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Ignition Characteristics of a Burner with 2-Level Combustion Spaces

Seung-Ryol Maeng*

Kongju National University, Chung Nam Cheoan City Seo Buk-Gu Cheoan Daero 1223-24, 31080, S. Korea; srmaeng@kongju.ac.kr

Abstract

Objectives: Since incineration of livestock excretions generates pollutants as necessity, it is important to develop a burner for reducing pollutants. 2-stage approaches, in which dry gas from 1st incineration stage is combusted, again at 2nd incineration stage, are widely used to reduce pollutants. Our work is for a burner used in 2nd stage. **Methods/Statistical Analysis**: For complete combustion we suggested the burner architecture with 2-level combustion spaces and designed its prototype. Basic architecture has two separated spaces and one is for slow combustion and another is for fast combustion. That leads to stable ignition and prohibits generation of pollutants. In the prototype, the ratio of diameters for heating, incomplete, and complete space is 1:2:5. To help complete combustion incoming gas can be heated and incoming air to combustion spaces is controlled, based on status of the burner in 1st stage incineration. **Findings**: A prototype has been implemented to verify the performance of suggested burner. We give a way to calculate the amount of air needed to completely combust waste and the corresponding capacity of an air blower. For example, the amount of air for pig excretions 100kg/h is 124.7 m^3/h and an air blower with the diameter 150mm generates air volume 7~30m3/min. On the other hand, only when temperature of 1st burner decreases within a tolerance, incoming gas is heated to 600 degree by electric coil. For simplicity experiments with petroleum gas is performed in different conditions. According to experiments, ignition rate is about 100% for heating condition and gas concentration more than 20%. For no heating, ignition rate is 95%. **Improvements/Applications**: Small business of livestock needs fast and least expensive way for processing waste and incineration is an alternative way. Our burner aimed at 2nd combustion of dry gas in incineration. Particularly, it is cost-effective in incineration of livestock excretions.

Keywords: Air Volume, Burner, Heat Control, 2-Level Combustion, Pollutants, 2-Stage Incinerations

1. Introduction

Mass breading of livestock, as a necessity, causes the environmental problem in processing excretions. Although there were various ways for processing excretions, incineration has been, recently, recognized as an alternative eco-friendly method[1–3]. It has the advantages in terms of the processing speed and the avoidance of water-pollution; nevertheless it also produces air-pollutants. So many researches on incineration process of waste have been focused on reducing the air-pollutants. The 2-stage incineration is widely used way, in which waste is pyrolized or carbonized by the primary burner and then the resulted gas combusted again by the secondary burner[4–7]. Therefore the secondary burner is directly related to production of air-pollutants.

The secondary burner is a device combusting the combustible gas and then generates various pollutants such as carbon oxides and sulfur oxides. These pollutants are generated in different conditions and the

*Author for correspondence

conditions are closely related to the burning space and the air volume. With low temperature and few amount of incoming gas for the secondary burner, no-ignition may be occurred. Too much air volume may turn off the flame. On the other hand, since a burner is usually worked in poor surroundings with dust and soot, it is likely to break down. Therefore it must be easily maintainable and cost-effective. Requirements for the secondary burner can be summarized as follows:

- Stability of ignition
- Reduction of pollutants
- Cost-effectiveness

Burning pyrolysis-gas, too much air supply and high temperature generate nitrogen oxides while less air supply and low temperature do sulfur oxides and dioxin. These contradictory conditions for pollutants make it difficult to develop a burner. However if these contradictory conditions are satisfied, pollutants can be reduced. That motivates our work.

Our basic idea is to separate an incineration space of a burner into two ones, small one and large one, and then to properly control air supply to them[8]. Small space makes ignition easy and prohibits generation of sulfur oxides. Large space and sufficient air supply lead to complete combustion of incoming gas. In this paper we extend our basic idea more completely and detailed the model by adding an air-supply and a preheating method. Based on these, a prototype was developed and its performance was validated by using combustible gas.

The prototype has tested under different conditions with combustible gas. We have found that the prototype is well working and ignition failure can be removed. Particularly, when incoming gas is heated in small space, no ignition problem could be solved and ignition stability was improved.

In next section, previous works are introduced. Section 3 shows our burner's architecture and its prototype. Section 4 gives the detailed description on the heater and the air-supplier. Testing results are given in Section 5 and finally concluding remarks in Section 6.

2. Previous Works

To improve the problems caused from direct incineration of livestock excretions, 2-stage approaches are mainly used in waste incineration. Basically 2-stage incineration uses two burners, the primary burner and the secondary one, as shown in Figure 1. Many researchers have interested in developing a burner for the second stage, called as the secondary burner, and Figure 2 shows the representatives[4–7].

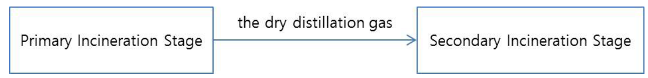


Figure 1. 2-stage incineration processes for waste.

In[4] proposed the burner architecture specialized in polymer waste, as shown in Figure 2(a). Basically it has adapted 2-stage incineration approach and designed a combustion burner for 2^{nd} incineration. Pyrolytic gas generated in 1^{st} incineration moves into 2^{nd} combustion burner through the tube. However it does not give a detailed solution to control amount of incoming air required for combustion and it has only a simple architecture which ignition source for 2-step combustion is added and by high temperature combustion, nitrogen oxide may be generated. With the integrated architecture, it is difficult to reassemble and maintain in fail. One

In[5] suggested a new burner, shown in Figure 2(b), in which, on the premise of incineration of solid wet fuel, the dry distillation gas from 1-stage burning is translated into a burner for 2-stage incineration and combusts it with additional source in the secondary burner. It also has a disadvantage to be difficult to control amount of incoming air and does not guarantee complete combustion.

As shown in Figure 2(b),[6] proposed a burner for the secondary combustion which mixes and reburns flame and pyrolytic gas. It has two separated spaces for combustion. To extend detention time of the mixture, the space for 2-level combustion is provided but there is no a detailed way to supply air for complete combustion. It has a reassembled architecture and is easily maintainable.

In[7], as shown in Figure 2(d), devised another type burner for the dry distillation gas combustion. It is similar with our work in that it has two spaces for 2-level combustion, but it is different in that it needs the additional heat source and air to two spaces is supplied without considering ignition.

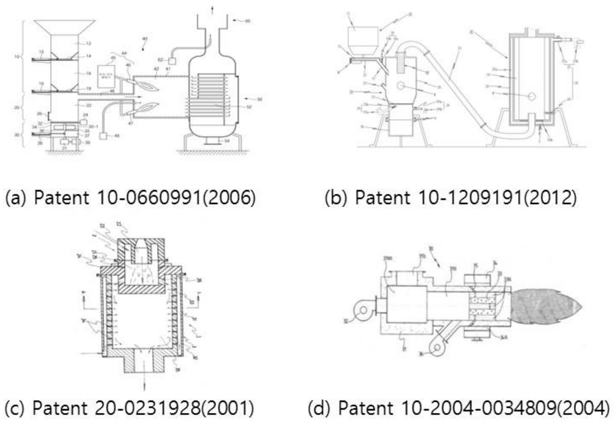


Figure 2. Burner Architectures for 2-stage Combustion.

3. Basic Architecture

Figure 3, the suggested burner has two separated combustion spaces in order to satisfy the contradictory conditions for pollutants and to guarantee the working stability in different situations. When the gas and air are mixed in a large space, they cannot be rapidly and sufficiently mixed and it may, as a result, cause no self-ignition and incomplete combustion. Sufficient air supply is helpful for ignition, but too much air may turn off flame.

According to our previous work[8], it consists of the complete combustion part and the incomplete combustion part. From now on, they are abbreviated as the complete part and the incomplete part, respectively. The complete part is for complete combustion and the incomplete part is for ignition and pollutants minimization. So, large amount of air is provided to the complete part while small amount of air to the incomplete part. This property differentiates our work from others. Ignition in the incomplete part leads to 2nd combustion in the complete part. The complete and incomplete parts have their own air tube. Inside temperature of the complete part increases to 1000 degree and pollutants such as nitrogen oxide, sulfur oxide, and dioxin are fully combusted.

In addition, the incomplete part is separated into two parts, called as the incomplete part and the heating part, respectively. The complete part has a structure to include the incomplete and they can be easily separated for maintenance. The incoming gas to the incomplete part is heated for helping self-ignition. For example, the gas of livestock excretions is heated by 500~600 degree, at which the primary burner generates the gas. For this, a thermometer can be attached in the primary burner. Only small amount of air for self-ignition is provided into the incomplete part for minimizing generation of nitrogen oxide. But too little air may cause no self-ignition while too much air may turn off the frame.

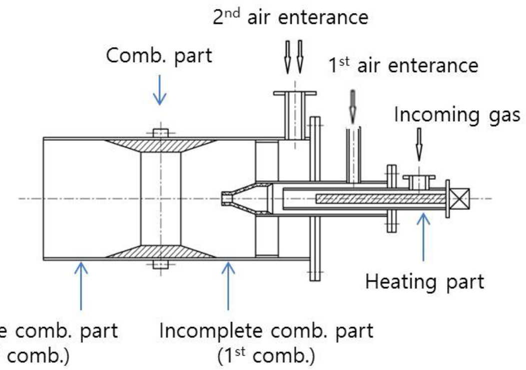


Figure 3. Suggested Buner Architecture with 2-level Combustion Spaces.

In next section, the air volume for incomplete combustion is calculated.

4. Prototype Design

4.1 The 2-Level Combustion Space

Basically, 2-stage incineration needs the primary burner and the secondary one as mentioned in Section 2. The prototype is also assumed to be connected to the primary burner and works along with that. It means that the prototype is controlled by combustion situation such as pressure and temperature of the outgoing gas from the primary burner. To control combustion of the prototype, a temperature gauge is installed in the primary burner as shown in Figure 4. Measured temperature is transferred to the combustion controllers such as an air blower and the heating part, and when it is below any one incoming gas to the 2nd combustion space is heated up to running average temperature of the primary burner.

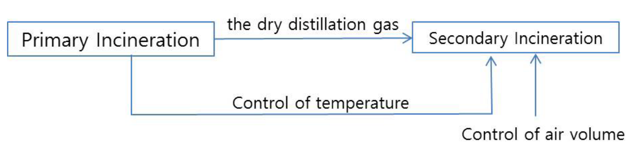


Figure 4. Cooperation of the primary burner and the secondary one.

Based on the basic architecture, the prototype was designed in order that the ratio of diameters for each part is 1:2:5. As a result, the diameter for the heating part is 50mm, one for the incomplete part 100mm, and one for the complete part 250mm. The lengths of each part are 200mm, 200mm, and 300mm, respectively. Without doubt, there is no a theoretical basis on the ratio of the diameter of each part. That only depends on the amount of gas for processing. In this design, we have focused on easy ignition and slow incineration of low concentration gas in the incomplete part.

The incomplete part and the heating part are important ones to determine the performance of suggested burner, which lead to self-ignition and solve no-ignition problem. In next section, control principles for these parts will be given.

4.2 Amount of Needed Air

As illustrated in previous section, the gas can be completely combusted by supplying sufficient air and an air supplier have to blow sufficient air into combustion spaces. Now it is time to discuss amount of air for the gas. Since it depends on the ingredients of the gas, we must analyze the gradients of waste generating the gas. Remember that the proposed burner aimed at livestock excretions, which is a value of fuel[9,10].

Given the ingredients of livestock excretions, we can calculate the theoretical amount of air for complete combustion using well-known chemical reaction formula[11].

$$\begin{aligned} &C + O_2 \rightarrow CO_2. \\ &H_2 + \frac{1}{2}O_2 \rightarrow H_2O. \\ &S + O_2 \rightarrow SO_2. \end{aligned} \tag{1}$$

For example, Equation 1 means that combustion of carbon 1kg needs oxygen 32/12 kg and generates carbon dioxide 44/12 kg. Therefore when a material 1kg includes C kg of carbon, H kg of hydrogen, S kg of sulfur, and O kg of oxygen the air needed for complete combustion are as following Equations 2.

$$O_2(V) = 22.\frac{4}{32\left(\frac{8}{3}C + 8H + S - O\right)Nm^3}. \tag{2}$$

But since the ratio of oxygen and nitrogen is 21 versus 79in the center of volume, the actual amount of air is given as Equation 3.

$$A(V) = \frac{O_2(V)}{0}.21. \tag{3}$$

For example, since the ratio of ingredients within pig excretions 1kg are as Table 1, the actual air volume is computed as Equation 4.

$$A(V) = 1.247\frac{m^3}{kg}. \tag{4}$$

Here minor elements were omitted for simplicity and moisture was assumed not to react with other ingredients.

In Section 4.1, since our prototype was designed to process waste 100kg/h, actual amount of air for the prototype is 124.7m^3/h. The rotary type blower[12] is widely used for small air volume under 30m^3/min and a blower with the diameter 150mm produces 7~30m^3/min.

Incoming air to the burner is divided by 70% versus 30% and each portion goes to the complete combustion part and the incomplete combustion part, respectively. The reason why the amount of air to the incomplete part is less than that of the complete part is to prohibit that a flame turns off. Turning off flame occurs when the pressure of incoming air is greater than that of a flame. That is similar to turning off of candle flame by a mouth. At this time, too much air pressure can make the air flow to the reverse direction and the careful design of an air controller is required.

4.3 Heating Algorithm

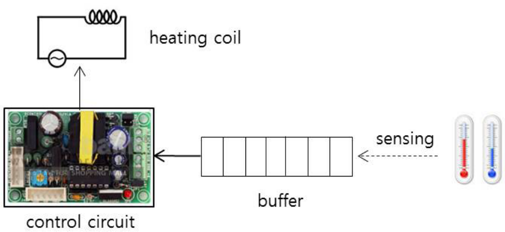
The heating part heats incoming air for ignition with small air volume. It is made with coil and coated by heat-proof material. By being connected to the electric power, it makes the heating space to 800 degree when the temperature of incoming gas becomes lower. These cases usually occur when combustion begins and ends.

Table 1. Composition Ratio of Pig's Excretions(1kg)

Carbon(C)	Hydrogen(H)	Oxygen(O)	Sulfur(S)	Nitrogen(N)	Water(W)	Others	Total
0.490	0.062	0.150	-	0.042	0.175	0.081	1.000

The heating part works along the primary burner. That is, it works when the temperature of pyrolysis equipment decreases below a specific temperature. Here the temperature means running average for a specific duration. Therefore the controller of the heating part must be designed to store real-time data.

Figure 5 shows the algorithm that receives real-time temperature from the primary burner and makes the heating part active. Figure 5(a) is a controller structure and Figure 5(b) is its control algorithm. Real-time data is first stored in buffer at interval of 5 seconds and by computing the average during 5 minutes the heating temperature is determined.



(a) Heating controller structure

```
#define RUNNING_TIME = 60, SENSING_INTERVAL = 2, TEMP_LIMIT = 600;
Procedure heatControl()
    begin
        loop
            if runningAverage() < TEMP_LIMIT then
                turnOnPower();
            else turnOffPower();
        end loop
    end
end procedure

Procedure RunningAverage()
    begin
        var t, sum, average;
        sum=0; n=0; t=0;
            while t < RUNNING_TIME
                sum = sum + GetTemperature();        n++;
                wait(SENSING_INTERVAL, t);
            end while
        average = sum / n;
    end
end procedure
```

(b) An algorithm

Figure 5. Control Algorithm for the Heating Part.

5. Experimental Results

To verify the performance of our burner we have developed a prototype as shown in Figure 6. The prototype design aimed to incinerate pig excretion and its capacity is for 100kg/h per a day. Implementation was based on the basic architecture and the prototype design illustrated in the previous section. As seen in Figure 6(a) it also consists of the complete part and the incomplete part, which includes the heating part. Figure 6(b) shows Combustion flame.

The main purpose of experiments is to test whether ignition of the heated and unheated gas is on or off in condition of different concentrations of combustible gas. For simplicity, we use petroleum gas in this experimentation. Experiments have been performed 20 times in heating and no heating situations, and in different concentrations of gas, respectively. Table 2 shows the experimental results. At these experiments, petroleum gas 300cc/min was provided into the heating part. In case of heating, the heating part was heated by 500 degree.

(a) (b)

Figure 6. The Prototype Implementation.

In the experiment, we could obtain the success rate of ignition which we expect. Ignition rate was about 100% when the heating part was heated and proper air-supplying was given to incoming gas while it was lower when no heating was given. It is possible to interpret the reason why the difference occurs to be at air control together heating of incoming gas. Conclusively, the proposed architecture can be used to combust the waste gas as the 2'nd burner.

Table 2. Ignition rate of the Prototype

Heating or not	Concentration (%)	# of ignitions(n)	Ignition rate (%)
heating	20	20	100
	40	20	100
	60	20	100
no heating	20	18	90
	40	19	95
	60	20	100

6. Conclusion

The burner architecture with 2-level combustion spaces is useful for reducing pollutants and stable in operation. Above all, it has no additional ignition source and ignition is only controlled by air supply. It has the separated spaces according to the pollutants generation conditions. The incomplete part is for slow combustion while the complete part is for fast combustion. Therefore less air is supplied to the incomplete part and much air is done to the complete part.

In this paper, we have designed a prototype of the burner with 2-level combustion spaces and implemented for verification of its performance. The design includes a burner's body, an air-supplier, and a heating controller. Of course, the heating controller is connected with a primary burner and its working depends on a primary burner's temperature.

To verify the performance of our prototype, we have tested the ignition success rate for several conditions. Although we use petroleum gas for simplicity, the experimental results, particularly for heated gas, show the ignition success rate about 100% for all conditions. It says that the proposed architecture is useful as a 2'nd burner in incineration of livestock excretions.

In this work, we did not analyze the pollutants after incineration of the gas due to experimental environment. Since pollutants must be prohibited from incineration, this analysis is very important. We leave the experiment for livestock excretions as future work.

7. Acknowledgement

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