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(54) **METHOD FOR HEATING AN INDUSTRIAL FURNACE, AND APPARATUS SUITABLE FOR CARRYING OUT THE METHOD**

VERFAHREN ZUR ERHITZUNG EINES INDUSTRIEOFENS UND VORRICHTUNG ZUR AUSFÜHRUNG DIESES VERFAHRENS

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Description

[0001] The present invention relates to a method for heating an industrial furnace by pulsating combustion, in which gaseous or liquid reactants, comprising an oxidizing agent and fuel, are fed to a burner, the volumetric flow of at least one of the reactants which emerges from the burner mouth being changed over the course of time.

[0002] Furthermore, the invention relates to an apparatus for heating an industrial furnace by pulsating combustion, having a burner, which includes feed lines for streams of gaseous or liquid reactants leading to a burner mouth, and having a device for varying the volumetric flow of at least one of the reactants over the course of time.

[0003] It is generally known to use fuel/oxygen burners in industrial furnaces for heating metal or glass melts. Compared to melting methods in which the oxidizing agent used is air, the use of oxygen increases the melting power of the furnace and reduces the energy consumption. The fuel saving is mainly based on the fact that the nitrogen content of the air does not have to be heated. The smaller quantities of off-gas which result reduce the overall size of off-gas purification installations.

[0004] The overall quantity of NO_x can be reduced considerably by the use of pure oxygen and fuel without any nitrogen. However, in industrial application, both the oxygen and the fuel may contain small quantities of nitrogen. These small quantities of nitrogen, in combination with the combustion using oxygen being hotter than combustion using air, at around 900°C, lead to an increased level of NO_x in the off-gas.

[0005] To avoid this, it is proposed in DE 692 16 317 T2, which has disclosed a method and an apparatus of the generic type described in the introduction, to cyclically vary either the quantitative flows of the fuel or those of the oxidizing agent using a solenoid valve which is arranged in the respective feed line, at a frequency of below 3 Hz. A similar concept using a solenoid valve is to be found in DE 693 02 060 T2. SU 857 642 proposes that the gas stream be periodically interrupted with the aid of a rotor.

[0006] Further processes and apparatuses for pulsed combustion are disclosed in US 5 302 111 and US 5 522 721, whereby the pulsation of the gases fed to burners is realised by mechanical means, e.g. electro valves or rotary valves.

[0007] The known procedures require the use of mechanical, moving components, such as valves, control flaps, rotors or the like, and complex measurement and control technology to effect the pulsating combustion. An additional factor is that the previous solutions are somewhat inflexible with regard to changing the frequency or amplitude of the pulsation. For example, control by means of solenoid valves only allows on and off states but does not permit any intermediate states. It is also only possible to change the pulsation frequency to a limited extent, for example depending on the switching

speed of the solenoid valves. Furthermore, the service life of solenoid valves is restricted to approximately 10 000 000 switching operations, which at a switching frequency of, for example, 1 Hz corresponds to a service life of approximately 6 months, which in practice leads to short maintenance intervals which are barely acceptable.

[0008] Therefore, the invention is based on the object of providing a method which allows a simple and flexible change to the flow during pulsating combustion.

[0009] Furthermore, the invention is based on the object of providing a low-maintenance apparatus of simple design which is suitable for carrying out the method.

[0010] With regard to the method, this object is achieved, by a method according to claim 1.

[0011] In the method the volumetric flow of at least one of the reactants involved in the combustion reaction - i.e. the fuel gas or the oxidizing agent - is varied over the course of time by causing at least one membrane to deflect. The membrane is arranged in a membrane space which is fluid-connected to the feed of the respective reactant to the burner and is therefore accessible to the reactant. The membrane space allows the membrane arranged in it to be deflected as far as possible without obstacle. The membrane space and the membrane arranged in it are also referred to below as a "membrane module".

[0012] In the membrane space, the membrane is deflected by electrical actuation in the presence of the reactant in question, and in this way the electrical power is converted into changes in volume - associated with changes in pressure - in the membrane space, as is generally known for loudspeakers.

[0013] The constructions and principles of operation which are known for loudspeaker construction, involving a vibrating membrane and excitation means, are fundamentally also suitable for generating the change in volume in the flow of reactant in the context of the method. Examples which may be mentioned include electrodynamic loudspeakers, electrostatic loudspeakers, ferroelectric loudspeakers, magnetic loudspeakers or ultrasonic loudspeakers. Designs without a mechanical membrane, as used for ion or plasma loudspeakers, in which the surrounding atmosphere is excited by modulated high voltage, so that the resulting local ionization causes thermal expansion and therefore sound pressure, are in principle also suitable for carrying out the method.

[0014] The changes in volume of the membrane space are determined by frequency, amplitude and profile of the change in the volumetric flow of the reactant at the burner mouth over the course of time. Therefore, the method, by virtue of the electrically excited deflection of the membrane, allows the flow of the reactant to be changed without this requiring any moving or rotating components, apart from the membrane. The membrane itself is subject to very little wear, and consequently a long service life and long maintenance intervals can be achieved.

[0015] Furthermore, the change in the volumetric flow of the reactant(s), in addition to the on and off states, may also encompass any desired intermediate values for the maximum amplitude or a predetermined volumetric flow profile over the course of time, such as for example a square-wave, sawtooth, sinusoidal or trapezoidal profile. Equipping the supply lines for both the fuel and the oxidizing agent with membrane modules of this type also makes it readily possible to vary the volumetric flow of both reactants, for example independently of one another over the course of time or as a function of one another over the course of time, for example in-phase, in opposite phase or in phase-shifted fashion. The method allows a preset time profile, for example a square-wave profile, to be accurately maintained without significant dead times or slippages.

[0016] The additional design outlay required for this type of configuration of a burner is only slight; it is even possible for an existing burner to be retrofitted without major outlay, in which case a corresponding membrane module with actuation is incorporated into the existing feed line.

[0017] It has proven particularly appropriate for the electrical actuation to be effected by means of an electromagnet, by the latter acting on the membrane or on a ferromagnetic body connected to the membrane.

[0018] This is a simple design principle for the membrane module, as is known, for example, for conventional ferroelectric loudspeakers. The amplitude and frequency of the membrane oscillation are in this case predetermined by electrical pulses of the electromagnet. Membrane modules of this type are distinguished by being robust and operationally reliable.

[0019] It is advantageous for the electrical actuation of the membrane to comprise a control unit.

[0020] The change in the volume of the gas stream of the relevant reactant or reactants over the course of time can be set and controlled in a particularly simple way by means of the control unit. Predetermined deflection cycles can be passed through under programme control and are easy to adapt of necessary.

[0021] It has proven particularly favourable for the back-flow of the reactant out of the membrane space to be avoided or reduced by means of a restricting device provided in the reactant feed.

[0022] The restricting device prevents or reduces a back-flow of the reactant. This measure ensures that the changes in volume produced in the membrane space act in the direction of the burner mouth and not, or to a lesser extent, "towards the rear" in the direction of the source of the reactant in question. This effect of the restricting device becomes more effective the closer to the membrane space it occurs.

[0023] Valves, flaps, throttles or diaphragms can be used as the restricting device. However, moving mechanical components should as far as possible be avoided, and consequently it is preferable for the restricting device to be designed as a throttle or diaphragm.

[0024] The throttle or diaphragm is in this case installed in the feed line, as close as possible to the entry to the membrane space. This results in a pressure drop in the direction of the membrane space, which prevents a back-flow of the reactant and promotes an effective change in the volume in the direction of the burner mouth. This measure converts the change in the volume of the membrane space into a change in the flow or velocity of the reactant at the burner mouth without attenuation and in a simple, rapid and particularly effective way without the need for moving parts.

[0025] The method allows a constant volumetric flow of the reactant upstream of the restricting device.

[0026] It is not the volumetric flow of the reactant upstream of the restricting device which is varied over the course of time, but rather a change in volume is imposed on the flow, which has been constant up to that point, purely by the movement of the membrane, resulting in a change in the velocity at which the reactant flows out at the burner mouth over the course of time. A constant volumetric flow as far as the restricting device is simple to implement; it is therefore possible to dispense with mechanical components or change in the volumetric flow, such as valves or the like.

[0027] In a particularly preferred method variant, a minimum level for the volumetric flow of the reactant, which the volumetric flow does not drop below at any time even when the volumetric flow is changing, is predetermined.

[0028] In this case, a base load is predetermined as a partial quantity of the total volumetric flow of the corresponding reactant, and the volumetric flow does not drop below this partial quantity at any time even during a change in the volumetric flow. In the simplest case, this is achieved by a bypass parallel to the membrane space.

[0029] On account of the variation in the volumetric flow of the reactants or a reactant over the course of time, pressure fluctuations may occur in the furnace space, which can lead to the ingress of external air and therefore accordingly to a rise in the emission of NO_x. This is prevented if the load level does not drop below the predetermined base load of the reactant or if - ideally - a pressure drop in the furnace space is avoided.

[0030] In this respect, it has proven particularly appropriate if at least two burners are provided for heating the industrial furnace, with the volumetric flow of the reactant to one burner being changed in the opposite phase to the volumetric flow of the reactant to the other burner.

[0031] As a result of the volumetric flow to the two burners, which may; for example, be arranged opposite and offset with respect to one another in the furnace space, being changed in opposite phase, an approximately constant pressure is always maintained in the furnace space, so that there is no risk of the admission of external air. This effect can be achieved even if the volumetric flows of a plurality of pairs of burners change in opposite phase.

[0032] In this context, it has proven particularly advantageous for the membrane spaces of the two burners to be arranged adjacent to one another and to be separated

from one another by a common membrane.

[0033] On account of the fact that the membrane spaces of the two burners share one membrane, the volumetric flows of the reactant can be changed in opposite phase without the need for a separate control device. The membrane divides the membrane spaces on both sides, so that even in the event of a defect in the membrane, there is no leakage into the environment, but rather it is only the pulsating combustion which is disrupted. This improves the operational reliability of the apparatus.

[0034] It has proven particularly expedient for the volumetric flow of the fuel at the burner mouth to be changed.

[0035] In this case, it is preferable for the volumetric flow of the oxidizing agent to be kept constant.

[0036] With regard to the apparatus, the object referred to above is achieved, by an apparatus according to claim 11.

[0037] The apparatus comprises a membrane, which can be deflected and is mounted such that it can oscillate, and an electrical actuation, which can be used to mechanically deflect the membrane. The change in the volumetric flow of at least one of the reactants involved in the combustion reaction - i.e. the fuel gas and/or the oxidizing agent - is brought about by means of the membrane deflection. For this purpose, there is a membrane space which is accessible to the reactant in question and in the simplest case is arranged in the feed line for the respective reactant in the vicinity of the burner mouth.

[0038] The membrane and the excitation means are correspondingly made to match the designs which are standard in loudspeaker construction. In this respect, reference is made to the explanations given above in connection with the method.

[0039] The apparatus by electrically exciting the membrane, allows virtually any desired, predetermined change in the volumetric flow of the reactant over the course of time without requiring any moving parts, apart from the membrane. The membrane itself is subject to very little wear, and consequently a long service life and long apparatus maintenance intervals can be achieved.

[0040] Furthermore, in addition to the on and off states, the change in the volumetric flow of the reactant(s) may also include any desired intermediate values between zero and the maximum amplitude or a predetermined volumetric flow profile over the course of time, such as for example a square-wave, sawtooth, sinusoidal or trapezoidal volumetric flow profile. It is also possible for the volumetric flows of fuel and oxidizing agent to be varied independently of one another by equipping the supply lines for both fuel and oxidizing agent with membrane modules of this type; by way of example, these volumetric flows can be varied in-phase, in opposite phase or in phase-shifted fashion.

[0041] The outlay involved in providing a burner with this equipment is low, and even retrofitting an existing burner by incorporating a suitable membrane module in combination with an electrical actuation into the existing gas line does not require major structural outlay.

[0042] Advantageous configurations of the apparatus will emerge from the subclaims. Where configurations of the apparatus mentioned in the subclaims correspond to the method procedures described in subclaims relating to the method, reference is made, for additional explanation, to the statements given above in connection with the corresponding method claims.

[0043] The invention is described in more detail below on the basis of exemplary embodiments and a patent drawing, in which, in detail:

Figure 1 shows a glass melting tank with a plurality of burners mounted in the side wall for pulsating combustion, in the form of a diagrammatically depicted plan view,

Figure 2 shows various changes in volumetric flows of a reactant over the course of time for pulsating combustion,

Figure 3 superimposes a variable volumetric flow on a constant base load,

Figure 4 shows various changes in the volumetric flows of fuel and oxidizing agent over the course of time,

Figure 5 shows a phase-shifted change in volumetric flows between fuel and oxidizing agent, and

Figure 6 shows a further embodiment of a membrane module for operating with opposite-phase change in the volumetric flow of a reactant to two burners.

[0044] The plan view represented in Figure 1 diagrammatically depicts a glass melting tank 1 with a plurality of structurally identical natural gas/oxygen burners 3, 3a, 3b, 3c, which are mounted in pairs offset with respect to one another, pointing into the furnace space 18, on the opposite side walls 2 of the tank 1.

[0045] The burners 3, 3a, 3b, 3c are simple tube-in-tube burners with an inner tube 4 for supplying fuel, which is coaxially surrounded by an outer tube 6, forming an annular gap 5 for oxygen to pass through. The reactants which emerge from the burner mouth 7 react with one another to form a burner flame 8. The feed connection pieces for natural gas and oxygen are denoted by reference numerals 9 and 10.

[0046] To generate pulsating combustion, a change in volume is imparted to one or both gas streams (oxygen and natural gas). For this purpose, membrane modules 11 and 12 are arranged between the burner and the feed lines 9 for natural gas and 10 for oxygen, respectively.

[0047] These membrane modules in each case comprise a membrane space 13, in which two electrodynamic loudspeakers each having a membrane 14 are mounted opposite one another. The membranes 14 each comprise

a gastight, stretchable material and deflections are imparted to them in phase by means of an electromagnet 15. That side of the membrane 14 which is remote from the membrane space 13 is located in the open atmosphere.

[0048] The parameters for the change in volume inside the membrane space 13, such as frequency, amplitude or phase shift between the two reactants of the same burner 3 or another of the burners 3a, 3b, 3c are predetermined by one control module 16 for both membrane modules 11 and 12. As seen in the direction of flow of the respective gas, a diaphragm 17 is fitted in the feed line 9, 10 immediately upstream of the respective membrane space 13.

[0049] The text which follows provides a more detailed explanation of the method according to the invention by way of example with reference to the tube-in-tube burner 3 in the glass melting tank 1 which is diagrammatically depicted in Figure 1.

[0050] Each of the burners 3, 3a, 3b, 3c is designed for heating power of 200 kW. During normal operation, 20 m³/h of natural gas (CH₄) and 40 m³/h of oxygen are fed in.

[0051] The change in the volumetric flow of the natural gas emerging at the burner mouth 7 by means of the membrane module 11 is effected by deflections being imposed on the membrane 14 by means of the control module 16, which deflections cause a volumetric flow which changes over the course of time with a frequency of, for example, 1 Hz. The time profile of the volumetric change produced in this way has a precise square-wave profile. The changes in volume cause changes in through-flow, which continue via the membrane space 13 into the inner tube 4 as far as the burner mouth 7 and as a result cause a variable flow velocity of the natural gas at the burner mouth 7.

[0052] The size and displacement of the membrane 14 and the volume of the membrane space 13 are designed in such a way that the natural-gas volumetric flow of 40 m³/h can be completely switched on and off at a frequency of 1 Hz, so that a mean volumetric flow of 20 m³/h (s.t.p.) results. The diaphragm 17 prevents the natural gas from flowing back into the natural-gas feed line 9 and in this way ensures that the change in volume generated by the membrane 14 acts entirely as a change in the volumetric flow of natural gas at the burner mouth 7.

[0053] The profile of the deliberately altered volumetric flow of natural gas over the course of time ideally has a square-wave profile, as is diagrammatically depicted in Figure 2a).

[0054] To minimize pressure fluctuations within the glass melting tank 1 and the ingress of external air, the membrane modules 11 of a pair of burners in each case operate in opposite phase. The pressure profile at the burner 3 (and at the burner 3a) is in opposite phase to the pressure profile at the burner 3c (and at the burner 3b). Compared to normal operation, pulsating combustion of this type reduces the NO_x emission level by 30%,

without any adverse effect on the radiation properties of the flame. A similar effect results if the membrane modules of two adjacent burners 3, 3a are in opposite phase. Figures 2 to 5 diagrammatically depict further suitable procedures for pulsating combustion.

[0055] Figure 2 shows a square-wave (a), sawtooth (b), sinusoidal (c), trapezoidal (d) and a freely selectable or random (e) change in volumetric flow. All the through-flows illustrated are in the positive range, i.e. the volumetric flow which results is at all times higher than a predetermined minimum base load.

[0056] The change in volumetric flow shown in Figure 3 a provides for a constant proportion of the gas flow (base load 31), on which a further, deliberately changed proportion of the gas flow 32 is superimposed. The resultant volumetric flow 33 (Figure 3b) never adopts a negative value, since this would lead to undesirable flash-backs. For safety reasons, the minimum volumetric flow which results must always be positive and must not drop below a defined level.

[0057] As a result of the supply lines of both the natural gas and the oxygen being equipped with membrane modules 11 or 12, it is also possible for the volumetric flows of both reactants to be varied, for example independently of one another over the course of time or as a function of one another over the course of time, for example in phase, in opposite phase or in phase-shifted fashion.

[0058] Figure 4a) shows a suitable volumetric flow profile over the course of time for the situation in which both the natural-gas flow and the oxygen flow are varied. In the exemplary embodiment, the change 41 in the volumetric flow of the oxygen has double the frequency and amplitude of the change 42 in volumetric flow of the natural gas. Figure 4b) diagrammatically depicts a method variant in which the oxygen flow is kept constant over the course of time.

[0059] In the illustration presented in Figure 5a), the changes in volumetric flow of oxygen 51 and natural gas 52 over the course of time are in phase and only the amplitudes differ. In the illustration presented in Figure 5b), the modulation profiles for oxygen 51 and natural gas 52 are phase-shifted.

[0060] The control unit 16 can also easily be used to generate changes in volumetric flow which do not have a fixed, recurring period.

[0061] The embodiment of a membrane module 60 which is illustrated in Figure 6 is suitable in particular for operation with opposite-phase supply of a reactant to two separate burners (not shown in the drawing). The two burners in this case divide the membrane module 60. The membrane 61 divides the two membrane spaces 62 and 63, which are of equal size. The electromagnet 64 is provided in the membrane space 62. The gas inlet and gas outlet of the membrane space 62 for one burner are indicated by connection pieces 65, and the gas inlet and gas outlet of the membrane space 63 for the other burner are denoted by connection pieces 66.

[0062] The two maximum deflections of the membrane

61 into the respective membrane spaces 62 and 63 are represented by dashed lines 67. The reduction in volume caused by the deflection into one membrane space 62 produces an increase in volume of the same magnitude and at the same time in the other membrane space 63. This therefore ensures that the volumetric flows for the natural gas to the two burners alter precisely in opposite phase.

[0063] In the method according to the invention, the deflection in the membrane is associated with an increase and reduction in the volume of the membrane space. The changes in volume effect mass transfer without producing a soundwave. However, the method according to the invention is not restricted to this particular application. It is also possible, using a moving membrane, to generate pressure waves - without mass transfer - which allow pulsating combustion. In this case, the deflection direction of the membrane corresponds to the main direction of propagation of the burner flame.

Claims

1. Method for heating an industrial furnace by pulsating combustion, in which gaseous or liquid reactants, comprising an oxidizing agent and fuel, are fed to a burner (3), the volumetric flow of at least one of the reactants which emerges from the burner mouth (7) being changed over the course of time, **characterized in that** the change in the volumetric flow of the reactant over the course of time is generated by electrical actuation imparting deflections to at least one membrane (14) in a membrane space (13) which is connected upstream of the burner mouth (7) and is accessible to the reactant, which deflections cause changes to the volume of the membrane space.
2. Method according to Claim 1, **characterized in that** the electrical actuation is effected by means of an electromagnet (15) by the latter acting on the membrane (14) or on a ferromagnetic body connected to the membrane (14).
3. Method according to Claim 2, **characterized in that** the electrical actuation of the membrane (14) comprises a control unit (16).
4. Method according to one of the preceding claims, **characterized in that** the back-flow of the reactant out of the membrane space (13) is avoided or reduced by means of a restricting device (17) provided in the reactant feed.
5. Method according to Claim 4, **characterized in that** the restricting device (17) is designed as a throttle or a diaphragm.
6. Method according to Claim 4 or 5, **characterized in that** the volumetric flow of the reactant is constant upstream of the restricting device (17).
7. Method according to one of the preceding claims, **characterized in that** a minimum level for the volumetric flow of the reactant, which the volumetric flow does not drop below at any time even when the volumetric flow is changing, is predetermined.
8. Method according to one of the preceding claims, **characterized in that** at least two burners (3; 3a, 3b, 3c) are provided for heating the industrial furnace (1), with the volumetric flow of the reactant to one burner (3, 3b) being changed in the opposite phase to the volumetric flow of the reactant to the other burner (3a, 3c).
9. Method according to Claim 8, **characterized in that** the membrane spaces (13) of both burners (3; 3a, 3b; 3c) are arranged adjacent to one another and are separated from one another by a common membrane.
10. Method according to one of the preceding claims, **characterized in that** the volumetric flow of the fuel at the burner mouth (7) is changed.
11. Apparatus for carrying out the method according to one of Claims 1 to 10, having a burner (3), which includes feed lines (9, 10) for streams of gaseous or liquid reactants leading to a burner mouth (7), and having a device for varying the volumetric flow of at least one of the reactants over the course of time, **characterized in that** the device for varying the volumetric flow over the course of time comprises at least one membrane (14), which is arranged in a membrane space (13) that is connected upstream of the burner (3) and is accessible to the reactant, and on which deflections can be imposed by means of an electrical actuation, which deflections cause a change in the volume of the membrane space (13).
12. Apparatus according to Claim 11, **characterized in that** the electrical actuation comprises an electromagnet (15), which acts on the membrane (14) or on a ferromagnetic body connected to the membrane (14).
13. Apparatus according to one of the preceding claims, **characterized in that** the feed line (9, 10) for the reactant leading to the membrane space (13) is provided with a restricting device (17) for avoiding or reducing a back-flow of the reactant.
14. Apparatus according to Claim 13, **characterized in that** the restricting device (17) is designed as a throttle or a diaphragm.

15. Apparatus according to one of the preceding apparatus claims, **characterized in that** at least two burners (3, 3a, 3b, 3c) are provided for heating the industrial furnace (1), it being possible for the volumetric flow of the reactant to one burner (3, 3b) to be changed in the opposite phase to the volumetric flow of the reactant to the other burner (3a, 3c).

16. Apparatus according to Claim 15, **characterized in that** the membrane spaces (13) of the two burners (3; 3a; 3b; 3c) are arranged adjacent to one another and are separated from one another by a common membrane (61).

17. Apparatus according to one of the preceding apparatus claims, **characterized in that** the membrane space (13) is provided in the feed line (9, 10) for feeding the reactant to the burner (3).

18. Apparatus according to Claim 17, **characterized in that** the membrane space (13) is provided in the feed line (9) for the fuel.

Patentansprüche

1. Verfahren zum Erhitzen eines Industrieofens durch pulsierende Verbrennung, in der gasförmige oder flüssige Reaktanden, die ein Oxidationsmittel und einen Brennstoff aufweisen, einem Brenner (3) zugeführt werden, wobei der Volumenfluss wenigstens eines der Reaktanden, der von der Brennermündung (7) ausgeht, im Laufe der Zeit geändert wird, **dadurch gekennzeichnet, dass** die Änderung des Volumenflusses des Reaktanden im Laufe der Zeit durch elektrische Betätigung erzeugt wird, die wenigstens einer Membran (14) in einem Membranraum (13), der auf der Einlassseite der Brennermündung (7) verbunden ist und für den Reaktanden zugänglich ist, Durchbiegungen erteilt, wobei die Durchbiegungen Änderungen des Volumens des Membranraums veranlassen.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** die elektrische Betätigung mittels eines Elektromagneten (15) **dadurch** ausgeführt wird, dass der Letztere auf die Membran (14) oder auf einen mit der Membran (14) verbundenen ferromagnetischen Körper wirkt.

3. Verfahren nach Anspruch 2, **dadurch gekennzeichnet, dass** die elektrische Betätigung der Membran (14) eine Steuereinheit (16) aufweist.

4. Verfahren nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** der Rückfluss des Reaktanden aus dem Membranraum (13) mittels einer in der Reaktandenzufuhr vorgesehenen Begren-

zungsvorrichtung (17) vermieden oder verringert wird.

5. Verfahren nach Anspruch 4, **dadurch gekennzeichnet, dass** die Begrenzungsvorrichtung (17) als eine Drosselklappe oder als eine Federplatte ausgelegt ist.

6. Verfahren nach Anspruch 4 oder 5, **dadurch gekennzeichnet, dass** der Volumenfluss des Reaktanden auf der Einlassseite der Begrenzungsvorrichtung (17) konstant ist.

7. Verfahren nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** ein Minimalpegel für den Volumenfluss des Reaktanden, unter den der Volumenfluss zu keiner gegebenen Zeit fällt, selbst wenn sich der Volumenfluss ändert, vorgegeben wird.

8. Verfahren nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** wenigstens zwei Brenner (3, 3a, 3b, 3c) zum Erhitzen des Industrieofens (1) vorgesehen sind, wobei der Volumenfluss des Reaktanden zu einem Brenner (3, 3b) in der entgegengesetzten Phase zu dem Volumenfluss des Reaktanden zu dem anderen Brenner (3a, 3c) geändert wird.

9. Verfahren nach Anspruch 8, **dadurch gekennzeichnet, dass** die Membranräume (13) beider Brenner (3; 3a; 3b; 3c) aneinander angrenzend angeordnet sind und durch eine gemeinsame Membran voneinander getrennt sind.

10. Verfahren nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** der Volumenfluss des Brennstoffs an der Brennermündung (7) geändert wird.

11. Vorrichtung zum Ausführen des Verfahrens nach einem der Ansprüche 1 bis 10 mit einem Brenner (3), der Zuleitungen (9, 10) für Ströme gasförmiger oder flüssiger Reaktanden umfasst, die zu einer Brennermündung (7) führen, und mit einer Vorrichtung zum Ändern des Volumenflusses wenigstens eines der Reaktanden im Laufe der Zeit, **dadurch gekennzeichnet, dass** die Vorrichtung zum Ändern des Volumenflusses im Laufe der Zeit wenigstens eine Membran (14) aufweist, die in einem Membranraum (13) angeordnet ist, der auf der Einlassseite des Brenners (3) verbunden ist und für den Reaktanden zugänglich ist und der mittels einer elektrischen Betätigung Durchbiegungen auferlegt werden können, wobei die Durchbiegungen eine Änderung des Volumens des Membranraums (13) veranlassen.

12. Vorrichtung nach Anspruch 11, **dadurch gekenn-**

zeichnet, dass die elektrische Betätigung einen Elektromagneten (15) aufweist, der auf die Membran (14) oder auf einen mit der Membran (14) verbundenen ferromagnetischen Körper wirkt.

13. Verfahren nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** die Zuleitung (9, 10) für den Reaktanden, die zu dem Membranraum (13) führt, mit einer Begrenzungsvorrichtung (17) versehen ist, um einen Rückfluss des Reaktanden zu vermeiden oder zu verringern.

14. Vorrichtung nach Anspruch 13, **dadurch gekennzeichnet, dass** die Begrenzungsvorrichtung (17) als eine Drosselklappe oder als eine Federplatte ausgelegt ist.

15. Vorrichtung nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** wenigstens zwei Brenner (3, 3a, 3b, 3c) zum Erhitzen des Industrieofens (1) vorgesehen sind, wobei es möglich ist, dass der Volumenfluss des Reaktanden zu einem Brenner (3, 3b) in der entgegengesetzten Phase zu dem Volumenfluss des Reaktanden zu dem anderen Brenner (3a, 3c) geändert wird.

16. Vorrichtung nach Anspruch 15, **dadurch gekennzeichnet, dass** die Membranräume (13) der zwei Brenner (3; 3a; 3b; 3c) angrenzend aneinander angeordnet sind und durch eine gemeinsame Membran (61) voneinander getrennt sind.

17. Vorrichtung nach einem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** der Membranraum (13) in der Zuleitung (9, 10) vorgesehen ist, um den Reaktanden dem Brenner (3) zuzuführen.

18. Vorrichtung nach Anspruch 17, **dadurch gekennzeichnet, dass** der Membranraum (13) in der Zuleitung (9) für den Brennstoff vorgesehen ist.

Revendications

1. Procédé de chauffage d'un four industriel par combustion pulsée, dans lequel des réactifs gazeux ou liquides, comprenant un agent oxydant et un combustible, sont amenés à un brûleur (3), le débit volumétrique d'au moins un des réactifs qui émerge de l'embouchure (7) du brûleur variant avec le temps, **caractérisé en ce que** la variation du débit volumétrique du réactif avec le temps est générée par un actionnement électrique qui imprime des déflexions à au moins une membrane (14) dans un espace de membrane (13) qui est connecté en amont de l'embouchure (7) du brûleur et qui est accessible au réactif, lesdites déflexions entraînant un changement du volume de l'espace de membrane.

2. Procédé selon la revendication 2, **caractérisé en ce que** l'actionnement électrique est réalisé au moyen d'un électroaimant (15) par l'action de ce dernier sur la membrane (14) ou sur un corps ferromagnétique qui est connecté à la membrane (14).

3. Procédé selon la revendication 2, **caractérisé en ce que** l'actionnement électrique de la membrane (14) comprend une unité de commande (16).

4. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** le reflux du réactif hors de l'espace de membrane (13) est évité ou réduit au moyen d'un dispositif de restriction (17) qui est prévu dans l'alimentation du réactif.

5. Procédé selon la revendication 4, **caractérisé en ce que** le dispositif de restriction (17) est conçu sous la forme d'un étrangleur ou d'un diaphragme.

6. Procédé selon la revendication 4 ou 5, **caractérisé en ce que** le débit volumétrique du réactif est constant en amont du dispositif de restriction (17).

7. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'**un niveau minimum pour le débit volumétrique du réactif est prédéterminé, ledit débit volumétrique ne descendant jamais en dessous de ce niveau minimum même lorsque le débit volumétrique est modifié.

8. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'**au moins deux brûleurs (3; 3a, 3b, 3c) sont installés pour chauffer le four industriel (1), le débit volumétrique du réactif vers un brûleur (3, 3b) étant modifié dans la phase opposée au débit volumétrique du réactif vers l'autre brûleur (3a, 3c).

9. Procédé selon la revendication 8, **caractérisé en ce que** les espaces de membrane (13) des deux brûleurs (3; 3a, 3b, 3c) sont formés à proximité l'un de l'autre et sont séparés l'un de l'autre par une membrane commune.

10. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** le débit volumétrique du combustible à l'embouchure (7) du brûleur varie.

11. Appareil pour exécuter le procédé selon l'une quelconque des revendications 1 à 10, comprenant un brûleur (3) comprenant des lignes d'alimentation (9, 10) pour des courants de réactifs gazeux ou liquides qui mènent à une embouchure de brûleur (7), et comprenant un dispositif pour modifier le débit volumétrique d'au moins un des réactifs avec le temps, **caractérisé en ce que** le dispositif pour modifier le

débit volumétrique avec le temps comprend au moins une membrane (14) qui est agencée dans un espace de membrane (13) qui est connecté en amont du brûleur (3) et qui est accessible au réactif, et sur laquelle des déflexions peuvent être imprimées par l'intermédiaire d'un actionnement électrique, lesdites déflexions entraînant un changement du volume de l'espace de membrane (13). 5

12. Appareil selon la revendication 11, **caractérisé en ce que** l'actionnement électrique comprend un électroaimant (15) qui agit sur la membrane (14) ou sur un corps ferromagnétique qui est connecté à la membrane (14). 10

13. Appareil selon l'une quelconque des revendications d'appareil précédentes, **caractérisé en ce que** la ligne d'alimentation (9, 10) pour amener le réactif à l'espace de membrane (13) comprend un dispositif de restriction (17) qui est destiné à éviter ou à réduire le reflux du réactif. 15 20

14. Appareil selon la revendication 13, **caractérisé en ce que** le dispositif de restriction (17) est conçu sous la forme d'un étrangleur ou d'un diaphragme. 25

15. Appareil selon l'une quelconque des revendications d'appareil précédentes, **caractérisé en ce qu'**au moins deux brûleurs (3, 3a, 3b, 3c) sont installés pour chauffer le four industriel (1), le débit volumétrique du réactif vers un brûleur (3, 3b) pouvant être modifié dans la phase opposée au débit volumétrique du réactif vers l'autre brûleur (3a, 3c). 30

16. Appareil selon la revendication 15, **caractérisé en ce que** les espaces de membrane (13) des deux brûleurs (3; 3a, 3b, 3c) sont formés à proximité l'un de l'autre et sont séparés l'un de l'autre par une membrane commune (61). 35 40

17. Appareil selon l'une quelconque des revendications d'appareil précédentes, **caractérisé en ce que** l'espace de membrane (13) est formé dans la ligne d'alimentation (9, 10) qui amène le réactif au brûleur (3). 45

18. Appareil selon la revendication 17, **caractérisé en ce que** l'espace de membrane (13) est formé dans la ligne d'alimentation (9) du combustible. 50

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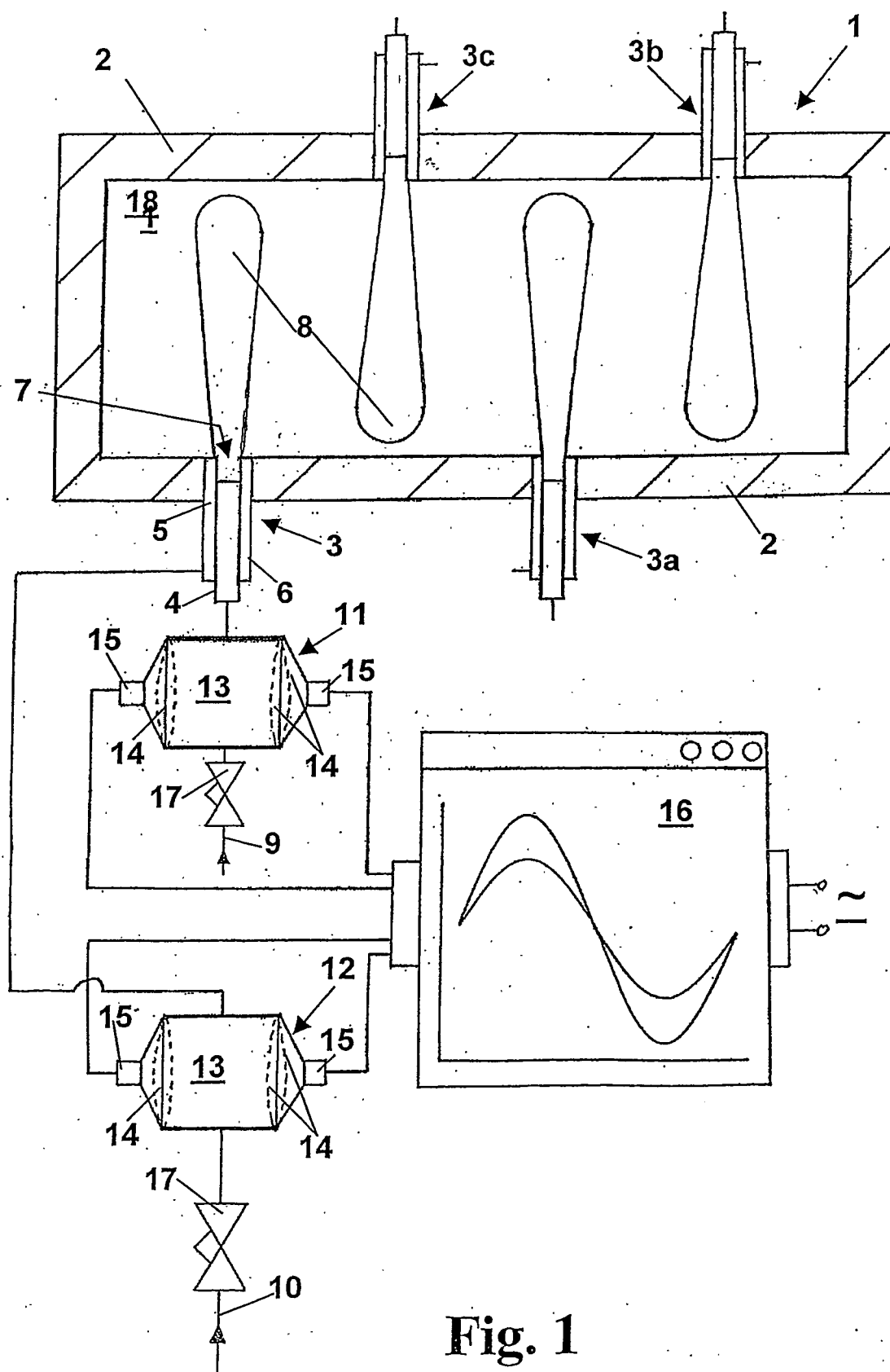


Fig. 1

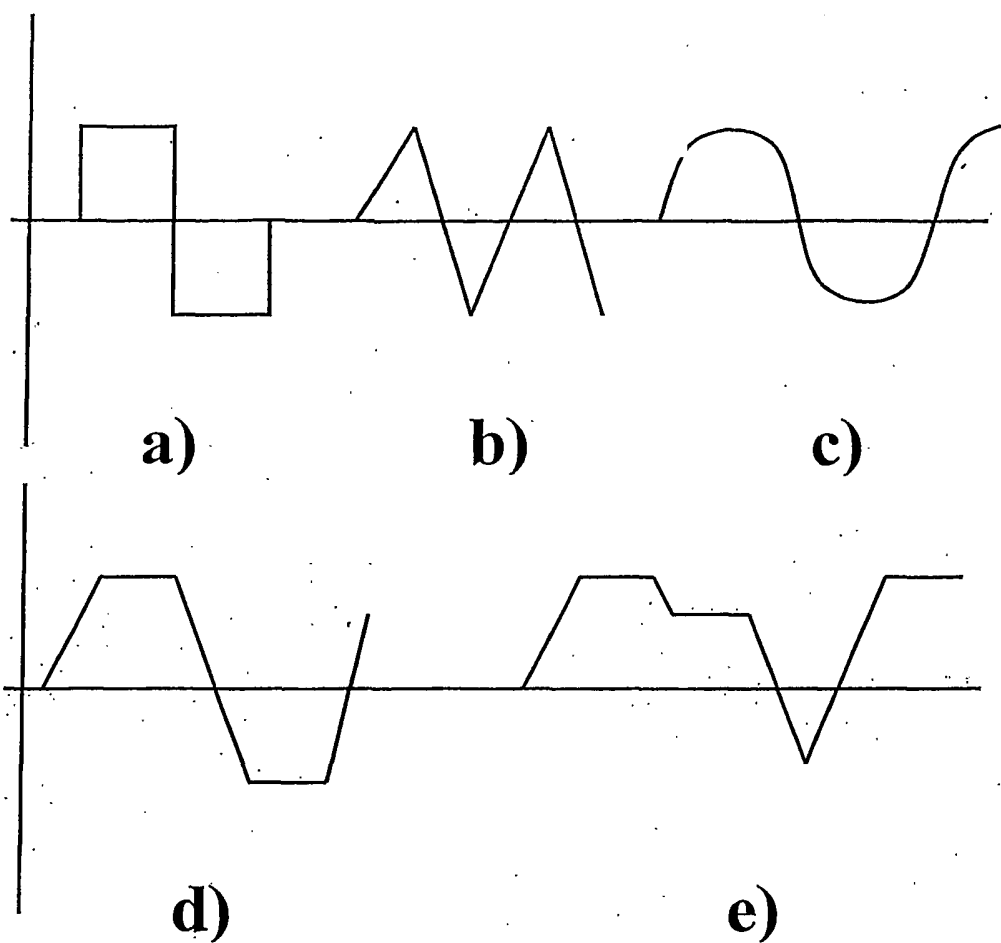


Fig. 2

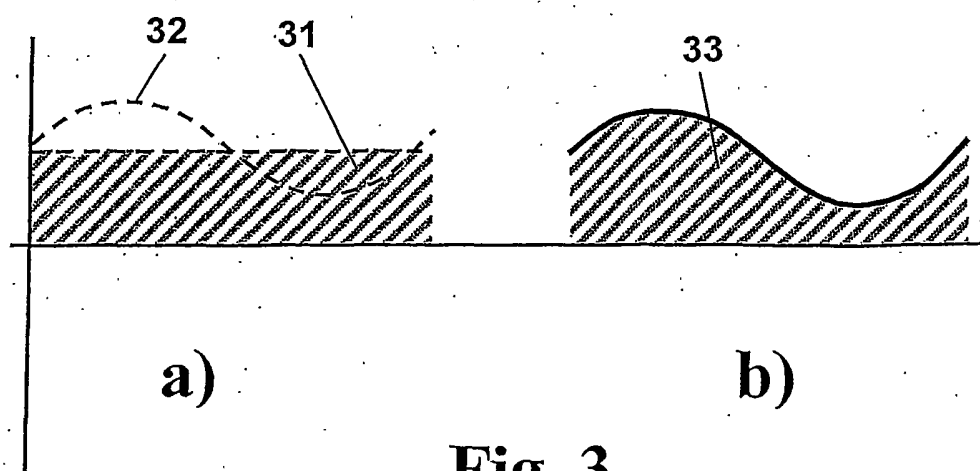


Fig. 3

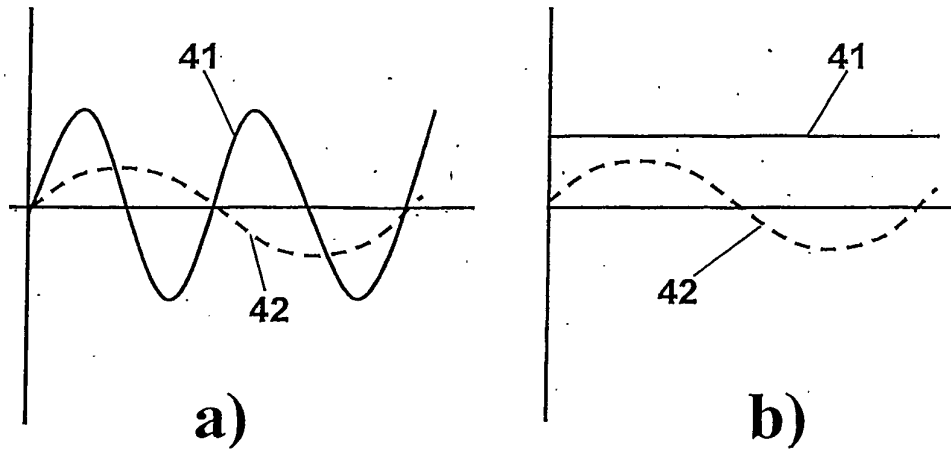


Fig. 4

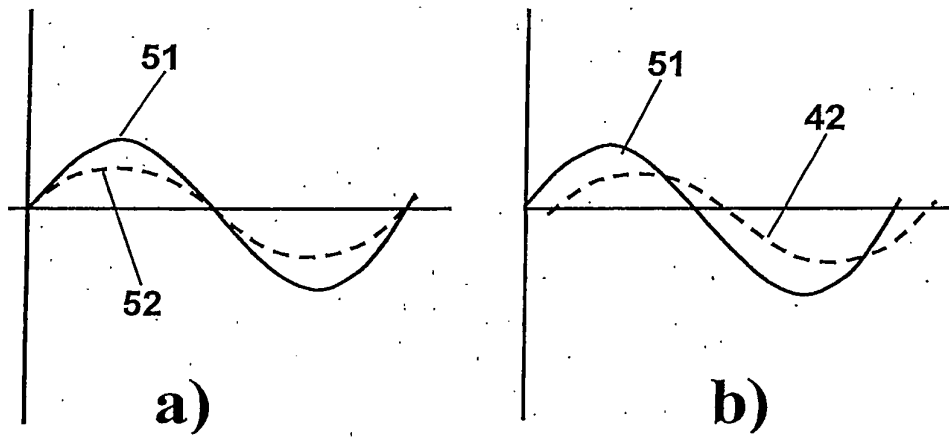


Fig. 5

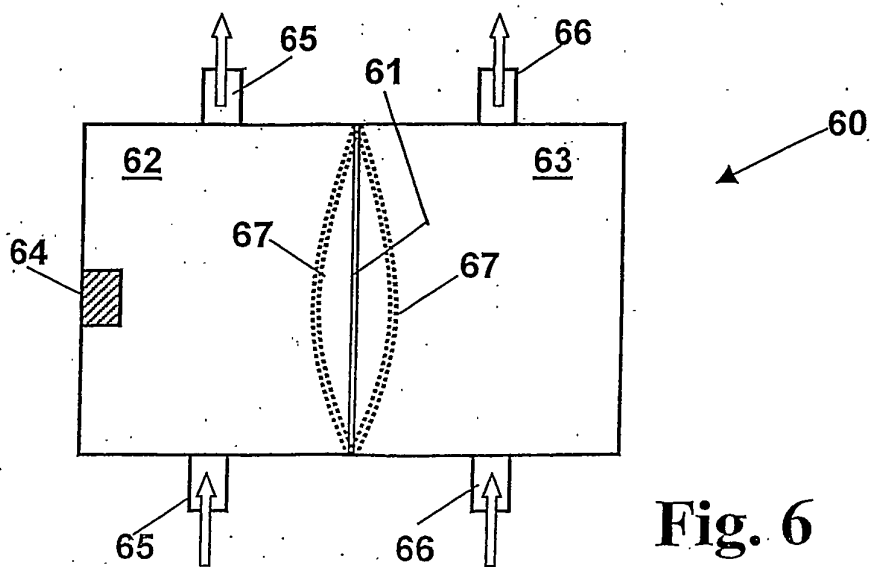


Fig. 6

REFERENCES CITED IN THE DESCRIPTION

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