustion device 11 is then stopped. Then, at step S21, the control device 15 activates the ignition device 13 to ignite the combustible gas M filled in the detonator 22. The combustible gas M is then ignited while flowing through the first passage 24 of the

detonator 22, and burns such that flame C spreads from the base end 22a to the front end 22b. When the flame C from the detonator 22 reaches the combustor 23, combustion takes place such that the flame C spreads from the base end 23a to the front end 23b through the second passage 25.

5 [0049] At step S22, the control device 15 determines whether the flame occurrence timing detection sensor 14 detects a pulse (ON) produced with flame occurrence. If the control device 15 determines that the flame occurrence timing detection sensor 14 does not detect a pulse (ON) (No), at step S31, the control device 15 determines whether a predetermined waiting time set in advance has passed since the ignition device 13 is
10 activated. If the control device 15 determines that the waiting time has not passed (No), the process waits as it is. However, if the control device 15 determines that the waiting time has passed (Yes), at step S32, the control device 15 estimates that the ignition of combustible gas M by the ignition device 13 is failed, and at step S33, the control device 15 activates the alarming device 16.

15 [0050] On the other hand, if the control device 15 determines that the flame occurrence timing detection sensor 14 detects a pulse (ON) (Yes), at step S23, the control device 15 determines whether the detected pulse length τ_d is the threshold τ_t or less. If the control device 15 determines that the detected pulse length τ_d is not the threshold τ_t or less (No), at step S24, the control device 15 determines that deflagration occurs, and at step
20 S25, the control device 15 determines that the combustion device 11 has abnormal combustion. Then, at step S26, the alarming device 16 is activated. At step S27, the mixture ratio of fuel F and oxidizer A in the combustible gas M supplied to the combustion device 11 is adjusted.

[0051] On the other hand, at step S23, if the control device 15 determines that the
25 detected pulse length τ_d is the threshold τ_t or less (Yes), at step S28, the control device 15 determines that detonation occurs, and at step S29, the control device 15 determines that the combustion device 11 has normal combustion.

[0052] [Second Embodiment]

30 FIG. 6 is a schematic diagram to illustrate the intensity of detonation in a shock wave generation system according to a second embodiment. The basic configuration of the second embodiment is the same as that of the foregoing first embodiment and will be described using FIG. 1. The members having the same functions as those of the

foregoing first embodiment will be denoted by the same signs and will not be further elaborated.

[0053] As illustrated in FIG. 1, the shock wave generation system 10 includes the combustion device 11, the combustible gas supply device 12, the ignition device 13, the flame occurrence timing detection sensor 14, the control device (determination device) 15, and the alarming device 16.

[0054] The control device 15 functions as a determination device and determines detonation, deflagration, and backfire (spontaneous ignition) based on a detection result from the flame occurrence timing detection sensor 14. When determining detonation based on a detection result from the flame occurrence timing detection sensor 14, the control device 15 estimates the intensity of a detonation wave based on the propagation speed of flame.

[0055] The intensity of detonation is estimated according to the duration of flame C occurring in the combustor 23, that is, the pulse length τ_d from when the flame occurrence timing detection sensor 14 detects flame C and turns pulse ON to when the pulse turns OFF. In other words, the intensity of detonation of flame varies with the amount of combustible gas M filled to be supplied to the combustor 23. Thus, the detonation can be estimated to have a higher intensity when the pulse length τ_d is the threshold τ_t or less and the pulse length τ_d is longer.

[0056] As illustrated in FIG. 6, in determination of detonation, when the pulse length τ_d of the shock wave S (flame) is the threshold τ_t or less, a maximum shock wave with the highest intensity is when the pulse length $\tau_d =$ the threshold τ_t . For example, when the pulse length τ_d is a pulse length τ_{d1} shorter than 1/2 of the threshold τ_t , a first shock wave has a low intensity. On the other hand, when the pulse length τ_d is a pulse length τ_{d2} longer than 1/2 of the threshold τ_t , a second shock wave has a high intensity. The threshold τ_t is set in consideration of margin.

[0057] As illustrated in FIG. 1, the control device 15 controls the combustible gas supply device 12, based on the intensity of detonation (shock wave S) estimated from the pulse length τ_d of the shock wave S. For example, the control device 15 increases or decreases the amount of combustible gas M filled to the combustion device 11 or adjusts the mixture ratio of fuel F and oxidizer A in the combustible gas M, based on the intensity of detonation (shock wave S). As a result, the intensity of shock wave S

can be set to the optimum intensity for the capacity of the furnace 101.

[0058] [Third Embodiment]

FIG. 7 is a schematic configuration diagram illustrating a shock wave generation system according to a third embodiment. The members having the same functions as those of the foregoing first embodiment will be denoted by the same signs and will not be further elaborated.

[0059] As illustrated in FIG. 7, a shock wave generation system 10A includes the combustion device 11, the combustible gas supply device 12, the ignition device 13, flame occurrence timing detection sensors 14A and 14B, the control device (determination device) 15, and the alarming device 16. The combustion device 11, the combustible gas supply device 12, the ignition device 13, the control device 15, and the alarming device 16 are almost the same configuration as in the first embodiment.

[0060] The first flame occurrence timing detection sensor 14A and the second flame occurrence timing detection sensors 14B detect the timing of occurrence of flame C caused by combustion of combustible gas M. A plurality of the (two in the present embodiment) flame occurrence timing detection sensor 14A and second flame occurrence timing detection sensor 14B are disposed at a distance from each other in the direction of gas flow in the combustor 23 in the combustion device 11. The flame occurrence timing detection sensor 14A and the second flame occurrence timing detection sensor 14B are disposed to be oriented in a direction that intersects the direction of flow of combustible gas M or flame C (shock wave S) in the second passage 25 of the combustor 23. The flame occurrence timing detection sensor 14A is disposed on the upstream side in the second passage 25, and the second flame occurrence timing detection sensor 14B is disposed on the upstream side in the second passage 25. The first flame occurrence timing detection sensor 14A and the second flame occurrence timing detection sensor 14B detect flame at two different locations in the direction of gas flow in the second passage 25 of the combustor 23. The first flame occurrence timing detection sensor 14A and the second flame occurrence timing detection sensor 14B are optical sensors that detect light emission from flame C occurring in the combustor 23, and the detection method is the same as in the first embodiment.

[0061] FIG. 8 is a time chart to illustrate a method of detecting detonation, deflagration,

and backfire.

[0062] As illustrated in FIG. 7 and FIG. 8, the combustible gas supply device 12 supplies and fills the detonator 22 with combustible gas M, which is a mixture of fuel and oxidizer, through the fuel supply unit 31 and the oxidizer supply unit 41. Then, at
 5 time t_2 , the ignition device 13 is activated and ignites the combustible gas M in the detonator 22. The combustible gas M is then ignited while flowing through the first passage 24 of the detonator 22, and burns such that flame C spreads from the base end 22a to the front end 22b. When the flame C from the detonator 22 reaches the combustor 23, combustion takes place such that the flame C spreads from the base end
 10 23a to the front end 23b through the second passage 25, thereby generating a detonation-induced shock wave S.

[0063] The control device 15 determines detonation, deflagration, and backfire (spontaneous ignition), based on the timing of occurrence (propagation speed) of flame C detected by the first flame occurrence timing detection sensor 14A and the second
 15 flame occurrence timing detection sensor 14B. The first flame occurrence timing detection sensor 14A and the second flame occurrence timing detection sensor 14B are optical sensors and detect flame C (e.g., ultraviolet light rays). The first flame occurrence timing detection sensor 14A and the second flame occurrence timing detection sensor 14B turn pulse ON when flame C occurs, and turn pulse OFF when
 20 flame C is extinct. When fuel burns, the fuel detonates or deflagrates depending on the propagation speed of flame C. When the propagation speed of flame C is the speed of sound or less, deflagration occurs, and when the propagation speed of flame C exceeds the speed of sound, detonation occurs to produce a shock wave S.

[0064] The first flame occurrence timing detection sensor 14A and the second flame
 25 occurrence timing detection sensor 14B are spaced apart by a distance L in the direction of gas flow in the second passage 25. This arrangement causes a time difference Δt between the timing when flame is detected by the first flame occurrence timing detection sensor 14A (pulse ON) and the timing when flame is detected by the second flame occurrence timing detection sensor 14B (pulse ON). The time difference Δt is
 30 inversely proportional to the propagation speed of flame C. The control device 15 determines a combustion state of fuel (combustible gas M), based on the time difference Δt of shock wave S (the propagation speed of flame C).

[0065] Here, a threshold V_t of propagation speed of flame C is set between deflagration and detonation. The threshold V_t of propagation speed between deflagration and detonation is, for example, a propagation speed of 1000 m/s. In other words, detonation is when the propagation speed $L/\Delta t$ calculated from the distance L and the calculated
 5 time difference Δt is the threshold V_t or more, and deflagration is when the propagation speed $L/\Delta t$ is less than the threshold V_t .

[0066] The control device 15 therefore determines detonation when the propagation speed $L/\Delta t$ is the threshold V_t or more, and determines deflagration when the propagation speed $L/\Delta t$ is less than the threshold V_t . In other words, when the pulse
 10 from the first flame occurrence timing detection sensor 14A turns ON at time t_3 and the pulse from the second flame occurrence timing detection sensor 14B turns ON at time t_4 , the time difference Δt_1 is short, and the propagation speed $L/\Delta t_1$ is the threshold V_t or more, so the control device 15 determines detonation. On the other hand, when the pulse from the first flame occurrence timing detection sensor 14A turns ON at time t_3
 15 and the pulse from the second flame occurrence timing detection sensor 14B turns ON at time t_5 , the time difference Δt_2 is long, and the propagation speed $L/\Delta t_2$ is less than the threshold V_t , so the control device 15 determines deflagration.

[0067] In operation of the boiler, the combustible gas M filled in the combustor 23 may spontaneously ignite due to heat from flue gas rising through the interior space 103 of
 20 the furnace 101. The control device 15 determines a backfire due to spontaneous ignition, based on the timing of occurrence of flame C detected by the first flame occurrence timing detection sensor 14A or the second flame occurrence timing detection sensor 14B. In other words, at time t_2 , the ignition device 13 is activated and the combustible gas M in the detonator 22 is ignited, and then the combustible gas M
 25 ignites and a detonation-induced shock wave S is generated. However, if the combustible gas M filled in the combustor 23 spontaneously ignites, the flame occurrence timing detection sensors 14 and 14B detect flame C before the ignition device 13 is activated. When the ignition device 13 is activated at time t_2 to ignite the combustible gas M, if a backfire (spontaneous ignition) occurs, the pulse turns ON at
 30 time t_1 , which is T_a before time t_2 , and the pulse turns OFF at time t_4 . The control device 15 determines a backfire if the pulse turns ON at time t_1 before time t_2 at which the ignition device 13 is activated.

[0068] The method of determining a fuel combustion state by the shock wave generation system 10A according to the third embodiment is almost the same as that of the first embodiment and will not be further elaborated.

[0069] The third embodiment differs from the first embodiment in the position of the flame occurrence timing detection sensors 14 and 14B. However, the flame occurrence timing detection sensors 14 and 14B according to the third embodiment may be added to the flame occurrence timing detection sensor 14 according to the first embodiment. In this case, detonation can be determined more accurately.

[0070] [Operation Effects of Present Embodiment]

10 According to a first aspect, the shock wave generation system includes: the combustion device 11 having the gas passage 21 through which combustion gas flows from a base end to a front end, the front end having an opening; the combustible gas supply device 12 that supplies combustible gas M from the base end to inside of the combustion device 11; the ignition device 13 that ignites the combustible gas M
15 supplied to the combustion device 11; the flame occurrence timing detection sensor 14, 14A, 14B that detects the timing of occurrence of flame C caused by combustion of the combustible gas M; and the control device (determination device) 15 that determines spontaneous ignition of the combustible gas M before ignition by the ignition device 13, based on a detection result from the flame occurrence timing detection sensor 14, 14A,
20 14B.

[0071] In the shock wave generation system according to the first aspect, the control device 15 determines spontaneous ignition of the combustible gas M before ignition by the ignition device 13, based on the timing of occurrence of the flame C caused by combustion of the combustible gas M. As a result, a fuel combustion state can be
25 determined.

[0072] According to a second embodiment, in the shock wave generation system according to the first aspect, the control device 15 further determines detonation and deflagration based on a propagation speed of the flame C detected by the flame occurrence timing detection sensor 14. This configuration enables detailed
30 determination of a fuel combustion state.

[0073] According to a third embodiment, in the shock wave generation system according to the second aspect, when the control device 15 determines detonation, the

intensity of a detonation wave is estimated based on the propagation speed of the flame C. With this configuration, the intensity of the detonation wave can be adjusted according to a target to which the shock wave is applied, by estimating the intensity of the detonation wave.

5 [0074] According to a fourth aspect, in the shock wave generation system according to any one of the first to third aspects, the flame occurrence timing detection sensor 14, 14A, 14B is an optical sensor that detects light emission from the flame. With this configuration, flame can be easily identified by detecting infrared, visible, and ultraviolet light rays.

10 [0075] According to a fifth aspect, in the shock wave generation system according to any one of the first to fourth aspects, the combustion device 11 includes the detonator 22 having the base end 22a connected to the combustible gas supply device 12, and the combustor 23 having the base end 23a connected to the front end 22b of the detonator 22, and the flame occurrence timing detection sensor 14 is disposed to face toward the
15 opening 23c of the combustor 23. With this configuration, the flame occurring in the combustor 23 can be easily detected by a single flame occurrence timing detection sensor 14.

[0076] According to a sixth aspect, in the shock wave generation system according to any one of the first to fifth aspects, the combustion device 11 includes the detonator 22
20 having the base end 22a connected to the combustible gas supply device 12, and the combustor 23 having the base end 23a connected to the front end 22b of the detonator 22, and a plurality of the flame occurrence timing detection sensors 14A and 14B are disposed at a distance from each other in a direction of gas flow in the combustor 23. With this configuration, the flame occurring in the combustor 23 can be easily detected.

25 [0077] According to a seventh aspect, in the shock wave generation system according to any one of the first to sixth aspects, when the control device 15 determines spontaneous ignition of the combustible gas M, the combustible gas supply device 12 stops the supply of the combustible gas M. This configuration can improve safety.

[0078] According to an eighth aspect, in the shock wave generation system according to
30 the seventh aspect, when the control device 15 determines spontaneous ignition of the combustible gas M, purge gas P is supplied to the inside of the combustion device 11. This configuration can improve safety.

[0079] In the foregoing embodiments, the shock wave generation system is applied to a dust removing device that removes dust adhering to an inner wall surface of a furnace, an outer surface of a heating tube, and the like in a refuse incinerator, an integrated coal gasification combined cycle power plant, a boiler for power generation, and the like.

- 5 However, the application is not limited to these. The shock wave generation system can be applied to, for example, a propulsion engine that radiates shock waves through an opening of a combustion device and receives a reaction force as thrust, a power engine that turns a turbine, a device that radiates shock waves through an opening of a combustor and uses the high pressure of the shock waves to exert a physical action
- 10 (destruction of a structure, separation of materials, etc.) on an object near the opening, and a device that uses the high pressure of shock waves to exert a physical action (destruction of a structure, separation of materials, etc.) on an object inside a combustion device.

Reference Signs List

- 15 [0080] 10, 10A Shock wave generation system
- 11 Combustion device
 - 12 Combustible gas supply device
 - 13 Ignition device
 - 14 Flame occurrence timing detection sensor

20 14A First flame occurrence timing detection sensor

14B Second flame occurrence timing detection sensor

 - 15 Control device (determination device)
 - 21 Gas passage
 - 22 Detonator

25 23 Combustor

 - 24 First passage
 - 25 Second passage
 - 31 Fuel supply unit
 - 32 Fuel supply channel

30 33 Fuel cylinder

 - 34 Pressure reducing valve
 - 35 Mass flow controller

	36	Safety device
	37	Fuel supply valve
	38	Check valve
	41	Oxidizer supply unit
5	42	Oxidizer supply channel
	43	Oxidizer cylinder
	44	Pressure reducing valve
	45	Mass flow controller
	46	Safety device
10	47	Oxidizer supply valve
	48	Check valve
	51	Cross junction
	52	Combustible gas supply channel
	53	Purge gas channel
15	54	Blower
	55	Purge gas supply valve
	61	Wall
	62	Optical window
	63	Optical fiber
20	64	Attachment member
	F	Fuel
	A	Oxidizer
	M	Combustible gas
	C	Flame
25	S	Shock wave

CLAIMS

[Claim 1]

A shock wave generation system comprising:

5 a combustion device having a gas passage through which combustion gas flows from a base end to a front end, the front end having an opening;

a combustible gas supply device configured to supply a combustible gas from the base end to inside of the combustion device;

10 an ignition device configured to ignite the combustible gas supplied to the combustion device;

a flame occurrence timing detection sensor configured to detect timing of occurrence of flame caused by combustion of the combustible gas; and

15 a determination device configured to determine spontaneous ignition of the combustible gas before ignition by the ignition device, based on a detection result from the flame occurrence timing detection sensor.

[Claim 2]

The shock wave generation system according to claim 1, wherein the determination device determines detonation and deflagration based on a propagation
20 speed of flame detected by the flame occurrence timing detection sensor.

[Claim 3]

The shock wave generation system according to claim 2, wherein when the determination device determines detonation, an intensity of a detonation wave is
25 estimated based on the propagation speed of flame.

[Claim 4]

The shock wave generation system according to any one of claims 1 to 3, wherein the flame occurrence timing detection sensor is an optical sensor configured to
30 detect light emission from the flame.

[Claim 5]

The shock wave generation system according to claim 1, wherein the combustion device includes:

a detonator having a base end connected to the combustible gas supply device; and

5 a combustor having a base end connected to a front end of the detonator, and

the flame occurrence timing detection sensor is disposed to face toward the opening of the combustor.

10 [Claim 6]

The shock wave generation system according to claim 1, wherein the combustion device includes:

a detonator having a base end connected to the combustible gas supply device; and

15 a combustor having a base end connected to a front end of the detonator, and

a plurality of the flame occurrence timing detection sensors are disposed at a distance from each other in a direction of gas flow in the combustor.

20 [Claim 7]

The shock wave generation system according to claim 1, wherein when the determination device determines spontaneous ignition of the combustible gas, the combustible gas supply device stops supply of the combustible gas.

25 [Claim 8]

The shock wave generation system according to claim 7, wherein when the determination device determines spontaneous ignition of the combustible gas, a purge gas is supplied to the inside of the combustion device.