# Effects of Coating with Calcite together with Various Fire Retardants on the Fire Properties of Particleboard

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The fire properties of particleboard coated with calcite and a variety of fire-retardants (FR) was investigated. Four different chemicals, boric acid (BA), borax (BX), dolomite (DOL), and melamine (MEL), were added at the concentration of 1.0%, 3.0%, and 5.0% by oven-dry weight of calcite. The particleboard panels were tested according to the ASTM-E 69 standard to investigate their fire-retardant properties. The determination of weight loss, temperature, and the release of $O_2$, CO, and NO by the samples was measured and recorded over 30 s intervals during combustion of the materials. The results indicated that the BA coatings exhibited better thermal stability than the other chemicals. Consequently, the lowest weight loss and temperature was found for specimens treated with 5.0% BA. These chemicals were effective relative to the fire properties of coated particleboard surfaces, depending on the type and ratio of the chemicals to the calcite.

*Keywords: Particleboard; Fire-retardant; Dolomite; Boric acid; Borax; Melamine*

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## INTRODUCTION

Particleboards are a prominent element of the wood industry, primarily the furniture industry. Their production and consumption increase each year (Medved *et al*. 2011). Wood and wood-based materials, such as particleboard and fiberboard, are composed of hydrogen and carbon molecules. Wood-based materials are flammable, which limits their uses for many applications (Myers and Holmes 1977). Furthermore, when wooden material is exposed to high temperatures (approximately 250 °C), combustion may occur, which burns the material. The combustion process that occurs at high temperatures releases flammable gases from the wood surface. To decrease flammability, wood and wood-based materials are pretreated with fire retardant chemicals (Baysal *et al.* 2007). Thus, it is possible to increase the usage of wood-based materials by delaying or preventing fire spread. Fire retardants (FRs) are effective in changing the flammability properties of wood by decreasing the surface flame spread (Özçifci and Okcu 2008).

Boron compounds are commonly used to impregnate wood and wooden products (Ayrılmış *et al*. 2007; Winandy *et al.* 2008), and to increase pulp strength properties (Tutus *et al*. 2016). The most common fire retardant additives are boric acid, borates, ammonium phosphates, chloride, ammonium sulfate, borate, zinc chloride, sodium borate, phosphoric acid, and antimony oxide (Kozlowski *et al.* 1995). Regarding their fire retardancy and biological effectiveness, borax (BX) and boric acid (BA) are extensively used in a variety of applications in the wood preservation industry (Baysal 1994). When FRs are applied, the amount of heat and smoke release from the wood is reduced (Winandy *et al.* 2008). In another study, non-flammable mineral fillers were used in composites, resulting in reduced heat release and weight (Kozlowski *et al*. 1999). Calcite is a carbonate mineral and the most stable polymorph of calcium carbonate ($CaCO_3$). In addition, dolomite (DOL) is another mineral used as a fire retardant in certain applications. Dolomite is a type of calcium magnesium carbonate ($CaCO_3 \cdot MgCO_3$) that is widely available in nature (Adesakin *et al*. 2013). Dolomite can be used as an ornamental stone, a concrete aggregate, a source of magnesium oxide for the production of magnesium, or as a fire retardant for plastic composites in the pidgeon process.

Melamine (MEL) and its salts are used as FR additives in paints, plastics, and paper for adhesives and heat stability. However, there is limited research on the utilization of MEL and DOL as FRs in wood. Surface coating is one of the methods used to retard combustion and prevent the spread of fire. There is a direct relationship between the performance of coated panels, the structure of wood-based paneling, and the type of the coating material (Sparkes 1993). Because surface coating prevents the penetration of heat into the particleboard. This study investigated the effects of various chemical fire retardants and their concentration on fire retardancy in particleboard.

## EXPERIMENTAL

### Materials

The surface coating chemicals and their concentration ratios are presented in Table 1. The particleboard with the density of 0.680 gr $cm^{-3}$ and MEL were supplied by the Kastamonu Integrated Wood Company in Adana, Turkey. The borax and boric acid were supplied by the Tekkim San Company (İzmir, Turkey). Dolomite was obtained from the Doltaş Incorporation in Izmir, Turkey. The dry weight of calcite was considered when determining the rates of chemicals in the preparation process of the coating materials.

A blender was used to mix the coating materials of water, calcite, and melamine formaldehyde as well as the fire retardants, boric acid, borax, dolomite, and melamine powder. All materials were blended until homogenous. The pH values were maintained from 8 to 10, and the viscosity values of the mixtures were 100 cP to 150 cP.

The FRs were added into the coating mixture at the predetermined concentrations of 1.0%, 3.0%, and 5.0% loading, which was based on the oven-dry weight of calcite. The FR mixture was applied to the particleboard surfaces with a roller at the rate of 140 $g \cdot m^{-2}$. The particleboards were stored under 65 ± 5% relative humidity (RH) for air-drying and at 23 ± 2 °C during 2 days of incubation.

**Table 1.** Surface Coating Materials and their Concentration Ratios

| Material | Concentration Ratio (%) | | |
|---|---|---|---|
| Calcite | 100 | | |
| Boric acid | 1 | 3 | 5 |
| Borax | 1 | 3 | 5 |
| Dolomite | 1 | 3 | 5 |
| Melamine | 1 | 3 | 5 |
| Melamine formaldehyde | 20 | | |

### Determination of Fire Properties of Particleboards

To determine the amount of weight loss in the test samples, the combustion test (ASTM E69 2007) was implemented. The test samples included control (reference) samples, samples coated with calcite, and samples coated with calcite and FR. Prior to combustion, test specimens were conditioned at 23 ± 2 °C and 65 ± 5% RH for 2 weeks (Sweet *et al.* 1996). The test samples with dimensions of 9.5 x 19 x 1016 mm from the upper part of the combustion chimney were released below. The mechanism was prepared in a way to prevent the extension of butane gas flame from going higher than 25 cm, and the heat from exceeding 1000 ºC. Testo 340 M gas analyzers (Kahramanmaraş, Turkey) were used to measure the change in temperature, weight, and rates of $O_2$, CO, and NO in 30-s intervals. The experiment lasted 10 min total. Within the first 4 min, the combustion was with flame source, and in the last 6 min, the combustion was without a flame source. The experiment was replicated 6 times for each type of surface coating formulation. The combustion test apparatus and the samples are shown in Fig. 1.

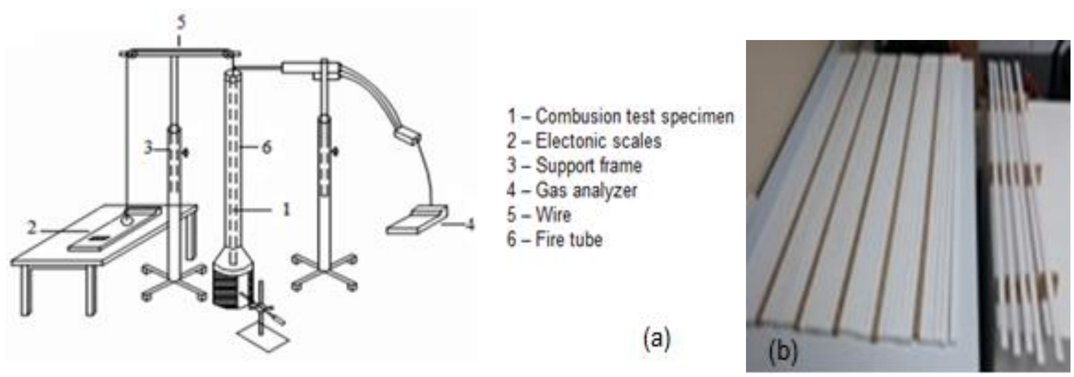


**Fig. 1.** The combustion test apparatus (a) and the test samples (b)

## RESULTS AND DISCUSSION

### Fire Performance

The weight loss of the control samples, the samples coated with calcite, and the samples coated with the FRs are shown in Fig. 2. The weight loss of the control samples (90.4%) was greater than the samples coated with calcite (84.8%) and the samples coated with the FRs (55% to 75%). The decrease in the weight loss indicates the increase in fire properties for the particleboard. Thus, the fire resistance of the particleboard was improved by the coating process. It was determined that calcite, used in the surface coating, and also with a contribution from the content of dolomite, has a positive effect on the fire resistance. In Fig. 2, the weight loss value of the samples with 1.0%, 3.0%, and 5.0% BA were 68.0%, 61.4%, and 54.4%, respectively. Thus, there was a decrease in weight reduction when the concentration of BA in the coating material increased. The weight loss of the samples containing BX were 73.6%, 60.6%, and 55.3% for the loading levels of 1.0%, 3.0%, and 5.0%, respectively. The maximum weight loss for the 1.0%, 3.0%, and 5.0% loading levels of MEL-coated particleboards were 75.4%, 71.4%, 65.8%, respectively, while the maximum weight loss of DOL-coated particleboards at the same concentrations were 81.7%, 78.4%, and 75.8%, respectively. The lowest weight loss was observed in the particleboards coated with 5.0% BA. This result reflects that BA activates charring and retards fire in wood (Tomak *et al.* 2012).

Compared with similar studies using MDF (Istek *et al.* 2013; Özçifci and Okcu 2008), the values determined in the present study were higher. The effect of BA on the fire property of the particleboard was greater than that of the BX, MEL, and DOL. With increasing amounts of FRs, the fire properties of the particleboards improved. Increasing the amount of the FRs caused a noticeable reduction in the weight loss (Hashim *et al.* 2009). This result shows that FRs thermally insulate the substrate and provide a physical barrier against oxygen diffusion to resist burning (Wan Hanafi and Hornsby 1993). FRs chemicals heat-absorbing reduces the flame temperature and increases the amount of residue. Boron compounds reduce the weight loss of wood, and they are also effective as a fire retardant coating for wood samples (Temiz *et al*. 2008).

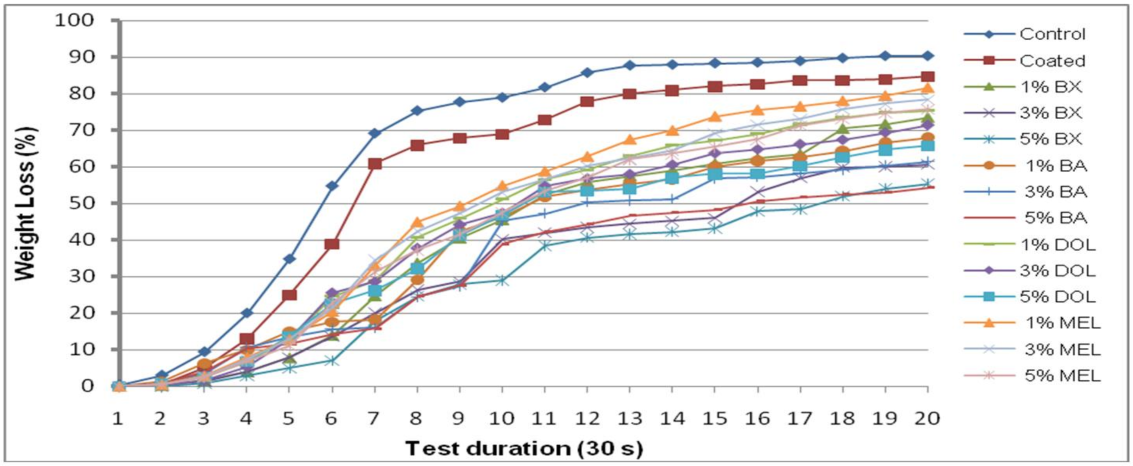


**Fig. 2.** Average weight loss

The temperature changes during combustion are presented in Fig. 3. The maximum burning temperature of 430 °C was observed in the control samples, while the maximum burning temperature of 400 °C was observed in the samples coated with calcite (Fig. 3). Therefore, the burning temperature of the control samples was approximately 11% higher than the coated samples, demonstrating that the coating process positively affected the fire retardancy properties of the particleboards.

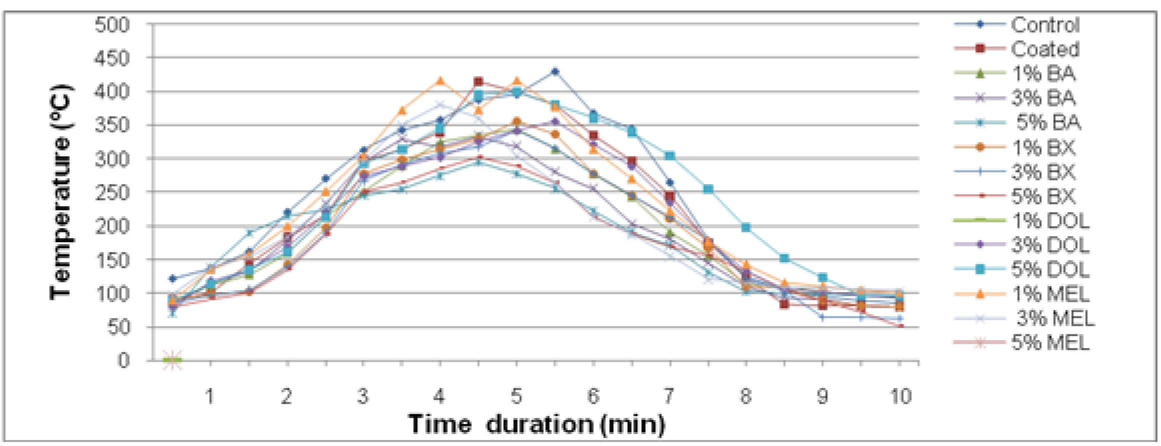


**Fig. 3.** Average temperatures of particleboards during combustion

The approximate burning temperatures for the 1.0%, 3.0%, and 5.0% loading levels of BA were 344 °C, 334 °C, and 295 °C, respectively. After adding 1.0%, 3.0%, and 5.0% of MEL into the coating formulation, the maximum temperature values were 417 °C, 403 °C, and 381 °C, respectively.

The increase in the ratio of the FRs led to a decrease in the burning temperature for all of the samples. The lowest temperature change was observed in samples containing BA, while the highest temperature variations were observed in samples containing MEL. The burning temperature was reduced as the FR loading increased from 1.0% to 5.0%. These results were consistent with the results of Baysal (2003). FRs increase the charring rate at low temperatures and improve thermal insulation (Kolmann and Cote 1968). The FR chemicals used in this study affected the combustion mechanism by increasing carbonization upon exposure to high temperature, thereby acting as an isolation material, increasing the fire retardant properties against high temperatures and reducing the emission of flammable gases (Özdemir and Tutus 2013).

The ratios of $O_2$, CO, and NO in the control and coated samples are presented in Figs. 4 through 6. A rapid reduction of the weight of the control samples between the range of 300 °C to 430 °C was observed. This effect was attributed to the decomposition of hemicelluloses and cellulose that form char and volatile gases, such as CO, $CO_2$, $CH_4$, and $CH_3OH$ (Liodakis *et al.* 2002).

Figure 4 shows that the lowest $O_2$ concentration from the control samples was 16.1%; however, the lowest $O_2$ concentration from the coated particleboards was 16.5%. Decreasing the ratio of $O_2$ during combustion was effective on the burning speed of the test samples. At the 1.0%, 3.0%, and 5.0% loading levels of FRs, the $O_2$ concentration for BX was 18.1%, 18.3%, and 18.6%, respectively, while the amount for DOL was 17.1%,17.3%, and 17.6, respectively. Lastly, the amounts for MEL were 16.7%, 16.8%, and 17.0% at the loading levels of 1.0%, 3.0%, and 5.0%, respectively. For the samples with BA, the $O_2$ concentration during the burning tests was 18.0%, 18.1%, and 18.3%, respectively. The change in $O_2$ concentration was related to the type and ratio of the FR chemicals, although the rate of $O_2$ in air is normally 21% (Yapıcı *et al.* 2011). A wood sample treated with FR chemicals requires a higher oxygen concentration to burn (Ashley and Rothon 1991). Thus, the particleboard samples coated with FRs burned less quickly as a result of the decreased oxygen. Likewise, if flames are present, the fire temperatures increase and more oxygen becomes available from thermally induced convection.

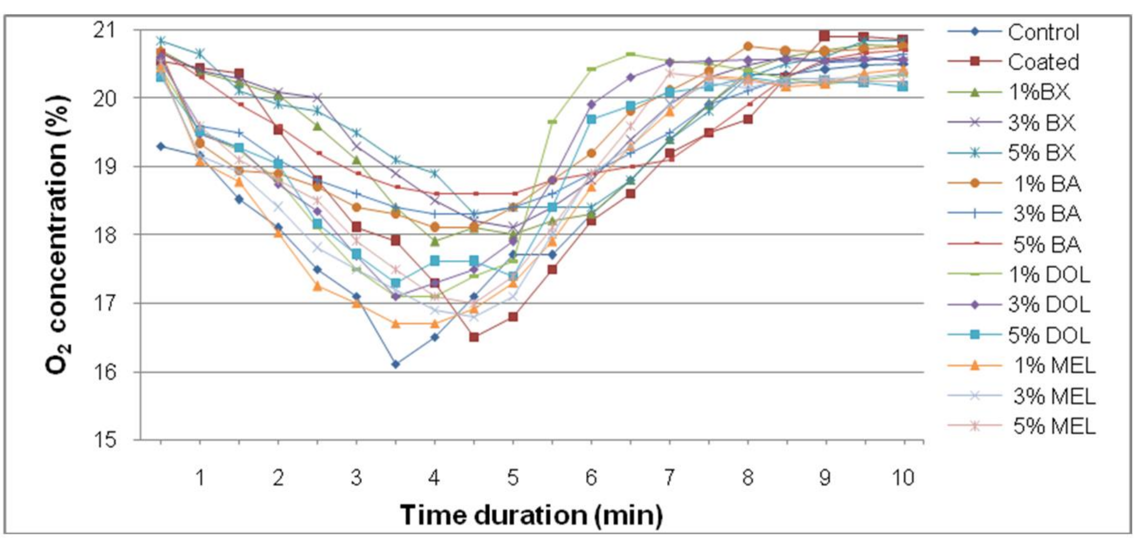


**Fig. 4.** Average oxygen values during particleboard combustion

The CO emissions for the control and coated samples were the highest of all the samples. Figure 5 presents the differences in CO emissions after burning the control and coated samples. The CO concentration for the control samples was 1631 ppm, while the rate was 1278 ppm for the coated particleboards. Therefore, the coatings positively affected the fire retardant properties of particleboards.

The CO measured for the particleboard samples treated with 1.0%, 3.0%, and 5.0% BA were 1282 ppm, 1273 ppm, and 1121 ppm, respectively; 1278 ppm of CO was produced by burning the control coated samples without FRs. The samples with MEL or BX exhibited values of 1454 ppm, 1401 ppm, and 1303 or 1301 ppm, 1235 ppm, and 1172 ppm, respectively. For the DOL, the CO emissions were 1431 ppm, 1394 ppm, and 1264 ppm, respectively, at the same concentrations. Compared with the control samples, the FR chemicals decreased the level of CO emissions by decreasing combustion.

This data indicated that adding FRs reduced emissions of CO. Thus, the highest emission of CO was obtained from the control samples (1631 ppm). The lowest value of CO emissions was observed in the samples coated with 5.0% BA. The gaseous product released from the thermal decomposition of materials depends on the oxygen availability, chemical composition, and fire temperature (Mouritz *et al.* 2006). The quantity of CO emissions from the particleboard was higher than that of the samples coated with a mixture of the calcite and FRs. Figure 5 shows that the amount of CO initially increased with the addition of FRs, and then began to decline slightly. The FR-treated particleboards tended to show lower heating degrees and smoke release than the control samples. Because reduced smoke release is important for human health, this reduction may be advantageous from an environmental and human safety perspective. Therefore, it establishes the characterization of the smoke properties of construction and interior materials to a great extent (Lee *et al.* 2011).

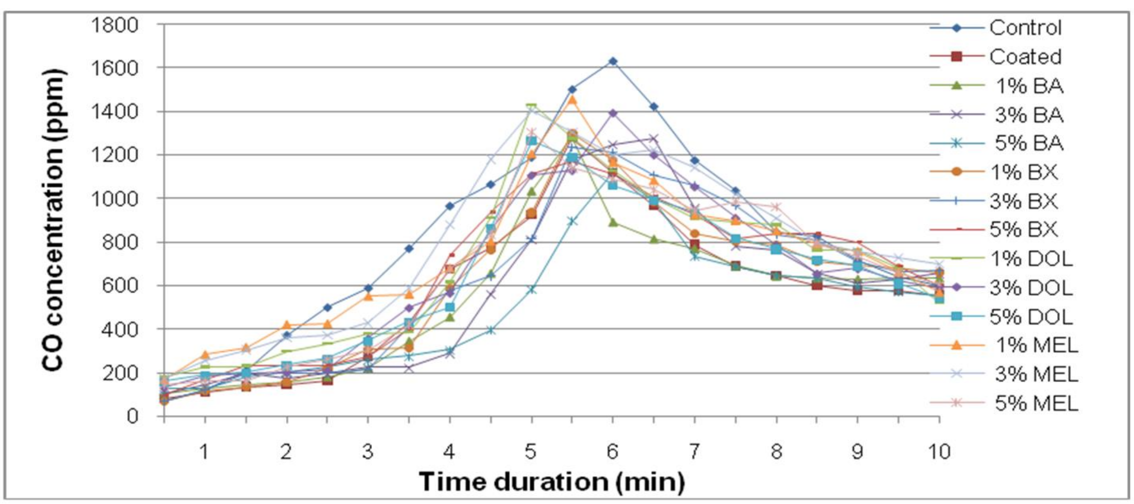


**Fig. 5.** Average CO values during particleboard combustion

As shown in Fig. 6, the amount of NO emissions during the burning process initially increased and then decreased at the end of the test. The coated particleboards had less NO emissions. The amount of NO emissions from the control samples and coated samples were 254 ppm and 242 ppm, respectively. The NO emissions of all samples initially increased and then gradually decreased over time. Compared with the control samples, the FRs had a positive effect on the NO emissions from the coated particleboards. A higher yield of char can restrain flame combustion. The FRs in the coated mixture decrease the flammability of volatile products and increase the char content. The FR-treated wood materials exhibited a lower smoke release rate and heating rate than untreated wood (Winandy *et al.* 2008).

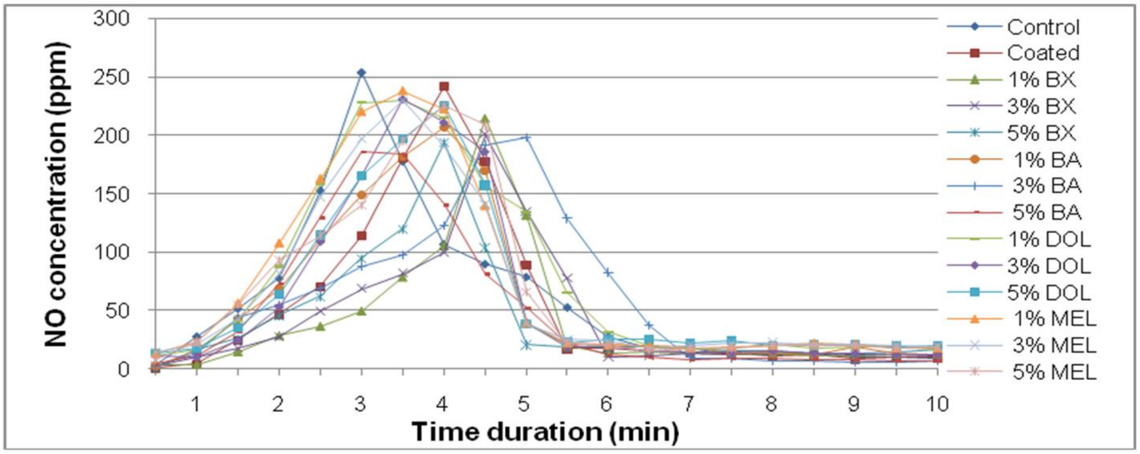


**Fig. 6.** Average NO emissions during particleboard combustion

## CONCLUSIONS

1. Commercially manufactured particleboard was coated with a mixture of coating materials, including a binder, calcite, water, and FR chemicals. The coating process enhanced the fire retardant properties and thermal stability of the particleboards. Weight loss was reduced as the ratio of fire retardants to calcite increased.
2. The weight loss decreased with increasing concentration of FRs. The formulation with 5.0% BA provided the highest fire retardancy in terms of the weight loss (54.4%), while the samples with 1.0% MEL provided the lowest fire retardancy, with a weight loss of 81.7%.
3. The lowest $O_2$ consumption rate was observed in the samples coated with MEL (1.0%), while the highest $O_2$ consumption ratio was observed in the samples coated with the BA (5.0%).
4. The highest CO emissions occurred in the control sample. In the samples containing FRs, the CO emission was lower than the control and the samples coated with calcite because combustion was hindered in FR-coated samples.
5. The greatest NO emission (254 ppm) was observed in the control sample, and the lowest NO emission (186 ppm) was observed in the sample coated with BA (5.0%).

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