Use of low-temperature plasma for stabilizing a combustion process under the utilization of waste products with high moisture content

V N Delyagin¹, N M Ivanov¹, A N Karzanov¹, V N Bocharov¹ and A A Kondrat’ev²

¹ Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences, 2B Central’naya ul., Krasnoobsk, Novosibirsk Region, 630501 Russia
² Novosibirsk State Agrarian University, 160 Dobrolyuhova ul., Novosibirsk, 630039 Russia

E-Mail: valdel@ngs.ru

Abstract. Thermal recycling and disinfection of waste products in different physical states represent a comprehensive solution to the problem of waste utilization. The utilization of waste materials with high moisture content (more 70...75%) is associated with a need to evaporate a significant volume of water and causes, as a consequence, substantial additional expenses on an energy source. To cut costs related to the utilization of wastes with a high amount of water it is suggested using a coal cleaning product – a coal-water slurry fuel. The direct combustion of incompletely mechanically dehydrated (to 70-75%) wastes with high water content (cake) is an economically efficient process. However, it poses a severe problem of combustion stabilizing. The paper presents outcomes of the research into the stabilization of thermal recycling waste materials with a high level of moisture by means of low-temperature plasma in the adiabatic vortex combustion chamber. To control a burning process in the technology adapter low-temperature plasma is supplied into the base of flame. An output of a plasma generator (power supply source) is estimated as 1 kW power input per 13 kg/h suspension fuel. A dynamic range of heat output for a coal-water slurry fuel and wastes is determined to be 70-100% when generating thermal energy and utilizing wastes with high moisture content by means of low-temperature plasma as a stabilizer of a combustion process. Experimental studies carried out on a machine simulator have proven the efficiency of low-temperature plasma for utilization and disinfection of waste products in commercial farming.

1. Introduction

Large-scale livestock breeding complexes and poultry factories are main pollution sources of the biological environment around metropolitan areas. As a rule, waste products are in different physical states – solid, liquid, and gaseous.

The utilization of multicomponent wastes via thermal processing leads to a significant cost increase. One of the possible solutions to this problem seems to be the use of a coal-water fuel – a product of coal cleaning [1]. In this case, a cost price of thermal energy is 3...4 times lower. The future for this utilization procedure is related to stabilizing the combustion of wastes with a high amount of water in a material to be recycled and in a fuel as well.
Recently, a solution to the aforementioned problem, i.e. to stabilizing combustion processes is reported to be found in the use of electrical and magnetic fields, electrical discharges, ozone and low-temperature plasma [2-8]. The study aims to evaluate the efficiency of utilizing waste materials with high moisture content by means of a coal-water slurry fuel and low-temperature plasma used as a stabilizer of thermal processes when recycling wastes.

2. Materials and Methods
A power technological adapter including a coronation electrical unit and a plasma generator (Figure 1) was mounted on an experimental unit (Siberian Research Institute of Mechanization and Electrification in Agriculture, Siberian Federal Research Center for Agrobiotechnologies, Russian Academy of Sciences) equipped with an adiabatic vortex combustion chamber (output 500 kW), where a material to be utilized is supplied directly into the furnace. The adapter was installed to provide both separate or tandem arrangement of air blasting unit, and a unit supplying low-temperature plasma into the flame. As a low-temperature plasma supply source we used a high-frequency streamer discharge. An output of a power source was as high as 3.5 kW. A voltage of a power source (no-load operation) was set 12 kV. For power production in the adiabatic vortex combustion chamber intended for the utilization of wastes we adapted a coal-water suspension mixed of coal cleaning wastes and pulverized coal fuel.

We modeled the low-temperature plasma supply on the example of coal-water slurry fuel (Figure 2 a) and pulverized coal fuel (Figure 2 b). The electrical and physical effect of charged particles on the behavior of combustion was assessed relying on the dynamics of temperature in the furnace (a response of the system). Parameters to be measured – a number of ion pairs (millions pairs/cm3), a volume of supplied ionized air (m3/min), input current and power of a plasma generator for charged particles (A, W), and a heat flow output (W).

Parameters to be controlled included an amount of air supplied into the furnace, fuel consumption, and a temperature field of a burner flame.

Parameters were measured and recorded using analytical-recording software. We used such measuring devices as temperature sensors, a differential pressure gauge, an ion number (MAC 01) gauge, a radiometer with a spherical probe, a thermal imaging camera Testo 885-2, pyrometers Testo 845 and “Calvin”, digital multiple-purpose meters ACTACOM, and a measuring device for electrical and magnetic fields PZ-70. Data were processed in the mathematical package “Statistica”.

Figure 1 A power technological adapter
Figure 2. Low-temperature plasma supply when using: a – a coal-water slurry fuel, b – a pulverized coal fuel.

3. Results and Discussion

Table 1 summarizes outcomes of experimental studies.

A value of the reduced electric field was determined as \( E/N \), where \( E \) – electric-field strength, \( N \) – concentration of neutral particles 800...1200 Td.

A number of negative air ions was varied from 1.28*10^5 to 8*10^5, that of positive ions was in a range from 1.47*10^5 to 1.00*10^6.

Plasma source parameters: source output 3 kW, fuel consumption 12...40 kg/h, volume of supplied initiated air 80...110 kg/h.

| Parameter                                      | Symbol | Value                  |
|------------------------------------------------|--------|------------------------|
| Temperature in the combustion zone inside the furnace (\( ^\circ \)C) | tc     | 960-1050 \(^\circ \)C  |
| Temperature of an applied mixture (\( ^\circ \)C) | tm     | 10/1051                |
| Output in view of coal-water slurry fuel (kg/h) | Vw     | 12-40                  |
| A number of ions                               | N      | 1.28*10^5 ...8*10^5    |
| -positive (N+/cm\(^3\))                        |        | 1.47*10^5 ...1*10^6    |
| -negative (N- /cm\(^3\))                      |        |                        |
| Air supply (kg/h)                              | V      | 80-110                 |
| Reduced electric field, Td                     |        | 800-1200               |
| Recombination time of air-ions (s)             | T      | 0.067...0.081          |
| Voltage on electrons of a plasma generator (kW)| U      | 12/4                   |
| Discharge current (A)                          | I      | 1-2                    |
| Moisture content in wastes (%)                 | W      | 72-75                  |
| Dynamic range                                  |        | 75-100                 |
| Specific output of a plasma generator, kW/(kg*h)| Vp     | 0.61                   |
| Ratio coal-water slurry fuel: wastes           |        | 3:1                    |
When experimenting with the combustion initialization of coal-water slurry and pulverized fuel mixtures, an impact of low-temperature plasma on the stabilization of a burning process appeared to be far significant than 3 g/s ozone supply into the flame base with a similar number of air-ions.

The combustion of wastes was stabilized more efficiently by means of a pulverized fuel than a coal-water slurry fuel.

An explanation is supposed to be that electrons under the given electric field frequency gain additional energy in a range 2...4 eV, therefore, plasma can be considered non-equilibrium. High-energy electrons committing with fuel and gas molecules form chemically active radicals CH and OH, which initiate the development of chain combustion reactions. Non-equilibrium plasma stimulates the strong inflammation with a great number of fire spots.

To stabilize a combustion process we suggest using non-equilibrium low-temperature plasma in the technology adapter, which is generated by a high-frequency spark discharge (energy of electrons to 4 eV) and supplied into the flame base. An output of plasma generator (power source) is determined as 1 kV input network power per 13 kg/h fuel (a ratio between a fuel and wastes kept at the humidity of 72...75% is 3:1).

The dynamic range of heat output in the running system “adapter – boiler unit” (thermal energy production and utilization of wastes with high moisture content) varies 70 to 100%.

Non-equilibrium plasma furthers the combustion stabilizing of fuel components with high moisture content in the process of utilization and disinfection of waste materials.

References

[1] Delaygin V.N., Murko V.I., Ivanov N.M., Revyakin E.L. Use of coal-water slurry fuel for power supply in agriculture M.: FSBSI “Rosinformagrotech”, 2013. – 92 p. (in Russian)
[2] Research and developments of Siberian Branch Russian Academy of Sciences in the field of energy efficient technologies / edit. by S.V. Alekseenko: SBRAS Press, issue 20, 2009. – 405 p. (in Russian)
[3] Malinovsky A.E., Lavrov F.A. On the effect of electric field on combustion processes in gases // Technical Physics. – 1931. – V.2, Issues 3-4. – p. 530-534 (in Russian)
[4] Wang F, Liu J B, Sinibaldi J, Brophy C, Kuthi A, Jiang C, Ronney P and Gundersen M A. IEEE Trans. Plasma Sci. 33 844–9 (2005)
[5] Pancheshnyi S V, Lacoste D A, Bourdon A and Laux C O. IEEE Trans. Plasma Sci. 34 2478–87(2006)
[6] Bao A, Utkin Y G, Keshav S, Lou G and Adamovich I V IEEE Trans. Plasma Sci. 35 1628–38(2007)
[7] Kosarev I N, Aleksandrov N L, Kindysheva S V, Starikovskaia S M and Starikovskii A Yu Combust. Flame 154 569–86(2008)
[8] Heywood J.B., Internal combustion engine fundamentals, McGraw-Hill international editions (1988).
[9] Sosnin E.A. Source of an atmosphere pressure plasma jet formed in the air or nitrogen actuated by a barrier discharge / E.A. Sosnin, et al. // Technical Physics. – 2016. – V. 86. – Issue 5. – № 4. – p. 151-153 (in Russian)