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[illegible] CHEMICAL FINISHING TECHNIQUES[1]

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CONTENTS

I. INTRODUCTION AND GENERAL CONSIDERATIONS

A review of "Durable Finishes" published by the United Nations in 1970(1) summarizes the requirements for functional properties in various end uses as shown in Table 1, and states that:

> "Present levels of finishing technology as regards available chemicals and technical equipment, permit the fulfillment of almost all requirements of consumers."

In fact, the demand for specific functional properties is continually altered by technological and sociological change, and some of the assumptions made just five years ago are no longer valid. Thus, it is appropriate to review again concepts and approaches which apply to the finishing of fabrics, specifically cotton-containing fabrics, in the context of continuing technological progress and of current requirements in the market place.

Durable finishes can be classified according to their function--the property they are designed to import or improve. The major areas of concern and of recent progress for durable finishing of cotton-containing fabrics are shown in Table 2. Easy-care finishing has been reviewed and discussed by others at this meeting(2). Finishes which improve release of oily soils are of particular importance for polyester/cotton blend fabrics of high polyester content, but are not generally required for 100% cotton fabrics or for blends in which the cotton content is higher than 50%. This paper will review approaches to durable finishes which are important for imparting water repellency, resistance to micro-organisms, and flame resistance to 100% cotton fabrics, and to those blend fabrics in which a high cotton content preserves the essential performance characteristics of cotton.

The continuing search for improved products and techniques for durable finishing, coupled with new knowledge of the chemistry, structure, morphology and fundamental properties of fibrous assemblies, has produced a new level of insight into conceptual definitions of finishing problems, of specific approaches, and of meaningful evaluation of results obtained. Thus, the pragmatic classification of functional finishes shown in Table 2 may be supplemented by a classification of durable finishes based on the predominant mechanisms of finish-substrate interaction as outlined in Table 3. Since crease-resistance and easy-care performance depend primarily on cross-linking of cellulose chains in the cotton fiber, finishes designed for this use must include polyfunctional molecules, small enough to penetrate the fiber rapidly, and capable of reaction with hydroxyl groups under mild conditions. Soil release and water repellent finishes on the other hand need affect only the surface properties of the fiber (wettability), and can be deposited on fiber surfaces as continuous films or coatings which do not react with the functional groups of the substrate. Resistance to micro-organisms is generally attained through the presence of compounds which prevent growth of fungi, mildew or bacteria: specific water insoluble compounds reportedly exhibit adequate durability, and yet diffuse sufficiently to come into contact with the micro-organisms and inhibit their growth. In the case of flame retardant finishes, effectiveness is determined by the chemical composition of the finish and by the presence of specific elements in amounts sufficient to minimize flame propagation in the treated fabric. The distribution of the finish, and the mechanism of insolubilization do not affect flame retardant effectiveness significantly, although these factors have important secondary effects on durability of the finish and on fabric properties ([illegible]).

The chemical composition of the finish, and the finish-substrate interactions outlined in Table 3 are primary considerations in selecting approaches to the modification of specific functional properties. However, the processing conditions required for application and the methods available for evaluating the effects obtained are also essential components of finishing developments.

Finishing processes traditionally have been based on impregnation from aqueous solution, drying, curing, and--in some cases--after-washing. In recent years, a considerable amount of work has been carried out on "non-conventional" processes for fabric finishing. The potential usefulness of non-aqueous systems, where water-sensitive reagents could be employed, has been investigated extensively(3), liquid ammonia has been suggested as a viable medium for several specific finishing processes(4) and treatments in which fabrics are exposed to a gaseous environment containing reagents and/or catalysts have been evaluated on a commercial scale(5). However, an overwhelming proportion of the yardage produced commercially is finished by conventional processing sequences in which padding from aqueous solution, drying, curing and washing still constitute the essential steps--preferably carried out as parts of a continuous operation. The specialized finishing techniquns discussed in this paper have actual or potential commercial significance, do not require extraordinary machinery, instrumentation or devices, and thus can be implemented in textile mill equipment which is either available, or readily adapted to specific processing requirements.

C. WATER REPELLENT FINISHES

Fabrics treated with water repellent finishes are not readily wet by water--but retain their porosity, texture and appearance. The surface of individual fibers is modified by the finish, while interstices between fibers and between yarns remain, in principle, essentially unchanged. (By contrast, the effectiveness of water repellent coatings depends on the formation of a continuous hydrophobic surface which alters the porosity of the fabric, and its permeability to air and moisture.) Several classes of durable water repellent finishes have attained commercial success. These are summarized in Table 4. Derivatives of long chain fatty acids (such as stearamidomethyl pyridinium chloride) were developed many years ago, and were thought of as reactive finishes, capable of covalent bonding with the hydroxyl groups of cellulose and proteins. In the light of recent knowledge of the fiber (cotton) structure and reactivity, the effects and durability obtained with this type of compound are now interpreted as resulting from deposition of hydrophobic, water insoluble compounds on fiber surfaces rather than -- the formation of covalent bonds. The silicone and fluorochemical polymers form a hydrophobic film on fiber surfaces. Effectiveness depends on the continuity of the film, and on the absence of contaminants which enhance wettings by water. Since the polymers are generally applied from aqueous emulsions by padding, drying and curing, the presence of residual emulsifiers on the finished fabrics can pose problems. Manufacturers of the silicone and fluorochemical emulsions have developed formulations containing "non-rewetting emulsifiers" specifically selected to avoid this shortcoming. The amount of water repellent applied is generally 3-6% (on the weight of fabric treated) for the fatty compounds, 1-2% for the silicones and 0.5% or lower for the fluorochemical. In part, these differences reflect the relative efficiencies of the compounds, and in part also the high chemical cost of the silicone and of the fluorochemical polymers. Formulations have also been developed and synergistic effects have been claimed for combinations of fatty acid derivatives and fluorochemicals(6). Advantages in efficiency have been claimed for the application of silicones and of fluorochemicals from chlorinated solvents(7) but it is not known whether this approach is used commercially. The details of specific formulations and procedures used for the application of water repellent finishes are generally considered proprietary, and are dependent on the fiber composition and construction of the fabric treated. Construction is particularly important in determining the required amount of water repellent, and the optimum conditions of processing. The level of water repellency obtained is evaluated by standard test procedures, and standards for wetting and water penetration of fabrics have been defined by the American National Standards Institute(8). From the results of these tests, industry defines the performance of a given fabric as "water repellent" (resists wetting), "shower resistant" (protects against water penetration during a brief shower), "rain resistant" (protects against water penetration in moderate rain), and "storm resistant" (protects atainst water penetration in heavy rain).

III. FINISHES IMPARTING RESISTANCE TO MICRO ORGANISMS

Finishes which impart resistance to micro organisms (bacteria and fungi) can, in principle, be grouped according to several approaches summarized in Table 5. The fiber may be chemically modified to resist attack: for example, conversion of cellulose to diacetate or triacetate yields a fiber which does not support mold growth, and even acetyl degrees of substitution lower than 2 have a significant effect. This approach essentially implies a chemical transformation of polymer and fiber which has far reaching consequences on the properties and performance of the products.

In a second approach, a resin which provides an impermeable barrier to bacteria and fungi is added to the fabric. This approach is generally used for industrial fabrics, where considerations of porosity, permeability and appearance are secondary.

Improvements in rot resistance and bacteriostatic properties have also been obtained on cotton in conjunction with the application of crosslinking agents, of fire retardant finishes, and of other finishing agents insolubilized in situ. The most effective approach to rot resistance through application of resins has been the polymerization of N-methylol-melamine derivatives in water-swollen fabric(9) which is known as the ARIGAL(R) process (Ciba Geigy). Cotton fabric treated in this manner is reported to retain 100% of its strength after soil burial for up to 15 weeks. The mechanism by which polyfunctional N-methylol compounds and other finishes capable of generating formaldehyde inhibit the growth of micro-organisms in treated cotton may entail restricted diffusion of moisture into the cross-linked fibrous substrate, as well as slow controlled release of formaldehyde from treated fabric or from the resin network formed in or on fibers in the course of application.

The direct [illegible] which [illegible] improved resistance to micro-organisms [illegible] the deposition of active compounds which are effective bactericides or fungicides. These must be efficient, non-discoloring, durable to washing and, above all, non-toxic to humans. The balance between activity, which implies diffusivity in the system, and durability to washing, which implies lack of solubility and resistance to leaching in water is particularly difficult to attain. Few among the numerous claims found in the patent literature describe compounds which are in commercial use. Tables 6 and 7 show compounds which have been used commercially for fabric finishing: those listed in Table 6 have varying degrees of solubility, and generally limited resistance to leaching. For the organometallic compounds shown in Table 7, activity depends on the presence of heavy metal. Copper compounds are both fungistatic and bacteriostatic, and extensively used for preservation of tent canvas and sandbags, even though they impart a green color to the treated fabrics. Tin compounds have the advantage of being colorless, but they exhibit varying degrees of toxicity. Zinc compounds have lower activity, but lower toxicity as well. Mercury compounds (not shown in Table 7), have been essentially ruled out by the Environmental Protection Agency due to potential cumulative toxicity effects. Generally speaking, compounds designed to inhibit mildew and rot are used primarily for military and institutional fabrics. They are effective in low concentrations and applied by pad/dry/techniques from emulsions or organic solvents. Durability to leaching depends on the solubility of the specific compound, and durability to laundering is at best limited. The relative effectiveness of some of the compounds, shown in Tables 6 and 7, and the concentrations used in fabric finishing, vary greatly: for example, for the highly effective (and now forbidden) phenyl mercuric acetate, a 0.01% concentration is sufficient to give 50% strength retention after ten days' soil burial. For copper-8-quinolinolate, the needed concentration is 0.05%; and for salicylanilide, 0.5%.

IV. FLAME RETARDANT FINISHES

Research and development work on flame retardant finishing has been greatly stimulated by recent legislation in the U.S., and in other countries. At this time, this field is perhaps the most important, and certainly the most active area of investigation in textile chemistry.

Durable flame retardant finishes for cotton-containing fabrics may be defined as those which impart self-extinguishing behavior, and are not removed in laundering. A fabric which is described as "self-extinguishing" when placed in a vertical position and ignited at the bottom, will not continue to burn after the source of ignition is removed. The conditions of testing (specimen size and mounting, source, site and time of ignition, etc.) must be carefully defined when indicating self-extinguishing behavior, but, in the U.S., the term is generally used with reference to the conditions specified for the test of the U.S. children's sleepwear standard (23) which is a modification of previously developed vertical flammability tests.

Finishing of cotton and cotton blend fabrics to impart self-extinguishing behavior and flame resistance durable to laundering, involves problems which are far more complex than those encountered in other finishing processes. Firstly, the amount of insolubilized or fixed finish required is considerably greater than for other functional finishes: the added nonfibrous material tends to impair the aesthetics and performance properties of the fabric, and to increase its cost greatly. Secondly, finish uniformity and durability must be rigorously controlled since deviations can have disastrous consequences in litigation or product liability suits. Lastly, results of tests for the evaluation of flammability are critically dependent on a large number of variables and laboratory testing of finish fabric becomes an exacting and costly part of finishing development, and quality control.

Interest in the application of flame retardant compounds to cotton fabrics dates back to the seventeenth century(24), when clay and plaster paris were applied to canvas used for theater curtains as flame retardant. From that time until World War II, investigations of textile flame retardants were limited to water soluble salts, even though in 1913, William Henry Perkin defined the requirements for flame retardant finishes in words which still apply today(25):

> "A process, to be successful must, in the first place, not damage the feel or durability of the cloth, or cause it to go damp as so many chemicals do, and it must not make it dusty. It must not affect the colors or the design woven into the cloth or dyed or printed upon it; nothing (such as arsenic, antimony or lead) of a poisonous nature or in any way deleterious to the skin may be used and the fireproofing must be permanent, that is to say, it must not be removed even in the case of a garment which may possibly be washed 50 times or more. Furthermore, in order that it may have a wide application, the process must be cheap."

Progress from Perkin's time to World War II is well documented in a book by Little(26), which remains a classic cornerstone of our current knowledge on flame retardant finishing techniques for cotton fabrics. In this book, important generalizations are set forth concerning the chemistry of fire retardants for cotton. The outstanding effectiveness of phosphorus is recognized; and the foundation is laid for most subsequent work on the mechanism for inhibiting combustion in cotton fabrics, and on approaches to the development of durable finishes.

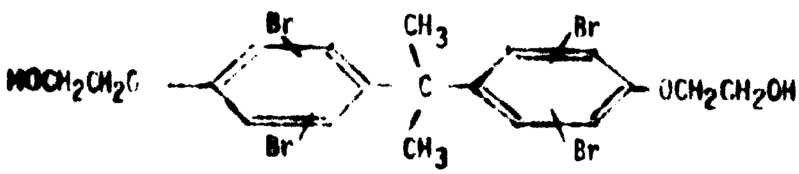
It is now established that phosphorus-containing compounds exert their flame retardant action by decomposing to species which alter thermal degradation reactions in the substrate and decrease the concentration of combustible products while enhancing dehydration reactions (27). It has also been shown that phosphorus containing flame retardants are more effective when used in conjunction with nitrogen-containing compounds (28). In a 100% cotton fabric, the presence of a sufficient amount of phosphorus (2% to 4%, depending on fabric construction), preferably in conjunction with nitrogen (2% to 6%) effectively imparts self-extinguishing behavior. When durability of the flame retardant finish is required, the phosphorus and nitrogen must be insolubilized either in substitutent groups covalently bonded to cellulose hydroxyls, or in a crosslinked polymer network formed in or on fibers. Phosphorus and nitrogen thus must be part of molecules capable of forming a three-dimensional polymer "in situ" and/or of reacting with the fabric substrate during the finishing process. The amount of finish required to attain the desired phosphorus content in the treated fabric depends primarily on the phosphorus content of the "active" flame retardant species, and on the insolubilization yield (efficiency) in the finishing process. The chemical stability of the insolubilized products determines the amount of finish retained in laundering (durability). Phosphorus compounds used in durable flame retardant finishes must meet the requirements summarized in Table 8 and, in addition, compatibility with nitrogenous co-reactants and with additives must be considered. The essential requirements for the finishing process include absence of toxic compounds, and, preferably, the use of conventional equipment and procedures in the finishing plant. The overall objectives of satisfactory (or adequate) fabric performance (including but not limited to flame resistance), aesthetics, and economics must of course be met.

Numerous organophosphorus compounds and formulations have been evaluated for flame retardant finishing of cotton fabrics over a period of 20 or 30 years. Many have failed to meet one or more among the critical requirements outlined, and thus have not attained commercial status. At this time, only three chemical systems are used commercially in the U.S. The summary presented in Table 9 indicates the organophosphorus compound, the other essential components of the finish (if any), and the principal mechanism of finish insolubilization for these systems. Salient information on the finishing processes is summarized in Table 10.

Performance properties of the finished cotton fabrics are considered acceptable, with advantages in fabric hand or strength retention claimed for specific fabric/finish combinations by individual chemical manufacturers or textile mill processors. However in all instances, the finish stiffens the fabric somewhat, causes tensile strength losses of about 20-30%, and tear strength losses of about 35-45%, depending on the fabric construction and finish add-on. Treated fabrics are self-extinguishing according to the vertical flammability test specified in the children's sleepwear standard (23), initially and after 50 launderings with high phosphate detergents. Accumulation of calcium and magnesium salts (which may occur on laundering in hard water without adequate amounts of phosphate) impairs flame resistance. This effect is reversible and flame resistance can be restored by rinsing with acid. Bleaching with hypochlorite, on the other hand, accelerates loss of finish and flame resistance is irreversibly lost. In brief, commercial flame retardant finishes for cotton fulfill the requirements outlined (Table 8) only in part. More efficient organophosphorus compounds are needed in order to decrease the amount applied and, therefore, side effects and costs. Research to develop new reagents is continuing with this objective in mind. For example, results obtained in the laboratory with amides of chloromethyl phosphonic acid and of methyl phosphonic acid (33), (34) demonstrate considerable progress towards the goal of imparting self-extinguishing behavior at low weight gains.

Finishing of polyester/cotton blend fabrics is far less advanced. The problem is complex, since the two fibers differ in their physical response, and in the course of their chemical degradation at elevated temperature. Flame retardant finishes that are effective on 100% cotton do not necessarily decrease the flammability of polyester/cotton blends--at least not in terms of the results obtained in the vertical flammability test for self-extinguishment(23). Finishes applied to blends from aqueous solutions tend to penetrate cotton fibers preferentially, and the concentration of reactive compounds in the cotton becomes exceedingly high. Furthermore, the concentration of hydroxyl groups in the total substrate is lower in the case of blends (in proportion to the polyester content), and the stoichiometry of the insolubilization reactions is inevitably affected by these factors. Extensive research activity on durable flame retardant finishes for polyester/cotton blends during the last few years has resulted in considerable progress(35), and some promising approaches are emerging even though commercially finished blend fabrics containing 50% or more polyester are not available. Table 11 shows some finishing systems claimed to be effective on polyester/cotton blends. Flame retardancy is obtained through the presence of phosphorus, or bromine, or combinations of these elements. In these finishes, compounds containing phosphorus and/or bromine are not reacted with the substrate. Adequate durability to washing is related to the solubility characteristics of the flame retardant compounds, and to the use of resin binders in the finish formulation. Large amounts of the finishes are needed to impart self extinguishing behavior to the fabric and fabric stiffness is a major problem in most instances.

A bromine-containing polyester (Dacron 900F(R), a copolymer in which part of the ethylene glycol is replaced by the brominated glycol below)



is now available from the Dupont Company in semi-commercial quantities. When "conventional" polyester fibe in polyester/cotton blend fabrics is replaced by this copolymer fiber (which contains approximately 6% Bromine), or by an equivalent modified polyester fiber, lower amounts of flame retardant finish are required to meet a given flammability test and undesirable effects on fabric properties are reduced. The major problem then becomes one of cost.

In summary, the goal of imparting durable flame resistance to 100% cotton fabrics without significantly altering aesthetics and performance properties is now within reach. For polyester/cotton blends, research must continue for some time to come and new approaches must be developed before a comparable status is reached.

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Table 1

	CREASE RESISTANT (WASH AND WEAR)	WATER REPELLENT	OLEOPHOBIC	FLAMEPROOF	BACTERIOSTATIC & FUNGISTATIC
WOVEN (OUTERWEAR)	●	◔	◔	◔	◔
WOVEN (LININGS AND UNDERWEAR)	◔	○	○	◔	◑
KNITTED (OUTERWEAR)	●	◔	◔	◔	◔
KNITTED (LININGS AND UNDERWEAR)	◔	○	○	◔	◕
BED LINEN	○	○	○	◔	◔
UPHOLSTERY (CURTAINS, DRAPERIES, CARPETS, ETC.)	◑	◑	◔	●	◔
INDUSTRIAL FABRICS (AWNINGS, TENTS, ETC.)	○	●	◔	●	●

● PROPERTY DESIRED ○ PROPERTY NOT REQUIRED

Table 2. Durable finishes for cotton-containing fabrics

DESIRED PROPERTY	CURRENT TECHNOLOGICAL APPROACHES
EASY CARE (DURABLE PRESS)	REACTION OF COTTON WITH CROSSLINKING AGENTS
RELEASE OF OILY SOILS	(A) HYDROPHILIC, POLAR POLYMERS. (B) POLYMERS CONTAINING PERFLUOROALKYL GROUPS AND HYDROPHILIC SEGMENTS.
WATER REPELLENCY	(A) COMPOUNDS CONTAINING LONG CHAIN ($>C_{16}$) ALKYL GROUPS. (B) POLYSILOXANES. (C) POLYMERS CONTAINING PERFLUOROALKYL GROUPS.
RESISTANCE TO MICRO-ORGANISMS (MILDEW, ROT, BACTERIA)	(A) ORGANOMETALLIC COMPOUNDS (B) HALOGENATED PHENOLS (C) ANILIDES (D) SUBSTRATE MODIFICATION
FLAME RESISTANCE	(A) ORGANOPHOSPHORUS COMPOUNDS (B) HALOGENATED COMPOUNDS

Table 3. Finish-substrate interactions in Durable finishes for cotton-containing fabrics

FINISH-SUBSTRATE INTERACTIONS	EASY CARE (CROSS-LINKING)	SOIL RELEASE	WATER REPEL-LENCY	RESIST-ANCE TO MICRO-ORGANISMS	FLAME RESIST-ANCE
FINISH DISTRIBUTION					
1. INSIDE FIBER	●				●
2. ON FIBER SURFACES		●	●	●	●
FINISH INSOLUBILIZATION					
1. COVALENT BONDING (REACTION WITH OH)	●				●
2. IN SITU POLYMERIZATION OF MONOMERS					●
3. INSOLUBILIZATION OF PREFORMED POLYMER		●	●		●
4. DEPOSITION OF INSOLUBLE COMPOUNDS			●	●	●

Table 4. Durable water repellent finishes

CHEMICAL TYPE	PROTOTYPE	DURABILITY TO WASHING	DRY CLEANING
DERIVATIVES OF LONG CHAIN FATTY ACIDS	$[C_{18}H_{37}CONH-CH_2\overset{+}{N}C_5H_5]Cl^-$	GOOD	POOR
POLYSILOXANES (SILICONES)	$HO-Si(CH_3)_2-[O-Si(CH_3)_2-]_n OH$	MODERATE	GOOD
POLYPERFLUORO-ALKYL ACRYLATES (FLUOROCHEMICAL)	$\{CH_2-CH(COOCH_2(CF_2)_nCF_3)\}_n$	GOOD	GOOD

Table 6. Approaches to antibacterial and antifungal finishes

APPROACH	PRINCIPLE	EXAMPLES
CHEMICAL MODIFICATION	CHANGE IN CHEMICAL STRUCTURE OF SUBSTRATE	A. ACETYLATION B. CYANOETHYLATION
RESIN BARRIER	COATING FIBERS WITH SUBSTANCE WHICH IS IMPERVIOUS TO MICRO-ORGANISMS	--
IN SITU FORMATION OF CROSSLINKED RESIN	CONTROLLED RELEASE OF FORMALDEHYDE AND/OR CELLULOSE CROSS-LINKING	POLYCONDENSATION PRODUCTS OF A. POLYMETHYLOL MELAMINE B. TETRAKIS HYDROXY METHYL PHOSPHONIUM CHLORIDE (THPC)
DEPOSITION OF ACTIVE BACTERIOCIDAL OR FUNGICIDAL COMPOUNDS	CONTROLLED RELEASE OF ACTIVE INGREDIENT FROM TREATED SUBSTRATE	A. SURFACE ACTIVE AGENTS B. PHENOLS C. ANILINES D. ORGANOMETALLIC COMPOUNDS

Table 6. Effective compounds in finishing for resistance to micro-organisms

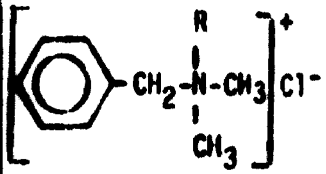
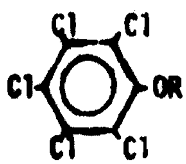
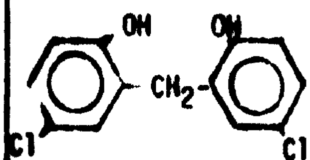
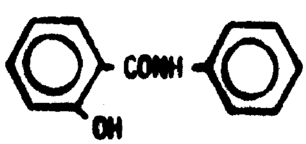
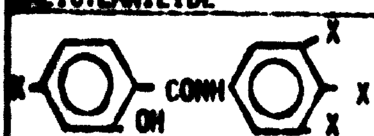
TYPE	STRUCTURE (EXAMPLES)	REF.	APPLICATIONS AND LIMITATIONS
SURFACE ACTIVE AGENTS	 R = $C_{12}H_{25}$- , $C_{14}H_{29}$- QUATERNARY AMMONIUM COMPOUNDS	(10)	BACTERICIDES. WATER SOLUBLE (LIMITED DURABILITY TO LAUNDERING)
PHENOLS	 R = H , $-COC_{11}H_{23}$ PENTACHLOROPHENOL (AND ESTERS)	(11), (12)	ROTPROOFING AGENTS: SODIUM SALT IS WATER SOLUBLE AND LEACHED EASILY. (R=Na) LAURATE ESTER (R= $COC_{11}H_{23}$) LESS EFFICIENT BUT MORE LEACH-RESISTANT
	 2.2'METHYLENEBIS 4-CHLOROPHENOL	(13), (14)	ROTPROOFING AGENT. APPLIED FROM ORGANIC SOLVENT OR EMULSION.
ANILIDES	 SALICYLANILIDE	(15)	BACTERICIDE AND ROTPROOFING. APPLIED FROM ORGANIC SOLVENT.
	 X = Cl,Br HALOGENATED SALICYLANILIDES	(16)	HALOGENATED DERIVATIVES HAVE SHOWN SOME SIDE EFFECTS (CONTACT SENSITIZING).

Table 7. Organometallic compounds in finishing for resistance to micro-organisms

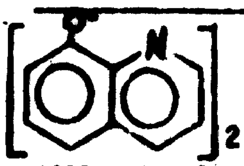
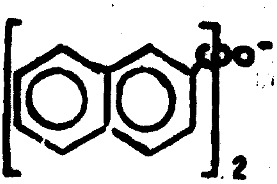
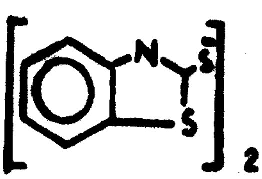
STRUCTURE (EXAMPLES)	REF.	APPLICATIONS AND LIMITATIONS
 Cu^{++} COPPER-8-QUINOLINOLATE	(17), (18)	ROTPROOFING OF OUTDOOR FABRICS, SOLUBILIZED WITH OLEICACID OR CASTOR OIL FOR APPLICATION FROM SOLVENT. IMPARTS GREEN COLOR.
 Zn^{++} ZINC NAPHTHENATE	(19)	MOLD INHIBITOR, FUNGISTATIC ACTIVITY.
 Zn^{++} ZINC-2-MERCAPTO BENZOTHIAZOLE	(20)	FUNGISTATIC ACTIVITY
$[(CH_3)NCS^-(=S)]_2$ Zn^{++} ZINC DIMETHYL DITHIO-CARBAMATE	(20)	FUNGISTATIC ACTIVITY. CAN BE PRECIPITATED IN SITU FROM SODIUM SALT AND Zn SULFATE.
$(C_4H_9)_3Sn$-X; X = CH_3COO, C_6H_5COO; TRIBUTYL TIN ACETATE, BENZOATE	(21), (22)	FUNGISTATIC AND BACTERIOSTATIC EFFECTS ON FABRIC AT VERY LOW CONCENTRATION.

Table 8. Phosphorus compounds used in durable flame retardant finishes

REQUIREMENT	OBJECTIVE
CAPABLE OF INSOLUBILIZATION BY POLYMERIZATION WITH COMONOMERS AND/OR BY REACTION WITH OH	DURABILITY OF FINISH TO LAUNDERING
HIGH PHOSPHORUS CONTENT	LOWEST POSSIBLE ADDED WEIGHT IN TREATED FABRIC
LOW CARBON CONTENT	LOWEST POSSIBLE ADDED FUEL IN TREATED FABRIC
ABSENCE OF IONIC SITES (AFTER INSOLUBILIZATION)	AVOID ION EXCHANGE WITH METALS IN LAUNDERING

Table 9. Commercial chemicals for flame retardant finishing of cotton fabrics

ORGANOPHOSPHORUS COMPOUND	COREACTANT(S) REQUIRED	INSOLUBILIZATION MECHANISM	TRADE NAME (MANUFACTURERS)	REF.
$(CH_3O)_2P(=O)-CH_2CH_2CONHCH_2OH$	-	REACTION WITH CELLULOSE OH	PYROVATEX CP (CIBA-GEIGY)	(29)
$[(HOCH_2)_4P]^+ X^-$ X=Cl, OH, etc.	NH_3, NH_2CONH_2, etc.	IN SITU POLYMERIZATION WITH COREACTANT (POLYCONDENSATION)	THPC, THPOH (HOOKER CHEMICAL, AMERICAN CYANAMID, ALBRIGHT AND WILSON)	(25), (30), (31)
$[-O-P(=O)(OCH=CH_2)-OCH_2CH_2-]_n$	$CH_2=CHCONHCH_2OH$	IN SITU POLYMERIZATION (FREE RADICAL)	FYROL 76 (STAUFFER CHEMICAL CO.)	(32)

Table 10. Flame retardant finishing processes for cotton fabrics

CHEMICAL SYSTEM (see Table 9)	PROCEDURE (Essential steps)	% FINISH (RANGE) APPLIED	% FINISH (RANGE) INSOLUBILIZED	% P IN FINISHED FABRIC (range)
PYROVATEX CP+ N-METHYLOL MELAMINE+ +ACID CATALYST	PAD/DRY; CURE (320-350°F); WASH.	30-40	20-30	2-2.5
THPOH (neutralized THPC)	PAD; DRY TO 10% MOISTURE; EXPOSE TO NH_3 GAS; OXIDIZE/WASH.	30-40	25-35	3-5
FYROL 76 + N-METHYLOL ACRYLAMIDE + + FREE RADICAL CATALYST	PAD/DRY; CURE (300-350°F); WASH.	25-35	20-30	2-4

Table 11. Durable flame retardant finishes for polyester/cotton blend fabrics

FLAME RETARDANT COMPOUNDS IN FINISH	INSOLUBILIZATION ON FABRIC	REF.	PROBLEMS IN TREATED FABRIC
CONDENSATION PRODUCTS OF TETRAKISHYDROXYLMETHYL PHOSPHONIUM CHLORIDE (THPC) (PHOSPHONIUM OLIGOMER)	IN SITU POLYMERIZATION	(36)	HIGH % P NEEDED; STIFFENING; HIGH COST.
THPC + N-METHYLOL COMPOUNDS + TRIS-2.3-DIBROMO-PROPYL PHOSPHATE (TBPP)	TBPP "TRAPPED" BY POLYMER FORMED IN SITU	(37)	STIFFENING; LIMITED DURABILITY OF BROMINE
THPC + N-METHYLOL COMPOUNDS + POLYVINYL BROMIDE (PVB)		(38)	STIFFENING; DISCOLORATION
DECABROMO DIPHENYL OXIDE + + ANTIMONY OXIDE + ACRYLIC BINDER (P.44)	BINDING OF SOLID INSOLUBLE FLAME RETARDANT COMPOUNDS.	(39)	STIFFENING; DUSTING, WHITENING; LIMITED RESISTANCE TO ABRASIVE WEAR.

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