The intractable cigarette 'filter problem'

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ABSTRACT

Background When lung cancer fears emerged in the 1950s, cigarette companies initiated a shift in cigarette design from unfiltered to filtered cigarettes. Both the ineffectiveness of cigarette filters and the tobacco industry's misleading marketing of the benefits of filtered cigarettes have been well documented. However, during the 1950s and 1960s, American cigarette companies spent millions of dollars to solve what the industry identified as the 'filter problem'. These extensive filter research and development efforts suggest a phase of genuine optimism among cigarette designers that cigarette filters could be engineered to mitigate the health hazards of smoking.

Objective This paper explores the early history of cigarette filter research and development in order to elucidate why and when seemingly sincere filter engineering efforts devolved into manipulations in cigarette design to sustain cigarette marketing and mitigate consumers' concerns about the health consequences of smoking.

Methods Relevant word and phrase searches were conducted in the Legacy Tobacco Documents Library online database, Google Patents, and media and medical databases including ProQuest, JSTOR, Medline and PubMed.

Results 13 tobacco industry documents were identified that track prominent developments involved in what the industry referred to as the 'filter problem'. These reveal a period of intense focus on the 'filter problem' that persisted from the mid-1950s to the mid-1960s, featuring collaborations between cigarette producers and large American chemical and textile companies to develop effective filters. In addition, the documents reveal how cigarette filter researchers' growing scientific knowledge of smoke chemistry led to increasing recognition that filters were unlikely to offer significant health protection. One of the primary concerns of cigarette producers was to design cigarette filters that could be economically incorporated into the massive scale of cigarette production. The synthetic plastic cellulose acetate became the fundamental cigarette filter material. By the mid-1960s, the meaning of the phrase 'filter problem' changed, such that the effort to develop effective filters became a campaign to market cigarette designs that would sustain the myth of cigarette filter efficacy.

Conclusions This study indicates that cigarette designers at Philip Morris, British-American Tobacco, Lorillard and other companies believed for a time that they might be able to reduce some of the most dangerous substances in mainstream smoke through advanced engineering of filter tips. In their attempts to accomplish this, they developed the now ubiquitous cellulose acetate cigarette filter. By the mid-1960s cigarette designers realised that the intractability of the 'filter problem' derived from a simple fact: that which is harmful in mainstream smoke and that which provides the smoker with 'satisfaction' are essentially one and the same. Only in the wake of this realisation did the agenda of cigarette designers appear to transition away from mitigating the health hazards of smoking and towards the perpetuation of the notion that cigarette filters are effective in reducing these hazards. Filters became a marketing tool, designed to keep and recruit smokers as consumers of these hazardous products.

For a product as simple as a cigarette, no more than a short stick of cured, shredded, flavoured, and paper-wrapped leaf, devising a true filter to reduce intake of its combustible by-product was a surprising technological challenge.[1]

Richard Kluger

INTRODUCTION

It has been well documented that cigarette companies responded to the 'lung-cancer scare' of the early 1950s by investing heavily in the design and marketing of filter-tipped cigarettes.[2] As far as cigarette consumers were concerned, the presence of what the industry called a 'filter' on the end of a cigarette implied a reduction of harmful smoke constituents entering their bodies. 'The one word, 'filter,'' reasoned Congressman John Blatnik in 1957, 'may give (smokers) a big connotation built up in the past'.[3 4] His assumption was accurate; in the 1950s cigarette companies did not have to work hard to establish the myth of cigarette filter efficacy. This public faith in filtration provided a window of time for cigarette engineers to conduct extensive research in an effort to actually develop a cigarette filter that delivered on the public's assumptions. Some tobacco industry scientists foresaw the difficulty of the task, and as of 1954, industry members began referring to this issue as the 'filter problem'.[5 6] In this paper I explore the technical nature of the 'filter problem' from the cigarette industry's point of view. I argue that while many cigarette designers did set out to reduce smoking hazards with filters, the technological complexity of the cigarette 'filter problem' frustrated their attempts. What appears for a time to have been a genuine effort to eliminate or significantly reduce the presence of some of the most dangerous substances in mainstream (inhaled) smoke devolved into a series of ineffective attempts to manipulate how smokers consumed their tobacco. Even while people might admit upon reflection that 'clean smoke' or 'harmless smoke' is paradoxical, few in the 1950s would ever have anticipated the impracticability of substantively reducing the smoker's exposure to health risks with filter-tipped cigarettes.

It was in the tobacco industry's immediate interest to let the public assume that the science of cigarette smoke filtration was simple. Aside from the 1957 Blatnik report, which targeted the industry's misleading marketing claims about filtered cigarettes, there was a lack of visible media and scientific criticism that may have helped to counter the public's ignorance throughout the 1950s and early 1960s.[3] Nonetheless, despite a period of skyrocketing filtered cigarette sales, cigarette company executives realised that even the relatively inconspicuous bad press of the mid-1950s presaged ever-increasing criticism of their product. If cigarette designers could reduce levels of harmful substances in mainstream smoke before public criticism of smoking became widespread, then perhaps the looming threat of another, more permanent sales decline could be avoided. In fact, the major cigarette companies tried very hard to apply the latest science and technology to engineering filter tips that would make cigarettes less hazardous. Yet, despite soliciting the help of independent research agencies and America's giants of industrial chemical and synthetic fibres research, including Dow, DuPont, Eastman Kodak, and Celanese, the fundamental science of cigarette design prohibited what the public wanted: a safe cigarette. While scientists on both sides of Cold War divide were launching animals and men into orbit, cigarette engineers at Philip Morris, British American Tobacco, Lorillard and other companies could not separate the 'satisfying' aspect of smoking from its health consequences.

METHODS

The primary source of documents on which this paper is based was obtained from the expert search function at the Legacy Tobacco Documents Library online database, http://legacy.library.ucsf.edu/action/search/expert, assembled at the University of California, San Francisco (UCSF). Searching the phrase 'filter problem' yielded some 300 documents, although this number fluctuated over the months as documents were uploaded or removed from the database. Many of these search results were redundant, unreadable or lacked relevant historical information. Thirteen documents were identified that provided the most interesting historical insight about the 'filter problem' in terms of efforts to understand what to filter from mainstream smoke, how to filter it and how to economically produce filtered cigarettes. The 13 documents that met these criteria were dated from 1954 to 1965, and directly involved the following groups: Philip Morris, Lorillard, British American Tobacco, DuPont's textile fibres department, Dow's experimental fibres division, Celanese, the Battelle Memorial research institution and the Kimberly-Clark Corporation. The limitations of relying heavily on these industry documents without corroborating the information they contain with other types of sources, such as personal communication with individuals named in the documents who may still be living, are acknowledged.

Given that much of this history concerned the development of new materials and methods, a GooglePatents search, http://www.google.com/patents, extending through the same date range was conducted with the phrase 'cigarette filter'. This phrase search returned patents involving related phrases such as 'cigarette filtration', 'cigarette filter production' and 'ventilated cigarette filter'. Between 1954 and 1965, numerous patents were issued to individuals and small companies for new filtered cigarette designs and methods of production. However, Eastman Kodak and Celanese dominate the patent record during these years, especially regarding large-scale production designs for filtered cigarettes. These two companies, then, became the focus of historical inquiry into the development of filtered cigarette production between the mid-1950s and mid-1960s.

In order to place these research and development events into proper historical context, medical and media histories of cigarette filters were investigated. Phrase searches were conducted in Medline and PubMed for relevant secondary medical studies, and in ProQuest and JSTOR for relevant secondary histories and media commentaries on filtered cigarettes. Fixed search terms, such as 'cigarette filter' and 'cigarette ventilation', were utilised along with the search stemming technique for variable phrases, such as 'cigarette smoke filt*' and 'cigarette vent*', that would return multiple variations of the searched stems ('filter', 'filtered', 'filtration', 'vents', 'ventilated', 'ventilation'). Finally, a manual search of topics related to these phrases was pursued in historical monographs devoted to the history of cigarettes, including Allan Brandt's *The Cigarette Century* and Richard Klugar's *Ashes to Ashes*.

RESULTS

The 'filter' concept

In 1950, an understanding of 'how and what to filter from (the) immensely complex mixture' of cigarette smoke relied on methods of chemical analysis and materials engineering beyond the abilities of cigarette companies.[1] The notion of filtering smoke to protect the lungs, however, predated cigarettes. Jean and Charles Dean had patented a protective fire fighter's mask in 1823, and Lewis Haslett had been awarded a patent for an 'Inhaler or Lung Protector' for coal miners and fire fighters in 1849.[7] Patents for cigarette mouthpieces, designed to keep tobacco out of the smoker's mouth, date from the late 19th century, while the vocabulary of 'filtering' cigarette smoke emerged at the turn of the 20th century. The first actual iteration of 'cigarette filter' appeared in a 1902 British patent entitled, 'New or Improved Means for Preventing or Minimising the Deleterious Effects of Tobacco Smoke'.[8] By the second decade of the 20th century, the language of 'filtering' tobacco smoke was becoming common. The word 'filter' was associated with a purifying action on mainstream smoke, as an Australian patent from 1911 spelt out in its title: 'Improvements relating to means for filtering or purifying smoke passing through cigarettes, cigars, or the like'.[9] Thus, in the face of lung cancer fears in the 1950s cigarette advertisers exploited the commercial etymology of the word 'filter', which long-connoted health protection through purification.

Research and development

In the wake of the second world war, Americans were smoking about 400 billion cigarettes each year, which necessitated a wholly automated and highly efficient manufacturing process.[10] Consequently, the suitability of a cigarette filter material depended on the workability of that material in the manufacturing machinery.[11] As Pauly *et al* observed in a 2002 *Tobacco Control* article:

> The speed at which cigarettes are made challenges the imagination—a single machine makes filter cigarettes at the rate of 15 000 or more per minute. This figure of 15 000 filter cigarettes per minute may be expressed also as 250 cigarettes per second; this is the equivalent of 50 cartons every 40 s… State-of-the-art production plants of major tobacco companies operate around the clock with multiple cigarette making and packing machines to produce millions of cigarettes daily.[12]

Natural fibres like cotton and wool possessed a relatively non-uniform structure, which would make it challenging to machine such fibres in mass filter production. Furthermore, it would be relatively difficult to obtain standardised filters from these natural fibres that would exert a uniform influence on mainstream smoke. What cigarette designers were looking for was a material that, ideally, could be custom-made. To this end, *synthetic* fibre technology, which had only recently begun to proliferate in the American market most notably in the form of nylon, seemed promising.

Like many of the large cigarette producers, Lorillard did not hesitate to solicit the help of America's top chemical companies to overcome the 'filter problem'. In December of 1954, F J MacRae, the assistant manager of Plastics Technical Service at Dow Chemical, wrote to Lorillard, 'Mr. C. W. Frost of our New York Office has advised us of your interest in evaluating experimental material for (cigarette) filters'. MacRae went on to say that, 'since (our) polyfiber possesses an exceedingly high surface to mass ratio and the product is in physical form which might lend itself readily to being formed into a cigarette filter, it is our thought that this product might be of interest to you for your work in filter investigations'.[13] In fact, Lorillard had turned to Dow for additional help with the filter problem after having achieved little success with DuPont's synthetic fibres.

Lorillard's director of research, H B Parmele, had been in regular contact with W W Watkins, DuPont's acetate sales development manager, throughout 1954. In February, Watkin's wrote to Parmele, 'We were naturally disappointed that our crimped regular acetate tow did not perform more satisfactorily for you'.[14] Both DuPont's and Dow's development of synthetic 'polyfibers' was nascent in the early 1950s. DuPont's first commercially successful synthetic fibre was nylon, which it developed just before the second world war, and the company produced only one other viable synthetic fibre by the early 1950s: the polyester, Dacron.[15] Synthetic fibre engineering represented cutting edge science at this time, and the cigarette industry's early attempts to obtain a machinable filter material from DuPont, Dow and others were often frustrated, as one of Watkins's letters typifies:

> I am sorry that the results reported in your letter of February 25, 1954, were not more promising. I am inclined to agree with your conclusion; namely, that we will have to devise a radically different approach to the filter problem if we are going to satisfy your requirements. I am sorry to say that I do not know just what this new approach may be.[5]

Nonetheless, the appeal of synthetic fibres was sufficient to warrant continued experimentation, as natural materials proved too problematic to incorporate into the cigarette manufacturing process. Researchers at Philip Morris, for example, realised just as those at Lorillard did that, 'the advantage of… a 'tow' of synthetic fibres is that they lend themselves to simple methods of additive applications and the handling is more simplified and thus would be more appealing from the point of view of production'.[16]

Philip Morris funded research at the Textile Research Institute in Princeton, New Jersey, in 1954 to narrow down the fibre options for use as a filter.[17] The Princeton team surveyed most of the existing cigarette filters on the market, carefully considering both 'filter efficiency' (the percentage of tar removed by the filter from mainstream smoke) and production costs. A notable filter design included in their assessment was Lorillard's Kent Micronite cigarette filter. This consisted of tightly packed creped paper that supported an array of asbestos fibres. Interestingly, the Princeton team judged the Micronite filter to be too effective; most smokers disliked Kent's bland taste and tough smoking draw (Micronites filtered 30% of tar particulate from mainstream smoke). In fact, Kent never garnered more than around 1% of the cigarette market.[18] Of more immediate concern, the Micronite filter was too structurally complicated for Philip Morris's design goals. The Princeton team's conclusion was unequivocal: not only was synthetic cellulose acetate fibre the most machinable for mass cigarette production, but pound for pound it was also the cheapest.

Cellulose acetate fibres are produced by treating raw cellulose, usually obtained from wood pulp, with acetic anhydride (a common acid reagent) in the presence of a catalyst. Cellulose acetate flake precipitates out of the reaction, which is then dissolved in acetone to yield a viscose solution. This solution is spun rapidly and allowed to extrude through small spinnerets into an area of warmed air where the acetone rapidly evaporates. Multiple solid, uniform strands of cellulose acetate filament are left behind. These filaments are combined into a 'tow': a ribbon consisting of many cellulose acetate strands.[19] The tow is packaged and shipped to cigarette manufacturers where it is machined into a continuous tube of cellulose acetate foam the diameter of a cigarette and cut into segments before being treated and affixed to the cigarette, an elaborate mechanical process that took years to perfect. Celanese Corporation and Eastman Kodak were two of the leading innovators in this area of filter research and development. 'The manufacture of filter rods from tow', elaborates one of Celanese's patent applications, 'is an expensive process involving manufacture of tow, opening of the tow bundle, precision topical application of plasticiser, forming the opened tow bundle into a rod, (and) wrapping and gluing the rod and cutting the rod into suitable lengths', all at rapid manufacturing speeds and without direct human assistance.[20] Yet, beyond the engineering complexity in this aspect of cigarette production, two fundamental questions about the science of smoke filtration continued to befuddle researchers: precisely how and exactly what to filter from mainstream cigarette smoke.

The tobacco industry knew that nicotine was primarily responsible for smokers' 'satisfaction' (ie, addiction). 'On the other hand,' wrote cigarette designers working for British American Tobacco in 1958, 'an important contribution to the immediate taste' of cigarettes appeared to originate, at least in part, from the vaporous phase of mainstream smoke.[21] Much of the mainstream smoke consisted of vapours that were recognised to be 'extremely important in imparting taste and aroma to the smoke', but that were also thought to include 'many of the irritable and/or physiologically active materials found in smoke'.[22] The aerosol of vaporous liquid and solid particulates is called 'tar'. The ability of a cellulose acetate cigarette filter to stop some fraction of this tar from entering smokers' lungs depended on two factors: (1) the probability that a given smoke particle would impact the surface of a filter element, and (2) the probability that the particle would remain attached to the filter surface after impact.[23] Increasing these probabilities—and hence the filter's efficiency—was the agenda of cigarette researchers.

Tar particles average only about 0.3 μm in diameter, and the velocity of mainstream smoke falls somewhere between 200 cm/s and 400 cm/s.[23] Cigarette researchers proposed various ways to increase the probability of contact between tar particles and filter fibres. Prominent among them was a design to induce electrostatic forces through chemical and/or physical means. Another was to augment natural eddy diffusion of tar particles around filter filaments. With eddy diffusion, even if a particle did not impact a filament directly it might re-circulate behind the filament and adhere to the reverse side, much like flowing water swirls in the wake of a stable boulder. To enhance eddy diffusion, researchers considered flattening out filter filaments, thereby increasing fluid turbulence.[23]

To induce electrostatic attraction between tar particles and cigarette filter filaments, researchers considered arranging filter fibres of opposing charge in parallel lines, which theoretically could be accomplished by coating fibres with oppositely charged metals. Neutrally charged tar particles entering this region would pass closer to one side of the line of filaments or another. As a particle approached the negatively charged filament line, its charge would become positive; after contact with the filament, the positive charge would be neutralised, leaving the particle with a net negative charge. This, in turn, would induce a strong electrostatic attraction to the opposite, positively charged filament wall. In this way, tar particles would bounce around from one filter wall to another, dramatically increasing the probability that they would stick to the filter filaments at some point.[23]

There is little evidence to suggest that these designs were ever mass-produced. Even for those ambitious filter designers who did manage to push their own, often clever, filter concepts through the US Patent Office, they seldom saw their ideas adopted by cigarette manufactures. Harry Frost Jr of Michigan, for example, designed a filter that could be 'activated' just before use by crushing a fluid container within the filter to moisten the cellulose acetate and enhance absorption of tar (a principle discussed below). Frost's contention that 'moisture in the tobacco during smoking produces a 'live' filtration', which, if augmented, could 'catalyze or accelerate the absorption of poisonous ingredients' was correct. However, his filter would have required mass production methods exceeding the cost and complexity parameters sought by cigarette producers.[24]

The industry documents convey a general enthusiasm for reducing the tar inhaled with mainstream smoke. In addition, the consensus by the end of the 1950s was that cellulose acetate filters would do nothing to stop smokers from inhaling the gases generated by tobacco combustion. The objective of Philip Morris's researchers in 1959 was typical: 'An acceptable filter should be able to retain at least 50% of the smoke particles with a pressure drop not exceeding 2.5 inches of water at a flow rate of 17.5 cc per second'.[23] This would cut mainstream smoke tar in half without significantly affecting the draw of a puff. In the late 1950s, however, the best cellulose acetate filters were reducing mainstream tar by some 15–30%, so if researchers wanted to double this filtration efficiency they would have to overcome uncomfortably high draw resistance and the bland taste that had suppressed sales of Kent Micronite filters.[25]

The most obvious way to continue to raise filter efficiency without increasing puff efforts was to 'vent' the filters. Patents for ventilated cigarettes become conspicuous in the 1960s. The designs featured small punctures about the filter shaft surface that allowed a portion of air to suffuse into the smoker's puff at the base of the cigarette, just outside the smoker's mouth. An early patent for a ventilated filter filed by Olin Chemical Corporation in 1959 and issued in 1962 stated that the primary purpose of the ventilation design was to provide smokers with a filtered cigarette that drew like an unfiltered cigarette.[26] According to a group of research consultants working with Philip Morris, the adoption of ventilated filters represented a panacea for the cigarette industry:

> The use of ventilated filters breaks through the limitation on the reduction of smoke delivery posed by the pressure drop inherent in mechanical filters of extremely high efficiency. Further, dilution tends to restore, to some degree, the balance between the gas phase and particulate content of the smoker which is skewed when high degrees of mechanical filtration, alone, are employed.[27]

Ventilation did more than simply bypass uncomfortably high draw resistance. By siphoning some of the mainstream puff volume from the base of the cigarette, the volume and velocity of the air moving through the cigarette shaft of ventilated cigarettes was decreased. This lowered the temperature of the burning cigarette and reduced the oxygen level at the site of combustion. 'Chemical processes in the pyrolysis and combustion zone are extremely temperature and oxygen dependent' announced Philip Morris researcher Allen Kassman at the 38th annual Tobacco Chemists' Research Conference in November 1984. By the time of that conference cigarette industry scientists had learned that 'even small changes in (mainstream) flow rate bring about significant changes in the minor chemistry of the smoke'.[28] One of the unanticipated effects of ventilated filters, then, appeared to be a reduction of mainstream toxic gas concentrations. Given the reduced velocity of air drawn through the cigarette shaft, carbon monoxide and nitric oxide generated during combustion were among the toxic gases more likely to diffuse than to be inhaled in the mainstream.[28] With the prospect of successfully reducing their concentrations in mainstream smoke via ventilation, selective filtration seemed like a legitimate design goal among cigarette researchers.

Outside the laboratory, however, cigarettes designed to exhibit selective filtration were adversely affected by smokers' behaviour. Altered burn rates, mainstream smoke taste and mainstream smoke composition meant altered smoking habits, generally in the form of higher volume and velocity draws by the smoker (compensation). This, in turn, counteracted selective filtration of toxic gases. 'Selective filtration is of practical value and has been sought after avidly', wrote a team of Celanese company researchers, but 'unfortunately not always with clearly demonstrable results'.[22] As more and more compounds in cigarette smoke were identified, a pattern emerged: manipulating one type of smoke compound or one dynamic of cigarette design usually precipitated a cascade of countereffects.

Through their efforts to make mainstream smoke less toxic, cigarette researchers had opened a Pandora's box to reveal how many potentially dangerous substances mainstream smoke contained. Towards the end of his 1961 presentation to the R&D Committee at Philip Morris, Dr H Wakeham, vice president of R&D at the time, emphasised that carcinogens were dispersed through 'practically every class of compounds in smoke', and that available technology would 'not permit selective filtration of particulate smoke'.[29] At the end of Dr Wakeham's presentation, cigarette designers at Philip Morris realised that they either had to abandon selective filtration, or entirely rethink cigarette filter design. Cigarette designers working for other companies were reaching similar conclusions, and through the mid 1960s they increasingly sought the help of other corporations that specialised in the research and development of advanced chemicals and materials.

In 1965, Lorillard hired the Celanese Corporation to reexamine the filter problem. Celanese researchers affirmed that cellulose acetate was the most practical basic filter material, in part because of their discovery that it could be treated in ways that might enhance its efficiency. It could be plasticised with triacetin to make it flexible and durable, and long-lasting humectants like glycerol and propylene glycol could be added to keep the cellulose acetate fibres moist (the design principle of Harry Frost Jr's patent, mentioned above). A number of tar components, including acetaldehyde, acetone, acetic acid and phenols, were more ‘chemically reactive with, or had a pronounced affinity’ for moist cellulose acetate.[22] Despite this, Celanese researchers concluded that no matter how much tar cellulose acetate filtered out, it would never effectively filter toxic mainstream gases. Nor, they asserted, would ventilation entirely solve this problem. Nearly 20 years later at the 1984 tobacco chemists’ research conference, Kassman reaffirmed that ‘ventilation serves to reduce the quantities of (carbon monoxide and nitric oxide) but does not significantly alter their deliveries relative to tar’.[28] Smokers tended to puff vented cigarettes relatively vigorously to obtain ‘satisfaction’, which undermined selective toxic gas filtration.

In their effort to preserve a balance of tar (which contained nicotine) while selectively reducing toxic gas levels in mainstream smoke, Celanese researchers in the mid 1960s focused on three physical processes within filters: (i) Brownian diffusion of gas molecules, (ii) adsorption of gas molecules to the surfaces of filter elements and (iii) absorption of the vaporous tar aerosol into the filter elements. Brownian diffusion drives gas molecules from mainstream smoke to nearly all the surfaces of filter fibres during a regular puff.[22] Brownian diffusion occurred rapidly, taking about half the time that the smoke passed through the filter for complete molecular diffusion to occur. The problem was that gas molecules did not adsorb to filter surfaces on contact. The ‘condensation of (gas) molecules on the filter surface’ was necessary if mainstream gases were to be reduced.[22] Absorption, the third principle process involved in smoke filtration, occurred when vaporous droplets of tar, such as phenols, liquid paraffin hydrocarbons and water contacted and then diffused into filter fibres. Evidence of this effect was the ‘wicking’ action of cellulose acetate for condensed phenol molecules’ and water, and the consequent moistening of the filter as the cigarette was smoked.[22] Analysis of cellulose acetate filter efficiency during the last puffs of a cigarette had led to the discovery that absorption rates positively correlated with the filter’s moisture content. While this prompted interest in treating cellulose acetate filters with moisteners, as discussed above, Celanese researchers determined that *ab*sorption of tar vapour or any other moisture into cellulose acetate fibres prevented the *ad*sorption of gaseous elements. The hygroscopic quality of cellulose acetate was the reason why cellulose acetate filters had been ineffective at trapping harmful mainstream gases.

Celanese researchers found that, ‘the use of impregnated charcoals and other adsorbents to selectively adsorb toxic gases (was) frequently described in the literature dealing with gas masks’ worn in battle during the first and second world wars.[22] Charcoal is almost completely non-hygroscopic, which would prevent it from absorbing tar and leave it free to adsorb gases. Incorporating a small region of charcoal somewhere into a cellulose acetate filter plug seemed appropriate. Activated charcoal is solid carbon that is processed to maximise its porosity, and hence its surface area to mass ratio. One gram of activated charcoal can have a surface area of several hundred square metres. In the porous labyrinth of activated charcoal, toxic gas molecules in mainstream cigarette smoke would be more likely to adsorb, while tar would continue to absorb into the hygroscopic cellulose acetate sections. Unfortunately, laboratory testing of new activated charcoal filters did not yield promising results. In one series of tests, Celanese researchers ‘found no significant difference in carbon monoxide yield between filtered and unfiltered cigarettes’, while ‘hydrocarbons were found in essentially equivalent amounts in the fourth puff coming from unfiltered, (cellulose) acetate filter, and charcoal filter cigarettes’.[22] It became evident that ‘filter cigarettes, even those containing appreciable quantities of adsorbent charcoal, (did) not selectively reduce the levels of permanent gases in cigarette smoke’. One reason for the ultimate ineffectiveness of activated charcoal to adsorb toxic gases was the high temperatures to which the charcoal filter regions were exposed as the burning ember of the cigarette approached. Even when certain toxic gasses were adsorbed in early puffs, the heat of the last few puffs seemed to ‘re-volatise’ any adsorbed gas molecules. In America today, virtually no cigarette filters contain charcoal.

Changing the agenda

Although cigarette filter researchers developed a significant body of scientific knowledge about smoke flow dynamics and filter engineering by the middle of the 1960s, their principal realisation was that the ‘filter problem’ could not be practically solved. They had confronted an engineering contradiction: to design a cigarette filter that would appreciably reduce the health hazards imposed by smoking (caused by tar, nicotine and gases) while preserving the taste and ‘satisfaction’ that smokers craved (provided by tar, nicotine and gases). Thus, alternative manipulations to cigarette design continued to be made in order to perpetuate the popular belief that ‘safe’ cigarettes were possible. Chemist Claude Teague, a filter researcher working for R J Reynolds, found that manipulating the pH in cellulose acetate-based filters produced discolorations in the filter during smoking:

> The cigarette smoking public attaches great significance to visual examination of the filter material in filter tip cigarettes after smoking the cigarettes. A before and after smoking visual comparison is usually made and if the filter tip material, after smoking, is darkened, the tip is automatically judged to be effective. While the use of such colour change material would probably have little or no effect on the actual efficiency of the filter tip material, the advertising and sales advantages are obvious.[30]

Even while industry researchers failed to actually engineer effective filters, there were ways to engineer the *illusion* of effective filters.

Filter ventilation became the most exploited means by which reductions in measured tar and nicotine yields were maintained. Nearly all filtered brands now incorporate vents.[31] Ventilated cigarette filters have enabled cigarette producers to attach terms like ‘ultra light’ and ‘low tar’ to their brands, which technically delimit tar yield per cigarette to between 1 mg (ultra light) and 15 mg (low tar). Vents allow upwards of 50% air dilution of mainstream smoke in some of these brands, which consequently cuts tar yields in half, at least in the laboratory. When the Federal Trade Commission (FTC) began testing cigarettes for tar and nicotine yields in 1967, ‘the test procedure was essentially the same as that developed by researchers at major cigarette manufacturers: a machine takes a 35 ml puff of 2 s duration once a minute until a fixed butt length is reached’.[31]

A standardised laboratory test permitted cigarette producers to anticipate test conditions and design cigarettes according to target measurements. Ventilated cigarettes are designed primarily to accommodate this standard testing procedure rather than to yield certain tar measurements when smoked by average consumers. Cigarette producers adhered to FTC-mandated sales-weighted nicotine yields of cigarettes as limits on those yields dropped steadily from 1968 to 1997, from about 22 mg per cigarette to about 12 mg.[32] Vented cigarettes may yield 12 mg of nicotine when affixed to a smoking machine, but these brands are designed to exhibit what the cigarette industry refers to as ‘elasticity’; human smokers can easily obtain substantially more tar and nicotine than laboratory tests suggest. 'Studies inside and outside the cigarette industry have found considerable evidence that many smokers block filter vents with their fingers or lips', usually without knowing.[33] Filter vents are practically impossible to see with the naked eye, and blocking even a portion of them can increase tar and nicotine yields well above laboratory results.

CONCLUSION

Even though filtered brands currently constitute over 90% of the entire cigarette market, as early as the mid-1960s the Surgeon General judged cigarette filters to be useless in reducing harm to the average smoker.[34] Indeed, epidemiological data gathered between the 1970s and early 2000s continue to support the conclusion that the nearly universal adoption of cigarette filters has done little to protect smokers. In 2010, a team of investigators from the USA and Japan asserted in the *International Journal of Cancer* that 'the shift from nonfilter to filter cigarettes appears to have merely altered the most frequent type of lung cancer, from squamous cell carcinoma to adenocarcinoma'.[35] Likewise, there is still no compelling evidence that cigarette filters have done anything to mitigate other health hazards of smoking such as heart disease.

However, during the research and development phase of filtered cigarettes in the 1950s and 1960s, few argued that filters *could not* be designed to reduce the hazards of smoking. Could one claim that cigarette companies' efforts to develop filtered cigarettes were a complete farce from the very beginning? It does not seem so. In fact, the opinions of prominent health authorities from the period suggest that uncertainty regarding the potential health protection cigarette designers might provide through filters persisted at least through the middle of the 1950s. In a 1955 medical monograph edited by an epidemiologist at the Sloan-Kettering Institute for Cancer Research, which included a foreword by one of the chief editors of the *New England Journal of Medicine*, the possibility of protective cigarette filters was not dismissed:

> It remains to be shown whether removing a small percentage of the tar will decrease the carcinogenic activity of this material. The answer to this question cannot be given until such time as we know what the active carcinogenic component of tobacco tar really is... whether a given filter is successful in removing or reducing the carcinogenic properties of tobacco smoke cannot be ascertained at this time.[36]

The fundamental paradox of cigarette smoke filtration that has become so clear eluded many people inside and outside the tobacco industry until the mid 1960s: that which is harmful in mainstream smoke and that which provides the smoker with 'satisfaction' are essentially one and the same. Ventilation represented not so much a panacea in the pursuit of harm reduction as an ultimate surrender to this intractable principle.

This study did not identify direct evidence in tobacco industry documents that tobacco company executives or cigarette researchers in 1950s seriously doubted that their efforts would eventually make cigarettes less hazardous. Nor is it evident that everyone in the industry involved in early research to reduce toxic gas levels in mainstream smoke through selective filtration or ventilation thought the effort was futile. The industry's willingness to privately hire the help of major technology companies such as DuPont, Dow, Eastman Kodak and Celanese to solve the 'filter problem' suggests the opposite. Undoubtedly, there has been a plethora of disingenuous marketing of the health benefits of filtered cigarettes, as several historians have already elucidated.[30] Still, the available historical evidence suggest that many of the early efforts to make smoking less harmful by designing effective filters were sincere, and were motivated by the belief that it was only a matter of time and money until scientific solutions to the 'filter problem' were found. This period was an age of big science, of NASA, of the explosion of the plastics market, of the discovery of the DNA double helix. From the perspective of cigarette filter engineers in the 1950s with blank checks for filter research, 'safe cigarettes' would not necessarily have appeared as a technological impossibility. Although cigarette engineers have known for decades that filters are ineffective in reducing the health consequences of smoking, the early history of this research and development agenda might be separated from the misleading marketing of filtered cigarettes that has persisted for nearly 60 years. In so doing, further consideration may be given to the examination of other historical cases where well intentioned, well funded science was pursued within otherwise unscrupulous corporate contexts.

What this paper adds

Since it has been well argued that the nearly universal shift to filtered cigarettes has not substantively reduced the health hazards of smoking, many investigators have turned their attention to exploring the potential negative impacts of cigarette filters. Some have revealed that cellulose acetate filters may themselves pose an acute health hazard to smokers by contributing to the toxic load of mainstream smoke. Others are now presenting compelling evidence that used and discarded cigarette filters represent a significant source of environmental pollution. While evidence mounts that cigarette filters do more harm than good, there is a need for a fuller understanding of the origin of cigarette filters as a technological product of relatively sophisticated research and development. This paper helps to illuminate how and why the discarded synthetic plastic cigarette filters that inundate our environment were created to begin with. In so doing, this paper contributes historical perspective to the recognition that cigarette filters are a defective technology.

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