Design and Development of CYO with Adjustable Smoke Volume

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Abstract. In order to realize the adjustable and controllable smoke volume in the process of cigarettes’ combustion and satisfy the different tar taste needs of consumers, a connector which can adjust the smoke volume was designed in this paper. By adjusting the angle of two rotatable sector surfaces, the tar can be controlled by adjusting the size of the air passage inside the intake passage. The physical parameters of the connector are calculated by ANSYS software, and the connecting effect is simulated. CYO cigarettes connected by the very connector are verified. The results show that the connector achieves the sticky effect and the tightness similar to the conventional cigarettes. Internal control sector can be easily rotated, and there is no obvious gap at the splice. There is no obvious leakage at the splice and connecting point during the smoking process. There is no significant difference between smoking evaluation and smoke detection with conventional cigarettes, and the ideal design effect is achieved.

1. Introduction

RYO (Roll-Your-Own): refers to rolling their own cigarettes by the purchase of cigarette paper, tobacco, filter rods and other materials[1-3]. FM (Factory Making) refers to cigarettes made by factories, whose form is fixed and single[4-8]. CYO (Connect Your Own) is a new type of cigarette, which combines the advantages of FM and RYO cigarettes[9]. On the basis of the existing mature processing technology, precision processing of cigarette sticks and filter rods, a closed combination splicing function connector is designed to complete diversified production. CYO cigarettes break through the design idea of conventional cigarette adhesive, adopt combination design, which lets consumers own more rights to choose independently.

At present, most cigarettes sold in the market are of fixed smoke volume. There are usually fixed tar content, carbon monoxide content and nicotine content on the label of cigarette box. But for some young consumers, they prefer to adjust the smoke volume according to their own taste. As a result, a kind of cigarette which can adjust the smoke volume by using filter rod has emerged. Some scholars have studied the relevant patents. Fei Xiang et al. provided a production device and a production method of rotary filter rod, including a silo and a cutting device arranged under the silo, in order to meet the new technology of rotary adjustable ventilation rate of cigarette filter[10]. Dai Jiahong et al. invented a rotating filter rod with built-in independent mandrel, which can realize full circumferential rotation, increasing the interactive experience of consumer suction, and meeting different consumer habits[11]. Despite the development of rotary filter rods by researchers, there are still some problems...
such as unstable quality, range limits of changeable filter rods, and failure of adjustment when suction reaches half.

In this paper, a separated component with adjustable smoke volume is designed. Tar can be controlled by adjusting the angle of two rotatable sector surfaces, and then by adjusting the size of the internal air intake passage. The physical parameters of the connector were calculated by ANSYS software, and the splicing effect was simulated. The CYO cigarettes spliced by the connector were validated. There was no significant difference in smoking evaluation and smoke detection between the two types of cigarettes, and the ideal design effect was achieved.

2. Experimental

2.1. Through simulation calculation, the model of gas flow in connector was established, the model of influence of connector on smoking resistance of separated cigarettes and the model of influence of connector on temperature of separated cigarettes were established.

(1) The ISO standard pumping mode conditions of GB/T 19609-2004 were used to simulate the pumping conditions. The pumping time was 2 s per puff, one puff per 60 s, and the pumping capacity was 35 ml.

(2) Under ISO standard smoking mode, the simulated number of smoking times was 7 times, and the temperature at the interface between the end of cigarette and the filter rod was determined. Temperature data was obtained from previous experiments.

(3) The project requires simulating the smoke resistance and temperature of smoke passing through connectors and filter rods. The peak and average values of smoke resistance and temperature were determined for simulating the smoking process in each inhalation. The cross section is selected at the outlet of the connector (Z = 30 mm), the middle of the filter rod (Z = 15 mm), the back of the filter rod (Z = 7 mm) and the end of the filter rod (Z = 0 mm). There are 7 groups of data for each cross section (7 simulations by aspiration).

(4) For the simulated boundary conditions, the parameters of the filter rod, such as the heat transfer coefficient of cellulose acetate fiber, the porosity of the filter rod, the inertia resistance coefficient of the filter rod and the viscous resistance coefficient of the filter rod, the standard value or the empirical value was adopted.

2.2. Producing and connecting CYO components

2.3. According to the national standard GB5606.4-2005, the results of sensory evaluation of cigarettes were analyzed and compared.

3. Simulation and calculation

3.1. Determination of end temperature of cigarettes under standard smoking mode

According to GB/T 19609-2004, under ISO suction mode, the suction time per puff is 2 s, and the suction capacity is 35 ml per 60 s.

ISO suction mode velocity expression:

\[ v = 0.61 \sin \left( \frac{\pi t}{Z} \right) \]  

(1)

3.2. Geometric model and mesh generation of connector and filter rod

The material of the filter rod is cellulose acetate fiber. The size of the tow is 3.0Y32000, the circumference is 24.5mm, the length of the filter rod is 30mm, and the wall thickness of the filter rod is 0.08mm. Four kinds of connectors and filter rods were modeled by UG software. The geometric model of connector flue duct was obtained by DesignModeler of ANSYS.
3.3. Selection of turbulence model
Standard k-ε two-equation turbulence model, unsteady 3D separation implicit solver, SIMPLE algorithm and standard wall function are used to deal with the near-wall region. Smoke and nicotine flow are considered as steady flow, and nicotine is considered as continuous phase, which is simulated under Euler model.

3.4. Determining the Mathematical Model of Computation
In the process of simulation, it is assumed that nicotine and smoke are continuous multiphase flows running through each other, satisfying the conservation laws of quantity, momentum and energy respectively.

The smoke is defined as a continuous phase, which is simplified as nicotine (granular phase q) and smoke (gas phase p). The smoke is simulated under Mixture model as a continuous two-phase flow through each other. The volume fraction represents the space occupied by nicotine (granular phase) and smoke (gas phase). The volume fraction equation of smoke is as follows:

$$\sum_{q=1}^{n} \alpha_q = 1$$

(2)

Where, $\alpha_q$ is the volume fraction of Phase q.

1) The conservation equation of mass is as follows,

$$\frac{\partial}{\partial t} (\alpha_q \rho_q v_q) + \nabla \cdot (\alpha_q \rho_q v_q v_q) = \sum_{p=1}^{n} (m_{pq} - m_{qp}) + S_{mq}$$

(3)

Where, $\rho_q$ is the density of Phase q, kg/m$^3$; $v_q$ is the velocity of Phase q, m/s; $m_{pq}$ is the mass transfer from Phase P to Phase q, kg/(m$^3$.s); $m_{qp}$ is the mass transfer from Phase q to Phase p, kg/(m$^3$.s); $S_{mq}$ stands for the quality source phase of Phase q, kg.

2) The momentum conservation equation is as follows,

$$\frac{\partial}{\partial t} (\alpha_q \rho_q v_q v_q) + \nabla \cdot (\alpha_q \rho_q v_q v_q v_q) = -\alpha_q \nabla P + \nabla \tau_q +$$

$$\sum_{p=1}^{n} (R_{pq} + m_{pq} v_{pq} - m_{qp} v_{qp}) + F_q$$

$$\tau_q = \alpha_q \mu_q \left[ (\nabla v_q + \nabla v_q^T) \right] - \frac{2}{3} \alpha_q \mu_q \nabla v_q I$$

(5)

$$\sum_{p=1}^{n} R_{pq} = \sum_{p=1}^{n} K_{pq} (v_p - v_q)$$

(6)

Where, P is the pressure, Pa; $\tau_q$ is the stress-strain tensor of Phase q, kg/(m$^3$.s$^2$); $R_{pq}$ is the interaction force among phases; $F_q$ contains all external forces, including the thermal swimming force of particles in Brownian motion; $\mu_q$ is the viscosity of Phase q (kg/ms); I is the unit tensor; $K_{pq}$ is the momentum exchange proportional coefficient among phases.

3) The energy conservation equation is as follows,
\[
\begin{align*}
\frac{\partial}{\partial t}(\alpha_q \rho_q H_q) + \nabla \cdot (\alpha_q \rho_q \mathbf{v}_q H_q) &= -\alpha_q \left( \frac{\partial P}{\partial t} \right) + \tau_q : \nabla \mathbf{v}_q - \nabla q_v + \\
\sum_{p=1}^{n} (Q_{pq} + m_{pq} \mathbf{H}_{pq} - m_{qp} \mathbf{H}_{qp})
\end{align*}
\] (7)

Where, \( H_q \) is enthalpy of Phase q, J/kg; \( \mathbf{q}_q \) is heat flux, W/m²; \( Q_{pq} \) is the heat exchange between Phase p and q, W/m²; \( \mathbf{H}_{pq} \) and \( \mathbf{H}_{qp} \) are interphase enthalpy of Phase p and Phase q, respectively, J/kg.

Interphase energy transfer \( (Q_{pq}) \) is assumed to be a function of temperature difference,

\[ Q_{pq} = h_{pq} (T_p - T_q) \] (8)

\[ h_{pq} = \frac{6k_p \alpha_p \alpha_q N_{pu}}{d_p} \] (9)

Where, \( h_{pq} \) is the heat transfer coefficient between Phase p and q, W/(m².K); \( k_q \) is thermal conductivity of Phase q, W/(m.K).

4. Results and discussion

4.1. Connector geometry model and mesh generation

The material of the filter rod is cellulose acetate fiber. The size of the tow is 3.0Y32000, the circumference is 24.5mm, the length of the filter rod is 30mm, and the wall thickness of the filter rod is 0.08mm. The connector and filter rod are modeled by UG software.

ANSYS ICEM software is applied to mesh the geometric model of connector and filter rod runner. Tetrahedral mesh is used, and the boundary layer is refined. The grids of connector and filter rods are shown in Fig.1. Z = 0 mm is the filter rod sucking end, and Z = 30 mm is the connector outlet end, Z = 32 mm is the import end. Smoke flows from the cigarette end to the smoking end, and nicotine is intercepted inside the filter rod.

![Fig. 1 Mesh partition graph of the connector](image)

4.2. Determining the boundary conditions for calculation

(1) The connector adopts speed entrance, and the speed changes with time. In ISO mode, \( \mathbf{v} = 0.61 \sin(\frac{\pi t}{2}) \), which is loaded with UDF custom function. The time of each puff is 2s, one puff per 60 secs, and the suction capacity is 35 ml. A total of 7 puffs are smoked to determine the temperature at the boundary between the cigarette rod and the filter rod, and the boundary conditions was settled.

(2) Inlet temperature was set as 375K.

(3) Inlet velocity: UDF equation is introduced by standard suction.

(4) Export pressure: UDF equation was introduced by standard suction.
4.3. Standard Suction UDF Program
Authors write UDF program for outlet pressure and inlet velocity of connector and import it to Fluent for calculation. After calculation, variation of temperature through connector was simulated, which are shown in Fig. 2.

In summary, the distribution of temperature field and pressure drop field is centered on the geometric figure center of the connector, which expands from inside to outside in turn. The temperature decreases gradually from inside to outside, and the temperature of the fan-shaped overlapping part is slightly lower. The calculation can be used as an important basis for selecting suitable temperature for manufacturing component materials. As shown in Fig.3, the samples of CYO components were made according to the calculation results.

4.4. Manufacture and verification

The connecting point achieves the sticky effect and sealing property similar to that of conventional cigarettes. Internal control sector can be easily rotated, and there is no obvious gap at the splices. There is no obvious leakage at the splices and connecting point during smoking. There is no significant difference between smoking evaluation and smoke detection with conventional cigarettes, and the ideal design effect is achieved.
5. Conclusion
(1) An adjustable smoke volume CYO component was designed. Tar can be controlled by adjusting the angle of two rotatable sector surfaces, and then by adjusting the size of the internal air intake passage.

(2) The physical parameters of the component were calculated by ANSYS software, and the connecting effect was simulated. The distribution of temperature field is centered on the geometric figure center of the component, and then expanding from inside to outside. The temperature decreases gradually from inside to outside, and the temperature of the fan-shaped overlapping part is slightly lower.

(3) The validation of CYO cigarettes connected by the component shows that the component achieves the sticky effect and sealing property similar to that of conventional cigarettes.

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