Study on the influence of aging time and temperature and humidity on cable combustion characteristics

Qishen Lv [1], Zhiren Tian [1,*] Chengwei Zhang [1], Weili Zhao [1], Bo Gong [2], Jinqiang He [2]

[1] Shenzhen Power Supply Corporation, China Southern Power Grid Corporation, Shenzhen, China

[2] Electric Power Research Institute, China Southern Power Grid Corporation, Guangzhou, China

* Corresponding Author Email: 245454862@qq.com

Abstract. To investigate the effects of temperature and humidity on PVC cable combustion during thermal aging and its temporal variations. Three conditions: 85℃/90℃ thermal aging, 85℃/85% humidity damp-heat aging. Tested combustion characteristics with cone calorimeter, analyzed ignition time, heat release rate, fire performance index, smoke production rate, and CO/CO_2 volume fraction. Results: 85℃ aging and damp-heat aging increased ignition time from 17s to 27s, 90℃ aging had little effect, stable at 25s. During combustion, cable material changed from hot thick to hot thin, heat release rate decreased with aging days, peaking three times. 85℃ aging reduced heat release rate to 130 KW/m^2, 90℃ and damp-heat aging delayed to 160 KW/m^2 and 140 KW/m^2 respectively. Fire risk was higher for 6 and 5 days aging compared to 85℃. Aging days reduced flue gas, but high temperature and humidity increased production.

Keywords: Aging cable; thermal aging; damp heat aging; taper calorimeter.

1. Introduction

With socio-economic growth, wire and cable use has increased. Cable aging often causes fires, posing a hidden safety hazard. Studying aging cable combustion characteristics is crucial to prevent fire accidents.

Shu Zhongjun studied flame-retardant PVC cable combustion. Aging days raised fire risk, decreased by [1]. Zhang Zheng assessed cable fire risk via ignition time [2].Chen Shanqiu found cable radiation power raised fire risk by [3].Yan Long discussed thermal aging's impact on flame retardant cable sheath combustion and pyrolysis [4].He Long analyzed aging temperature's effect on flame retardant cable performance [5].Jia Wenna used a conical calorimeter to study flame retardant PVC cable combustion under thermal aging [6].Xu Jun studied thermal aging's impact on crosslinked polyethylene cable structure, noting aging raises cable base index [7].

Cable aging combustion performance is studied. Research often focuses on thermal radiation, ignoring temperature and humidity. This paper examines cable combustion under different temperature and humidity aging conditions. It assesses the factors' impact and offers a scientific basis for fire prevention of aging cables.

2. Experimental protocol design

2.1. Material preparation

In the material prep stage, the cable length was 30cm. Thermal and humid heat aging conditions were applied. According to GB / T 2951.12-2008 and GB / T 11026.1-2016. Condition 1: aging at 85°C; Condition 2: aging at 85°C and 85% humidity; Condition 3: aging at 90°C. Aging durations: 5, 10, 15, 20, 25, 30 days. 10 cables per set, total 18 sets. After aging, cables cooled for 24 hours and then dried for testing and analysis.

2.2. Equipment and experimental methods

The experimental equipment is the FTT standard cone calorimeter (CONE). The experiment process is carried out according to GB 31247-2014 and GB / T 16172-2007. The thermal radiation intensity was set to be 35KW/ m2, the cable was cut into 10cm, a total of 12 pieces, and put into the test iron box of 10cm 10cm for experiment, as shown in Fig.

(a) Pre-test. (b) post-test.

Fig 1. Photos before and after the trial.

3. Data analysis

3.1. Analysis of the influence of ignition time

As shown in the figure, under three different aging environmental conditions, with the increase of aging days, the ignition time of materials shows a trend of rising first and then stabilizing.

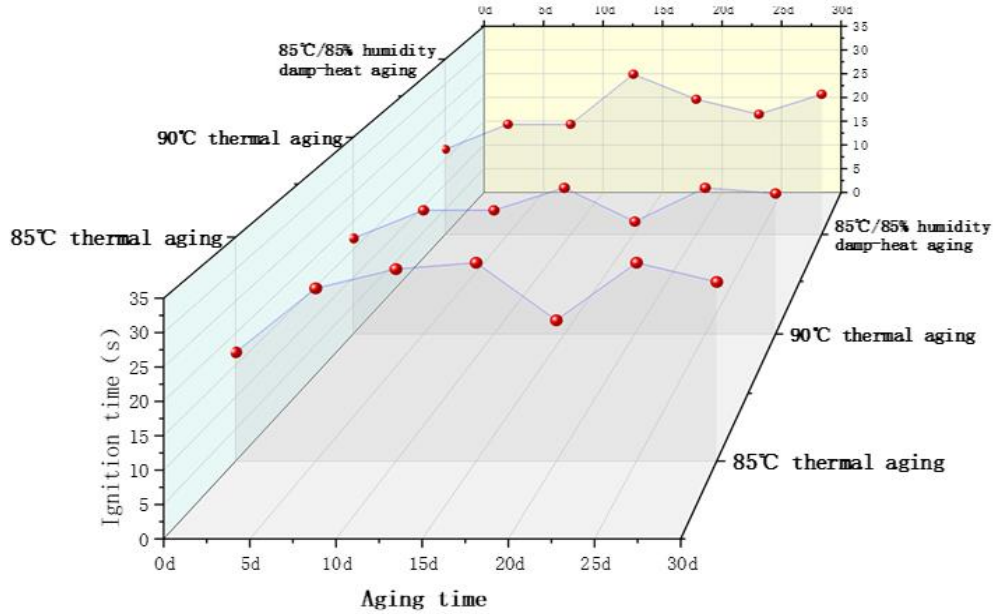

Fig 2. Comparison of the ignition time under the three aging working conditions.

The main reason is the cable's non-flame retardant property. The plastic additive decomposes, extending the ignition time of aging cable. When additives are depleted, ignition is due to plastic polymer's combustible small molecules, and the ignition time stabilizes.

The scatter plot of ignition time under three aging conditions was linearly fitted, yielding three linear equations.

85℃ Thermal aging:

$$Y = (0.24\pm0.19)\ X+(23.04\pm3.43) \tag{1}$$

90℃ Thermal aging:

$$Y= (0.21\pm0.10)\ X+(19.36\pm1.82) \tag{2}$$

85℃ Hot and heat aging:

$$Y= (0.30\pm0.15)\ X+(20.07\pm2.74) \tag{3}$$

Comparing slopes of three linear equations, it's concluded that temperature increase reduces slope and intercept under aging. In 90℃ thermal aging, temperature increases until ignition time stabilizes at 25s.

At the same temperature, introducing humidity causes a steep increase in equation slope. Humidity enhances ignition time change, with a notable growth rate. Under 85℃ humid heat aging, ignition time stabilizes at 27s, identical to 85℃ thermal aging.

3.2. Analysis of the effect on the heat release rate

Heat release rate maps were selected for the study. It is clearly observed that there are three significant peak heat release rates during combustion. As shown in Figure 3.

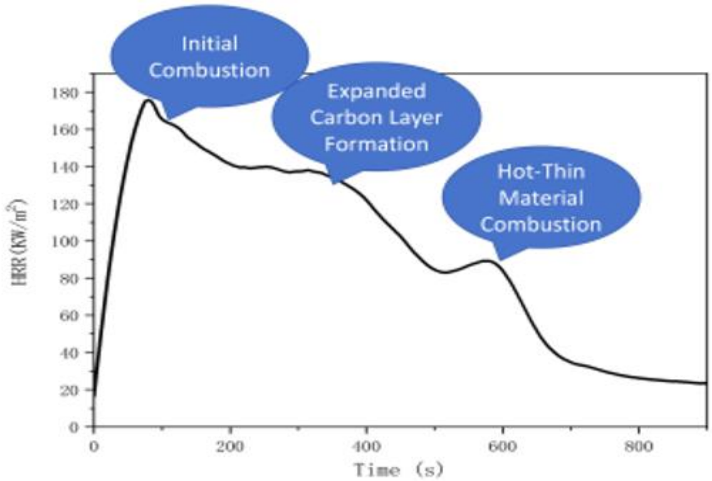

Fig 3. Heat release rate peak display.

The reasons for cable's heat release rate formation are:

Initial Combustion: Flame covers cable surface; cylindrical structure accelerates heat accumulation and combustion. Additives volatilize, causing a surge in HRR, forming the first peak.

Expanded Carbon Layer Formation: PVC burns to form a carbon layer, isolating heat and products. Layer formation may release heat, causing a second HRR peak.

Hot-Thin Material Combustion: Sheath reduces to film structure, affecting combustion. When front enters, heat transfers rapidly, heating to pyrolysis temperature.

(a)Heat thick (b) transition (c) hot thin

Fig 4. Structural change of the cable combustion process.

When hot-thin material reaches pyrolysis temp, it decomposes rapidly, releasing flammable gas. This gas mixes with air oxygen, causing a sudden combustion reaction under specific conditions, resulting in a rapid increase in heat release rate.

3.2.1. Overall analysis of the heat release rate

Taking the heat release rate of 85 ℃ thermal aging as an example, as the aging time increases, the heat release rate shows a decreasing trend.

The cable's initial heat release rate peak occurred at 62s after 30 days of aging, 8s earlier than the original 70s. The second and third peak times changed due to the cable's internal structure. The second peak time shortened to 252s after 30 days, 24s earlier than the original 276s. The third peak time advanced from 570s to 592s, 22s shorter after 30 days.

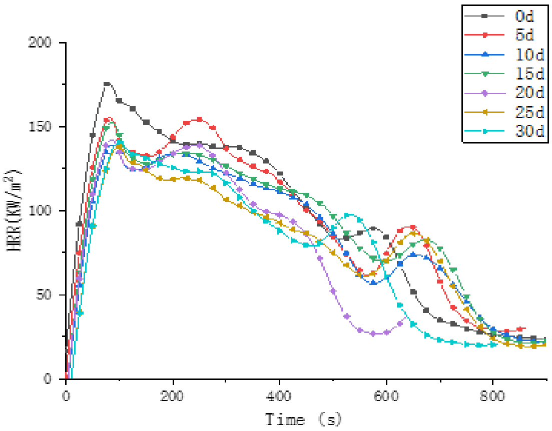

Fig 5. 85℃ Change in heat release rate for thermal aging.

To assess the effects of temperature and humidity on the heat release rate of aged cables during thermal aging, we analyzed the original sample and heat release rate curve after 30 days under varying conditions.

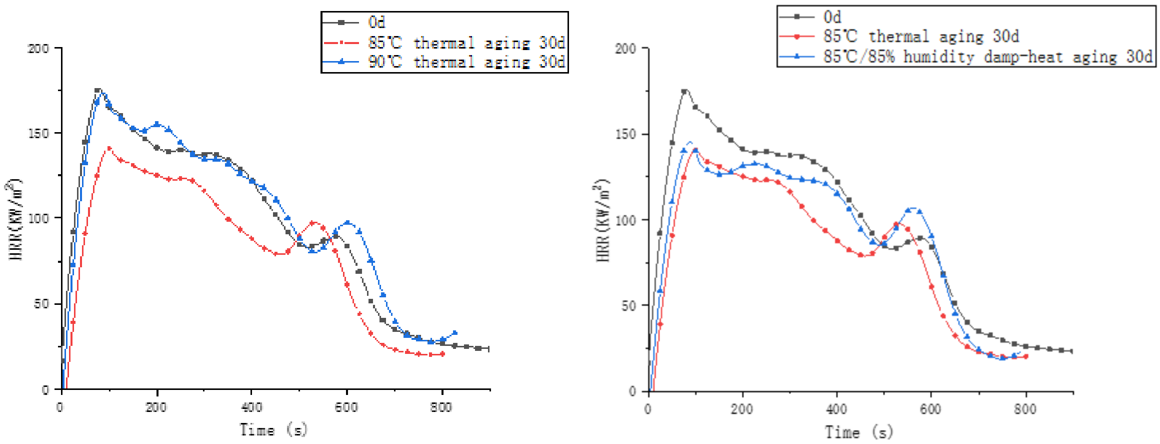

Fig 6. The influence of temperature and humidity on heat release rate.

In 85℃ and 90℃ aging maps, 90℃ releases more heat due to PVC cable's HCl precipitation at high temp, accelerating combustion. Peak heat release similar at 90℃, earlier at 85℃. Hot/humid conditions limit volatile additive loss, leading to higher heat release in humid aging vs. 85℃ aging.

3.2.2. Initial peak analysis of the heat release rate

The following figure shows the peak map of the initial heat release rates under the three aging conditions.

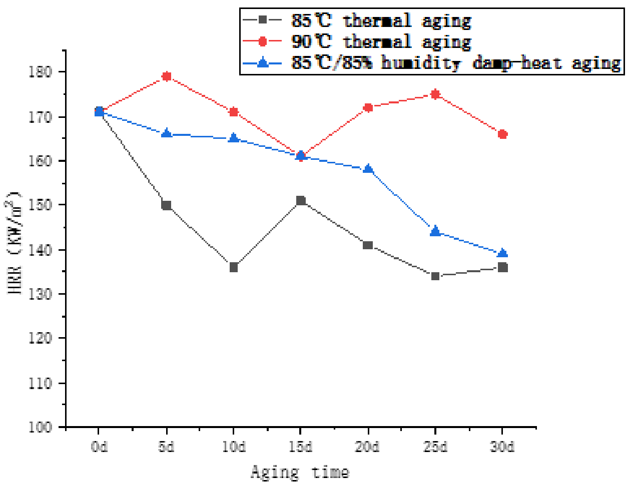

Fig7. Comparison of the heat release rates in the three aging conditions.

As depicted, the cable's peak heat release rate under 85°C thermal aging drops, rises, and stabilizes, fluctuating around 130 KW/m2. After additive burnout, plastic decomposition yields combustible gas, leading to peak rebound. Under 90°C aging, the rate stays at 160 KW/m2, exceeding other conditions. High-temp aging sustains a high release rate. In 85°C damp heat aging, the rate gradually decreases, stabilizing at 140 KW/m2 for 30 days. Damp and heat aging inhibits additives, yielding a higher release rate than heat aging alone.

3.2.3. Analysis of fire performance index

The following figure shows the change curve of fire performance index with aging time under thermal aging and humid heat aging conditions, respectively.

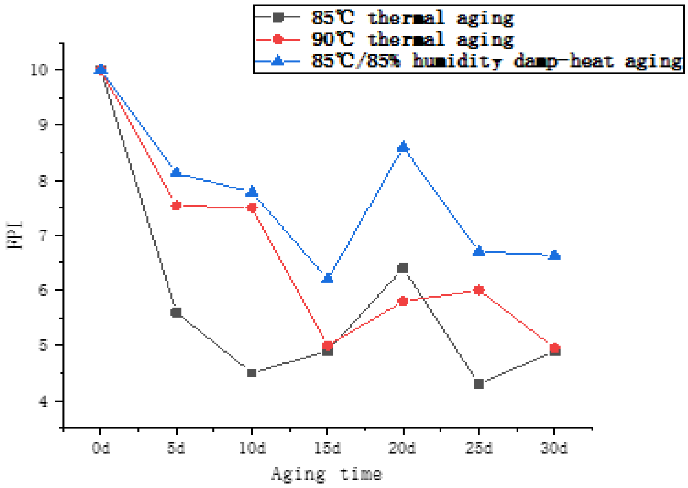

Fig 8. Comparison of the fire performance index in the three aging working conditions.

Under 85°C, 90°C, and damp-heat aging, fire performance index decreased. 85°C yielded lowest indices of 4, 90°C had index above 6 and stabilized at 5. High temp aging intensified HCl precipitation in PVC, reducing flame retardant halogen and increasing fire risk. Damp-heat aging prevented precipitation of combustibles, keeping fire performance index high.

3.3. Analysis of the flue gas

Cable toxicity assessment can focus on smoke production rate and CO/CO2 volume fraction.

3.3.1. Production rate analysis

Under 85°C aging, tobacco production rate decreased with aging days due to internal material aging, plasticizer and stabilizer precipitation, reducing flue gas during combustion. Peak smoke rate was 0.11 m3/s, decreasing to 0.08 m3/s after 30 days.

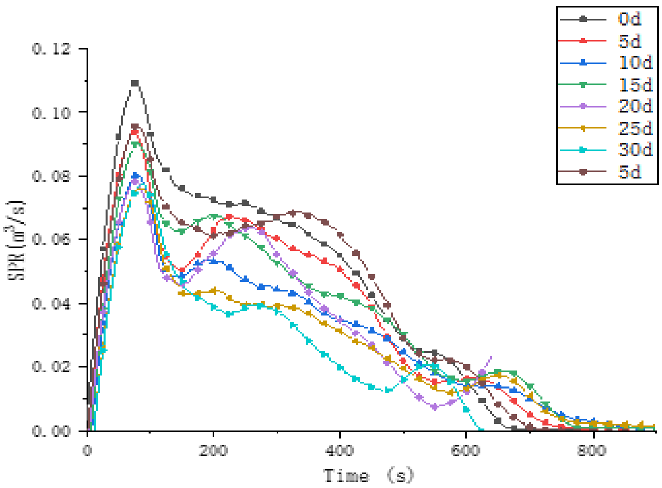

Fig 9. Changes in Smoke Production Rate during 85 °C Thermal Aging.

Similarly, in order to more accurately reveal how the temperature and humidity factors affect the smoke production rate of aging cables in the thermal aging process, the original sample and the smoke production rate curve after 30 days under various working conditions were selected for detailed and in-depth analysis.

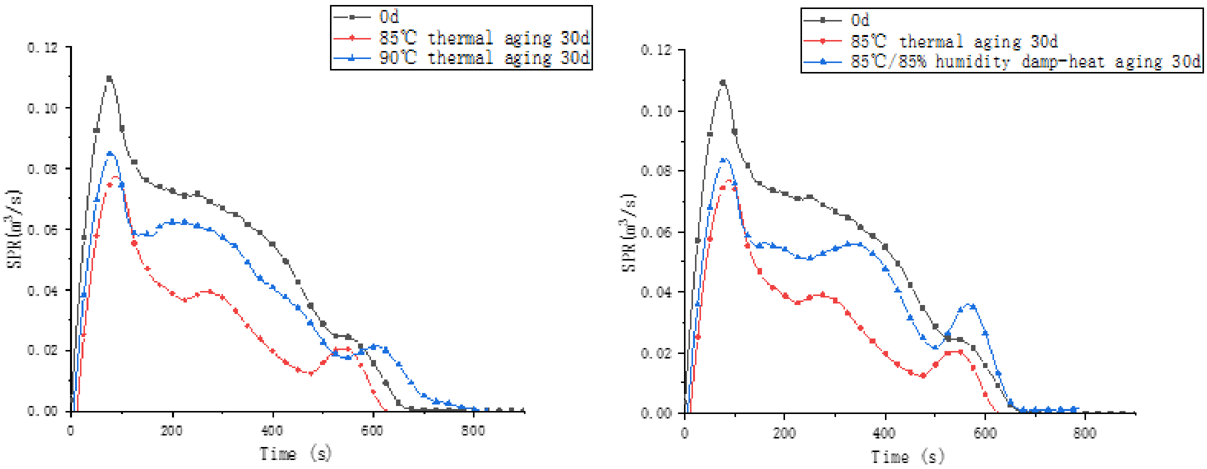

Fig 10. The influence of temperature and humidity on smoke production rate.

Under the condition of 90℃ high temperature aging, the precipitation of the cable HCl is accelerated, and the stabilizer is easier to precipitate, reducing the thermal stability of the cable when burning, making the cable easier to decompose and burn at high temperature, producing more smoke and toxic gases. The aging temperature increased, and the peak smoke production rate of the 30-day aging cable increased from 0.078 m3/s to 0.083 m3/s. Under the same temperature of 85℃ damp and heat aging, water vapor suppresses the precipitation of additives, mainly containing benzene ring compounds, and the smoke production rate is higher than that of thermal aging. The influence of humidity increases the peak smoke production rate of the 30-day aging cable from 0.078 m3/s to 0.082 m3/s, which is close to the high temperature aging condition.

3.3.2. CO and CO_2volume fractionanalyse

CO and CO under 85℃ thermal aging condition Volume fraction changes is shown below.

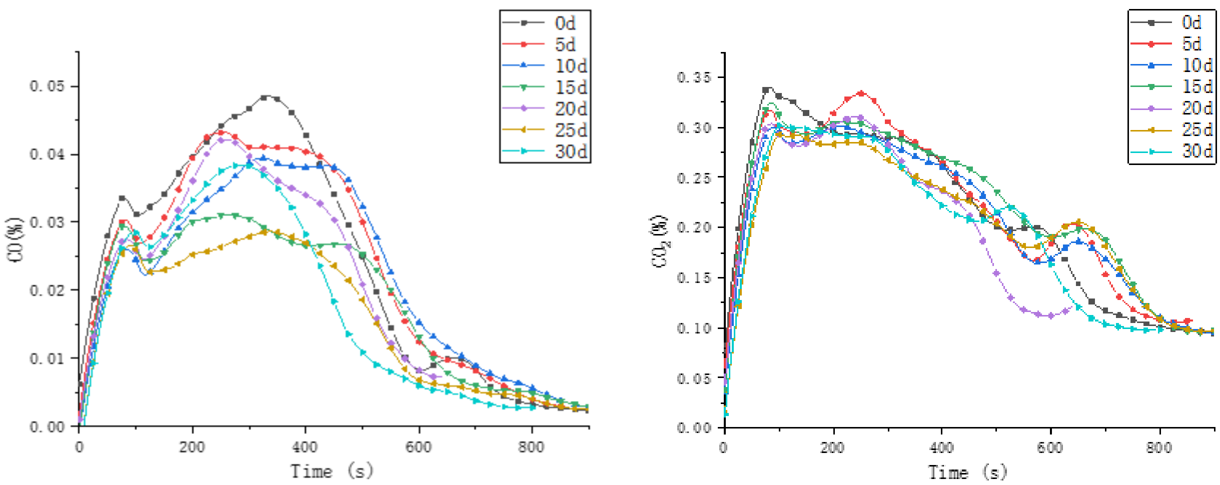

Fig 11. Changes in CO and CO_2 volume fractions with aging time under 85 ℃ thermal aging conditions.

With the increase of aging days, the base, hydroxyl, carbon and carbon double bonds in cable materials are increasing, and the increase of unsaturated hydrocarbons will lead to the increase of the amount of residual carbon, thus reducing the release rate of flue gas, and CO and CO2 the volume of the fraction.

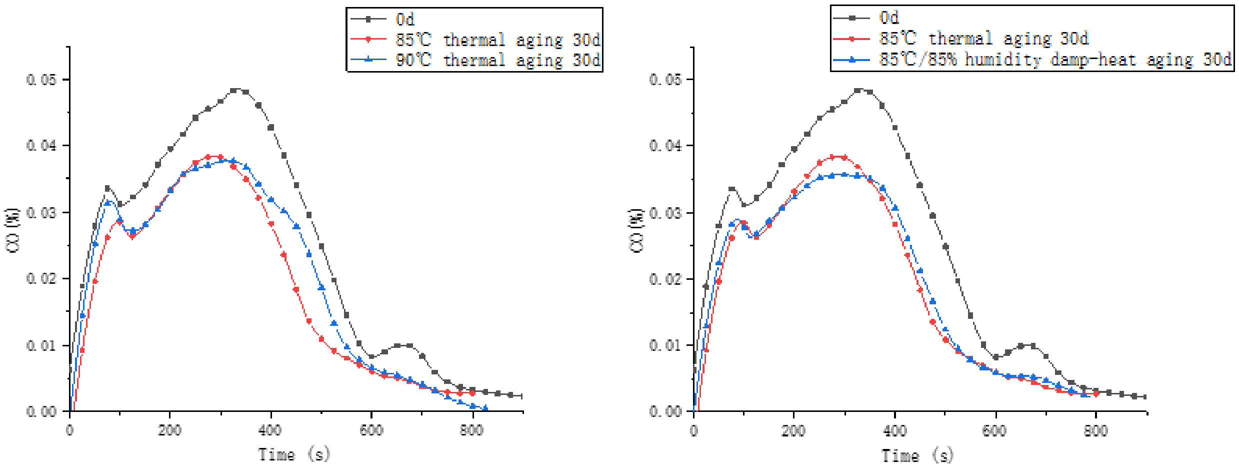

Fig 12. The influence of temperature and humidity on the volume fraction of CO

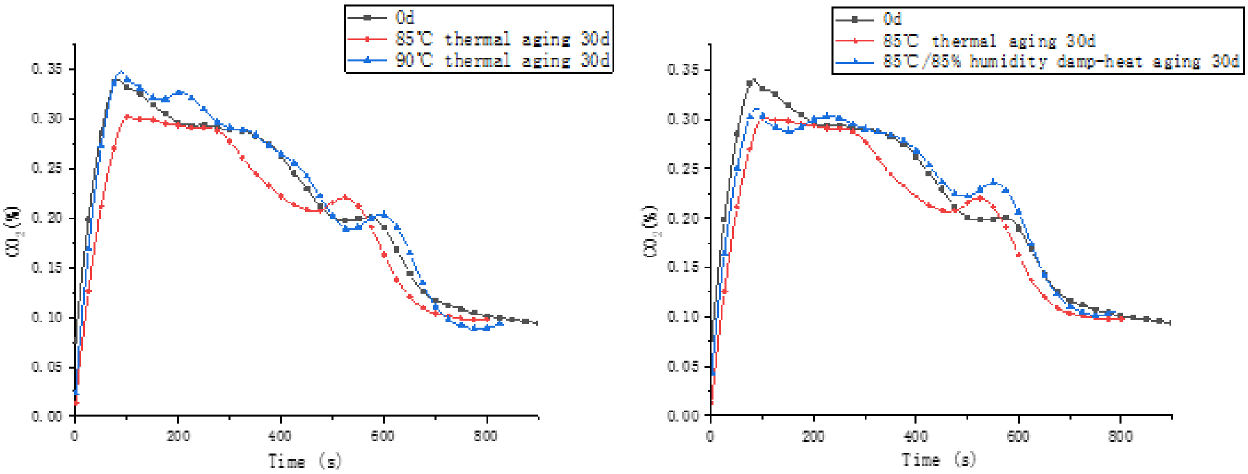

Fig 13. The influence of temperature and humidity on the volume fraction of CO_2

In 90°C thermal aging, PVC cable's internal structure is less stable than 85°C, with more radicals and small molecules. Faster oxygen reaction produces more oxidation products, which generate more CO and CO2 when burned. In damp-humid aging, PVC hydrolysis is hindered, reducing unsaturated bond formation. This results in lower residual carbon compared to thermal aging. Smoke release and CO/CO2 percentages are higher under 85°C damp-heat aging than thermal aging conditions.

4. Conclusion

The following conclusions are finally concluded:

After aging, PVC cable's plasticizer volatilizes, prolonging ignition time. Aging time accumulates, stabilizing ignition time trend. At 90°C, ignition time stable at 25s, with slight increase; at 85°C and 85°C damp-heat, stable at 27s, with larger increase.

When the PVC cable is burned, it turns from hot thick to hot thin, and the heat release rate has three peaks. Taking 85°C thermal aging as an example, the heat release rate decreased with days, from 170 KW/m2 to 130 KW/m2. High temperature aging makes the cable precipitate to HCl, the flame-retardant effect is weakened, the structure is unstable, and the high heat release rate is 160 KW/m2. The humidity suppresses the volatilization of the plasticizer in the cable, and the high heat release rate is 140 KW/m2.

The fire performance index decreased with the increase of aging days, while the FPI under 90°C thermal aging was stable at 6,85°C, and the FPI was stable at 5, which is higher than the 85°C thermal aging FPI of 4.

Aging cables produce more unsaturated bonds, higher residual carbon, and less smoke, CO, and CO2. High temperature aging intensifies free radicals, small compounds, and instability, raising flue gas. Humidity restricts plasticizer loss, also raising flue gas.

When used in high temp, high humidity environments, cables require special attention to fire prevention. All potential fire risks must be eliminated to ensure safe, reliable operation.

Acknowledgments

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