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A Study on the Estimation of Threshold of Crown Fire Transition with the Slope Conditions

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Abstract

As Simultaneous and massive forest fires are rapidly increasing along with climate change such as winter abnormally high temperatures, the need for systematic research and development of management technology to reduce fire damage from large-scale forest fires is emerging. Because the main mechanism of large fire is crown fire and spot fire in the coniferous forests vulnerable to forest fires, the understanding of fire behavior must take precedence in order to fire damage reduction. However, fire behavior research has mostly been developed based on empirical knowledge due to limitations in the scale of experimental equipment, which makes research data somewhat less accurate to show the characteristics of fire behavior at actual sites. In this work, we tried to physically observe the characteristics of crown fire behavior accompanying large forest fires through indoor combustion experiments with minimal exposure to environmental variables. Using large wind tunnel equipment, crown fire transition phenomenon from the surface fire was simulated, and the slope conditions and crown base height(CBH) thresholds of crown fire transition under Korean pine forest conditions were presented through items such as spread rate, flame characteristics, mass loss rate, and ignition. According to the results of this study, the rate of fire spread increased as the slope angle increased, the rate of fire spread of slope angle 30° was 14 times faster than slope angle 0°. Measured fire intensity ranged from 246.73 kW/m, ~ 2,602.96 kW/m, the fire intensity increased as the slope angle increases. The flame height and flame tilt decreased as the slope angle increased, the length of flame increased as the slope angle increased. The measured combustion rate decreased as the slope angle increased. The moisture content of canopy fuel measured higher as the crown base height increases under the same slope conditions, so the risk of forest fire ignition is determined to below. The results of this study can be used as basic data to fire behavior with the slope conditions.
Keywords: crown fire transition, fire behavior, surface fire, crown base height, fuel moisture content

Introduction

In recent years, the climate has changed rapidly around the world, and super-large wildfires have spread all over the world, mainly due to the abnormally high temperature approaching 50 degrees Celsius and the extremely dry atmospheric environment. In the crown fire that always accompanies a large forest fire, the heat energy generated from the indexing generally diffuses to the leaves and branches located in the upper layer of the tree planting by convection and radiant heat energy and ignites while raising the temperature of the crown fuel. And it will occur, leading to diffusion. Crown fire spread (diffuse) at a much faster rate than indexing, so once they occur, they have many difficulties to control, many social and economic problems, etc. (Rothermel, 1983; Albini & Stocks, 1986). Therefore, it is most important to prevent forest fire in advance before it occurs, and if a forest fire unavoidably occurs, it is essential to take effective measures to minimize the damage. In order to minimize the damage caused by wildfires, it should be prioritized to understand the occurrence and spread of wildfires and predict potential wildfires. In this regard, ongoing research is being conducted abroad to investigate the factors that affect wildfires and their diffusion relationships, and among many complex factors, wildfire behavior is particularly closely related to fuel, topography, and meteorological characteristics. (References to some previous studies in the dissertation). Tilt conditions affect flame characteristics and increase heat transfer, especially with non-combustible unburned fuels. The flow of wildfires by air is represented by a characteristic flame length that creates an angle towards unburned fuel, resulting in a close impact on convective and radiant heat intensities (M. Frederic et al., 2018). In the case of Korea, it was suggested through combustion experiments that the steeper the slope and the higher the wind speed, the higher the flame temperature would be (Kim, 2016), but almost the actual forest environment (index fuel amount, fuel humidity, etc.) (Kim, et al., 2017), it was not possible to reflect the conditions in consideration of the above, and there was a limit to the progress of the experiment without reducing it to the exact ratio. In this study, we adjusted the actual forest environment to an accurate ratio in order to observe the effect of indexing by slope and wind velocity conditions on crown fuel for pine, which is the most abundant coniferous tree species in Korea. A crown fire transition combustion experiment was conducted, in which the fuel was reduced and diffused from indexing to crown fire. In this way, we tried to construct basic data that can contribute to research on acid non-diffusion behavior by using items such as diffusion rate, flame intensity, combustion rate, and flame characteristics.

Methodology

1. Experimental equipment

The" crown fire transfer experimental device" was used to understand the combustion characteristics of the surface layer of pine trees under tilting conditions (Figure 1). This device can adjust the inclination in various ways, and has an index fuel plate (Fuel bed) and a crown fuel network (Crown fuel basket) attached to it, and can simulate the transition phenomenon of crown fire in which the flame of the index fuel is carried to the crown fuel. It's equipment. The inclination condition can be adjusted up to 30°, the standard of the index fuel plate is 1.8 m in length and width, the standard of crown fuel network is 0.9 m in length, and the standard of width and height is 0.3 m.

2. Experimental material

The material to be tested was selected from pine deciduous leaves, which are known to be vulnerable to wildfires among coniferous species. The fuel was collected in a pine forest and used in the experiment after undergoing a natural drying process for about one week. When conducting the experiment, the crown fuel was collected on the day of the experiment in order to maintain the water content as close as possible to the field conditions, and after the process of classifying the branches and leaves, only the leaves of the crown fuel were used in the experiment. Applying the water content analysis method presented by Anderson (1978) during the experimental process, the index fuel maintained a water content of about 12.8 ± 1.2%, and the crown fuel maintained a water content of 110.6 ± 12.3%, which was presented in the previous study in Korea. The conditions were similar to the average spring water content (Kwon, 2014).

3. Experimental method

The experiment in this study was carried out by reducing the actual forest to 1/9. Therefore, the fuel conditions per experiment are the fuel amount values of pine V-class salary (index fuel amount 1.282 kg / ㎡, crown fuel load presented in the existing research (Kim, 2015; Kim et al., 2017). It was recalculated based on the fuel amount of 2.03 kg / ㎡), reflecting the area of the Fuel bed (2.88 ㎡) and the experimental reduction rate. The slope gave conditions of 0˚, 10˚, 20˚ and 30˚, considering that more than 70% of South Korea's topography is less than 30° (KFS, 2016; Kim et al., 2017). When arranging the fuel in the experimental process, the average fuel layer thickness of the Korean pine forest was adjusted to 4.8 ± 0.3 cm, and the fuel was arranged as evenly as possible. And 3.15 m), 0.55 m (4.95 m),

After locating the crown fuel at a height of 0.75 m (6.75 m), the change in water content was observed.

The ignition source (Firebrand) used a torch equipped with Bhutanese gas, and after stopping the fire at the bottom of the combustion plate, the first 30 cm was set as a section for stabilizing the flame. In order to repeat the experiment in the same environment as much as possible, the experiment was carried out sequentially in a closed room where the influence of humidity and wind was minimized, and after repeating the experiment three times according to the inclination condition, the average value was utilized.

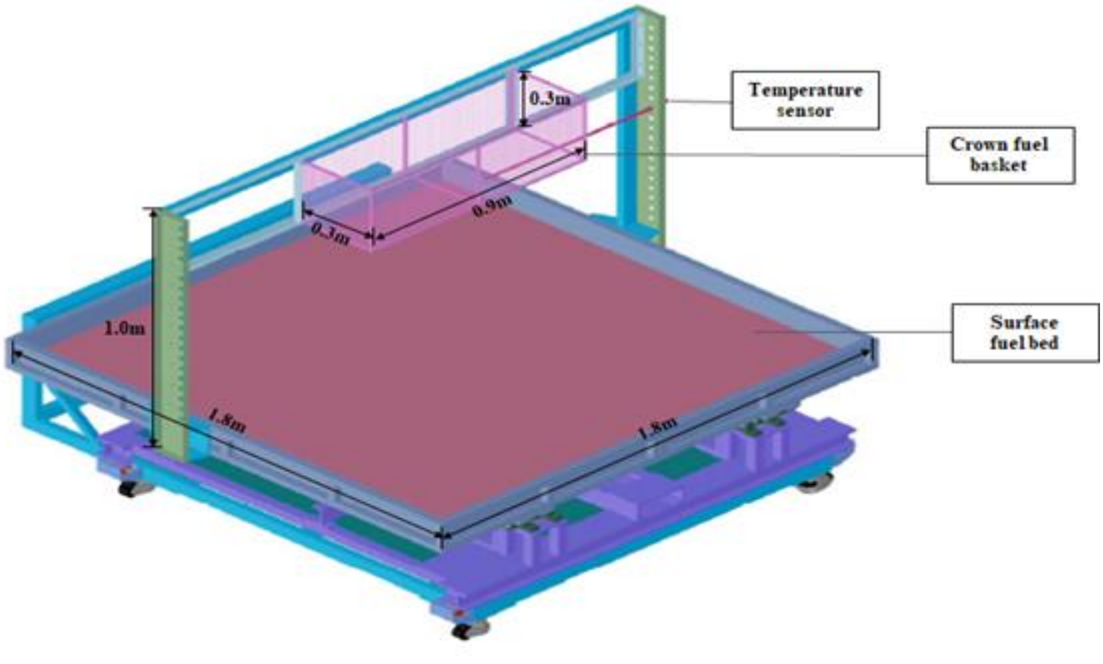

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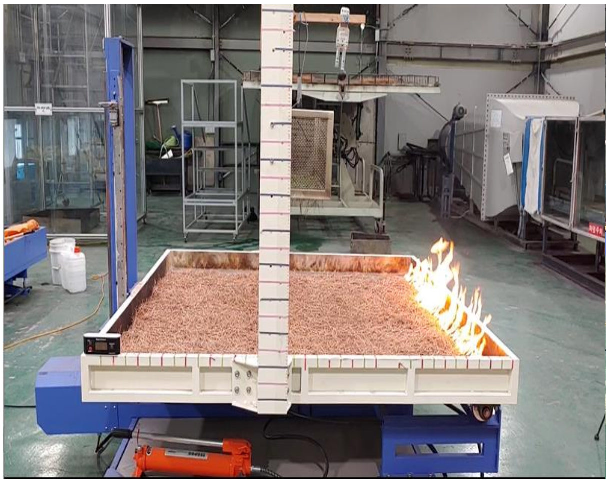
Fig. 1: [The equipment for laboratory combustion experiment]



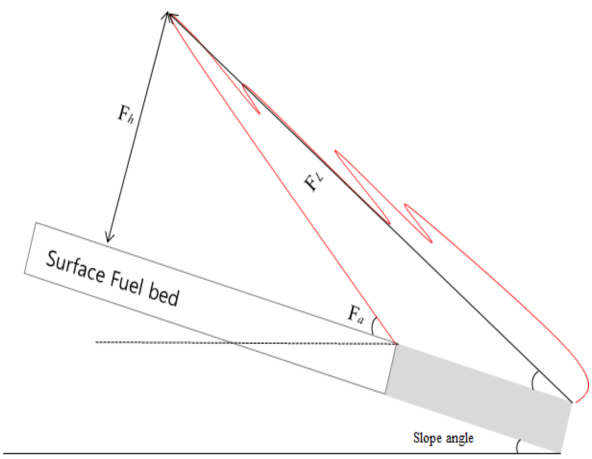
(a) Slope angle 0°

(b) Slope angle 10°

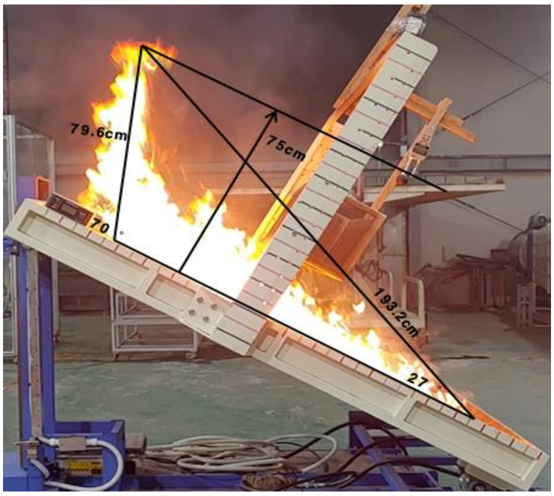
(c) Slope angle 20°

(d) Slope angle 30°

Figure 2. [The experimental equipment view with the slope conditions]



(a) Flame characteristics analysis diagram



(b) A view of flame characteristics analysis method

Figure 3. An analysis method of flame characteristics

Results

1. Rate of spread by the slope conditions

The result of analyzing the change in the diffusion rate of the mountain fire due to the inclination condition is the same as <Figure 4>. From the analysis results, it moves 0.30 cm / s under the condition of 0 ° inclination, 0.45 cm / s for 10 ° inclination, 0.86 cm / s for 20 ° inclination, and 3.30 cm / s for 30 ° inclination. bottom. At this time, the diffusion speed increases about 1.5 times from 0 ° to 10 °, about 1.9 times from 10 ° to 20 °, and about 3.9 times from 20 ° to 30 °. The diffusion speed at an inclination of 30 ° was about 14 times faster than that on flat ground. Looking at the results of existing studies, Dupuy et al (2011) found that 0 ° slope is 0.40 cm / s, 10 ° slope is 0.67 cm / s, 20 ° slope is 1.31 cm / s, and 30 ° slope is 30 ° through indoor combustion experiments. Since the result of the acid non-diffusion rate of 3.36 cm / s was obtained, it was the same as the value shown in this study.

As a result of analyzing the time to reach 1.8 m, which is the distance from the start point to the end point of the fire after ignition, the inclination of 0 ° is 450 seconds, the inclination of 10 ° is 330 seconds, the inclination of 20 ° is 180 seconds, and the inclination of 30 ° is 50 seconds. The steeper the slope, the shorter the time to reach a certain distance (1.8 m).

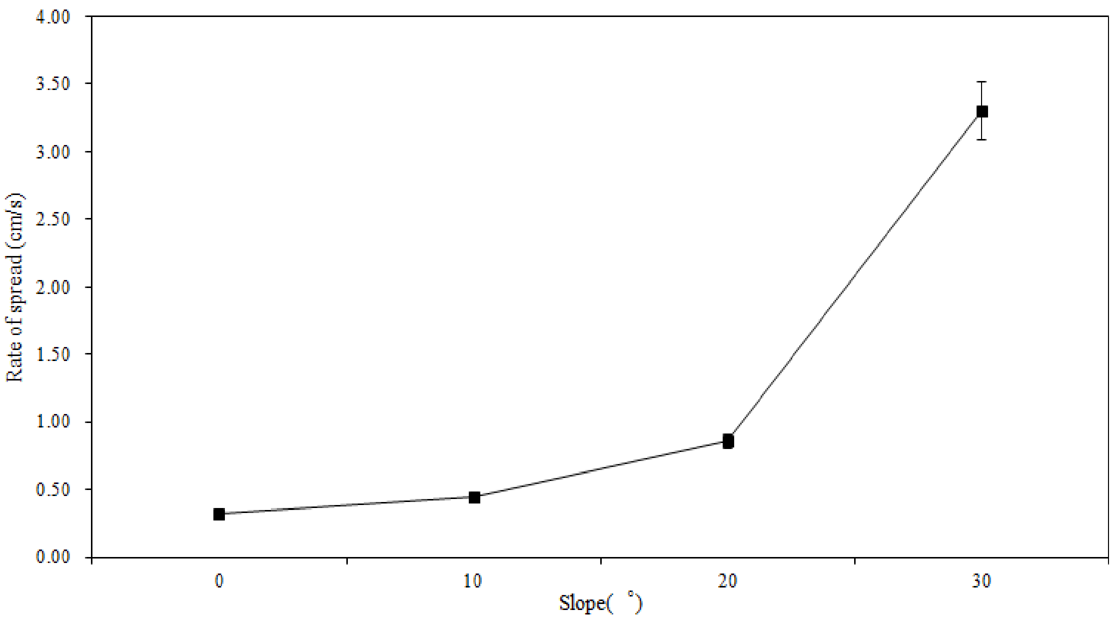


Figure 4. Rate of forest fire spread changes by the slope conditions (The bar is standard deviation)

2. Flame intensity due to inclination

As a result of measuring the flame intensity due to the inclination, the range was 246.7kW / m to 2,603.0kW / m as a whole, and the flame intensity tended to increase as the inclination became steeper (Figure 5). At this time, the flame intensity at an inclination of 30 ° was up to about 11 times higher than that on the flat ground. Looking at the results of existing studies, Kim, et al. (2017) have presented the mountain intensity range associated with inclination in windless conditions in the range of 75.8 kW / m to 227.4 kW / m, which is compared with this study. The results were slightly different (Table 2). This is because the width of the Fuel bed, which is a factor that affects the diffusion rate and intensity, is more than twice as wide as that of the existing research, and it seems that there was a phenomenon that the diffused flame increased the intensity while interacting with each other (Dupuy)., 1995). In addition, in this study, the form in which the flame develops using wide equipment with an open slope shows a pattern in which the actual forest fire spreads (a form in which the flower head advances in an oval shape). It is judged to be a numerical value that better reflects the reality of the actual forest compared to the research results (Dupuy, et al, 2011).

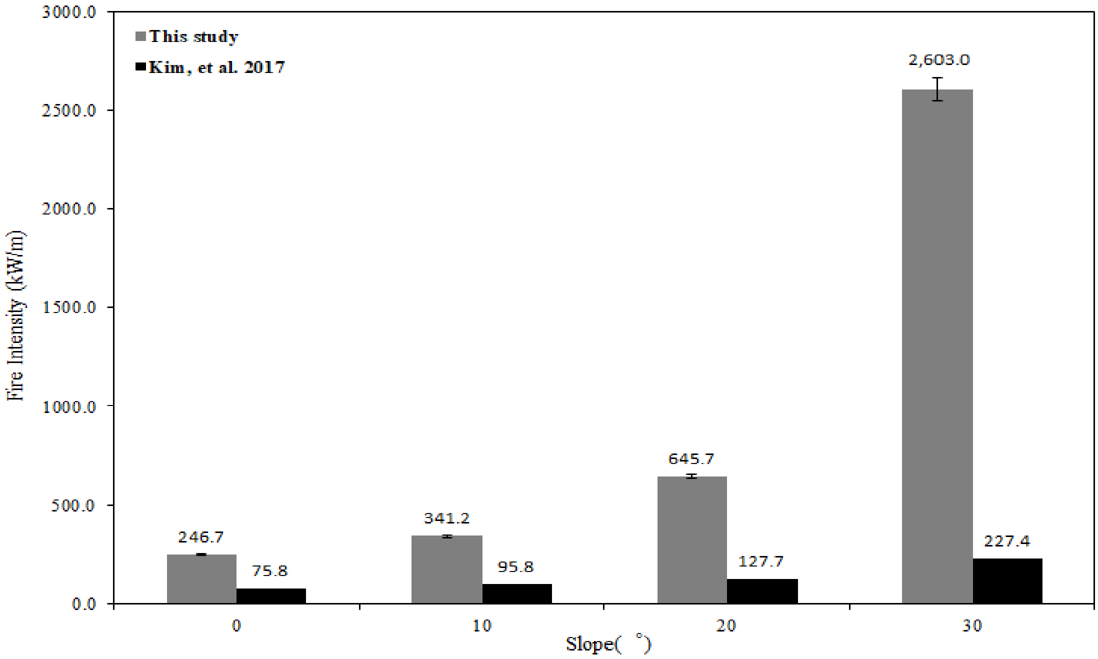
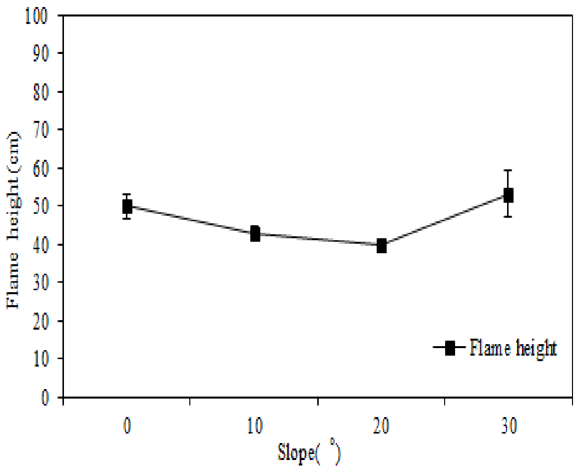


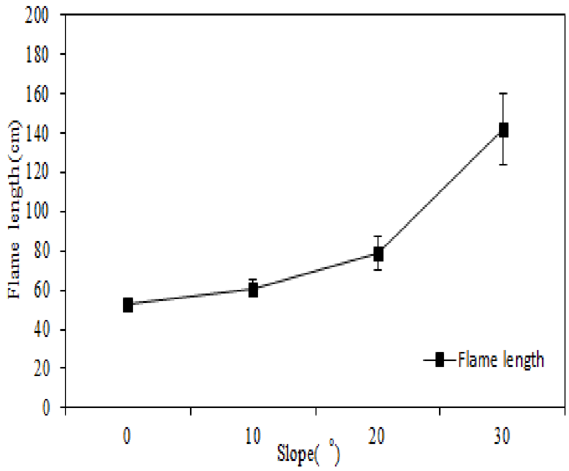
Figure 5. The comparison of fire intensity between the previous study and this study (The bar is standard deviation)

3. Flame characteristics due to inclination

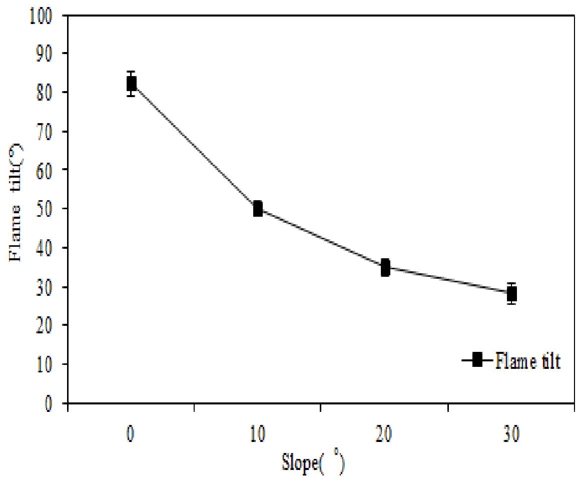
As a result of analyzing the flame characteristics according to the inclination condition, the flame height decreases to 20 ° as the inclination becomes steeper and increases from 30 °. The inclination of 20 ° was measured as 39.8 cm, and the inclination of 30 ° was measured as 53.2 cm (FIG. 6, a). A previous study (Kim, et al., 2014) suggested that the steeper the slope in no wind conditions, the more the flame tilts in the direction parallel to the ground surface, resulting in an increase in flame length and a decrease in flame angle. As a result of this study, the flame length was 52.9 cm under the condition of 0 ° slope, 61.1 cm at 10 ° slope, 79.1 cm at 20 ° slope, 142.0 cm at 30 ° slope, and the flame length increased as the slope became steeper (Figure). 6, b). The flame angle is measured as 82.3 ° for 0 ° slope, 50.2 ° for 10 ° slope, 35.0 ° for 20 ° slope, and 28.2 ° for 30 ° slope. The steeper the slope, the higher the flame angle. It was confirmed that it decreased (Fig. 6, c).



(a) Flame height



(b) Flame length



(c) Flame tilt

Figure 6. Flame characteristics changes by the slope conditions (The bar is standard deviation)

5. Water pipe fuel moisture content

In a previous study (Jang et al., 2016), the higher the water content of underground crown fuel, the lower the risk of crown fire because the heat consumption required for the transition from indexing to crown fire conversion increases. I presented it.

In this study, as a result of analyzing the change in the water content of the water pipe fuel due to the inclination condition, the remaining land was excluded from the condition of 0.35 m where the flame directly hit the crown fuel. Moisture content decreased and increased again at a slope of 30 °. At 0.55 m underground, crown fuel content decreased by about 9.2% when the slope increased by 10 ° and decreased by 15.6% when the slope increased by 20 °. At 0.75 m, the water pipe fuel content decreased by about 20.1% when the slope increased by 10 °, and decreased by 26.9% when the slope increased by 20 ° (Figure 7).

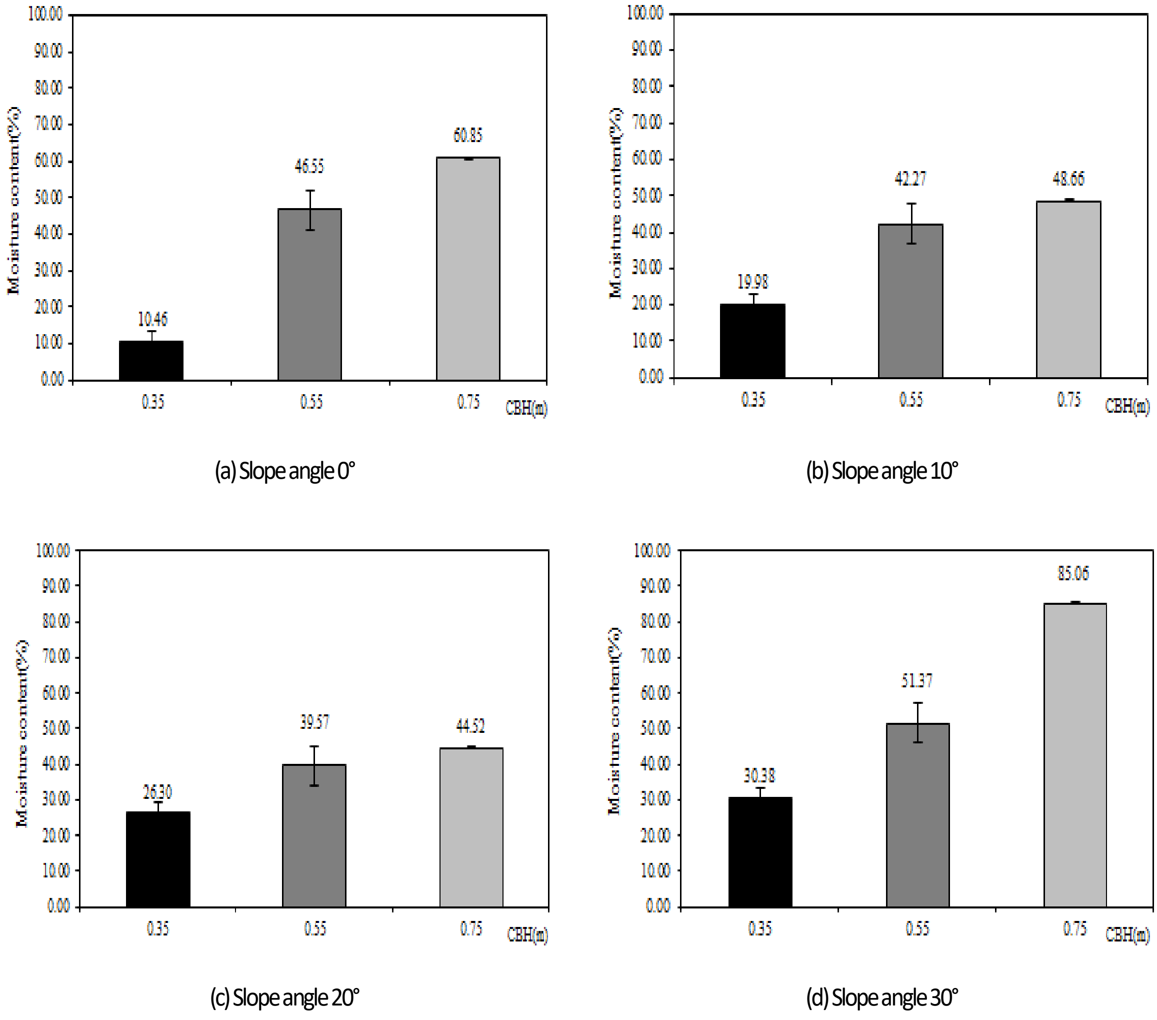


Figure 8. Moisture content of crown fuel changes by the slope conditions (The bar is standard error)

Discussion and Conclusions

In this study, we conducted an indoor acid non-combustion experiment with tilting conditions and observed changes in combustion characteristics. According to the research results, the steeper slope increases the diffusion rate up to 3.293 cm / s, and the flame intensity ranges from at least 246.73 kW / m to a maximum of 2,602.96 kW / m. Increased flame intensity. In addition, the water content of the crown fuel was measured higher as the underground became higher under the same inclination conditions. The domestic wildfire research that has been carried out to date lacks experimental research designed in consideration of the mountainous topography of Korean forests, and the wildfire strength is calculated using the constants presented overseas. There were many parts that did not match the domestic reality. In this study, we conducted an indoor combustion experiment on pine fuel, which is a representative coniferous tree vulnerable to wildfires, by applying the reduction rate with Korean forests. In addition, by expanding the scale of the experiment, we tried to proceed with a more accurate experiment. The results of this study help predict the non-diffusion behavior and intensity of mountains due to the slope conditions.

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