Steaming of cotton to prevent byssinosis—a plant study

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Imbus, H. R. and Suh, M. W. (1974). *British Journal of Industrial Medicine*, 31, 209-219. **Steaming of cotton to prevent byssinosis—a plant study.** Pulmonary function tests, respiratory questionnaires, and dust measurements were made in a cotton spinning plant during the processing of steamed cotton and after its discontinuance. During steaming the average drop in FEV₁ (Δ FEV₁) from the beginning to six hours into the work shift was 19 ml, and after steaming was discontinued 62 ml. In addition, the FEV₁ measurements, before work on the first day of the work week, were 60 to 100 ml higher during the time of steaming. The improvement in Δ FEV₁ with steaming was much greater for males than for females. Improvement was greatest in the higher dust areas, namely, opening, picking, blending, and carding, and less in spinning, winding, and twisting. Questionnaire results did not reveal any significant difference in the incidence of symptoms of byssinosis during the two periods, the reasons for which are not clear. There was an approximately 30% reduction in elutriated and total dust.

It has been known for some time that the washing of cotton markedly reduced or eliminated its potential for causing byssinosis (El-Batawi and El-Din Shash, 1962). Accordingly, in 1970 a study was undertaken by Duke University Medical Center and the North Carolina State Board of Health in co-operation with Burlington Industries to evaluate the effect of washing and other types of treatment upon cotton. An experimental chamber with a feeder and high-speed carding machine was designed and installed in a textile plant, and various types of treated cotton were processed.

Employees, without significant respiratory impairment, who exhibited the typical symptoms of byssinosis, of tightness in the chest, and/or temporary decrease in one second forced expiratory volume (FEV₁) on Mondays were tested to determine the frequency of symptoms and pulmonary function decrement. The results of this work published by Merchant *et al.* (1973) revealed a beneficial effect from washing, steaming, autoclaving, and utilization of better grades of cotton. Washing cotton changed the characteristics sufficiently to interfere with

processing it into yarn. Autoclaving appeared to present practical problems in the development of facilities capable of processing adequate amounts. Steaming appeared to offer the best short-term, practical, and feasible method of pretreatment.

An experimental production steamer was developed by the Company's central research staff. After successful production, and medical tests on the employees working with the cotton steamed therein, a prototype steamer was developed, and ultimately two production steamers capable of processing all of the plant's cotton were installed in a cotton-spinning plant. Over a period of several months raw cotton coming into the plant was steamed in gradually increasing amounts until ultimately 100% of the plant's production was from steamed cotton. The plant processes strict low middling cotton which is mixed with 25% rayon.

During and after the introduction of steaming medical studies were conducted by Duke University and the North Carolina State Health Department and are to be published in the future.

Because we believed that additional data were

necessary in order to make practical manufacturing decisions and for long-range planning, it was decided to conduct additional tests by the corporate medical department. Because of impending installations of new equipment, a decision was made to discontinue steaming in this plant. This afforded the opportunity to conduct tests before and after the discontinuation of the steaming. The following are the results of these tests.

Method

Medical and engineering

A total of 167 employees, including all volunteers from the first shift (approximately 95%), were surveyed. Of these, 133 subjects provided valid data for both steaming and non-steaming sequences. Thirty-four subjects were eliminated for a variety of reasons, including working on Sundays without a weekend break, presence for only a single day of testing, making it impossible to compare results, and poor technical quality of expirograms. The remaining 133 subjects, by sex and work area, are as follows:

	Male	Female	Total
Opening, picking, carding ¹	27	1	28
Spinning, winding, twisting	36	44	80
Shop and auxiliary areas	22	3	25
Total	85	48	133

¹Includes blending, drawing, and roving

Mean age for the subjects studied was 39.5 (range 20-62) for males and 44.5 (range 26-58) for females. The number of smokers was 52 (59.8%) out of 87 male subjects and 23 (50%) out of 46 female subjects. The difference in the ratio of smokers between the two sexes was found to be insignificant (χ^2 1.2—not significant at the 25% error level and under).

Byssinosis was graded according to the classification of Schilling *et al.* (1964). The two questionnaire surveys (once during steaming, once during the non-steaming period), combined with the results of six weeks' pulmonary function tests, provided the following categorization:

	Male	Female	Total
Reactor to cotton dust	31 (22)	15 (3)	46 (25)
Non-reactor to cotton dust	54	33	87
Total	85	48	133

Figures in parentheses show number of subjects with byssinosis grade $\frac{1}{2}$ or greater in either one or both questionnaire surveys.

Here, the definition of 'reactor' was somewhat arbitrarily chosen to include those with byssinosis grade 1/2 or greater, and those with an FEV₁ drop in the afternoon (1) greater than 10% twice or more, (2) greater than 10%

once and greater than 5% twice or more, (3) greater than 5% four times or more, or (4) greater than 3.33%, 4%, and 5% based on the average of 6, 5, and 4 weeks, respectively. Such a definition was proposed to examine the effect of steaming on those persons who appear to be more affected by cotton dust than others.

Dust sampling

Dust samples were obtained during the study in the periods with and without steaming utilizing the Lynch-Lumsden elutriator (Lynch, 1970).

The steaming apparatus developed by the corporate research and development, as described by Michaels and Whisnant (1972), was used to steam the cotton at a steam flow rate of approximately 1 000 lb (454 kg) per hour. Cotton was removed from the bale in the opening room of the plant, blended, and steamed before further processing. Due to blending requirements, the cotton was rebaled and stored for short periods of time. All other steps in processing the yarn were unchanged between steamed and unsteamed cotton.

Response criteria

Four response variables were compared for the two three-week periods, with and without steaming. The four variables were:

- (1) FEV₁ before work
- (2) FEV₁ after 6 hours' work
- (3) Δ FEV₁ = (2) - (1)
- (4) % Δ FEV₁ = [(3) $\div$ (1)] $\times$ 100

Each subject was tested four times each morning and each afternoon to obtain FEV₁ values. Then each of the above four variables was computed based on two different methods: (a) the average of the two highest FEV₁ readings out of the four, and (b) the average of all four FEV₁ readings.

Statistical analyses were carried out for both (a) and (b) separately.

Statistical analyses

Three distinct statistical methods were used in arriving at the conclusions given in this study:

- (1) cell mean analysis (Anderson and Bancroft, 1952) (least squares method based on unweighted means);
- (2) matched frequency analysis (least squares method based on proportional subclass numbers);
- (3) non-parametric test of improvement probability.

For brevity, only results from (1) and (3) are to be presented. Results from (2) were quite compatible with that from (1) and are thus omitted.

The 'cell mean analysis' compares an individual's average response during the first three-week period under steamed cotton with that obtained during the last three weeks without steaming, irrespective of his frequency of participation in each period as long as he participated in at least one week during each of the steaming and non-steaming periods. However, any difference between the individual's two averages can be tested by using a standard error derived from all available weekly data rather than the three-week averages. The last analysis was included in order to measure the change of improvement due to steaming from each of the four response criteria without regard to the magnitudes of improvement. Simply, it compares each and every steaming week with

each and every non-steaming week for forming all possible contrasts. Then the frequency of improved contrasts was divided by the total number of contrasts to obtain the probability of improvement. Here, an improved contrast means that the result from the steaming week was better than that from the non-steaming week. A person who participated in all six weeks provided a total of nine contrasts between steaming and non-steaming weeks.

The matched frequency analysis provides an exact least squares method based on an equal number of sample sizes (frequency of participation) during the steaming and non-steaming periods for any given individual. A part of all available data had to be discarded at random in order to perform this analysis. The above two analyses were adopted in place of the exact least squares method for 'two-way analysis of variance with interaction' for two reasons: (1) the exact method requires an unduly complicated computational process because of the large number of 'blocks' (subjects) and the unequal subclass sample sizes; and (2) the hypothesis testing of the main effect (steaming effect) can be debatable and conceptually

non-trivial at the presence of a significant interaction though the solution is available for the case of unequal subclass sample sizes (Anderson and Bancroft, 1952; Scheffé, 1959).

Results

Results in Tables 1 and 2 show that steaming is definitely effective in reducing FEV₁ drop (Δ FEV₁) after work for the overall population. Net improvement due to steaming is approximately 43 ml (± 24 ml) and 1.5% ($\pm 0.9\%$) in Δ FEV₁ and % Δ FEV₁ respectively for the total population. These figures, though small relative to morning FEV₁ values, represent 70% reduction in Δ FEV₁ (from -62 ml to -19 ml) by steaming cotton.

It is rather unexpected to note the improvement of the level of FEV₁ before work by 60-100 ml, almost uniformly for both sexes in all work areas. If such is really the case, the total benefit of steaming

TABLE 1
NET STEAMING EFFECT BY SEX AND REACTOR TYPE, BASED ON AVERAGE OF TWO HIGHEST READINGS

Sex and reactor type			3-week average readings					Net steaming effect/improvement ($\pm 95\%$ confidence limit)			
			Sample size	FEV ₁ (ml)		Δ FEV ₁	% Δ FEV ₁	FEV ₁ (ml)		Δ FEV ₁	% Δ FEV ₁
				Before work	After work			Before work	After work		
M R	S	31	31	3 145	3 085	-60	-1.9	75**	150***	75**	(± 47) 2.9** (± 1.9)
		U	31	3 070	2 935	-135	-4.8				
F R	S	15	15	2 351	2 223	-128	-5.2	103***	120***	17 ^{NS}	(± 65) 1.2 ^{NS} (± 2.8)
		U	15	2 248	2 103	-145	-6.4				
	R	46	46	2 887	2 804	-83	-3.0	85***	140***	55**	(± 38) 2.4** (± 1.6)
		U	46	2 802	2 664	-138	-5.4				
M NR	S	54	54	3 380	3 401	+21	+0.8	94***	142***	48*	(± 41) 1.6** (± 1.2)
		U	54	3 286	3 259	-27	-0.8				
F NR	S	33	33	2 368	2 369	+1	0	62**	75***	13 ^{NS}	(± 41) 0.2 ^{NS} (± 2.1)
		U	33	2 306	2 294	-12	-0.2				
	NR	87	87	2 996	3 010	+14	+0.5	81***	117***	36*	(± 30) 1.1* (± 1.1)
		U	87	2 915	2 893	-22	-0.6				
M	S	85	85	3 295	3 286	-9	-0.2	87***	145***	58***	(± 31) 2.1*** (± 1.0)
		U	85	3 208	3 141	-67	-2.3				
F	S	48	48	2 363	2 323	-40	-1.7	75***	89***	14 ^{NS}	(± 36) 0.5 ^{NS} (± 1.7)
		U	48	2 288	2 234	-54	-2.2				
Total	S	133	133	2 958	2 939	-19	-0.7	82***	125***	43***	(± 24) 1.5*** (± 0.9)
		U	133	2 876	2 814	-62	-2.2				

S = steamed cotton; U = unsteamed cotton; M = male; F = female; R = reactor; NR = non-reactor

* Significant at 5% error level

** " " 1% " "

*** " " 0.1% " "

NS Not significant at 5% error level

TABLE 2
NET STEAMING EFFECT BY SEX AND REACTOR TYPE, BASED ON AVERAGE OF ALL FOUR READINGS

Sex and reactor type			3-week average readings					Net steaming effect improvement ($\pm 95\%$ confidence limit)			
			Sample size	FEV ₁ (ml)		Δ FEV ₁ (ml)	% Δ FEV ₁	FEV ₁ (ml)		Δ FEV ₁	$\Delta\%$ FEV ₁
				Before work	After work			Before work	After work		
M R	S	S	31	3 063	3 000	-63	-2.1	70**	147***	77** (± 54)	3.0** (± 2.1)
		U	31	2 993	2 853	-140	-5.1				
F R	S	S	15	2 270	2 128	-142	-6.0	86**	121***	35 ^{NS} (± 66)	2.2 ^{NS} (± 2.9)
		U	15	2 184	2 007	-177	-8.2				
R	S	S	46	2 804	2 716	-88	-3.4	75***	139***	64** (± 42)	2.7** (± 1.7)
		U	46	2 729	2 577	-152	-6.1				
M NR	S	S	54	3 294	3 314	+20	+0.9	102***	155***	54* (± 43)	2.0** (± 1.3)
		U	54	3 193	3 159	-34	-1.1				
F NR	S	S	33	2 298	2 303	+5	+0.2	73**	90***	17 ^{NS} (± 46)	0.6 ^{NS} (± 2.2)
		U	33	2 225	2 213	-12	-0.4				
NR	S	S	87	2 916	2 931	+15	+0.6	90***	131***	41* (± 32)	1.4* (± 1.2)
		U	87	2 826	2 800	-26	-0.8				
M	S	S	85	3 210	3 200	-10	-0.2	90***	153***	63*** (± 34)	2.4*** (± 1.1)
		U	85	3 120	3 047	-73	-2.6				
F	S	S	48	2 289	2 248	-41	-1.7	77***	99***	22 ^{NS} (± 38)	1.1 ^{NS} (± 1.8)
		U	48	2 212	2 149	-63	-2.8				
Total	S	S	133	2 877	2 856	-21	-0.8	86***	133***	48*** (± 25)	1.9*** (± 0.9)
		U	133	2 792	2 723	-69	-2.7				

S = steamed cotton; U = unsteamed cotton; M = male; F = female; R = reactor; NR = non-reactor

* Significant at 5% error level

** " " 1% " "

*** " " 0.1% " "

NS Not significant at 5% error level

can be as high as 125 ml for the total population in terms of the response measured by FEV₁ after work.

The single largest difference in steaming effect is related to sex difference. Steaming significantly improves Δ FEV₁ and % Δ FEV₁ for males only (58 ml and 2.1%) but shows little effect on females (14 ml and 0.5%). This holds true among both reactors and non-reactors as well as among those working in spinning, winding, and twisting areas (Tables 3 and 4). Unfortunately, not enough female employees were in other areas (see population description in Method to confirm this). The differences in improvement of Δ FEV₁ and % Δ FEV₁ between male and female are found to be significant for the composite population (44 ml and 1.6%) and for the spinning, winding, and twisting areas (42 ml and 2.0%) but somewhat short of statistical significance for the reactor-non-reactor categories (19 ml and 1.3%) due mainly to reduced sample sizes. It is interesting to note that lack of improvement

among females is not due to an insignificant amount of FEV₁ drop during the steaming period (Fig. 2).

Examination of Tables 1 and 2 reveals that reactors (defined in Response Criteria) in general show a greater improvement in Δ FEV₁ and % Δ FEV₁ during steaming (55 ml and 2.4%) than non-reactors (36 ml and 1.1%), particularly among males (75 ml and 2.9%), but the differences are not fully convincing (not significant at 5% error level).

Among females, the difference between reactors and non-reactors is small and insignificant. A somewhat greater difference observed among males is partly due to the larger number of male reactors found in opening, picking, and carding areas compared to the remaining areas. This is to say that the difference is partially confounded with the effect of work area differences. As shown in Figs. 1 and 2, however, reactors exhibit much greater FEV₁ drop after work than non-reactors under both steamed cotton and unsteamed cotton.

TABLE 3
NET STEAMING EFFECT BY WORK AREA AND SEX, BASED ON AVERAGE OF TWO HIGHEST READINGS

Work area and sex		3-week average readings					Net steaming effect improvement (± 95 % confidence limit)			
		Sample size	FEV ₁ (ml)		ΔFEV ₁	%ΔFEV ₁	FEV ₁ (ml)		ΔFEV ₁	%ΔFEV ₁
			Before work	After work			Before work	After work		
O + P + C M	S	27	3 385	3 339	-46	-1.4	85**	163***	78** (± 50)	2.3** (± 1.5)
	U	27	3 300	3 176	-124	-3.7				
S + W + T M	S	36	3 284	3 277	-7	0	78**	136***	58* (± 55)	2.7** (± 1.9)
	U	36	3 206	3 141	-65	-2.6				
S + W + T F	S	44	2 400	2 357	-43	-1.8	78***	94***	16 ^{NS} (± 38)	0.7 ^{NS} (± 1.6)
	U	44	2 322	2 263	-59	-2.5				
S + W + T M + F	S	80	2 798	2 771	-27	-1.0	78***	113***	35* (± 32)	1.6* (± 1.2)
	U	80	2 720	2 658	-62	-2.6				
Sh + Aux M	S	22	3 203	3 236	+33	+0.9	104**	137***	33 ^{NS} (± 54)	1.0 ^{NS} (± 1.9)
	U	22	3 099	3 099	0	-0.1				

S = steamed cotton; U = unsteamed cotton; O + P + C = opening + picking + carding; S + W + T = spinning + winding + twisting; Sh + Aux = shop + auxiliary areas; M = male; F = female

* Significant at 5% error level

** " " 1% " "

*** " " 0.1% " "

NS Not significant at 5% error level

TABLE 4
NET SAMPLING EFFECT BY WORK AREA AND SEX, BASED ON AVERAGE OF ALL FOUR READINGS

Work area and sex		3-week average readings					Net steaming effect/improvement (± 95 % confidence limit)			
		Sample size	FEV ₁ (ml)		ΔFEV ₁	Δ%FEV ₁	FEV ₁ (ml)		ΔFEV ₁	%ΔFEV ₁
			Before work	After work			Before work	After work		
O + P + C M	S	27	3 304	3 260	−44	−1.3	94**	173***	79** (± 59)	2.5** (± 1.8)
	U	27	3 210	3 087	−123	−3.8				
S + W + T M	S	36	3 195	3 187	−8	0	81**	151***	70** (± 55)	3.2** (± 1.9)
	U	36	3 114	3 036	−78	−3.2				
S + W + T F	S	44	2 326	2 281	−45	−2.0	82***	104***	22 ^{NS} (± 40)	1.1 ^{NS} (± 1.7)
	U	44	2 244	2 177	−67	−3.1				
S + W + T M + F	S	80	2 717	2 688	−29	−1.1	81***	124***	43** (± 33)	2.0** (± 1.3)
	U	80	2 636	2 564	−72	−3.1				
Sh + Aux M	S	22	3 119	3 148	+29	+0.9	100***	132***	32 ^{NS} (± 61)	1.0 ^{NS} (± 2.0)
	U	22	3 019	3 016	−3	−0.1				

S = steamed cotton; U = unsteamed cotton; O + P + C = opening + picking + carding; S + W + T = spinning + winding + twisting; Sh + Aux = shop + auxiliary areas; M = male; F = female

* Significant at 5% error level

** " " 1% " "

*** " " 0.1% " "

FIG. 1. Average FEV_1 before and after work for males, based on average of two highest readings.

The question naturally arises whether the effect of steaming is uniform in all work areas. For this the composition of our study population was less than ideal. A valid comparison was possible only within males since almost all females were located in one area. Comparing males in different work areas, the ΔFEV_1 and $\% \Delta FEV_1$ improvements are the largest for those working in opening, picking, blending, and carding areas (78 ml and 2.3%). These are somewhat greater in ΔFEV_1 only than the average for spinning, winding, and twisting areas (58 ml and 2.7%) or that for shops and auxiliary areas (33 ml and 1.0%) where the levels of dust are

accordingly lower. Despite such a trend, however, the differences are not quite statistically significant (Table 3). Apart from the net improvement figures, it is significant to note that FEV_1 after-work averages for those working outside the opening, picking, and carding areas are actually essentially the same or sometimes higher than the corresponding FEV_1 before-work averages (Fig. 3, middle and right). Although statistically insignificant, the order of magnitudes of ΔFEV_1 improvement coincides with those of the levels of respirable dust.

The probability of improving ΔFEV_1 and $\% \Delta FEV_1$ due to steamed cotton is roughly 60%

FIG. 2. Average FEV_1 before and after work for females, based on average of two highest readings.

FIG. 3. Average FEV_1 before and after work for males by work area, based on average of two highest readings.

TABLE 5
PROBABILITY (%) OF IMPROVEMENT DUE TO STEAMING BY SEX AND REACTOR TYPE ($\pm 95\%$ CONFIDENCE LIMIT)

Sex and reactor type	No. of all possible contrasts	Based on average of all 4 readings				Based on average of 2 highest readings			
		FEV_1		ΔFEV_1	$\% \Delta FEV_1$	FEV_1		ΔFEV_1	$\% \Delta FEV_1$
		Before work	After work			Before work	After work		
M R	181	55.8 (± 7.4)	70.2 (± 6.8)	63.3 (± 7.2)	63.5 (± 7.2)	58.3 (± 7.3)	70.4 (± 6.8)	64.6 (± 7.1)	65.7 (± 7.1)
F R	102	74.5 (± 8.6)	78.9 (± 8.1)	58.3† (± 9.8)	59.8† (± 9.8)	81.9 (± 7.6)	80.9 (± 7.9)	57.8† (± 9.8)	59.8† (± 9.8)
R	283	62.5 (± 5.8)	73.3 (± 5.3)	61.5 (± 5.8)	62.2 (± 5.8)	66.8 (± 5.6)	74.2 (± 5.2)	62.2 (± 5.8)	63.6 (± 5.7)
M NR	292	66.6 (± 5.5)	75.7 (± 5.0)	58.9 (± 5.8)	58.9 (± 5.8)	66.3 (± 5.5)	74.0 (± 5.1)	57.2 (± 5.8)	57.4 (± 5.8)
F NR	171	62.6 (± 7.4)	71.1 (± 6.9)	59.4† (± 7.5)	59.6† (± 7.5)	62.6 (± 7.4)	71.9 (± 6.9)	55.3† (± 7.6)	54.7† (± 7.6)
NR	463	65.1 (± 4.4)	74.0 (± 4.1)	59.1 (± 4.6)	59.2 (± 4.6)	64.9 (± 4.4)	73.2 (± 4.1)	56.5† (± 4.6)	56.4† (± 4.6)
M	473	62.5 (± 4.5)	73.6 (± 4.1)	60.6 (± 4.5)	60.7 (± 4.5)	63.2 (± 4.4)	72.6 (± 4.1)	60.0 (± 4.5)	60.6 (± 4.5)
F	273	67.0 (± 5.7)	74.0 (± 5.3)	59.0 (± 6.0)	59.7 (± 5.9)	69.8 (± 5.6)	75.3 (± 5.2)	56.3† (± 6.0)	56.6† (± 6.0)
Total	746	64.1 (± 3.5)	73.7 (± 3.2)	60.0 (± 3.6)	60.3 (± 3.6)	65.6 (± 3.5)	73.6 (± 3.2)	58.6 (± 3.6)	59.1 (± 3.6)

M = male; F = female; R = reactor; NR = non-reactor

† Difference from 50% not significant or barely significant at 5% error level

TABLE 6
PROBABILITY (%) OF IMPROVEMENT DUE TO STEAMING BY WORK AREA AND SEX
(+95% CONFIDENCE LIMIT)

Work area and sex	No. of all possible contrasts	Based on average of all 4 readings				Based on average of 2 highest readings			
		FEV ₁		Δ FEV ₁	% Δ FEV ₁	FEV ₁		Δ FEV ₁	% Δ FEV ₁
		Before work	After work			Before work	After work		
O + P + C M	165	62.1 (± 7.6)	72.4 (± 7.0)	68.5 (± 7.2)	69.1 (± 7.2)	60.6 (± 7.6)	70.0 (± 7.2)	63.6 (± 7.5)	64.8 (± 7.4)
S + W + T M	175	66.0 (± 7.2)	75.1 (± 6.5)	56.6† (± 7.5)	56.0† (± 7.5)	65.7 (± 7.2)	73.1 (± 6.7)	55.4† (± 7.5)	55.7† (± 7.5)
S + W + T F	246	66.3 (± 6.0)	74.8 (± 5.5)	61.0 (± 6.2)	61.8 (± 6.2)	68.9 (± 5.9)	75.8 (± 5.5)	58.5† (± 6.3)	59.1† (± 6.3)
S + W + T M + F	421	66.2 (± 4.6)	74.9 (± 4.2)	59.2 (± 4.8)	59.4 (± 4.8)	67.6 (± 4.6)	74.7 (± 4.2)	57.2 (± 4.8)	57.7 (± 4.8)
Sh + Aux M	133	58.3 (± 8.6)	72.9 (± 7.7)	56.0† (± 8.6)	56.4† (± 8.6)	63.2 (± 8.4)	75.6 (± 7.5)	61.7 (± 8.4)	61.7 (± 8.4)

O + P + C = opening + picking + carding; S + W + T = spinning + winding + twisting; Sh + Aux = shop + auxiliary areas; M = male; F = female

† Difference from 50% not significant or barely significant at 5% error level

with minor variations due to sex, reactor/non-reactor, and work area differences. The probabilities are convincingly greater than 50% with exceptions in female categories. The improvement probabilities for FEV₁ levels before and after work are estimated roughly at 65 and 75%, respectively. Again, justification of these figures requires the assumption that steaming can improve the pre-exposure morning FEV₁ readings (Tables 5 and 6).

In order for the steaming to be effective, the probability of improvement has to be greater than 50%. It does not, however, measure the magnitudes of improvement at all. Therefore, a higher probability is not necessarily due to a higher magnitude of improvement in terms of Δ FEV₁ or % Δ FEV₁. In fact, such is the case for male v female comparison (Table 6) within spinning, winding, and twisting areas. While the net improvements for male (58 ml and 2.7%) are greater than that for female (16 ml and 0.7%), the order is reversed in terms of their improvement probabilities (55.4% and 55.7% for male; 58.5% and 59.1% for female). Otherwise the effects due to sex, reactor/non-reactor, and work area, as found from Δ FEV₁ and % Δ FEV₁, hold true for the improvement probabilities.

With a few exceptions, the steaming effects estimated by using the average of all four readings (Tables 2 and 4) are uniformly greater than that based on the average of two highest readings (Tables 1 and 3), and the physiological implication of this may be significant. Since the average of all four is

identical with the average of the two highest and the two lowest readings, the improvement figures based on the two lowest readings will be even greater than that based on all four readings (Tables 2 and 4) by exactly the same amounts observable between the latter and the figures obtained from the two highest readings (Tables 1 and 3). Thus the Δ FEV₁ and % Δ FEV₁ improvements based on the two lowest readings are 53 ml and 2.3% for the total population compared to 43 ml and 1.5% based on the two highest readings. For another example, the improvement in Δ FEV₁ due to steaming becomes as high as 79 ml, 53 ml, 60 ml, and 21 ml, respectively, for male reactors, female reactors, male non-reactors, and female non-reactors, based on the average of two

TABLE 7
INCIDENCE OF BYSSINOSIS

Byssinosis grade	Steaming		Non-steaming	
	No.	%	No.	%
0	116	81.1	109	82.0
1/2	14	9.8	8	6.0
1	12	8.4	14	10.5
2	1	0.7	2	1.5
All byssinotics	27	18.9	24	18.0
Total	143	100.0	133	100.0

TABLE 8
EFFECT OF STEAMING ON LEVELS OF RESPIRABLE DUST AND TOTAL DUST (IN PARENTHESES)
(UNIT = mg/m³)

Location	Steamed			Unsteamed			Averages		Diff.
	5/28	6/4	6/11	7/16	7/23	7/30	Steamed	Unsteamed	
Wastehouse	0.99 (2.18)	2.34 (5.72)	1.83 (3.73)	1.72 (3.44)	2.63 (4.37)	1.03 (1.23)	1.72 (3.88)	1.79 (3.01)	0.07 (-0.87)
Blending	1.03 (2.38)	1.75 (3.53)	(NA) (2.10)	3.71 (5.43)	2.39 (5.52)	5.19 (5.57)	1.39 (2.67)	3.76 (5.51)	2.37 (2.84)
Opening	2.03 (4.29)	2.55 (5.23)	2.10 (2.80)	2.25 (5.65)	6.72 (9.90)	3.06 (NA)	2.23 (4.11)	4.01 (7.76)	1.78 (3.65)
Picking	2.26 (2.61)	2.33 (5.08)	2.56 (3.84)	3.01 (7.72)	2.88 (11.30)	2.60 (4.49)	2.38 (3.84)	2.83 (7.84)	0.45 (4.00)
Carding	1.39 (NA)	1.79 (NA)	1.42 (2.39)	1.86 (9.36)	1.72 (3.20)	1.10 (2.36)	1.53 (2.39)	1.56 (4.97)	0.03 (2.58)
Drawing	0.85 (NA)	0.69 (NA)	0.88 (NA)	0.90 (NA)	0.89 (NA)	0.82 (1.75)	0.81 (NA)	0.87 (1.75)	0.06 (NA)
Roving	0.49 (NA)	0.94 (NA)	0.48 (NA)	0.64 (NA)	0.61 (NA)	0.74 (3.08)	0.64 (NA)	0.67 (3.08)	0.03 (NA)
Spinning	0.49 (0.84)	0.60 (1.53)	0.54 (1.24)	0.56 (12.11)	0.47 (1.33)	0.50 (3.23)	0.54 (1.20)	0.51 (5.57)	-0.03 (4.37)
Winding	0.49 (NA)	0.45 (NA)	0.46 (NA)	0.63 (9.03)	(NA) (1.27)	0.55 (2.36)	0.47 (NA)	0.59 (4.22)	0.12 (NA)
Twisting	0.49 (NA)	0.36 (NA)	0.37 (NA)	0.19 (3.96)	0.52 (0.93)	0.57 (2.95)	0.40 (NA)	0.42 (2.61)	0.02 (NA)
Average resp. dust	1.05	1.38	1.20†	1.55	1.94†	1.61	1.21	1.70	0.49*

NA = not available

† NAs are substituted by the departmental averages obtained from the other two weeks in obtaining the weekly average

* Statistically significant at 5% error level

lowest readings. Surprisingly, the Δ FEV₁ and % Δ FEV₁ improvement figures for female (30 ml and 1.6%) can be shown to be statistically significant, based on the two lowest readings.

Table 7 summarizes the questionnaire results of all those who participated and were interviewed during steaming and after its cessation. Differences in symptoms during and after steaming were not apparent.

It is now of practical interest to examine if the significant improvements in FEV₁ measures were realized through an equally substantial reduction of dust level due to steaming.

Table 8 and Figs. 4 and 5 show that steaming reduced the average level of respirable dust by roughly 30% (0.49 mg/m³) for the whole plant and 35% (0.79 mg/m³) for the preparation areas (opening, picking, blending, carding, drawing, roving). At the same time the level of total dust dropped from

FIG. 4. Average levels of respirable dust under steamed cotton and unsteamed cotton.

FIG. 5. Average levels of total dust under steamed cotton and unsteamed cotton.

6.52 mg/m³ with unsteamed cotton to 3.25 mg/m³ with steamed cotton for the first four departments in the preparation area. This amounts to a 50% reduction due to steaming. Within the spinning area alone the total dust was lowered by 78% due to steaming. All these reduction figures were found to be statistically significant at a little over 5% error level. It is most important to note the uniformity of dust levels within the steaming and non-steaming periods as a firm proof that the quality of raw material had been uniform throughout the experimental period.

Comments

Schilling and colleagues (1964) described the symptomatology and grading of byssinosis. Subsequently, McKerrow, McDermott, Gilson, and Schilling (1958) described a decrement in respiratory function, during the working day, of those with byssinosis. Bouhuys *et al.* (1967) proposed a functional classification based upon this decrement, utilizing the FEV₁. It was believed this decrement of FEV₁ would provide an objective test to study the effects of cotton dust exposure and was believed to be of experimental and epidemiological significance.

This study shows that the decrement of FEV₁ during the working day is lessened by steaming. This improvement occurred throughout the plant and to a reasonably consistent degree. Also of interest is the apparently greater benefit from steaming when using the average of all four or the lower two FEV₁ readings at each testing. This may be due to the tendency of the 'reactive' bronchus to tighten up when repeated forced expiratory efforts are made. A reduction of reactivity by using steamed cotton would then be even more apparent when utilizing the average of all four readings v the two highest.

Interestingly enough, this study has also shown a higher average FEV₁ obtained before and after

exposure to cotton during the steaming process as compared to that obtained after the steaming was discontinued. The explanation for this is certainly unclear. It is tempting to postulate as follows:

When breathing in the unsteamed cotton environment the lungs are in a more or less chronic state of reaction or bronchospasm and the reactivity that is observed during plant-wide routine surveys of exposed employees may be only the 'tip of the iceberg'. During the prolonged period wherein steaming was utilized this reaction was eliminated, but it returned after steaming was discontinued.

The structure of data excludes the possibility of artificially generating a higher average FEV₁ during the steaming period since the averages were obtained by testing identical subjects during both periods. In addition, those tested were for the most part sophisticated subjects with good reproducibility of results. Results and graphs were carefully checked for technical accuracy and any that did not appear to be satisfactory from a technical viewpoint were eliminated. It is known, however, that other influences may affect FEV₁ determinations, notably, outside environmental conditions, prevalence of respiratory infections, and even perhaps unknown internal in-plant influences. None of these was readily apparent as these tests were done during the summer periods, during a minimum of weather changes, and no changes were knowingly introduced into the environment. Neither period coincided with ragweed or with other heavy pollen season; however, pollen counts were not done. In order to validate this apparent increase in FEV₁, repeated similar studies would be necessary, and at this time we are prepared to draw no conclusions that this would be reproducible and consistent.

Without further speculation concerning the significance of the change of baseline levels we are faced with evaluating the beneficial effect of the reduction in pulmonary function reaction, and evaluating this benefit with respect to an acute effect, into long-term prevention of pulmonary disability. It has been established that individuals showing a decrement of pulmonary function are at an increased risk of pulmonary impairment (Imbus and Suh, 1973). There is some question of cause and effect in that individuals who have pre-existing pulmonary disease would be expected to be more reactive and therefore, as a group, would have lower average predicted FEV₁. Nevertheless, considering these data, combined with a knowledge of the nature of the progression of byssinosis, it is logical to expect that repeated reactions may in some individuals result in permanent impairment. Certainly, considering both potential chronic effects and the discomfort and temporary impairment produced by acute effects, anything which would decrease this reaction would be highly desirable.

The symptoms of byssinosis are also highly significant as predictors of ultimate impairment, and also can be considered a reaction. Only approximately one-fourth of those with byssinotic symptoms exhibit an FEV₁ drop of 10% or greater. We therefore suggest that the symptoms of byssinosis, and the decrement of FEV₁, may be produced in two different areas of the airways. The decrement of FEV₁ is largely associated with constriction of large and medium airways, while symptoms may be associated with small airway constriction. Although no reduction in byssinotic symptoms was found in our study, Merchant *et al.* (1973) did describe a marked reduction in symptoms in their experimental chamber tests. Evaluations done in other plants of the company following significant dust level reductions have resulted in a decrease in byssinosis symptoms and in the decrement in FEV₁.

Possible explanations for the absence of reduction of byssinosis symptoms observed in this study are:

1. The short-term interval between the steaming experiment and the stoppage of the steaming did not allow for redevelopment of symptoms.

2. The possibility exists that production steaming reduces one aetiological factor responsible for the decrement of FEV₁ but does not affect other aetiological factors.

Any preprocessing procedure which does not alleviate the symptomatology would not be expected to offer complete protection. Nevertheless, it appears that steaming is effective as a partial control measure of the pulmonary function response to cotton dust. As to the degree of its long-term effectiveness in preventing impairment, only prolonged observation would clarify this point.

Translated into a practical course of action at this time, we would make the following recommendations to those considering the use of steaming:

1. Dust control should be the primary means of control of byssinosis.

2. Where new dust control measures are being installed, there is an excellent opportunity for industry so involved to do medical testing and dust evaluation before and after such installation. These will provide data of the reduction of symptoms and pulmonary function reaction after such installation. Any improvement then can be compared with the improvements from steaming, reported herein.

3. In the event that dust control measures are not effective to a satisfactory degree, steaming should be considered as an adjunct.

4. Steaming should be considered as an interim

measure where suitable dust control is not practical or feasible at the present time. (In the United States there are now long delays—up to three years—in obtaining such equipment after orders are placed. This is, of course, in addition to any delays occasioned by making necessary capital commitments.)

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Received for publication 17 December 1973

Accepted for publication 18 February 1974