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INTRODUCTION

The current Cigarette Design Model (CDM) has evolved from a few hundred lines of FORTRAN code in 1986 to almost 500 pages of code in a 1997 version. A number of people have refined, or attempted to refine, the program over the years. New features have been added, several different versions co-existed at one time, and three attempts to improve the program and the graphical user interface have been undertaken. Currently, we are in the process of applying "good laboratory practices" to the management of the program.

The purpose of this document is to detail the methods used to solve the complex problem of relating cigarette-design features to cigarette performance. It is intended to be independent of any particular implementation of the program. The theories, equations, approximations, and assumptions are described in this document, along with appropriate references to the literature.

Our vision of the Cigarette Design includes an easy-to-use tool that will allow users to predict the performance of both conventional and unconventional products. The model will be the repository of the most up-to-date knowledge of the effects of cigarette design on cigarette performance. The program must be well engineered so that refinements, modifications, improvements, and new knowledge can be easily included and verified. The program must be rigorous, flexible, accurate, reliable, easily maintained, and exhaustively validated through an assessment of the performance of a wide variety of cigarette designs. Any modifications to the program should be accompanied by further experimental cigarette data that can be added to a database for model validation. The program must have a user interface that allows users with a wide range of needs to easily access and exercise the program. The program needs to allow designers to test new concepts computationally, thereby requiring a concerted effort to add features and knowledge to the program on a continuing basis.

CDM OVERVIEW

The CDM works by calculating dynamic and static properties of a Control cigarette, and uses these properties as a starting point for predicting how construction changes will alter the performance of a Prototype cigarette. Based on the user-specified design of the Control, the program calculates the flow, pressure drop, and ventilation levels of the *unlit* Control. The same properties are calculated for a *lit* Control in which the tobacco column is shortened, and a "coal" has been added. The smoke-removal efficiency for each cigarette segment is calculated. Based on the calculated "coal volume" of the lit Control and the cigarette efficiencies, the amount of material generated at the "coal" is calculated, along with the amount of tobacco consumed during and between puffs. At this point, the Control is fully characterized, and a puff-by-puff delivery profiles are calculated.

The process is then repeated for the Prototype cigarette. The user specifies design changes and the Program re-calculates the performance parameters. The control has served as a baseline for the prototype. The performance of the unlit Prototype is calcuated and then it is shortened and a "coal" is added. The performance is re-computed…yadda, yadda, yadda.

THE CONTROL CIGARETTE

1. *Specification of Construction*

The CDM requires fairly complete construction information about both the Control cigarette and the Prototype cigarette. The first level of required information includes a routine description of the cigarette's construction, much like what is needed to specify a Semi-works run. A significant deviation from a routine specification concerns the blend – the CDM requires no tobacco-blend formulation information other than its expanded-tobacco content. The program assumes that the Prototype's tobacco filler is the same as the Control's. Indeed, the reason for having a Control is to calculate its tobacco-blend specific properties and extrapolating these properties to the Prototype.

Table 1 lists the cigarette-construction parameters required by the model.

Cigarette Design Parameter	Units	CDM Variable Name
Tar Delivery	mg per cigarette	CONTROLTAR
Nicotine Delivery	mg per cigarette	CONTROLNIC
Water Delivery	mg per cigarette	CONTROLH2O
Carbon Monoxide Delivery	mg per cigarette	CONTROLCO
Menthol Delivery	mg per cigarette	CONTROLMEN
Puff Count	puffs per cigarette	CONTROLPUF
Static Burn Time	min	CONTROLSBT
Cigarette RTD	mm water	CONTROLRTDm
Cigarette Length	mm	CONTROLLENm
Cigarette Circumference	mm	CONTROLCIRm
Filter RTD	mm water	CONTROLFRTDm
Filter Length	mm	CONTROLFLENm
Filter DPF		CONTROLFDPF
Tipping Paper Length	mm	CONTROLFTPLENm
Filter Ventilation	%	CONTROLFDILP
Wrapper Permeability	CORESTA	CONTROLPERMc
Wrapper Additive		CONTROLADDt
Additive Level	%	CONTROLADDp
Tobacco Weight	g	CONTROLTWTg
Shred Cut Width	cuts/inch	CONTROLCPI
Filler Expanded Tobacco	%	CONTROLETp

In addition to these construction parameters, the user may specify further details of construction. Filter construction can be a mono-filter of cellulose acetate tow, paper, or polypropylene fibers. The filter may be specified as a dual filter - two filters in series or parallel (concentric), each segment containing CA tow, paper, or PP fibers.

In each case, the user must specify the length, circumference, and RTD of each segment. The default specification is a mono-filter containing CA-tow.

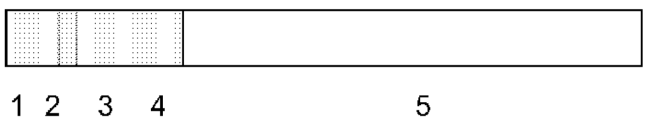
The details of filter ventilation may be specified. The default is a single row of laser-perforations in the tipping paper located 12.5 mm from the mouth-end. The specific ventilation may be described including the type of ventilation, e.g., laser-perforated tipping paper or on-line cigarette-filter ventilation. This choice affects the relationship between vent pressure drop and ventilation and will be described in the ventilation section of this document. The user may also specify the location and relative weighting of each vent row. The weighting option allows each row to have a different vent size and is included to further the designers capabilities.

A more detailed description of the cigarette-wrapping paper may be included. The user may specify the wrapper basis weight, chalk type and content, and the presence of paper perforations. The chalk types include Albacar and Multifex forms of calcium carbonate. Perforated wrappers require the inclusion of the permeabilities of the base sheet with and without perforations. The default values for the tobacco-wrapping paper are: no perforations, a basis weight of 23 m^2/g, and 27% Albacar chalk.

Finally, the user may choose the smoking regime used to measure the performance of the cigarette. The puff volume, puff duration, puff interval, and butt length may be specified. The default smoking regime is the current FTC methodology. An attempt has been made to account for the different smoking procedures used throughout the world. The user may specify ISO, DIN, UK.. The method used to include the various smoking processes is based on our analysis of a correlative study performed in 1985 and is now very dated.

2. *Flow and Pressure Drop in the Unlit Control*

In the CDM, the cigarette subdivided into segments, the segment boundaries being either where a change of material or flow occurs. For example, a conventional cigarette with two rows of filter vents would comprise five segments:



1. filter segment from the mouth-end to the first row of vents,
2. filter segment from the first row of vents to the second row of vents,
3. filter segment from the second row of vents to the end of the filter,
4. tobacco segment overwrapped by tipping paper,
5. tobacco segment covered by cigarette wrapper