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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
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CDC
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A Review and Recommendations Regarding Batch Kier Washed Cotton

by
The Task Force for Byssinosis Prevention
(formerly the Industry/Government/Union Task Force for Washed Cotton Evaluation)

Member organizations:

Agricultural Research Service, U.S. Department of Agriculture
Amalgamated Clothing and Textile Workers Union
American Textile Manufacturers Institute
Cotton Incorporated
National Cotton Council of America
National Institute for Occupational Safety and Health

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FOREWORD

The Occupational Safety and Health Act of 1970 (Public Law 91-596) states that the purpose of Congress expressed in the Act is "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources." In the Act, the National Institute for Occupational Safety and Health (NIOSH) is authorized to develop and establish recommended occupational safety and health standards and to conduct such research and experimental programs as are necessary for the development of criteria for new and improved occupational safety and health standards.

Criteria for a Recommended Standard...Occupational Exposure to Cotton Dust, a major NIOSH policy document, was published in 1974. The recommendations for a cotton dust standard contained in that criteria document made no mention of washed cotton. Shortly after promulgation of a comprehensive cotton dust standard by the Occupational Safety and Health Administration (OSHA) in 1978, new interest focused on evaluating the potential role of washed cotton in the prevention of byssinosis and related occupational respiratory disorders among cotton textile mill workers. Consequent to a special congressional appropriation to the U.S. Department of Agriculture (USDA) beginning in 1980, NIOSH (at the request of the Secretary of Agriculture) joined with other organizations to establish a government/industry/union task force to collaborate on research to evaluate washed cotton as a potential means of preventing byssinosis. Along with NIOSH, member organizations in this partnership included the Agricultural Research Service (USDA), the Amalgamated Clothing and Textile Workers Union, the American Textile Manufacturers Institute, Cotton Incorporated, and the National Cotton Council of America. The washed cotton research completed by these Cooperators during the early years of the partnership proved of great value to OSHA in its review of the original cotton dust standard and its promulgation of a revised standard in 1985. Much of that work was summarized in a monograph published in 1986 by the U.S. Department of Agriculture. The current publication reviews the earlier work, summarizes more recent research on batch kier washing of cotton, and provides recommendations regarding prevention strategies involving washed cotton.

Representatives of each of the six cooperating organizations have contributed greatly to the content and form of this document. Each of these organizations has reviewed the document and shares responsibility for the conclusions reached and the recommendations made. The exemplary nature of this government/industry/union partnership on washed cotton research has been lauded by OSHA and by the Office of Technology Assessment, and the Institute is pleased to take a lead role in transmitting this publication to OSHA and supporting its dissemination through the cotton industry.

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SUMMARY

The OSHA comprehensive cotton dust standard, originally promulgated in 1978 and revised in 1985, requires medical monitoring of workers and administrative controls as adjuncts to dust control for preventing occupational respiratory disease from cotton dust exposure. The standard also provides for alternative preventive strategies, including substitution of washed cotton for untreated cotton.

The 1978 standard completely exempted cotton that has been severely washed at 100°C for 30 min in a batch kier system (Table 1). However, the resulting fiber was characterized by severe processing difficulties in textile manufacturing. In 1980, a research program was initiated to evaluate the potential effectiveness of less severe washing of cotton. Conducted with funds from a special congressional appropriation to the U.S. Department of Agriculture, this research was conducted under the auspices of a tripartite (Industry/Government/Union) Task Force on Washed Cotton Evaluation (subsequently renamed the Task Force for Byssinosis Prevention).

Task Force studies demonstrated that mild washing (essentially water rinsing) of cotton in a continuous batt or rayon rinse system physically removes dust from the cotton and also markedly reduces adverse airway response to residual dust. In contrast, card-generated dust from cotton that was mildly washed in a now-outmoded batch kier washing system (though much less potent than dust from unwashed cotton) was found in some cases to retain measurable airway activity. The variable results observed in the early batch kier washing studies were attributed to channeling of wash and rinse solutions through the cotton, which prevented thorough washing of the cotton fiber. Channeling was caused by nonuniform hand loading directly from the bale without mechanical opening, cleaning, or prewetting.

In 1985 OSHA revised the washed cotton provisions in the cotton dust standard. In addition to specifying severe washing conditions necessary for complete exemption, the revised standard added partial exemptions for cotton that has been mildly washed in a continuous system (Table 1). No exemptions were provided for cotton that has been mildly washed in a batch kier system. Partly because of the extremely limited availability of continuous systems for washing cotton and the potential availability of production capacity on modern batch kier systems, OSHA solicited additional research to evaluate batch systems further.

Recent Task Force investigations have evaluated the effectiveness of mild washing on batch kier systems at two different companies using state-of-the-art automated systems for mechanically opening and thoroughly wetting cotton fiber during the kier-loading process. Results of several washing trials on different blends of cotton indicated that modern batch kier systems are capable of mildly washing cotton as effectively as the already partially exempted continuous batt process. This research has shown that mildly washing cotton in batch kier systems (using modern equipment that assures thorough wetting of the cotton fiber and no reuse of wash or rinse water) is, with respect to effectively removing potential respiratory toxicity, equivalent to mildly washing cotton on a continuous batt system. Assessment of washing effectiveness in these studies has been largely based

on substantial removal of dust and on marked reduction of residual dust toxicity as measured by endotoxin content and by elimination of acute human ventilatory response. On the basis of results of experimental exposure studies and observational studies of workers exposed to cotton or other organic dusts, these beneficial effects can be expected to prevent chronic as well as acute respiratory effects in exposed workers.

In conclusion, the Task Force recommends that OSHA add mild washing in a modern batch kier system as an acceptable method to wash cotton under the 1985 cotton dust standard (Table 2). The Task Force also makes other recommendations intended to encourage voluntary substitution of washed cotton for unwashed cotton as a means for reducing potential risk of occupational respiratory disorders among workers exposed to cotton dust.

Table 1. Summary of occupational health regulatory history of washed cotton in the United States

Year	Rule	Exemptions for various washing conditions	Comments
1978	OSHA Cotton Dust Standard [43 Fed. Reg. 27351 (1978)]	**Severe wash :** Complete exemption for cotton "thoroughly washed in hot water" and "known in the cotton textile industry as purified or dyed."	It was "not clear what cleansing processes ... qualify cotton for exemption" [50 Fed. Reg. 51120 (1985)]. Severely washed cotton is extremely difficult to process into textiles.
		Mild wash: None.	Mildly washed cotton was not addressed in standard.
1985	Revised OSHA Cotton Dust Standard [50 Fed. Reg. 51120 (1985)]	**Severe wash:** Complete exemption for "medical grade (USP) cotton, cotton that has been scoured, bleached, and dyed, and mercerized yarn."	These processes are more severe than the mild wash. Severely washed cotton is extremely difficult to process into textiles.
		Mild wash: Partial exemptions* for cotton washed: (i) on a continuous batt system or rayon rinse system; (ii) with water; (iii) at a temperature of no less than 60°C; (iv) with a water-to-fiber ratio of no less than 40:1; and (v) with bacterial levels in the wash water controlled to limit bacterial contamination of the cotton. *Exemption from all requirements except medical surveillance and medical recordkeeping *for higher grade cotton* (low middling light spotted or better) washed per above conditions. *Exemption from all requirements except for medical surveillance, medical recordkeeping, and a 500-µg/m^3 permissible exposure level (PEL) for airborne dust measured by the vertical elutriator sampler *for lower grade cotton* (below low middling light spotted) washed per above conditions.	Facilities for mildly washing cotton are limited. The continuous batt system used in the Task Force evaluations had a production capacity of only 500 lb/hr for washing cotton, and the rayon rinse system has very limited availability.

Table 2. Summary of Task Force recommendations for near-term future regulation of mildly washed cotton

	Recommended exemptions for various washing conditions	Comments
Recommended amendment of OSHA Cotton Dust Standard	**Severe Wash:** No change from 1985 Revised OSHA Standard	Severe washing was not a focus of Task Force consideration. These processes were not further considered.
	Mild wash: Partial exemptions* for cotton washed, either: (A) on a continuous batt system or rayon rinse system, (i) with water, (ii) at a temperature of no less than 60°C, (iii) with a water-to-fiber ratio of no less than 40:1, and (iv) with bacterial levels in the wash water controlled to limit bacterial contamination of the cotton; or (B) on a batch washing system, (i) with water, (ii) with cotton fiber mechanically opened and thoroughly prewet prior to forming the cake, (iii) for low temperature process, at a temperature of no less than 60°C with a water-to-fiber ratio of no less than 40:1, or for high temperature process, at a temperature of no less than 93°C with a water-to-fiber ratio of no less than 15:1, and (iv) with a minimum of one wash cycle followed by two rinse cycles for each batch, using fresh water in each cycle. *Exemption from all requirements except medical surveillance and medical recordkeeping *for higher grade cotton* (low middling light spotted—grade code 52—or better) washed per above conditions. *Exemption from all requirements except for medical surveillance, medical recordkeeping, and a 500-$\mu g/m^3$ permissible exposure limit (PEL) for airborne dust measured by the vertical elutriator sampler *for lower grade cotton* (below low middling light spotted—grade code 52) washed per above conditions.	The purpose of this recommendation is to encourage voluntary substitution of washed cotton for unwashed cotton as a strategy to prevent respiratory disorders induced by cotton dust. Compared to unwashed cotton, mildly washed cotton can be more difficult and more costly to process into fine textiles, so potential uses will probably involve smaller novelty or niche markets. Mild washing may enhance textile processing characteristics of some cotton (e.g., "sticky" cotton), and may also enable value-added special effects (e.g., special dyeing characteristics for novelty yarns; improved quality of rotor-spun yarns). Under the new USDA classification system begun in 1993, low middling light spotted cotton corresponds to color grade code 52, leaf grade code 5.

CONTENTS

ABBREVIATIONS

CFR	Code of Federal Regulations
^{0}C	degree Celsius
cu	cubic
FEV_1	forced expiratory volume in one second
g	gram
hr	hour
m	meter
m^3	cubic meter
mg	milligram
min	minute
ng	nanogram
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
lb	pound
PEL	permissible exposure limit
µg	microgram
USDOL	United States Department of Labor
USDA	United States Department of Agriculture
USP	United States Pharmacopeia

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"Those whose commitment is to the public's health must simultaneously follow promising lines of inquiry while taking maximum advantage of what is presently known to control or eliminate occupational disease" [Wegman et al. 1983].

INTRODUCTION

In 1971, the Occupational Safety and Health Administration (OSHA) adopted a 1-mg/m^3 (total dust) permissible exposure limit (PEL) for cotton dust. Subsequent OSHA rulemaking led to the eventual promulgation of a comprehensive Federal occupational health standard for cotton dust in 1978 [43 Fed. Reg. 27351 (1978)]. In the 1978 standard, OSHA established different 8-hr time-weighted average (TWA) PELs for gravimetrically measured airborne cotton dust for different work areas of textile mills. In the absence of any known "safe level of exposure" [41 Fed. Reg. 56498-56527 (1976)], the lowest PEL—200 µg/m^3 (0.2 mg/m^3) of airborne dust as measured by the vertical elutriator cotton dust sampler—was considered the lowest feasible level that could be achieved in many operations [NIOSH 1974].

As with all comprehensive standards promulgated by OSHA, the 1978 standard included provisions for medical monitoring of workers and administrative controls as adjuncts to dust control for prevention of occupational respiratory disease from cotton dust exposure. In fact, by the early 1980's, these approaches together appear to have accounted for a substantial reduction in the prevalence of byssinosis in many U.S. cotton textile mills [Merchant 1983]. However, a NIOSH-sponsored committee remained concerned that "even at very low concentrations of cotton dust, a considerable proportion of cotton textile workers may be at risk of developing byssinosis" [ASPH 1986]. (This concern reflected an earlier NIOSH conclusion that "even at levels of 0.1 or 0.2 mg/cu m there has been a definite incidence of byssinosis" [NIOSH 1974]. The concern was recently supported by evidence suggesting that dust-related accelerated decline in cotton textile workers' lung function occurs even at the 200-µg/m^3 PEL among those who smoke [Glindmeyer et al. 1991].)

The continuing (albeit much lower) risk of byssinosis, the costs of further controlling dust, and the realized and potential future costs of compensating affected workers represented ample reasons to pursue alternative preventive strategies, including substitution of cotton treated to reduce toxicity for untreated cotton in textile mills [Millar 1988].

WASHED COTTON IN THE 1978 OSHA COTTON DUST STANDARD

Background

More than 30 years ago, a study of workers processing medical grade cotton (severely washed with alkali scour and bleach) found that despite very high dust levels (median concentration of 12 mg/m^3 by electrostatic precipitation), exposed workers had no symptoms of byssinosis, whereas the prevalence rate for such symptoms was 25% in a comparison group working with unwashed cotton (median concentration less than 7 mg/m^3) [El-Batawi and El-Din Shash 1962]. This same study also found no decrease in ventilatory capacity over the workshift among medical cotton workers; this finding was in contrast to an overall significant acute reduction in ventilatory capacity among workers processing unwashed cotton.

In the early 1960s, leading authorities on byssinosis, intrigued by the implications for prevention of these and related findings, commented in a summary report of a conference:

> As there is evidence that there are very few cases of byssinosis among workers in mills processing cotton which is treated with sodium hydroxide and bleached with hypochlorite, and that the pharmacologically-active substances are water soluble, the possibility should be considered of washing the cotton to remove the harmful substances before it is processed [Schilling et al. 1963].

Experimental studies by McDermott and colleagues included exposures of human subjects to dust from washed cotton. This dust had only half the histamine-releasing activity of dust from unwashed cotton and caused only minimal changes in airways resistance and forced expiratory volume in one second (FEV_1) despite "no change in the physical properties of the dust clouds compared with the unwashed cotton" [McDermott et al. 1968]. The investigators concluded that compared with a "large increase in airways resistance induced by exposure to dust from unwashed cotton, washed cotton dust in similar concentration and particle size does not produce any response" [McDermott 1969].

In an experimental study employing card-generated cotton dust and selected mill employees, Merchant and colleagues demonstrated that acute ventilatory responses were substantially reduced or eliminated by severely washing cotton before processing [Merchant et al. 1973]. Overall, processing strict low middling (grade code 41) cotton that had been washed not only reduced respirable dust concentrations by more than 80% but also reduced frequency of byssinosis symptoms by nearly 90% compared with processing unwashed cotton of the same grade. Furthermore, mean FEV_1 increased slightly during the washed cotton exposures in contrast to substantial mean FEV_1 reduction in response to dust from the unwashed cotton. The investigators summarized by stating that "of the dust that remained after washing, no biological activity could be detected by our indicators, although the respirable dust level with one trial was as high as 0.26 mg/m^3" [Merchant et al. 1973]. However, the resulting fiber did not process well in yarn manufacturing, and the authors recommended that "because washing cotton appears to eliminate completely biological activity, further efforts should be made to wash cotton...in a manner compatible with subsequent processing" [Merchant et al. 1973].

1978 Complete Exemption for Severely Washed Cotton

Based on "the effectiveness of the washing process in significantly reducing or eliminating the biological effects of cotton dust," a provision of the 1978 standard exempted cotton "thoroughly washed in hot water" and "known in the cotton textile trade as purified or dyed" [43 Fed. Reg. 27351 (1978)].

Limitations of the 1978 Complete Exemption for Severely Washed Cotton

In retrospect, the 1978 OSHA standard was admittedly—

> ambiguous as to the exact washing processes which would produce non-reactive cotton. The only cotton which was clearly covered by it was the severely washed cotton tested by Dr. Merchant. ...Although "purified or dyed" cotton was exempted, it was not clear what cleansing processes must be included to qualify cotton for exemption [50 Fed. Reg. 51120 (1985)].

In practice, the least severe wash approved for exemption was a batch system with water/wetting agent at 100°C for 30 min. The resulting fiber, characterized by severe technical processing difficulties, could not feasibly be used to manufacture quality yarn. Therefore, although the Department of Labor reported in 1979 that "washed cotton technology is ...on the verge of technological and economic feasibility" [USDOL 1979], there was a need for substantial research to evaluate the effectiveness of less severe washing as a means for eliminating or substantially reducing the cotton dust hazard. In response, in 1980 and following years, the United States Congress appropriated funds for "high-priority research to develop solutions to the byssinosis health hazard caused by prolonged exposure of textile mill workers to cotton dust" [Committee on Appropriations 1980].

WASHED COTTON IN THE 1985 REVISION OF THE STANDARD

Background

Additional studies were subsequently conducted under the auspices of a tripartite (government/industry/union) Task Force on Washed Cotton Evaluation (now the Task Force for Byssinosis Prevention), which comprised the following member organizations: Agricultural Research Service (formerly the Science and Education Administration) (U.S. Department of Agriculture); National Institute for Occupational Safety and Health (U.S. Department of Health and Human Services); National Cotton Council of America; Cotton Incorporated; American Textile Manufacturers Institute; and Amalgamated Clothing and Textile Workers Union.

These extensive and carefully controlled human exposure studies demonstrated that mild washing (essentially water rinsing) of cotton on a continuous batt or rayon rinse system has two major effects relevant to occupational respiratory disease prevention among cotton textile workers. First, mild washing physically removes dust from the cotton, generally reducing subsequent generation of respirable dust by about 50% (range, 35% to 67%). Second, mild washing markedly reduces the acute airway toxicity of residual dust, as measured by acute ventilatory responses of experimentally exposed human subjects. Both beneficial effects were shown to vary somewhat depending on specific washing methods used and on the initial potency of the cotton washed. Details have been published elsewhere [Wakelyn et al. 1986].

In contrast to mildly washed cotton from continuous batt and rayon rinse systems, mildly washed cotton from a batch kier washing system (though clearly much less potent than unwashed cotton dust) was found in some cases to retain significant acute airway activity in the human exposure studies, as measured by acute ventilatory responses [Castellan 1986]. The variable results observed were attributed to channeling of wash and rinse solutions through the cotton, which prevented thorough removal of dust and soluble material from the cotton fibers. Channeling was caused by hand loading directly from the bale without mechanical opening, cleaning, or prewetting.

1985 Exemptions for Washed Cotton

In 1985,on the basis of a review of the existing data, comments, and Task Force recommendations [OSHA Docket H-052], OSHA substantially revised the washed cotton provision in the cotton dust standard. In clarifying the previously ambiguous washed cotton exemption, the revised standard provides a complete exemption only for "medical grade (USP) cotton, cotton that has been scoured, bleached and dyed, and mercerized yarn" [OSHA 1985]. Importantly, the 1985 revision adds partial exemptions for mildly washed cotton (as described in the following paragraphs); but consistent with Task Force recommendations, it provides no exemptions for batch kier washed cotton [50 Fed. Reg. 51120 (1985)].

Exemption from all requirements of the standard except for medical surveillance and medical recordkeeping is provided for higher grade cotton (low middling light spotted, or better—i.e., color grade code 52 or better and leaf grade code 5 or better according to the current classification system [USDA 1993a]) that is washed: (1) on a continuous batt system or rayon rinse system, (2) with water, (3) at a temperature of no less than 60°C, (4) with a water-to-fiber ratio of no less than 40:1, and (5) with bacterial levels in the wash water controlled to limit bacterial contamination of the cotton.

Lower grade cotton (i.e., below color grade code 52 or below leaf grade code 5 by the current classification system [USDA 1993a]) that is washed as specified in the preceding paragraph for higher grade washed cotton and is also bleached is exempted from all requirements of the standard except for medical surveillance, medical recordkeeping, and a 500-$\mu g/m^3$ PEL for airborne dust measured by the vertical elutriator sampler. With respect to washed cotton of mixed grades, the 1985 revised standard specifies that the requirements for the grade with the most stringent requirements would apply.

Limitations of the 1985 Partial Exemptions for Mildly Washed Cotton

The availability of continuous batt washing systems (including rayon rinse systems) for washing cotton is extremely limited. The continuous batt system used in the Task Force evaluations had a production capacity of only 500 lb/hr and is unavailable for commercial washing of cotton. The rayon rinse system has a much lower production rate for washing cotton, and the few rayon rinse systems available in the United States are fully utilized in rayon production. In contrast, production capacity on modern batch kier systems is much higher, and essentially all cotton washing for medical uses (e.g., cotton balls, surgical sponges, etc.) and essentially all cotton dyeing for textile uses (e.g., stock dyeing for denim products, etc.) utilizes batch kier processes.

OSHA's Director of Policy anticipated the limitations of the 1985 revised standard in stating that "OSHA hopes to receive additional information as to acceptable cotton washing methods and alternative ways of predicting human respiratory response to cotton dust exposure" [Goldin 1984]. This, together with the projected availability of batch kier systems (in contrast to continuous batt or rayon rinse systems) for washing cotton, and along with improved technology for modern batch kier systems already in use for medical grade washing and stock dyeing of cotton, led to further evaluations of batch kier systems as a means of pretreating cotton to reduce toxicity.

RECENT EVALUATIONS OF MILDLY WASHED COTTON

Initial Studies of Modern Batch Kier Washing

As mentioned above, the earlier batch kier washing trials had been performed on systems involving hand loading of cotton fiber without prior mechanical opening or prewetting. This resulted in incomplete wetting of cotton fibers during the washing process, which was probably the cause of the inconsistent results observed in the earlier studies of batch kier washing. In 1988, Task Force investigators visited two companies utilizing batch kier processes with automated systems for mechanically opening and thoroughly wetting cotton fiber during the kier-loading process. To evaluate the effectiveness of batch kier washing using this state-of-the-art opening and wetting technology, arrangements were made to wash cotton on one of these commercial systems for comparison with the same cotton washed using a continuous process as partially exempted in the 1985 revised standard. The study [Perkins and Berni 1991] is summarized in the following paragraphs.

A blend of Midsouth cotton of predominantly grade code 52 (i.e., color grade code 52 and leaf grade code 5 according to the current classification system [USDA 1993a]) was selected as a worst-case test. This is the lowest grade that, following a continuous process wash, would be exempted under the 1985 revised standard from all provisions except for medical surveillance and medical recordkeeping. Furthermore, over a recent 5-year period, less than 10% of the cotton crop was lower than this grade [USDA 1989, 1990, 1991, 1992, 1993b, 1994]. Part of the blended cotton was left unwashed, part was mildly washed using a continuous-wash system according to process criteria stipulated in the 1985 revised OSHA standard, and part was mildly washed in the modern batch kier system—two kiers each of two different washing conditions. One of the batch kier wash conditions involved temperature and water-to-fiber ratio as specified in the 1985 revised standard for continuous wash systems. The other wash condition—lower water-to-fiber ratio and shorter wash time, but with a higher temperature—was considered *a priori* to be more commercially feasible.

Compared with the unwashed cotton, all three mild washings resulted in substantial and statistically significant reduction of card-generated airborne cotton dust—in each case by at least 50%. In addition, the three different mild wash treatments were highly effective and statistically equivalent in reducing the endotoxin content of card-generated airborne elutriated dust. As a result, the concentration of airborne endotoxin—a more specific indicator of the respiratory hazard contained in cotton dust than gravimetrically measured dust concentration (see Appendix)—was very effectively reduced by all three washings, from more than 300 ng/m^3 for the unwashed cotton (at a dust level of 1.98 mg/m^3) to less than 10 ng/m^3 for each of the washed cottons (at dust levels ranging from 0.35 mg/m^3 to 0.89 mg/m^3). These low airborne endotoxin levels generated during card processing of the washed cottons were all below a relative "threshold" for acute airway response in humans described previously by NIOSH investigators in this same setting [Castellan et al. 1987]. Given the well-recognized interlaboratory variability associated with measurement of endotoxin activity in dust samples [Perkins 1992; Chun and Perkins 1994], it is important to note that the endotoxin assays were from the same NIOSH laboratory using the same standards that were used in the earlier studies.

In sum, the results of this research clearly demonstrated that the modern batch kier system is capable of mildly washing cotton as effectively as the already partially exempted continuous batt process. However, after reviewing the research results and obtaining input from selected Task Force member organizations, OSHA was disinclined to provide any new exemption for batch kier washed cotton without first having "additional data from washing trials involving a range of cotton blends at more than one washing facility," as well as more information on implications for chronic respiratory disease potential of mildly washed cotton [Adkins 1990]. Over the past several years, research findings have been generated that provide this additional information.

Additional Studies of Modern Batch Kier Washing

To further assess the effectiveness of mildly washing cotton in modern batch kier systems, another blend of predominantly color grade code 52 and leaf grade code 5 cotton (this time grown in Texas) was washed on a batch kier system operated by another company [Jacobs et al. 1993; Perkins and Olenchock 1995]. Washing, done at 60°C and a 40:1 water-to-fiber ratio as stipulated in the 1985 revised standard for continuous wash systems (or, alternatively, at 93°C and 17:1 water-to-fiber ratio), resulted in a reduction of at least 50% in dust-generating capacity (compared with the unwashed cotton) under identical carding rates and ventilation conditions. In addition, this batch kier washing resulted in a statistically significant 19- to 55-fold reduction of endotoxin concentration in card-generated elutriated dust (compared with dust from the unwashed cotton), based on blinded endotoxin assays from the NIOSH laboratory, which has demonstrated reproducibility of its carefully standardized endotoxin assay procedures over the period covered by all the relevant studies [Perkins and Olenchock 1995]. These endotoxin assay results indicated that airborne levels of endotoxin for the washed cotton were less than half the relative "threshold" of 9 ng/m^3 defined by that same NIOSH laboratory [Castellan et al. 1987]. (Jacobs and colleagues independently reported an airborne concentration of endotoxin on the order of 50 ng/m^3 —a 12-fold reduction for the washed cotton [Jacobs et al. 1993]. Such between-laboratory discrepancies in endotoxin results are common and may arise from differences in extraction and assay procedures.)

On the basis of human ventilatory responses to experimental exposures to dust from this washed cotton, Jacobs and colleagues concluded that their results "suggest that modern batch-kier systems can effectively remove the acute pulmonary toxicity of cottons washed at 60°C and a 40:1 water-to-fiber ratio" [Jacobs et al. 1993]. The endotoxin assay results from the NIOSH laboratory on card-generated airborne dust samples support this overall conclusion. Current evidence offers a basis for accepting the measurements of acute human airway response and airborne endotoxin made during the washing studies—not only as indicators of potential acute respiratory hazard, but also as surrogates for the chronic respiratory hazard of cotton dust (see Appendix).

CONCLUSIONS

A substantial body of experimental evidence now exists to indicate that, with respect to removal of potential respiratory toxicity, cotton mildly washed in batch kier systems (using modern equipment that assures thorough wetting of the cotton fiber and no reuse of wash or rinse water) is equivalent to cotton mildly washed on a continuous batt system in a manner acceptable to OSHA under the washed cotton provisions of the current cotton dust standard. Specifically, mildly washing cotton in modern batch kier systems using two different systems on two different occasions and using two different "worst-case" cottons resulted in consistent and effective removal of dust from cotton and reduction of endotoxin content of residual dust. Furthermore, as assayed by the NIOSH laboratory, the concentration of endotoxin in airborne dust from each "worst-case" cotton that had been mildly washed on each modern batch kier system was less than 12 ng of endotoxin per mg of dust, indicating that exposures up to a dust concentration (measured by vertical elutriator) of 0.75 mg/m^3 would not exceed the "relative" threshold for an acute toxic effect on the airways described by NIOSH investigators [Castellan et al. 1987].

On the basis of these observations and the results of controlled exposures of human volunteers, the Task Force concludes that mild washing of cotton in modern batch kier systems will prevent the acute respiratory effects of occupational exposure to cotton dust. Because results of epidemiological observations of cotton textile mill workers have indicated a significant association between acute and chronic effects (see Appendix), the Task Force further concludes that mild washing of cotton in modern batch kier systems can also be expected to prevent the chronic effects of occupational exposure to cotton dust.

RECOMMENDATIONS

The Task Force for Byssinosis Prevention recommends the following:

1. OSHA should add mild washing in a modern batch kier system as an acceptable method to wash cotton under the 1985 cotton dust standard. Specifically, the pertinent part of the cotton dust standard [29 CFR[1] 1910.1043(n)] should be amended through the following additions in boldface type:

(n) Washed Cotton—

. . . .

(4) *Higher grade washed cotton.* The handling and processing of cotton classed as "low middling light spotted or better" **(color grade code 52 or better and leaf grade code 5 or better according to the current USDA classification system begun in 1993)** which has been washed:
(A) On a continuous batt system or a rayon rinse system
(i) With water,
(ii) At a temperature of no less than 60° C,
(iii) With a water-to-fiber ratio of no less than 40:1, and
(iv) With bacterial levels in the wash water controlled to limit bacterial contamination of the cotton.
(B) On a batch kier washing system[2]
(i) With water,
(ii) With cotton fiber mechanically opened and thoroughly prewet before forming the cake,
(iii) For low-temperature process, at a temperature of no less than 60° C with a water-to-fiber ratio of no less than 40:1; or, for high-temperature process at a temperature of no less than 93° C with a water-to-fiber ratio of no less than 15:1, and
(iv) With a minimum of one wash cycle followed by two rinse cycles for each batch, using fresh water in each cycle.

. . . .

2. Where feasible, users of raw cotton should consider washed cotton substitution, either complete or in part (as a blend), as an adjunct means to achieve compliance with the current OSHA PEL for cotton dust when other engineering controls have not been entirely effective. In addition, even if compliance with the OSHA PEL has been achieved, washed cotton substitution should be considered as a means to further reduce potential risk of occupational respiratory disorders among workers exposed to cotton dust.

3. Research should be conducted to optimize textile processing of mildly washed cotton and, as commercial experience is gained, information should be disseminated regarding applications in which washed cotton can be feasibly substituted for unwashed cotton. Dissemination of this information may serve to promote voluntary substitution of mildly washed cotton for unwashed cotton by cotton-consuming companies as a prevention strategy.

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[1] *Code of Federal Regulations.* See CFR in references.

[2] The purpose of this recommended revision is to encourage voluntary substitution of washed cotton for unwashed cotton as a strategy to prevent respiratory disorders induced by cotton dust.

APPENDIX

Steps in Modern Batch Kier Washing Processes

The processes common to most modern commercial batch kier washing operations are described in general terms in the following paragraphs.

Step 1. Mechanical Opening and Cleaning

Cotton in compressed form is taken from bales and is placed in opening hoppers where it is fed between lattice aprons that contain sharp, large-diameter spikes to begin the process of breaking up the batt of cotton into tufts to facilitate further processing and removal of trash. After this initial opening, the cotton typically passes through one or two additional stages of opening and cleaning in preparation for washing. The first mechanical cleaner that is almost always used is a "step" cleaner that uses air to convey the cotton through a series of rotating, spiked cylinders to remove extraneous material (mostly plant trash). The beating action of the rotating spikes loosens the heavier trash particles from the lint, and the particles then fall from the air stream to the waste chambers. Often a second stage of opening and cleaning is used to further open the cotton stock and remove small trash particles. Machines used in this second stage usually employ rotating cylinders containing saw teeth. This is a very vigorous mechanical treatment that can damage fibers and adversely affect cotton processing quality. Consequently, this second stage of cleaning is usually used only when the finished washed cotton must pass the USP ash test. Thus, mechanical processing is used to remove physical impurities from the cotton and to produce small fiber tufts (1 to 3g) to provide for effective wetting and packing in the cakemaking step. In the two effective batch kier washing trials described in the body of this report, mechanical opening and cleaning were accomplished by use of a spiked opener and a step cleaner in the first trial [Perkins and Berni 1991] and by use of a spiked opener, a step cleaner, and a fine-cylinder cleaner in the second trial [Perkins and Olenchock 1995].

Step 2. Prewetting and Cakemaking

The small cotton tufts produced in the mechanical process are conveyed by air to a cakemaking device designed to produce a doughnut-shaped cake of cotton that is thoroughly wet and packed to controlled, uniform density. This is accomplished by spraying the incoming tufts with a warm solution of water plus a wetting agent as they fall into the cylindrical container of the cakemaker. The spray is directed so that solution that does not contact the cotton tufts falls into the container. The entire container rotates slowly, and a mechanical tramper packs the wet cotton to produce the uniform cake. The amount of wetting solution used and the packing intensity are carefully controlled to produce the desired cake density. The prewetting during cakemaking is a key step to ensure that the cotton will be thoroughly wet even in the first cycle in the kier wash step.

Step 3. Kier Washing and Rinsing

Three cakes of prewet cotton are added to a kier for washing. The individual integrity of the cakes is maintained by separation of the cakes with perforated stainless steel discs. Kier capacity varies from about 1,500 to 2,300 lb of cotton (dry weight). In the washing cycle, washing solution (water plus wetting agent) at the selected temperature is pumped through the cakes from the inside to the outside. The solution passes through the cakes in the kier to an outside expansion tank and then back through the cakes. The solution is then dumped into the sewer; a new, clean washing solution is added to the kier; and the process is repeated. The number of cycles of new washing solution and the cycle times depend on preselected washing conditions. After the required number of cycles with washing solution, clean water is used in a number of rinsing cycles to complete the removal of dissolved impurities and residual wetting agent. The fact that the wash and rinse solutions in each cycle are not reused results in maximum removal of dissolved impurities.

Step 4. Centrifugation

After rinsing, the cakes are removed from the kier and are centrifuged individually to reduce moisture content to about 50% (wet basis).

Step 5. Drying and Baling

The centrifuged cakes are broken up mechanically by a series of large-diameter spiked cylinders to produce a batt of cotton that then passes through a tunnel dryer. Heated air, usually in the temperature range of 125° to 150°C, is forced through the batt to accomplish drying to a preselected moisture content range, usually about 4% to 8%. After drying, the cotton is fed through a mechanical opener-cleaner to remove residual trash and to break up the dried batt of cotton for feeding to the bale press for compression and packaging. The finished, covered bales are weighed (average weight is about 500 lb) and tagged for identification as appropriate.

Potential Markets for Mildly Washed Cotton

Most of the currently envisioned potential end uses for 100% mildly washed cotton would probably involve novelty or niche markets but could potentially result in significant expansions into other markets. Advantages of mildly washing raw cotton extend beyond the potential for achieving compliance with OSHA exposure limits and protecting worker health. Specifically, while washing generally adversely affects cotton textile processing, mild washing may actually enhance the textile processing characteristics of some cotton (e.g., "sticky" cotton). It may also enable value-added special effects (e.g., differential dyeing characteristics for novelty yarns and improved quality of rotor-spun yarns). Potential use of mildly washed cotton in cotton and cotton-synthetic yarns containing only a small proportion of washed cotton would also be possible, but (as with any potential application of washed cotton) washing-associated costs and benefits will need to be considered on a case-by-case basis and may prove limiting.

Acute and Chronic Respiratory Effects of Cotton Dust

Chronic Respiratory Effect: Relationship to Acute Effect

The progression from an initial acute and reversible pulmonary effect to an eventual chronic and irreversible effect has been implicit in clinical descriptions of byssinosis and is a key underlying assumption of the OSHA cotton dust standard [43 Fed. Reg. 27351 (1978), 50 Fed. Reg. 51120 (1985)]. Yet as recently as 1986, it was emphasized that "a clear relationship between acute and chronic respiratory disease in cotton workers has not been established, and a prospective study is necessary to investigate this relationship" [ASPH 1986]. Such a study has recently been completed, and the results of this large prospective study of 1,664 U.S. cotton textile workers indicate a significant association between acute (across-shift) decline and longitudinal decline in lung function [Glindmeyer et al. 1994]. This is an extremely important observation with respect to results of the cotton washing studies because it supports the contention that the acute respiratory response measured in washed cotton studies is a valid predictor for the chronic hazard potential of cotton dust.

Acute Respiratory Effect: Relationship to Endotoxin

The search for a measure of the acute and chronic respiratory toxicity of cotton dust more specific than airborne gravimetric dust concentration has increasingly centered on bacterial endotoxin. Several studies have documented an association between endotoxin concentration and respiratory symptoms of exposed individuals; even more clearly, they have demonstrated a relationship between endotoxin and across-shift FEV_1 decrement among humans exposed to cotton dust [Rylander and Haglind 1983, 1986; Castellan et al. 1984, 1987; Rylander et al. 1985]. The most definitive findings were reported by NIOSH investigators, who observed a clear exposure-response relationship between mean FEV_1 response and endotoxin concentration ($P<0.00001$), though dust concentrations from the same set of exposures were not correlated with FEV_1 change ($P=0.43$) [Castellan et al. 1987]. All 51 exposures above 50 ng/m^3 endotoxin resulted in statistically significant mean FEV_1 responses, whereas none of the eight exposures below 10 ng/m^3 endotoxin did so, and a linear regression model based on the observed data predicted a "threshold" at approximately 9 ng/m^3 for the FEV_1 response [Castellan et al. 1987]. (As discussed above, because of differences in endotoxin extraction and assay methods between laboratories, results of endotoxin measurements from other laboratories may not be directly comparable to this "threshold.")

Although these experimental results do not by themselves prove that endotoxin is causal, the very clear exposure-response relationship between airborne endotoxin concentration and acute decline in FEV_1 is very unlikely to have been observed unless a predominant causal role is played by endotoxin or some other cotton dust component (or components) in a concentration that closely parallels that of endotoxin. On the basis of this exposure-response relationship, NIOSH concluded in a letter to OSHA that although "it is not now possible to offer a definitive opinion regarding chronic health effects, ... airborne endotoxin is a valid surrogate for the level of acute respiratory hazards of cotton dust" [Niemeier 1990].

Chronic Respiratory Effect: Relationship to Endotoxin

The demonstrated relationship between acute and chronic respiratory responses to cotton dust [Glindmeyer et al. 1994] and the demonstrated relationship of acute respiratory response and endotoxin [Rylander and Haglind 1983, 1986; Castellan et al. 1984, 1987; Rylander et al. 1985] together offer a basis for accepting the endotoxin measurements made during the washing studies as a surrogate for the chronic respiratory hazard of cotton dust, as well as for the acute respiratory hazard. Additional evidence for considering endotoxin inhalation a risk factor for chronic lung effects is provided by other studies that have demonstrated quantitative relationships between chronic respiratory effects and exposure to airborne, endotoxin-contaminated organic dust. These studies have involved textile mill workers [Kennedy et al. 1987; Sigsgaard et al. 1992], Dutch animal feed mill workers [Smid et al. 1992], and workers in the swine confinement industry [Zejda et al. 1994], an occupational setting in which an exposure-effect relationship of airborne endotoxin exposure with across-shift FEV_1 decrement has been reported [Donham et al. 1988; Heederick et al. 1991].

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