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Recent Advances in Cigarette Ignition Propensity Research and Development

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Abstract

Major U.S. cigarette companies for decades conducted research and development regarding cigarette ignition propensity which has continued beyond fire safety standards for cigarettes that have recently been legislated. This paper describes recent scientific advances and technological development based on a comprehensive review of the physical, chemical, and engineering sciences, public health, and trade literature, U.S. and international patents, and research in the tobacco industry document libraries.

Advancements since the first implementation of standards have made been in: a) understanding the key parameters involved in cigarette smoldering combustion and ignition of substrates; b) developing new cigarette and paper wrapper designs to reduce ignition propensity, including banded and non-banded cigarette paper approaches, c) assessing toxicology, and d) measuring performance. While the implications of manufacturers' non-safety related aims are of concern, this research indicates possible alternative designs should experience with fire loss and existing technologies on the market suggest need for improvement.

Keywords

ignition propensity; smoldering combustion; oxygen transfer; cigarette extinction test; consumer product safety

1. Introduction

Cigarettes and other lighted tobacco products are a leading cause of fire deaths and fire-related injuries in the U.S. and throughout the world. Estimated costs of smoking material caused fires in the U.S. in 2005 were 82,400 fires, 800 civilian deaths, 1,660 civilian injuries, $575 million in direct property damages and other economic loss including health care costs, lost productivity, and use of fire and emergency services. [1] A significant proportion of the deaths,

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injuries and destruction of property could be prevented through the introduction of fire safety standards for cigarettes, which would require cigarettes to be either self-extinguishing, i.e. would go out when not actively puffed, or have altered smoldering characteristics making a fire less likely. Twenty-seven states, Canada, and Australia have mandated ignition performance standards for cigarettes modeled after New York's Fire Safety Standards for Cigarettes, which was implemented in 2004. New Zealand, South Africa and members of the European Union are also moving towards cigarette fire safety legislation modeled after the standard used by the state of New York with planned introduction in some countries as early as 2009.

A Technical Study Group convened by the U.S. Consumer Product Safety Commission under auspices of The Cigarette Safety Act of 1984 reported to Congress in 1987 that developing a cigarette with a minimum ignition propensity was technically and apparently economically feasible. [2] In 1990, the Technical Study Group was renamed the Technical Advisory Group and given the primary mandate of developing tests to establish standards for reducing the ignition propensity of cigarettes. This group conducted a regression analysis that showed that the cigarette characteristics filter length, porosity, and pack type were associated with cigarette fire incidence rates, when controlling for smoker characteristics. [3]

The New York performance standard requires that a cigarette brand exhibit no more than 25% full-length burns on 40 tests by the *Cigarette Extinction Test* (CET) method, which was developed by the U.S. National Institute of Standards and Technology and adapted and published by American Society of Testing and Materials as ASTM E2187 *Standard Test Method for Measuring the Ignition Strength of Cigarettes*. Cigarettes that are designed to comply with this standard are commonly referred to as reduced ignition propensity cigarettes and have been shown to have a lower statistical probability of igniting upholstered furniture mockups. [4]

The New York performance standard does not require any particular cigarette design for achieving reduced ignition propensity. Numerous approaches have been pursued over more than 80 years of combined industry research and government research focusing on relations between cigarette design features, the thermo-physical properties of the smoldering cigarettes, and cigarette ignition propensity, and over 300 patents obtained despite industry public comments that fire safe cigarettes were not feasible. The major U.S. cigarette companies, Philip Morris, RJ Reynolds, Brown & Williamson, and Lorillard each had extensive testing programs that began in the late 1970s or early 1980s. [5] While over 90% of the cigarettes brands sold in the U.S. were certified by the New York Office of Fire Prevention and Control as compliant upon implementation of the performance standard in 2004, the tobacco industry has since continued its cigarette ignition propensity research and development.

The aims of ongoing industry research have been to: 1) advance the fundamental understanding of cigarette combustion and ignition of substrates; 2) identify new technologies that may be useful in designs for reducing cigarette ignition propensity; 3) improve manufacturing and quality assurance processes for producing reduced ignition propensity cigarettes; 4) identify potential improvements in reduced ignition propensity performance measurement; and 5) pursue consumer satisfaction and other non-safety-related commercial concerns so that sales will not be lowered. Since the effectiveness of existing standards for reducing fires and fire losses has yet to be determined based on population data, and new advances in ignition propensity research could potentially lead to less ignition-prone cigarettes than those on the market, a comprehensive review is needed of the state-of-the-art in cigarette ignition propensity research and development. This paper summarizes the science of cigarette ignition propensity prior to the New York performance standard, and describes the recent advances in research and technological development following the New York performance standard based on a systematic review of the public health, scientific, technological, trade literatures and internal industry information made available to the public following the Master Settlement Agreement between U.S. states and tobacco companies.

2. Methods

A comprehensive multidisciplinary review was conducted of the physical, chemical, and engineering sciences, and public health literature in addition to U.S. and international patents, and trade literature pertaining to the tobacco and pulp and paper manufacturing industries. Information sources researched were: abstracting and indexing databases (Chemical Abstracts®, Applied Science and Technology Abstracts®, Academic Search Premier®, Science Citation Index®, Pubmed®, and Web of Science®), issued patents and patent applications databases available from the United States Patent and Trademark Office [6] and the World Intellectual Property Organization (PatentScope®) [7]; business and trade literature (OneSource®, Factiva®, LexisNexis Academic®, Business Source Complete®, Thomson Research®), an annual reports database (Mergent®), and internal industry documents in the Legacy Tobacco Documents Library [8] and the British American Tobacco Documents Archive [9] (each containing more than 6–8 million documents created by major tobacco companies related to their advertising, manufacturing, marketing, sales, and scientific research activities. Information research was conducted based on subject areas, keyword, and names of authors, other persons, and organizations.

3. Reducing ignition propensity

3a. Smoldering combustion of cigarettes and ignition of substrates

The science of cigarette ignition propensity is based on an understanding of the thermo-physical properties of cigarette smoldering combustion described by Ohlemiller [10] and by Gann [11]. Smoldering combustion is a flameless, slow, low-temperature, oxidation of the tobacco rod and the paper wrapper in a burning cigarette not being actively smoked. [10] It is sustained by heat generated by the oxidation and thermal degradation of the tobacco and the paper wrapper at the thermal front, or burning ember, of the cigarette. The burning cigarette requires continued transfer of oxygen to the coal as oxygen within the tobacco rod is depleted. Oxygen is transferred from the surrounding air by diffusion across the paper wrapper by the force of partial pressure and by convection through the spaces between discrete pieces of tobacco in the rod. [10,11]

A smoldering process is generated in substrate materials such as the fabric of upholstered furniture when the smoldering cigarette remains in contact long enough to heat the substrate to its ignition threshold temperature. [12] The distribution of the thermal field and the surrounding partial pressure of oxygen determine whether the substrate material continues smoldering combustion or transitions to flaming combustion. The latter occurs when the gases released by pyrolysis of the cigarette mix with surrounding oxygen in flammable concentrations and a heat flux raises this mixture’s temperature above its threshold for ignition. [10,12]

3b. Cigarette ignition propensity

Since heat transport within a cigarette is a function of static burn rates, most approaches to lowering cigarette ignition propensity aim to modify the rates sufficiently to result in self-extinguishment prior to the cigarette’s ignition of a substrate. The heat impinging on the substrate is a function of the *mass burn rate*, the effective heat of combustion of the cigarette, the nature of the contact of the cigarette with the substrate, and the area, temperature, and shape of the cigarette coal. The linear burn rate is an indicator of how fast the cigarette coal moves, and reflects the length of time that heat flux impinges on given point on the substrate. [10, 14] All other things being equal, cigarette heat output increases with higher mass burn rate (a faster burning cigarette) [15], while a high linear burn rate exposes the substrate to a shorter period of more intense heat. [13]

Philip Morris scientists noted in 1977 that burn rates are primarily affected by cigarette paper wrapper attributes (porosity and burn additives), tobacco characteristics (type, cut width, additives, and moisture content), and cigarette construction (tobacco rod geometry and density). [16] Theoretical modeling of the relationship between cigarette design and smoldering suggests that aside from paper wrapper properties, cigarette circumference is the primary factor affecting mass burn rate, and tobacco density is the primary factor affecting linear burn rate, heat flux, and the total heat released. [17] The Technical Study Group similarly found the factors associated with ignition propensity to be paper wrapper properties such as permeability and porosity; chemical additives such as citrate, whose role is purportedly to have the paper burn at the same rate as the tobacco column, other additives to the tobacco; cigarette circumference; and tobacco density. [2]

3c. Role of the cigarette paper wrapper

Industry's main focus in the technological development of reduced ignition propensity cigarettes has been the composition and construction of the paper wrapper, particularly with respect to reducing permeability in order to reduce mass burn rate. Paper wrapper permeability regulates the diffusion of oxygen from outside of the cigarette to the inside and is thereby a major determinant of ignition propensity. The *diffusive capacity* of the paper wrapper, i.e. its resistance to the flow of an electric current when immersed in a non-aqueous solution of electrolyte and placed between two electrodes, has been found to be a direct indication of cigarette static burn rate and ability to sustain continuous smoldering combustion. [18–20] Cigarette paper wrappers' inherent permeability is based on composition and thickness, and is commonly designated in CORESTA units, measured in terms of volumetric flow rate of air (cm^3/min) per unit area of paper (cm^2) per unit pressure drop of water. [21] Paper filler materials such as $CaCO_3$ are used in some designs to provide either relatively high or low permeability depending on median particle size, and methods for calibrating filler concentrations and particle size in order to achieve designated paper wrapper permeability are described in a number of patents. [22,23]

Various designs for reducing ignition propensity incorporate in the paper wrapper burn altering chemical additives, which can either accelerate or retard burn rate, such as potassium citrate and other alkali metal salts, metals, or metal oxides [24]or permeability reducing constituents, such as additional paper, cellulose [25,26], or aqueous film-forming solutions (e.g., alginate, starch, tapioca, carrageenan, guar gum, pectin) [27,28], or various other polymers. Burn altering constituents are used either singly or in conjunction with paper permeability modifiers. [29] An early reduced ignition propensity cigarette design for example added potassium citrate in discrete amounts to paper that had a low diffusive capacity and inability to burn which was made by enhanced flax refining and adjustment of $CaCO_3$ content. [30] The potassium citrate caused the paper cellulose structure to begin to degrade at a lower temperature, increased the width of paper burn line, and allowed more oxygen to reach the coal and sustain smoldering combustion. Cigarette paper wrappers such as roll-your-own and small cigars are made without burn promoters and normally result in self-extinguishment apart from any other design modification. [31]

3d. Banded cigarette paper approaches

The most frequently patented and commonly recognized reduced ignition propensity design is *cigarette paper banding* in which circumferential bands generally comprised of permeability reducing substances such as those described above are placed periodically along the rod. Band permeability has a direct correlation with cigarette self-extinguishment rates [32]. Bands may reduce ignition propensity by disrupting heat transfer to an underlying substrate. [33] Theoretical analyses and empirical research have demonstrated that self-extinguishment rates are related to the porosity of the non-banded paper regions in banded paper, width and location of the bands, and additives used for other purposes as well such ash appearance. [34–36] Banded paper wrapper designs often also incorporate in the paper alkali metal burn promoters, burn retardants, and calcium carbonate fillers of various sizes and proportions.

Two methods are generally used in the manufacture of banded cigarette paper: a) water-or solvent-based *print banding*, in which film forming materials are typically applied using gravure or flexographic printing; and b) water-based *paper banding*, an online process in which additional cellulose fibers or paper are added as a fibrous slurry. [14,32] Early development and commercialization of banded paper technologies was carried out by Kimberly-Clark Corporation and its later spin-off Schweitzer Mauduit International, and by PM. [36, –38] PM's PaperSelect® wrapper used in its Merit® brand cigarettes beginning in 2000 is the first known banded cigarette paper on the market and was made with cellulose fiber bands. [39] These cigarettes anteceded New York's Fire Safety Standards for Cigarettes and were therefore not designed to meet reduced ignition propensity requirements. Schweitzer Mauduit International has patented a water-based print banding paper method that is intended for cigarettes to comply with reduced ignition propensity standards. This technology uses a film-forming alginate water-based solution, such as sodium or potassium alginate. [40]

RJ Reynolds has developed alternative banded paper approaches using a) formulations of inulins and/or guar guam [41]; b) two or more layers of bands, consisting of ethylcellulose or another film-forming material; and c) calcium carbonate [42] or magnesium hydroxide filler materials. [43,44] Lorillard has patented a banded paper approach using polybasic organic acid or other film- forming compounds in the band which also act to restrict the flow of air to the burning coal. [45]

3e. Non-banded cigarette paper approaches

RJ Reynolds and Brown & Williamson prior to its acquisition by RJ Reynolds developed non-banded paper wrapper approaches that rely on longitudinal, or co-axial, orientation of permeability-reducing materials with respect to the tobacco column, [46–48] in contrast to the circumferential orientation of paper banding. Specific longitudinal designs include: a) double wrapping of the tobacco rod in layers of regular cigarette paper and/or paper made from reconstituted tobacco; b) partial double wrapping of the paper wrapper by widening the region along the tobacco rod where the wrapper overlaps at the seam; and c) adding strips of reconstituted tobacco sheets to the interior of the wrapper.

4. Other research and development goals

4a. Assessing toxicology

A concern has been the possibility that reduced ignition propensity cigarette designs may result in changes in exposure to smokers due to burn temperature, changes in emissions, or smoker behavior and topography. Internal testing by Philip Morris and other companies found that banded cigarettes were substantially the same as regular cigarettes on a number of important measures of toxicology, including a range of chemical and biological assays despite decades of industry claims the reduced ignition propensity cigarettes would cause more harm [49–51]. Under the Fire-Safe Cigarette Act of 1990, the National Institute for Standards and Technology found no significant differences in levels of tar, nicotine, and CO in the smoke of reduced ignition propensity cigarettes brand and those of fourteen best selling commercial cigarette brand types. [4] Two recent scientific publications by RJ Reynolds, a company that had long opposed reduced ignition propensity regulations claiming increased risk, reported that toxicological testing of cigarettes representative of current marketed banded cigarette paper technologies show no significant differences. [52,53] Academic researchers at Harvard School of Public Health and Roswell Memorial Cancer Institute evaluated the effects of switching smokers from a conventional cigarette to an reduced ignition propensity version of their current brand and found no significant changes in numbers of cigarettes smoked or increases in carbon monoxide exposure. [54]

4b. Non safety-related goals

Industry research and development pertaining to cigarette ignition propensity generally include a range of commercial non-ignition propensity and non-safety-related aims. These typically aim to maximize consumer acceptability in terms of: a) maintaining the cigarette in a burning state when not in contact with a substrate; b) improving or optimizing the taste of the cigarette; c) masking the perception of secondhand smoke; d) providing appealing ash properties of the cigarette, such as white appearance and uniformity; and e) minimizing the cost of production.

Maintenance of the cigarette in a burning state when not in contact with a substrate is typically measured as the *free-air self-extinguishment* rate. Cigarettes with low free-air self extinguishment rate are intended to appeal to consumers by minimizing the need for relighting, even though this feature would not serve to reduce ignition propensity or promote fire safety. Recent Schweitzer Mauduit International patents describe the use of film-forming substances in combination with burn promoting agents with the aim to lower the rate of free-air self-extinguishment, and improve the taste, uniformity, and ash properties of the cigarette while reducing ignition propensity. [40,55] Free-air self extinguishment rate is lowered in these patents by the inclusion of a burn promoter such as citrate in the film-forming composition used for the bands. One Rothman's and Benson & Hedges patent has the aim to maintain the cigarette free-burn for up to two minutes even when the cigarette is set down on a surface. [24] A metal oxide is used in this patent in order to sustain smoldering combustion in lower permeability regions of the paper for a designated period of time or until the burning reaches a higher permeability region. [24] A Lorillard patent also describes the use of a combination of burn additives, burn retardants, and permeability reducing substances, such as polysaccharides, aiming to minimize free-air self extinguishment rates and provide uniform smoke taste and perception while reducing ignition propensity. [29]

Additional non-safety related goals pertain to efficiency and economics of production. PM's *Moving Orifice Device* for example is equipment designed to apply uniform and continuous fiber slurry bands while using an optical inspection to inspect, measure, and control band width and spacing. [56,57] The effect on cigarette ignition propensity of manufacturing processes to provide band uniformity has not been demonstrated. Inventors with a firm Mebtec Technology, Inc. have patented an alternative method for controlled placement of brands and claim that a cigarette with a single band of zero porosity or two such bands can increase self-extinguishment rates to 100%. [58,59].

4c. Performance measurement

The New York performance standard uses the ASTM 2187-04 based on the Cigarette Extinction Test first developed by the National Institute of Standards and Technology. The Cigarette Extinction Test determines whether a cigarette laying on multiple layers of filter paper acting as a heat absorbing substrate generates enough heat to continue burning without self-extinguishing. [4] National Institute of Standards and Technology reported that both the CET, and an alternative measure of ignition propensity, the *Mock-Up Ignition Method*, produced similar results for routine measurement of the propensity of cigarettes to ignite soft furnishings. [4,60] Performance under both methods was linked with reduced ignition behavior in full-scale real fabric upholstered furniture. [61]

Manufacturers have explored the use of infrared imaging for cigarette ignition propensity research and development and performance measurement. Infrared imaging provides a direct measure of radiant coal power, i.e. the heat energy radiated per unit time, from a cigarette in non-contact free smolder. Advantages of infrared imaging for measuring temperature include: a) avoiding physical contact which could affect precision of measurement, b) providing full-field, direct measurement of radiant power, and c) rapidity. Philip Morris used radiant coal power measurements by infrared imaging to develop a semi-empirical model of ignition propensity and found agreement between the percentages of total burns predicted by the model and cigarette ignition propensity as measured by the Cigarette Extinction Test and proposed using the semi-empirical model to increase reliability and efficiency of measuring cigarette ignition propensity. [61]

5. Recent advanced research and development

Cigarette manufacturers' and pulp and paper suppliers' ongoing research has included development of various mathematical and computer-based models to understand the factors related to cigarette ignition propensity and smoldering. Muramatsu [62] and by Eitzinger and Pirker [63] recently reviewed modeling approaches taken since the earliest theoretical research by Sir Alfred Egerton in 1962. [64]. One model formulated by Japan Tobacco International scientists is based on the assumptions that the interaction between tobacco shreds and the paper wrapper plays an important role in the burning cigarette and that the burn rate at the cigarette periphery controls burning propagation. [65] Burn propagation in the Japan Tobacco International model consists of these steps: a) The paper wrapper burns continuously until it is extinguished at the point where the paper makes contact with the tobacco shreds, charring the paper and the tobacco; b) An oxidation reaction then begins in the tobacco shreds below the burnt paper and generates heat; c) The paper wrapper near the charred point is then heated by the burning tobacco shreds and ignites. Japan Tobacco International researchers concluded that the rate of temperature increase near the charred line and the time required to ignite the charred paper is the rate-determining step.

A mathematical model of cigarette smoldering recently developed by Philip Morris scientists predicts linear burn rate and temperature and density profiles in the pyrolysis zone of a smoldering cigarette and estimates the coal length and the maximum coal temperatures during free smoldering. [66] Philip Morris proposed that the model could serve as a tool for exploring important parameters of the cigarette smoldering processes, including heat generation in the burning zone and its dependence on the mass burn rate.

Muramatsu of the Tobacco Institute of Japan [62] and scientists at WFT Research, a paper manufacturer affiliated with Trierenberg [63] developed other mathematical models of cigarette smoldering including simulation of the thermodynamics of cigarettes during smoldering and puffing in free air and when lying on a substrate and prediction of linear burn rate. This model suggests that low diffusion coefficients are required for high self-extinguishment rates in print-banded papers.

RJ Reynolds scientists recently developed an apparatus for testing printed bands and measuring the gas diffusion capacity of cigarette paper. They found that the gas diffusion coefficient is an intrinsic property of paper independent of the paper thickness and concluded that both the diffusion coefficient and thickness of the paper can contribute to burn rate and ignition propensity. [18] They also observed that the diffusion capacity of paper was determined by small pores which are occluded by low permeability bands, and found that diffusion capacity values varied much less than permeability measurements.

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Philip Morris S.A. (in Switzerland) obtained a 2007 patent for a "slit-banded paper" approach to reducing cigarette ignition propensity in which the banded regions of the paper have "gaps" of higher permeability situated between discrete areas of lower permeability. [67] The lower permeability areas of the bands are comprised of constituents typical of other banded papers, while the higher permeability "slits" have perforations that become occluded by a filler material which melts when in proximity to the burning coal, creating a zone with increased permeability. The patent notes that various banding configurations of this design exhibited average full-length burn rates of 2.5% or less, although the cigarette with a certain banding configuration (three 2 mm zones of low permeability separated by 1 mm zones of higher permeability) exhibiting the highest full-length burn rate was considered to provide the best results since its free-air self extinguishment rate was the lowest (20%). [67]

RJ Reynolds recently further developed its non-banded paper approach by using longitudinal inner wrapper strips comprised of alkali metal salts, such as sodium alginate or sodium carboxymethyl cellulose. [68] The alkali metal content was noted to be correlated with higher self-extinguishment rates and higher threshold ignition temperatures; cigarettes with strips having sodium content greater than 27.2 mg per gm generally exhibited 80% or greater self-extinguishments. [68]

Miquel Y Costas & Miquel, a cigarette paper manufacturer in Spain obtained a recent patent for reducing paper wrapper permeability with a gum arabic or acacia gum coating on the internal side of the wrapper applied either over the total surface area or in bands, and use of fire-retardant filler such as aluminum hydroxide, calcium sulfate, or magnesium hydroxide. [69]

A researcher at University of Jena in Germany obtained a recent patent for a cigarette designed to meet the ASTM E2187-04 standard with an alternative approach to paper wrapper modification. [70] The tobacco is mixed with dihydrate calcium sulfate or gypsum which dehydrates from the heat of the burning cigarette releasing water from the endothermic reaction and lowering the temperature from between 742 and 863°C to between 610 and 691°C.

6. Reduced ignition propensity cigarette and paper market

Eighteen percent of the cigarettes sold in North America are now produced with reduced ignition propensity cigarette paper according to Schweitzer Mauduit International, and the proportion is expected to rise to 40% with increasing legislation by the third quarter of 2008 and to national distribution by as early as 2010. [71] The cigarette paper industry has recently consolidated, with ignition propensity remaining an active and competitive area of research and development. Schweitzer Mauduit International's banded papers using water-based alginate solution and the burn promoter citrate are currently sold on the market under the trade name Alginex™. [72] Although the companies that use this paper if any are not known, Schweitzer Mauduit International presently has an exclusive supply arrangement with Philip Morris USA obligating the cigarette company to purchase their jointly-developed reduced ignition propensity paper for 100 percent of its banded cigarette paper requirements for a minimum period of seven years. [71] Schweitzer Mauduit International is also obligated by this agreement to supply the paper to Philip Morris USA for a minimum of thirteen years. [71]

RJ Reynolds and Lorillard reportedly had in-house reduced ignition propensity cigarette technologies at the time the New York law came into effect and they may now each be purchasing from Schweitzer Mauduit International and/or other paper suppliers. U.S. cigarette manufacturers have begun to commit to voluntarily compliance nationwide with reduced ignition propensity standards, including Nat Sherman (as of February, 2007), [73] New Century Tobacco Group (FACT brand as of June, 2007), [74] Liggett (as of January 2009) [75], and

RJ Reynolds (as of end of 2009). [76]. Lorillard, Commonwealth, and Philip Morris are the largest U.S. cigarette manufacturers that have not yet made this commitment possibly due to complications of distribution, and may soon follow. Cigarette paper manufacturers in Europe, such as MYC have recognized the potentially increasing demand from the emerging North American reduced ignition propensity cigarette paper market and the possibility of legislation mandating reduced ignition propensity cigarettes in the European Union. MYC announced plans to produce at least two varieties of reduced ignition propensity cigarette paper beginning in early 2009. [77] Other possible suppliers or entrants into the market include Trierenberg Holding Company in Austria, DelfortGroup, and Swiss Quality Paper (formerly Papierfabrik).

7. Summary and Conclusions

Following decades of research and development, cigarette and cigarette paper manufacturers were readily able to comply with cigarette ignition propensity standards by the time of first implementation in New York [2]. They have since continued to advance the scientific research of cigarette combustion and ignition propensity despite public claims that it is not possible. This article describes further advances that have been made with respect to: a) understanding the key parameters involved in cigarette combustion and ignition of substrates; b) developing new cigarette and paper wrapper designs for reduced ignition propensity; c) improving reduced ignition propensity cigarette manufacturing and quality assurance processes; and d) identifying infrared imaging as a potential enhancement for ignition propensity performance measurement.

Many of the cigarette ignition propensity approaches identified are designed around existing performance standards and include various other non-safety-related goals, such reducing free-air self extinguishment rate, improving taste characteristics and ash appearance, minimizing cost or other factors. The effects on fire safety of various goals related to the commercial interest of maintaining consumers are not determined.

Reduced ignition propensity cigarettes presently on the market all use a paper wrapper based approach, predominantly banded paper. The band composition and geometry may vary between products of the various manufacturers and the amounts of burn additives such as citrate, and other permeability reducing constituents, such as calcium carbonate filler also vary from brand to brand. An increasing number of potential approaches to reduce cigarette ignition propensity with potentially less fire risk are described in patents and the scientific literature.

Further research is needed to better define the relative roles of the common design parameters and to determine which technologies are most effective in reducing fires and fire losses. As population data become available to assess their effects further research should examine the relative effectiveness of reduced ignition propensity technologies on the market and to recommend changes in design or performance standards should they be needed.

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