비흡연시 발생하는 담배연기의 증발 및 열분해에서 일어나는 이동현상 해석

이성철

한양대학교 화학공학과

Analysis of the transfer phenomena during the evaporation and pyrolysis of naturally smoldering cigarettes

Sung-Chul Yi, Ph.D., P.E.

Department of Chemical Engineering, Hanyang University,
17 Haengdang-dong, Seongdong-gu, Seoul 133-791, Korea

Introduction

Due to the increased concern over smoking and health problems in recent years, there has been an increased demand by smokers for milder tobacco in which the smoke components that are harmful to health have been reduced, that is, for a "safer tobaccos". In response to these demands, the developement and use of new filters, porous paper, and new tratment technologies for the raw tobacco, etc., have been pursued so that there has been a steady trend toward the production of milder cigarettes.

The methods for reducing the toxic components in smoke can generally be divided into those which act in the generation of the smoke components and those which act after the smoke components have been generated, such as by absorption and filtration with filters. The focus on the generation of the smoke components is considered to be of particular importance, however, in the effort to reduce and eliminate toxic components. The response to the demand for safer cigarettes by controlling the generation of smoke components cannot be considered without taking into account improvement of the smoldering process, which is linked to the generation of smoke components.

There have been many reports on the smoldering rate and temperature distribution of cigarettes [1, 2, 3] since these parameters have been shown to have an effect on the generation of smoke [2]. However, there have been very few reports analyzing the smoldering rate and smoldering temperature, or the smoldering mechanism. For instance, Gugan [4] has quantitatively analyzed the smoldering cone of naturally smoldering cigarettes using a one-dimensional model. Baker [5] also analyzed the distribution of temperature and gas components using a simplified model. He calculated the rate of the formation of CO_2 and CO inside continuously puffed cigarettes, and the amount of heat evolved due to chemical reaction. Also for the smoldering of tobacco, Summerfield et al. [6] presented a one-dimensional model for continuous puffing based on a series of integrated equations using the laws of the conservation of mass, energy and momentum. The relationship between the puff velocity and the ambient oxygen concentration and smoldering rate were analyzed using the model. They report that the theoretical experimental values agree well quantitatively. They also showed that in order to clarify smoldering process of tobacco, it is necessary to develop a precise smoldering model.

The natural smoldering of cigarettes is stationary [2] and the temperature distribution in the radial direction of the nonreaction zone and evaporation-pyrolysis zone is relatively flat [2]. Therefore, each phenomenon in these noncombusting zones is represented by one-dimensional stationary model. The following evaporation-pyrolysis process can be regarded as a heat and mass transfer phenomenon.

Before writing down the model equations, following assumptions were made:

(1) The water content of tobacco is evaporated with an increase in temperature of the zone by heat transferred from the smoldering zone. On the other hand, the unreacted tobacco pyrolyzes and is converted to smoke components and carbonaceous residue. The vapor and smoke components are emitted from the outer surface of the cigarette through the periphery of the element. Consequently, an element that is partially pyrolyzed consists of 3 components of unreacted tobacco, carbonaceous residue, and unevaporated water.

(2) The recondensation of water vapor and smoke inside the element is regarded.

(3) The pyrolysis zone lacks oxygen [2], and therefore the oxidation of unreacted tobacco, carbonaceous residue, and smoke by the ambient oxygen in the element can be disregarded.

(4) There is no difference in temperature between the solid and gas phases inside the element.

(5) The flow of gas inside the element can be disregarded.

(6) Heat is lost to the outside of the element due to free convection.

(7) Heat transfer within the element can be represented as the effective thermal conductivity.

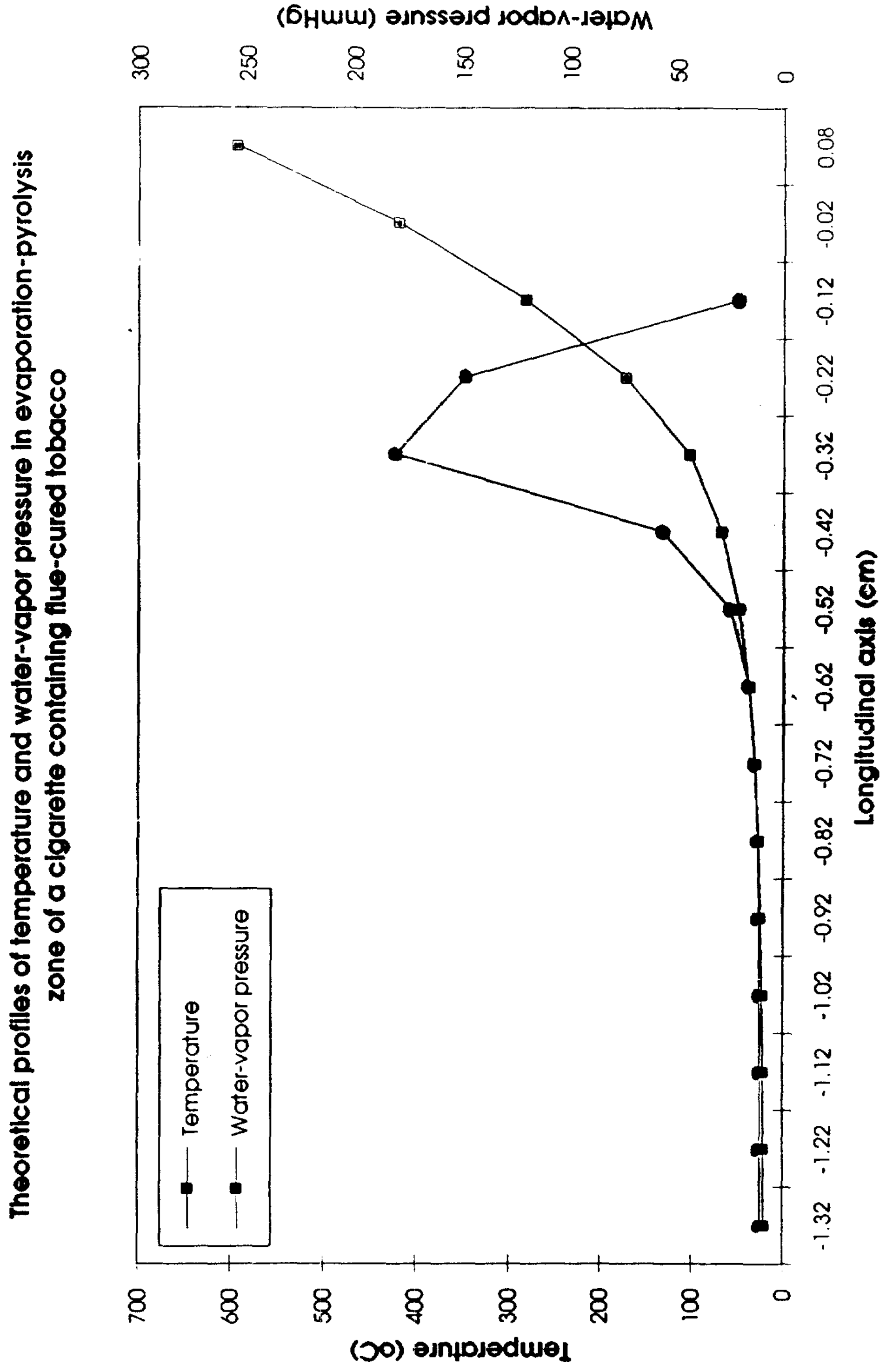
Conclusion

A one-dimensional model was established using heat and mass equations.

The set of model equations were solved by the implicit BDF method and theoretical temperature and density distribution profiles were predicted for the evaporation-pyrolysis zone. These theoretical profiles agree well with the temperature distribution profiles determined using a thermocouple and the density distribution profiles measured using changes in b-ray transmissivity. The basic mechanism of evaporation and pyrolysis of naturally smoldering cigarettes can be explained using the model. Then, parametric studies of each type of tobacco on the shape of the temperature and density distribution profiles to control the smoldering rate were conducted.

References

1. Baker, R. R. and Kilburn, K. D.: *Beitr. Tabakforsch*, **7**, 79 (1973).
2. Muramatsu, M.: *Heat Transfer Jap. Res.*, **2**, 7 (1972).
3. Touey, G. P. and Mumpower II, R .C.: *Tobacco Science*, **1**, 33 (1957).
4. Gugan, K.: *Combust. Flame*, **10**, 161 (1966).
5. Baker, R. R.: *Combust. Flame*, **30**, 21 (1977).
6. Summerfield, M., Ohlemiller, T. J., and Sandusky, H. W.: *Combust. Flame*, **33**, 263 (1978).


Theoretical profiles of temperature and water-vapor pressure in evaporation-pyrolysis zone of a cigarette containing flue-cured tobacco
Temperature
Water-vapor pressure
Temperature (oC)
Water-vapor pressure (mmHg)
Longitudinal axis (cm)
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
-1.32
-1.22
-1.12
-1.02
-0.92
-0.82
-0.72
-0.62
-0.52
-0.42
-0.32
-0.22
-0.12
-0.02
0.08