Study on the influence factors of the release characteristics of IQOS cigarette smoke

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Abstract. In order to clarify the reasons for the good smoke release characteristics of IQOS, the factors that are beneficial to the smoke release characteristics of IQOS were studied by comparing the K (the amount of released smoke was less) and IQOS. The components of IQOS and K which were easy to be released were characterized by the GC-MS. The thermal release characteristics of IQOS, K and the original tobacco powders of K were characterized by the thermogravimetric analyzer (TG). The main compounds of the released smoke of IQOS and K were characterized by Py/GC-MS at two typical heating temperatures (260 and 330°C). The results show that: 1) the actual heating temperature of the IQOS was higher (330°C), which could promote the release of smoke. 2) IQOS tobacco stick has a porous structure with higher specific surface area, which was beneficial to the release of smoke. 3) IQOS contains more components which were easy to be released, thus the high concentration of smoke could be formed. 4) Though the content of the atomization agent in IQOS was lower than that in K, more atomization agent in IQOS could be released at the tobacco cracking temperature (330°C), thus the atomization property of IQOS was better.

1. Introduction

Traditional cigarettes can generate a large amount of harmful substances (derived from the cracking of tobacco at high temperature) during smoking. As the temperature increases, more harmful components such as aldehydes, benzenes, polycyclic aromatic hydrocarbons (PAHs), and CO can be generated, which are harmful for the health. In recent years, heat-not-burn tobacco (HnB) products are welcomed by the consumers because the HnB products are similar to the traditional cigarettes in terms of physiological feelings and smoking methods. Additionally, the harmful substances derived from the...
cracking of tobacco at high temperature are significantly decreased in the HnB products because the heating temperature of HnB products is much lower (usually lower than 350°C) [1-3].

HnB products can be divided into electric heating type, carbon heating type, and physicochemical reaction heating type according to the heat source [4, 5]. Among them, the electric heating type has the most extensive products development and technical researches [6, 7].

Although less harmful substances can be released from the HnB products, the actual heating temperature is also significantly lower than that of the traditional tobaccos [8], thus the released smoke is also less than that of the traditional tobacco, which reduces the smoking feelings. In order to enhance the quality of HnB products, the main goal is to increase the concentration of the smoke of HnB products. Among all the HnB products, the IQOS from Philip Morris International (PMI) is basically the best. The IQOS can release a large amount of smoke with high aroma components concentration during smoking, and the puff-by-puff release characteristics of IQOS is good. In recent years, the tobacco companies in China also try to develop the HnB products independently. While the products are inferior to IQOS to a certain extent, because the smoke concentration, aroma components concentration and puff-by-puff release characteristics are not good enough.

Analyzing the factors which contribute to the high concentration of smoke of IQOS, the quality-leading product, can help us to accelerate the independent development of high-quality HnB products. However, the current researches are mainly focused on the smoke release characteristics, smoke composition analysis, and toxicology of IQOS [9-13], few studies investigate the factors that promote the smoke release of IQOS. Therefore, this study aims to clarify the reasons that contribute to the good smoke release of HnB products through the comparison of the smoke release characteristics of K products (from Chinese company) and IQOS, and provide theoretical support to help the development of high-quality HnB products.

2. Materials and methods

2.1. Materials and instruments

K product (mint) was used as the representative of the HnB products from Chinese company, the IQOS (mint) was also used. The original tobacco powders of K, tetrahydrofuran (Chinese medicine, HPLC), glycerin (Aladdin, HPLC), propylene glycol (Chinese medicine, HPLC), menthol (Aladdin, 99.5%) were also used.

IQOS2.4 PLUS heater was used for IQOS smoke release, and the K heater was used for K smoke release. Microwave digestion apparatus (SINEO, MDS-6G), Gas chromatography mass spectrometry (ThermoFisher, Trace1300/ISQ), Thermogravimetric analyzer (PE, STA8000), BET (JW-BK100), Py/GC-MS (CDS Pyroprobe 5250).

2.2. Method

2.2.1. BET analysis. The pore size and specific surface area of K, IQOS and the original tobacco powders of K were analysed by BET. Before testing, all the samples were pre-treated at 120°C for 2 hours.

2.2.2. Tobacco stick extraction. The extractable components in the HnB products are the low-molecular, easily-released compounds, which are the main components of smoke. Therefore, in order to compare the difference between the extractable components of K and IQOS, the microwave digestion apparatus was used to extract the K and IQOS [14]. Before the extraction, thoroughly mix 1 g of HnB product sample with 20 ml of tetrahydrofuran. The extraction temperature program is as follows: the temperature is rapidly increased from room temperature to 150°C (below the tobacco sample cracking temperature), and the temperature is decreased after 30 minutes holding at 150°C. After the extraction, the sample was filtered by filter paper, and the extracted solution was collected. The solid residue was dried and weighed in an oven at 65°C.
2.2.3. Thermogravimetric (TG) analysis. The TG was used to study the thermal release characteristics of K, IQOS and the original tobacco powders of K. The thermal release characteristics of main atomization components commonly used in tobacco sticks were also studied. Experimental conditions: nitrogen atmosphere, flow rate is 100 mL/min; temperature rise from room temperature to 330°C, hold for 20 minutes, and the heating rate is 10°C/min.

2.2.4. GC-MS and Py/GC-MS analysis. GC-MS was used to analyse the extracts from K and IQOS. The capillary column HP-INNOWax(30m×0.25mm×0.25μm) was used to analyse the samples. 1 μL of sample (concentrated to 1 wt%) was injected into the injection port in a splitless configuration. The column was operated in a constant flow mode using helium as the carrier gas (1 μL/min, purity > 99.99%). The temperature of the injection port was set at 250°C. The column was initially maintained at 40°C for 3 min before it was increased to 250°C at a heating rate of 5°C/min, and thereafter held for 10 min. In order to analyse the composition of the released smoke from the tobacco sticks at typical heating temperatures (260 and 330°C), the analysis of IQOS and K tobacco sticks were performed at 260 and 330°C using the Py/GC-MS. The Py reaction time was 1 minute. The GC-MS settings are the same.

3. Results and discussion

3.1. Temperature change of the tobacco sticks during the smoking of IQOS and K

![Figure 1. Temperatures of the IQOS and K tobacco sticks during smoking.](image)

During the smoking of HnB products, its heater determines the heating temperature of the tobacco sticks. Temperature has a significant effect on the smoke release from tobacco sticks [8]. The heaters of IQOS and K are heated by a central heating rod, and the heat flow is diffused from the center of the tobacco sticks to the outside, so the external temperature of the tobacco sticks is lower than the center temperature of the tobacco sticks. Based on this, the temperature of the center and the outer wall of the IQOS and K tobacco sticks during smoking was measured. During the measurement, a miniature thermocouple (K type) is inserted into the corresponding positions in the tobacco sticks, and the
temperature data is recorded using a multi-channel data acquisition card. The collected temperature data is shown in Figure 1.

It can be seen from Figure 1 that the center temperature of the IQOS tobacco sticks is finally stable at around 330°C, while the center temperature of the K tobacco sticks is about 250°C, which is significantly lower than the IQOS tobacco sticks. The high heating temperature of IQOS tobacco sticks is one of the key reasons for its high concentration of smoke.

In addition, due to the thermal resistance, the temperature of the outer wall of the tobacco sticks is significantly lower than the center temperature. Therefore, during the actual smoking, the temperature of the cartridge is nonuniform, and the lower actual heating temperature of the external tobacco sticks will significantly reduce the smoke release amount. These results indicate that the temperature of the whole tobacco sticks should be high when developing the HnB products.

3.2. Pore and specific surface area characteristics of IQOS and K

The smoke release characteristics of the tobacco sticks are related to its pore structure. Therefore, the BET was used to analyse the IQOS, K and the original tobacco powders of K. The results are shown in Table 1 and Figure 2. The BET results show that the content of pore with different diameters and specific surface area of the tobacco sticks are increased after the original tobacco powders are prepared as the tobacco sticks. The specific surface area, average pore size, and total pore volume of IQOS are the largest. The rich pore structure and large specific surface area are conducive to the release of smoke during smoking. Additionally, the interaction between the tobacco residues and the released smoke during smoking is relatively weak when the sample is porous. Previous studies [15] have shown that the interaction between volatiles and semi-char during pyrolysis can promote the conversion of volatiles to solid-coke and reduces the content of released volatiles. Therefore, porous structure and large specific surface area are beneficial for smoke release and can increase the concentration of released smoke.

Table 1. Pore and specific surface area of the IQOS, K and raw materials of K.

| Sample          | Specific surface area m²/g | Total pore volume of adsorption cm³/g | Adsorption average pore size nm |
|-----------------|----------------------------|---------------------------------------|--------------------------------|
| Original K      | 1.018                      | 0.003                                 | 13.605                         |
| K               | 1.878                      | 0.005                                 | 11.252                         |
| IQOS            | 1.890                      | 0.008                                 | 17.899                         |

Figure 2. Pore size distribution of the IQOS, K and original tobacco powders of K.
3.3. Content and composition of IQOS and K tobacco stick extracts

Microwave extraction can extract the easily-released components of tobacco sticks non-destructively at relatively low temperatures, which is beneficial to analyse the components of the atomization agent added in tobacco sticks and the easily-released components of tobacco sticks [14]. Therefore, the microwave digestion instrument was used to extract and analyse the tobacco sticks to investigate the differences between IQOS and K.

Table 2. Weight of the tobacco samples before and after extraction.

| Sample | Before extraction (g) | After extraction (g) | Residue (%) | Comments |
|--------|-----------------------|----------------------|-------------|----------|
| K      | 0.9941                | 0.6380               | 64.18       | 3 tobacco sticks |
| IQOS   | 1.1627                | 0.7057               | 60.85       | 4 tobacco sticks |

Table 2 shows the mass changes of the IQOS and K tobacco sticks before and after the extraction. After the extraction, the IQOS tobacco stick has 60.85 wt% of solid residues, while the K tobacco stick has 64.18 wt% of solid residues. The results show that the content of extractable components in IQOS is higher, indicating that more smoke can be released from IQOS. Table 3 shows the compounds in the extracts of IQOS and K detected by GC-MS. The results showed that the contents of menthol, nicotine and butyrolactone in the IQOS extract were higher than those in the K extract, while the contents of glycerin and propylene glycol in the IQOS extract were lower than those in the K extract. Menthol, nicotine, and butyrolactone are the key substances that affect the smoking feelings, and their high concentration can help improve the tobacco stick quality. Glycerin and propylene glycol are the main components of the atomization agent. Although menthol is the aroma components, as the polyhydric alcohol, it may also have some atomizing effects on smoke. Therefore, the results show that the more atomization agent in the HnB products does not mean more smoke can be released. The release characteristic of the atomization agent is more important than its initial concentration in the tobacco stick.

Table 3. The main compounds and their relative content in the extracted solutions of IQOS and K.

| Chemicals                                    | K Percentage % | Peak area | IQOS Percentage % | Peak area |
|----------------------------------------------|----------------|-----------|-------------------|-----------|
| Chloropropyl formate                         | 0              | 0         | 1.48              | 2.85×10^8 |
| Tetrahydro-2-furanol                        | 2.70           | 4.75×10^8 | 3.65              | 7.04×10^8 |
| Propylene glycol                             | 2.14           | 3.76×10^8 | 1.32              | 2.55×10^8 |
| Butyrolactone                                | 3.68           | 6.47×10^8 | 5.31              | 1.02×10^9 |
| Menthol                                      | 8.81           | 1.55×10^9 | 21.32             | 4.11×10^9 |
| Ethanol, 2-nitro-propionic acid (ester)      | 2.73           | 4.79×10^8 | 0                 | 0         |
| Ethyl isopropyl acetamide                    | 1.22           | 2.15×10^8 | 0                 | 0         |
| Nicotine                                     | 10.72          | 1.88×10^9 | 11.25             | 2.17×10^9 |
| Neophytadiene                                | 1.89           | 3.32×10^8 | 1.32              | 2.54×10^8 |
| Glycerin 1, 2-diacetate                      | 3.33           | 5.85×10^8 | 1.00              | 1.93×10^8 |
| Glycerin                                    | 36.15          | 6.35×10^9 | 30.55             | 5.89×10^9 |
| N-nitroso                                    | 1.33           | 2.34×10^8 | 0                 | 0         |
| Tetratetracontane                            | 1.45           | 2.54×10^8 | 1.29              | 2.48×10^8 |
| 3-Aminopropyl Isopropyl Ether                | 0              | 0         | 2.11              | 4.07×10^8 |
| 1-acetate, 1,2, 3-glycerin                   | 0              | 0         | 1.11              | 2.13×10^8 |

3.4. Thermal release characteristics of glycerol, propylene glycol and menthol

TGA was used to study the thermal release characteristics of the atomization agent. Figure 3 shows the TG and DTG curves of glycerol, propylene glycol and menthol. It can be seen that the weight loss peak of menthol and propylene glycol is mainly at 250°C, and the weight loss peak of glycerin is
mainly at 300°C. Glycerin is the main component of the atomization agent. During the actual smoking, it is necessary to ensure the good release of glycerin thus the glycerin can promote the release of the aerosol components. Therefore, during the actual smoking, a sufficiently high temperature (over 300°C) of the tobacco stick is necessary for the good smoke release. According to the results in Section 2.1, due to the existence of the thermal resistance and heat dissipation, the external part of the tobacco stick cannot be heated to a sufficiently high temperature, so the released smoke will be reduced. It can be concluded that the higher heating temperature of IQOS not only promotes the release of the atomization agent, but also promotes the cracking of tobacco, which is one of the reasons for its high concentration of smoke.

![Figure 3. Thermal release characteristics of glycerol, propylene glycol and menthol.](image)

On the other hand, based on the actual heating condition of the tobacco stick, the external temperature of the tobacco stick is low. In order to enhance the atomizing effect of the atomization agent to promote the smoke release from the external part of the tobacco stick, it is necessary to use the atomization agent with components which have lower boiling point. It can be seen from Figure 3 that the weight loss peak of menthol and propylene glycol is mainly at 250°C. Therefore, increasing the ratio of menthol and propylene glycol in the tobacco stick can enhance the smoke release property of the tobacco stick at low temperature and increase the amount of smoke release.

3.5.  Release Characteristics of IQOS, K and the original tobacco powders of K

3.5.1.  Thermogravimetric analysis. In this section, TGA is used to analyse the effects of the thermal release characteristics on the smoke release of IQOS, K and original tobacco powders of K. Figure 4 shows the TG curves of IQOS, K and original tobacco powders of K. The results show that the tobacco stick has significant weight loss mainly at three temperatures: 105°C (loss of water), 250°C and 330°C. It can be seen from the TG curves of original tobacco powders of K that 330°C is the thermal cracking temperature of the tobacco powder itself. As shown in Figure 4, the weight loss at 250°C of the tobacco stick is due to the release of the atomization agent. However, Figure 3 shows that
glycerol is mainly released at 300°C when heated alone. These results indicate that the release temperature of the glycerol is decreased (250°C) after being added to the tobacco stick as the atomization agent, indicating that there are interactions between the tobacco and the atomization agent which can reduces the release temperature of the atomization agent components.

![Figure 4. Thermal release characteristics of the IQOS, K and original tobacco powders of K.](image)

The results in Figure 4 show that the weight loss peaks of IQOS at 250°C and 330°C are similar, while the weight loss peaks of K at 250°C is much larger. This result indicates that the release temperature of most atomization agent components in K is lower than the tobacco cracking temperature. Therefore, during the actual smoking, the atomization agent is released (before 330°C) before the tobacco is cracked to generate smoke, which cannot promote the release of the smoke. The atomization agent in IQOS also released at 250°C, but less than that of K. Therefore, more atomization agent in IQOS are released with the tobacco smoke at high temperature (330°C) together, which plays a good role in carrying smoke.

3.5.2. Composition of smoke released from tobacco stick at typical smoking temperature. Py/GC-MS was used to analyse the compositions of the released smoke at two typical smoking temperatures. To ensure the release of smoke, the heater was set to operate at 260°C (higher than 250°C) and 330°C. The main components in the smoke detected by Py/GC-MS are shown in Table 4 and Table 5.

The peak area of the compounds detected by GC-MS can be semi-quantitatively reflect the concentration. It can be seen from Table 3 and Table 4 that the concentration s of menthol and nicotine released from IQOS are significantly higher than those of K. The amount of glycerol released from K is basically the same as at 260 and 330°C, indicating that almost the atomization agents in K are released below the tobacco cracking temperature (330°C), thus the atomization agents in K cannot promote the smoke release. The glycerol in IQOS was not completely released at 260°C, and as the temperature increased to 330°C, release more glycerol was released. This result is consistent with the TG result, indicating that the glycerol in IQOS can be released at two stages, that is, one part of glycerol will be released at 260, and the other part of glycerin will be released at tobacco cracking
temperature (330°C). These will be beneficial for the smoke release. It can be speculated that a slow-release agent may be used in IQOS tobacco stick, which can inhibit the release of glycerin at 260°C, increases the release temperature of glycerin, thus more glycerin can be released at higher temperature, and therefore the glycerol can play a good role in smoke carrying. This may be one of the reasons for the high concentration of smoke from IQOS.

Table 4. Main compounds in the smoke of IQOS, K and original tobacco powders of K at 260°C.

| Chemicals                  | Original sample (%) | IQOS (%) | K (%) |
|----------------------------|---------------------|----------|-------|
| Acetaldehyde               | 1.6                 | 0        | 0     |
| Water                      | 10.71               | 5.71     | 6.2   |
| Hydroxy acetone            | 1.74                | 1.34     | 1.07  |
| Acetic acid                | 3.14                | 1.65     | 1.36  |
| Furfural                   | 1.5                 | 0        | 0     |
| 1, 5-dimethyl-1h-pyrazole  | 1.06                | 0        | 0     |
| Nicotine                   | 24.02               | 13.54    | 10.82 |
| Neophytadiene              | 1.25                | 0        | 0     |
| 5-hydroxymethylfurfural    | 1.5                 | 0        | 0     |
| Hexadecanoic acid          | 2.97                | 2.5      | 2.08  |
| Stearic acid               | 2.98                | 3.33     | 2.46  |
| Levomenthol                | 0                   | 2.5      | 0     |
| 1,2, 3-glycerin, 1-acetate  | 0                   | 1.21     | 0     |
| Glycerin                   | 0                   | 37.29    | 45.16 |
| Total peak area            | 1.608×10⁹           | 3.789×10⁹| 4.125×10⁹|

Table 5. Main compounds in the smoke of IQOS, K and original tobacco powders of K at 330°C.

| Chemicals                  | Original sample (%) | IQOS (%) | K (%) |
|----------------------------|---------------------|----------|-------|
| Water                      | 11.13               | 5        | 5.72  |
| Acetic acid                | 2.78                | 1.23     | 0     |
| Furfural                   | 1.13                | 0        | 0     |
| 2-furaldehyde, 5-methyl -  | 1.1                 | 0        | 0     |
| Nicotine                   | 23.16               | 16.78    | 12.65 |
| Neophytadiene              | 1.46                | 0.74     | 0     |
| 5-hydroxymethylfurfural    | 2.74                | 0        | 0     |
| Hexadecanoic acid          | 3.61                | 1.58     | 1.35  |
| Stearic acid               | 4.05                | 1.67     | 1.26  |
| Levomenthol                | 0                   | 2.58     | 1.95  |
| 1,2, 3-glycerin, 1-acetate  | 0                   | 1.45     | 0     |
| Glycerin                   | 0                   | 46.96    | 54.11 |
| Total peak area            | 3.244×10⁹           | 4.895×10⁹| 4.142×10⁹|

4. Conclusion
In this paper, the properties of two typical HnB products (IQOS and K) are compared, and the factors that promote the smoke release from IQOS tobacco stick are investigated. The research results show that the heating temperature of the IQOS is higher, which is helpful for the smoke release from the tobacco stick. IQOS tobacco stick have a high content of easily-released components and are easy to generate the smoke with high concentration. The IQOS tobacco stick have well-developed pore structure and large specific surface areas, which are beneficial to the release of smoke. During the actual smoking, the atomization agent in IQOS can be released in two stages, and more atomization agents can be released at the temperature (330°C) at which a large amount of smoke is generated by
the pyrolysis of the tobacco stick, thus more smoke can be generated from IQOS. The results in this study can provide theoretical support to increase the smoke from the HnB products.

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