THE EFFECT OF TWO CONCENTRATIONS OF A SOLID AND A LIQUID STARCH ON SELECTED PROPERTIES OF TWO COTTON FABRICS

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CHAPTER I

INTRODUCTION

"Cotton is the fiber which clothes the world" (24). This is especially true in Pakistan where the majority of the people wear cotton garments. If properly washed, starched and ironed, cotton garments give a neat, fresh and crisp appearance. Unstarched garments, on the other hand, may appear limp and unattractive. Starch makes washable clothing comparatively easy to get clean since much of the dirt is deposited on the starch film and is then washed out with the starch in the suds when the garment is laundered (25). For these reasons, starching is one of the most important aspects of laundering cotton fabrics.

The garments generally starched are men's shirts, men's and women's white cotton shalwars (trousers), cotton saries, cotton dupattas and other miscellaneous garments. In this study, two varieties of white cotton fabrics used for shalwars and men's shirts were selected, and some effects of high and low concentrations of a solid and a liquid starch on the fabrics were studied.

Shalwar is a part of the dress most commonly worn by the women of West Pakistan, especially the high school and college girls. The complete dress consists of a shalwar (trousers), a qameez (tunic and a dupatta (scarf). The complete dress could be of cotton, silk, or rayon, but cotton shalwars are of major interest because generally the shalwar is worn even with silk, rayon or any other synthetic fiber qameez and dupatta.

Whether the shalwar is home laundered or laundered by the washerman (dhobi), it is starched and ironed. Although starch gives a neat and crisp appearance to the cotton fabrics, it is desirable that it does not hinder the comfort and serviceability of the garment.

Considering the climatic conditions of Pakistan, which consist of long, hot and humid summers and short winters, it is important that garments have permeability and good water absorption for comfort.

From the point of view of appearance, white garments should stay white even after many launderings. Starching should not produce yellowing in the garments. At the same time, garments should be durable enough to be serviceable.

With these points in regard to appearance, comfort and serviceability in mind, the objectives in this study were:

1. To determine and compare the effects of solid and liquid starches of high and low concentrations on five selected properties of two cotton fabrics from Pakistan, namely:
   a. air permeability
   b. absorption
   c. reflectance
   d. stiffness
   e. tear resistance
2. To relate air permeability, absorption, reflectance and tear resistance to that of stiffness.

3. To relate the findings in objectives one and two to the appearance, comfort and durability of the fabrics for *shalwars* and men's shirts.

The experimental plan which was aimed toward realization of these objectives is described in later chapters.

CHAPTER II

REVIEW OF LITERATURE

The literature reviewed in this chapter is limited to a discussion of starches, their use in home laundering, and of five fabric properties which may be affected by starches, namely; air permeability, absorption, reflectance, stiffness and tear resistance.

Starch

There are numerous types of starches which may be obtained from the seeds of wheat, rice, and maize, from the pith of plants (sago), or from roots and tubers (tapioca and farina). The term "starch", without qualification, refers to wheat starch (27).

Marsh (3) refers to the work of Maquenne and Roux who succeeded in decomposing starch into two distinct substances which they termed amylose and amylopectin. The former showed the characteristic blue coloration with iodine and was soluble in boiling water, but amylopectin had to be boiled for dispersion and made into a viscous liquid. Later these two substances were termed α-amylose and β-amylose respectively.

The minor component "A fraction" or α-amylose, in the case of corn starch, appears to consist of long chainlike molecules. This fraction is unstable in a colloidal sense and is responsible for the gelling and so-called retrogradation of starch (43).

The major component "B fraction" or β-amylose is presumed to have a very large and ramified molecular structure, possibly a tree-like configuration with short linear branches. It yields reddish coloration with iodine. This fraction is stable colloidally and functions as a protective colloid for the "A fraction" (43).

Like cellulose, starch has the empirical formula $(C_6H_{10}O_5)_n$, but it contains small amounts of phosphoric and salicic acids. Starch is composed of chains of α-glucose residues and therefore differs from cellulose which consists of β-glucose residues.

Starch swells but is insoluble in cold water. The action of heat on the suspension brings about gelatinization. The granules swell very considerably, and with some starches, such as potato starch, the granules burst and release starchy material from the interior of the granule, which passes into solution. The ordinary starch paste, therefore, is not homogenous, for it consists of granules in various stages of swelling and disintegration.

It is well known that the granule size and shape, the gelatinization temperature, and the paste characteristics of various starches differ according to their origin.

In a general way, starches derived from grain seeds yield sols which gel or set back to a greater degree than those derived from tubers, such as potato and tapioca. A notable exception to this generalization is in the so-called waxy starches where, by selective hybridization, a variety of grain has been developed which yields a starch having the paste characteristics of one derived from a tuber (43).

The physical behaviour of starch and its various modifications may be traced primarily to two factors: the organization of the total starch substance in distinct granules, and the specific effects of the component fractions. A starch paste may function in two ways: it may be used for its floculant gel qualities and its absorptive power; or it may act as a sol, or protective colloid. These properties are derived directly from the A and B fractions respectively. In many instances it appears that only one action is required and the presence of the other starch component may even be detrimental (43).

The mere knowledge of the existence of starch fractions is insufficent to explain all the physical differences in the various starches. There are investigators who attribute these differences to the length and complexity of the glucose chain in the A-fraction, but there is still a scarcity of evidence to support this contention. Others conceive the differences to be due to the presence of small amounts of non-carbohydrate material occurring naturally in certain of the starches. For instance, the paste characteristics of potato starch can be markedly altered to resemble those of corn starch by absorbing fractional percentages of fatty acid on to the starch. The net effect of such treatment is to shorten the paste substantially so that it no longer has its native characteristics (48).

The use of starch as a stiffener and adhesive has been known from time immemorial. About 1560, the use of starch became popular in France and Holland as a means of stiffening the ruffles of the clothes of the nobility. The fashion spread to England in Elizabethan days. The early use of starch in the textile industry was as a size in weaving, and this practice was firmly established about 1750. The next development, which followed quickly, was the use of starch as a thickener in hand block printing (27).

In spite of recent developments in numerous synthetic finishing agents, starch still remains the most common and most important finishing agent for cotton fabric, particularly for white goods. It may be utilized as a filling or stiffening agent, as well as a binding agent for various inorganic compounds such as the well known China clay.

Each type of starch possesses characteristic properties which are utilized in obtaining different effects in finishing.

Although wheat starch gives a smooth thick feel to the cloth, imparting firmness and some solidity, it is apt to crack on the surface. The starched goods take a high gloss on beetling or calendering (27).

Farina or potato starch gives a soft and flexible finish, and in conjunction with a glazing agent, such as borax or wax, is capable of producing a high gloss without appreciable increase in weight. The viscous nature of the farina paste tends to prevent much penetration into the yarns of the fabric, so that starch is more on the surface, imparting a thick and crisp effect, which "mellows" on ageing and conditioning (27).

Rice starch on the other hand, penetrates better and gives a harder finish, with a fullness and firmness which is apt to be regarded as "boardy". It is of great interest in the laundering industry as a stiffener for it is less affected by humidity than other starches. Therefore, the garment holds its shape better even in humid climates (27). Maize starch pastes are relatively stable in viscosity, and the characteristic feel remains constant even with the well-boiled starch pastes. On account of the viscosity of its solution, maize starch gives a crisp effect which is slightly harsher than that from farina, and less than rice starch. The soluble starch from maize gives a finish somewhat similar to that from wheat starch.

Tapioca starch gives a thin and soft effect from the typical transparent gel of the paste, and the finish is tough and flexible as compared with maize or corn starch. However, it is rarely used alone.

Sago starch finds application mainly in sizing, for although it gives a thin, firm feel to the cloth, unfortunately it tends to crack, particularly on folding.

In addition to the common starches described earlier, there are some modified starches in use. These being:

Enzyme-modified starches:

The use of enzymes to modify starch for use in warp sizing has been practiced for some time. This treatment eliminates the effect of the granule structure on the paste and reduces the viscosity of the resulting colloidal solution to the desired value. For modifying the starch, diastatic enzyme preparations which contain a predominant amount of alpha-amylose should be used (46).

Commercial oxidized starch resembles raw starch in that it retains practically the same granule structure, is insoluble in cold water, and shows the characteristic starch colour reaction with iodine. When heated with water the unoxidized starch yields pastes or gels; whereas, the oxidized starches at equal concentration give thinner bodied solutions, the difference varying with the degree of oxidation (46).

Oxidized starch has a shorter cooking time, higher fluidity, and lower rate of congealing than the parent starch.

Films formed by drying oxidized starch paste are of a tough and horny character in comparison with the brittle films of the unoxidized starch (20).

The amount of sizing taken up by a fabric depends upon many factors (34). Among these are the following:

1. Twist of the yarn

   When yarns which are similar in every respect except twist are sized alongside each other the most highly twisted yarn takes up least sizing.

2. Yarn number

   When the same mixture of cotton is spun to different counts and the yarns are sized under the same conditions, more sizing is taken up by a pound of fine than by a pound of coarse yarn.

3. Different types of cotton

   Yarns of equal counts and twist spun from cottons of different origin take up sizing to different extents. The difference depends on the fineness of the lint, a coarse staple of high hair weight per centimeter being stiff, and not easily moulded into yarn form, so that it produces a bulky yarn which takes up sizing freely.

4. Nature of sizing

The amount of sizing which any one sort of yarn takes up depends on the composition and physical behaviour of the size. In dealing with this question it is well to consider that the weighting effect obviously depends both on the percentage of dry solids in the sizing (the concentration), and on the quantity of paste carried by the yarn. Of two sizings of equal viscosity, that which is the more concentrated has the greater weighting effect; if two sizings are equally concentrated but differ in viscosity, the more viscous is more freely taken up by the yarn; while if, as most commonly happens, viscosity and concentration increase together, the more concentrated, more viscous sizing has the greater weighting capacity.

5. Mechanical effects

Increasing the speed of the experimental machine increases slightly the amount of size put on the yarn. Doubling the pressure of the squeezing roller reduces by about one-tenth the amount of size taken by the yarn, while a modification of the roller surface by placing a thin cotton fent over its flannel cover is sufficent to reduce by one-third the amount of sizing applied.

6. Penetration of sizing into the yarn

Penetration of sizing as distinct from the amount taken up is greater when a cotton-faced squeezing roller is used than when bare flannel is employed. An increase of the pressure exerted by the roller drives the sizing deeper. In experiments where three times the normal pressure was applied, sizing was found throughout the yarn.

Air Permeability

The conditions of wear allow for relative motion between the fabric and the body, which results in displacement of air either through the fabric interstices or through vents in the clothing. The air under the fabric is therefore in a state of turbulence to a certain degree and is constantly de-saturated by admixture with air from outside the fabric. The freer the exchange of the air between the body and the clothes with that of the outside atmosphere, the more closely does the vapour tension of the air between the body and the clothes approach that of the outside atmosphere, with a consequent increase in the rate of loss of moisture.

This mode of transfer of moisture is described as ventilation, and is concerned with the passage of moist air as a whole, as distinct from passage by diffusion, which is, in comparison, a slower process. It is obvious that for a fabric of very low permeability, ventilation can only take place through the vents, but such a fabric will exert a more efficient bellows action than a more open one. On the whole, it is probable that a fabric of high permeability is preferable to one of low permeability, since in the former instance the air between the fabric and the body has greater freedom of exchange with that of the outside atmosphere (12).

The ease of passage of air through a fabric is expressed by its factor of permeability. In a more precise sense, the air permeability of a fabric is defined as the rate of flow of air under a different pressure through an area of the material (41). In their review of the literature, Black and Mathews (4) stated that Rubner (Lehrbuck der Hygiene, 1907) reported the earliest measurements of the air permeabilities of fabrics. From the time in seconds required for the passage of one cubic centimeter of air through one square centimeter of cloth under a pressure equivalent to 0.42 mm of water, he calculated the permeability for a one centimeter thickness of material.

Sale and Hedrick (36), investigated the heat insulation properties of blankets by determination of air permeability of materials.

Sieminski and Hotte (41), refer to work of Bellinger, who reported on the permeability of certain duck fabrics by measuring the back pressure developed upon forcing air at a constant rate through the fabric. They also have reviewed Draper's novel method of measuring with anemometer and stop-watch the air passed through felts by a high pressure blower.

Gregory (12), interested in the general problem of the transfer of moisture through fabrics, conducted determinations of air permeability. With an aspirator bottle arrangement, air was drawn through the fabric by allowing water to flow out of the bottle at a definite rate of flow of air through the sample. A water manometer measured the pressure drop across the specimen which was clamped over the end of a cylinder of known area. The arrangement was simple and similar to that employed by Sale and Hedrick (36).

In the work of Marsh (26) who published notes on the results of experiments relating to the permeability of fabrics, the sample was held between the ends of two tubes, edge leakage at the clamps being prevented by a mercury seal. Various orifices, wire gauze, capillary tubes, tubes filled with glass wool, and tapped tubes were all tried in conjunction with a micromanometer for the measurement of the air flow through the samples. Air was supplied from a centrifugal fan.

Barr (3) drew air through the sample and into a special balanced gasometer and measured the time for the passage of a given volume of air. The sample was held across a cylinder with a clamp designed to eliminate edge leakage.

As a result of his work on the measurement of the air permeability of fabrics, Clayton (7) wrote an exceedingly interesting and informative paper. He clamped specimens across a cylinder with a special mercury seal device to prevent edge leakage. Air of known temperature and relative humidity was blown through a capillary flow meter and then through the sample, the pressure differences across the fabric being recorded on an appropriate manometer. Clayton (7) investigated the effect of a number of experimental conditions and of cloth structures upon air permeability. He also introduced the concept of "Sectional Permeability".

Blue, for a Master's thesis, designed and built a permeability tester for fabrics to be used with both gaseous and liquid media. It is described in an article by Schwarz (39) on advances in textile technology. The fabric clamping device is an adaptation of that used by Carson (6) in his extensive treatment of the air permeability of papers.

Fabric finishes and their effect on the comfort of clothing through their influence on the air permeability of the fabric to which they were applied was the subject of an interesting paper by Grimes and Dillin (13).

Four finishes - starch, resin, plastic, and CMC - were applied to each of 13 fabrics to determine the effect of each finish on air permeability of the fabric. In 89 of 130 comparisons, finishes significantly affected permeability. In most cases differences in air permeability of fabric with different finishes were attributed to differences in the width of spaces between yarns.

An increase in concentration of the finishes resulted, in general, in a decrease in permeability with the exception of CMC and plastic finish containing CMC where the permeability was increased.

According to the definition of air permeability, various concepts have given rise to three general methods for the evaluation of the air permeability of a fabric:

1. In the first method the time is recorded for the passage of a given volume of air through an area of the material. The shorter the time, the more permeable to air is the sample. The Gurley Densometer (16) is an example of a type of instrument illustrative of this general method. The use of this type of apparatus is required in some government specifications (44). The results obtained are essentially empirical but might be converted into absolute units for rough measurements.
2. The second method used in the evaluation of the air

permeability of a fabric makes use of a consideration of the back pressure developed upon passage of air at a constant rate through the sample. The greater the back-pressure developed, the greater is the resistance of the fabric to air flow, and, therefore, the less permeable to air is the sample. Haven's so-called Porosity machine (17), originally designed for the Albany Felt Company, is based upon such a principle.

3. The third and the most generally applied method for the determination of the air permeability of a fabric is that in which a given pressure drop is maintained across the sample and the rate of flow of air through the sample is measured.

The instruments made by Frazier and by the American Instrument Company follow the design suggested by Schiefer and Boyland (38). The Schiefer and Boyland instrument employs orifice plates of different orifice diameter (1 to 16 mm) in conjunction with a manometer to give the air flow in cubic feet per minute per square foot of fabric.

This method was used for determination of air permeability in this experiment. Details will be given later in the description of the experiment.

Absorption

The ability of a textile material to take up water or other aqueous solutions plays an important role in comfort and serviceability of clothing; and it is a necessary property for many finished products, such as towels, surgical dressings, and humidifying wicks. It is also important in the comfort and hygiene of clothing (46).

The absorption of moisture may be considered under two headings: first, the absorption of water vapour, and secondly, the imbibition of liquid water (27). Natural fibers have an important property, their hygroscopic nature, which in combination with the large accessible surface allows rapid absorption and desorption of atmospheric water vapour with the consequent evolution or absorption of heat (28).

Absorbability and wetting-out both refer to the entrance of liquid into a yarn or fabric. Absorbability is the ability of the fabric to take up a liquid; wetting-out is a technical term applied to the ability of a liquid to enter a fabric and displace the air from the capillary spaces. Both terms refer to the same phenomenon, but absorbability refers to the fabric and wetting-out to the liquid (42).

Two factors are important in absorbency: the total amount of liquid absorbed, and the rate of absorption of the liquid. Sometimes one factor is measured, sometimes the other, and sometimes both.

According to Skinkle (42), the methods used in testing fabrics for absorbency and wetting-out agents (or penetrants) are:

1. Surface tension - This does not take capillary action into account and so is not always comparable with practical results.
2. Sinking time of a tuft of fiber or yarn or a patch of cloth - The sinking time of a patch of cloth is a test very often carried out in the industry because it is a rapid test, simple

to do, and requires no special apparatus. The results, however, may be erratic and cannot be satisfactorily reproduced.

3. Drave's method - Drave's method (8), which used to be a standard method in the American Association of Textile Chemists and Colorists Yearbook, 1931, is an elaboration and improvement of the sinking time method described earlier. The method is used for comparing different wetting agents. If the method is to be used for testing yarns or fabrics for wetting out, a lighter weight sinker is used.

4. Capillary travel method -

   a. Weireck method: This method is used for testing towelling. Water soluble eosin is applied to the strips very sparingly to serve as an indicator. The strips are allowed to touch the water and the stop watch is started. The height to which the water rises in 1, 5, 10 minutes is recorded. The results are compared with the tables for rating the fabric as to absorbency. The method measures the rate of absorption not always comparable to results obtained in practice.

   b. Haven's method: Haven's (17) method also measures the rapidity of absorption. The weighted ends of strips are allowed to dip into a tray of water and the position of the water in the strips is read at various time intervals. A plot of capillary travel against time is prepared and used in rating the fabrics for absorbency.

5. Absorption from a wet solid surface such as a wet brick or tile - The total absorption from a wet brick or tile surface may be measured by weighing the fabric before and after the test. The brick or tile is kept wet by immersion in water and the fabric is in position long enough to come to equilibrium. This test is said to be independent of relative humidity conditions.

6. Absorption on immersion in a liquid - It measures the total absorption. The excess water may be removed:

    a. By allowing the sample to drip for a standard length of time.

    b. By centrifuging.

    This is Lenher and Smith's (23) method, which determines the per cent increase in weight.

7. Larose method - Larose (22) had published in 1942 a method which measured rates of absorption. Weighed pieces of towelling were contacted with damp, porous plates for various periods of time and the moisture absorbed was measured and related to time.

8. Kettering's method - Kettering (21), in 1948, modified the apparatus of Larose (22) by adding a calibrated side arm which measured the flow of water to the porous plate volumetrically. This method was less time consuming and more

simple in operation than Larose's weighing method. The principles applied by Kettering were ideally suited to a system in which there would be no external influences such as capillarity of the source tube, roughness of the porous plate, or resistance of the plate. Observed phenomena would be due to the influence of the cloth alone. However, when each of these external influences is minimized, the rapidity of the phenomena increases so that timing becomes a great problem.

The theory of absorption behaviour is discussed by Buras, Goldthwait, and Kraemer (5), who have improved Kettering's volumetric method for determining rate of absorption by using a glass filtering funnel, and a flow meter for measuring rates. The method permits numerical evaluation of both rate of absorption and total amount of absorption. This method with certain modifications was used for the determination of absorption in this experiment. The details of the apparatus and the procedure for the measurement of absorption will be given later, under the methodology.

The theory of the absorption mechanism as described by Buras, Goldthwait and Kraemer, however, needs some discussion. The surface of the plate is the termination of many capillary channels which flare outward (but still remain of capillary size) to meet adjacent channels. The water rises along each capillary wall to the upper limit of the wall, where it meets the liquid at the upper limits of the adjacent capillaries. The columns of water merge to form a continuous wet surface.

There are three primary phenomena which a theory of absorption mechanism must explain: (1) time lag; (2) rate of absorption; (3) ultimate absorption.

The time lag is the initial period during which no significant volume of liquid is absorbed. Unless the contact pressure of the cloth against the porous plate is very great, the fabric is initially wetted only at the cross-over points of the yarns, where it is thickest. At these points, the water is drawn into the fiber bundle; the interfiber spaces filling rapidly. Because of the small volume of these spaces, the rate of absorption is quite small. As interfiber absorption continues, the walls of the interyarn spaces become wet, and these spaces, too, can be filled by capillary action. This marks the beginning of significant flow.

The rate of absorption has been defined as the ratio of absorptive forces to the resistance of the fabric to wetting.

$$I = E/R$$

The resistance, R, is the resistance to wetting centered in the initial contact areas, since all of the water entering the fabric must pass through them. The absorptive force, E, may be evaluated by extension of the tangents to the curves relating maximum rate of flow and *head to interception with the zero flow axis.

The relationship of ultimate absorption to head permits an additional evaluation of the absorptive forces. The absorptive forces

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*head: The effective difference in level, or head, is approximately the height of the source tube minus the height of the plate.

in the fabric can reasonably be attributed to the action of capillary channels within it. Practically all channels contribute to ultimate absorption, whereas, only the smaller ones are effective in the initial phase of absorption in which the maximum rate is observed.

In their report, Buras, Goldthwait and Kraemer (5) have given a plausible explanation of the absorption behaviour of purified cotton fabrics, as being due largely to spaces within the fabric rather than to absorption characteristics of the fiber itself.

Reflectance

Reflectance is the ratio of the intensities of light reflected by a specimen and by a standard reflector. It is of importance in evaluating colour, opacity, brightness, and luster.

Cotton fabrics become yellow and/or gray through use and improper care. Certain starches also produce a yellowish tinge in white cotton fabrics from continuous use of the starch and from ironing. A reflectometer utilizing light-sensitive photocells is normally employed for the determination of whiteness or yellowness of such fabrics. Typical of this type of instrument is the Hunter reflectometer (18), which has found wide use in the detergency field. The change in the white or soiled fabric may be expressed in terms of differences in the initial and after-laundering reflectances.

In the case of fabrics, papers and painted or enameled surfaces, the chief concern is the numerical description of properties such as the colour, gloss and surface texture.

Little quantitative information is available on the magnitude of colour differences to be encountered under varying directional conditions of illumination and observation. The problem becomes acute perhaps in the colourimetry of textile materials, because of the great range of colour, variable surface texture, and body structure presented by this class of materials.

McNicholas (29), in 1928 gave an account of the theory and use of the integrating sphere in three methods of reflectometry as proposed by Sharp and Little, Karrer and Taylor, respectively. This theory is discussed in connection with an absolute method in reflectometry involving no direct use of an integrating device. The method is based upon a general law of reciprocity, by means of which, certain reciprocal relations between the reflective properties for undirectional and diffused illumination are derived and applied in the method.

In another paper published in 1934, McNicholas has described apparatus used for reflectometry (30). This apparatus consisted essentially of two illumination units with sample holders, a ventilation system, and the photoelectric equipment, which contained the selective light filters for effective control of the spectral conditions of illumination on the sample.

Later a multipurpose reflectometer was developed by Hunter (18), primarily to measure apparent reflectance, specular gloss, and trichromatic coefficients. These measurements being useful in the ceramic, paint, textile, paper, and chemical industries to indicate lightness, gloss, and colour of finished articles. In the reflectometer, two light beams from a single source are directed along separate paths to two barrier-layer photo cells. Various types of these photo cells were studied to find which could be used most advantageously.

The reflectometer employs a substitution null method and requires a galvanometer to indicate equality of the currents generated by the two photo cells. For each sample tested, there is a photometric adjustment to restore equality of the currents. The amounts of photometric adjustment are measured on the direct reading scales, one of which is used for apparent reflectance and the other for specular gloss. Because of its high precision, the instrument is well suited for measuring small differences in apparent reflectance*, gloss, or colour of nearly identical samples. However, for greatest accuracy, it is necessary to correct the scale readings by calibration.

In tristimulus colourimetry described by Hunter (19), successive settings with the green, blue, and amber filters are used for each measurement of the tristimulus coefficients of a sample. Photo electric tristimulus colourimetry is direct and rapid, because the result of integration with respect to wave length is found automatically by the use of specially chosen source-filter-photo cell combinations. With this type of photoelectric colourimeter, the tristimulus specification of a

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*The reflectance of a surface is, by definition, the ratio of the total quality of reflected light to the total quantity of incident light regardless of directions. Apparent reflectance, on the other hand, always refers to some specified condition of view. The apparent reflectance of a surface for given directions of illumination and viewing is defined as the reflectance which a perfectly diffusing surface would need to possess in order to appear equally bright under the same conditions.

sample is found by setting upon it using in succession each of the three or more filters in an instrument (19).

Tristimulus measurements may be used to:

1. find the approximate trilinear coordinates of a surface colour,
2. measure the amount and direction of a colour change in a specimen,
3. measure the amount and direction of a colour difference between two samples,
4. furnish numerical measures of whiteness and yellowness.

Ross, Taube, Poole, and Thye (35), made a study of the effect of automatic clothes dryers on performance and certain properties of the fabrics, one of them being reflectance. In the study, fabrics were dried in automatic gas and electrically heated tumbler dryers, and, for comparison, on indoor racks and on outdoor lines protected and unprotected from the sun. With 50 dryings, all methods produced an increase in yellowness, which was measured by the multipurpose reflectometer. The gas dryer on all three settings caused significantly more yellowing than any other drying method. In electric dryers, fabrics dried in the cabinet generally yellowed less than those in the tumblers.

The yellowness of white cotton shirts and cotton fabrics was studied by Grimes and Werman (14), in connection with effectiveness and serviceability of four home-applied cotton fabric finishes. After 30 wear and laundering periods, each shirt was analyzed for changes in yellowness from the original.

It was found that the control was slightly more yellow than the original fabric. The shirts with starch, plastic and CMC finishes were less yellow and the resin more yellow than the original. Ranked in order from the least to the most yellow, for both the shirts and the swatches, were: plastic, CMC, starch, control and resin.

Stiffness

Stiffness is one of the characteristics of a fabric which goes into making up that important quality known as "hand". Other physical properties contributing to the hand of a fabric are compressibility, extensibility, resilience, density, surface contour, surface friction, and thermal character (2). Not all of these properties may be equally important.

In establishing any criterion of stiffness for flexible materials, the method should be quantitative, thereby providing a numerical expression of stiffness (32). A method for determining the stiffness of textile fabrics is reported by Grimshaw (15). He considered the stiffness of a fabric to be the ability of that fabric to support its own weight. The inch positions of each of the projected lengths were indicated on the graph. He studied qualitatively the differences in the stiffness of variously sized fabrics but did not attempt to interpret his results mathematically, a necessity in the development of a numerical measure of stiffness.

The ease with which a specimen may be bent or twisted can be stated as the flexibility of a material. This is distinguished from rigidity, which is a measure of the resistance offered by the sample to bending or to twisting. In the former case it is known as flexural rigidity and in the latter, as torsional rigidity. The rigidity, when related to the resistance to bending, is a measure of the stiffness (40).

Whether flexibility is considered, or rigidity in bending, or in twisting, there are two approaches to the problem. The first is concerned with measurements of deformation and the second, with measurements of the forces producing the deformation. Thus, all tests of these factors may be grouped into two large classes depending upon whether deformation is measured or whether force is measured.

In connection with any of the investigations of bending, it is necessary to take into account the weight of the specimen itself or else to so design the test method as to correct for or eliminate the weight of the specimen. It is possible, then, to determine the deformations which take place in a specimen which is allowed to deform with no forces other than its own weight or to apply definite forces to produce a deformation and measure both.

Abbott (1) has discussed different methods of measuring stiffness in his comparative study of five methods for the measurement of stiffness. The five methods being:

1. Cantilever Test

   This test was proposed by Pierce (33), and consists simply of allowing a one-inch wide strip of fabric to project as a cantilever from a horizontal platform and measuring the angle between the horizontal and the chord from the edge of the platform to the tip of the fabric.

2. Heart Loop Test

This method was also proposed by Pierce and consists of bending the ends of a one-inch wide strip of fabric through 270°, bringing the ends together, thus forming a heart-shaped loop, and measuring the length of this loop under the force of gravity.

A constant length of strip -- namely, 20 cm. was used for all fabrics. This also has been shown to be a rather unsatisfactory standard for comparison of stiffness (47). But while any one fabric might not be ranked in the correct order, the results considered as a whole cannot be misleading.

3. Schiefer Flexometer

Schiefer Flexometer (37) measures the amount of work required to fold a pair of samples. The samples are mounted between a fixed and a moving plate in such a way as to form a couple opposing the rotation of the moving plate towards the fixed one. The force required to cause this motion is transmitted through one of a series of calibrated spring strips. Thus, the amount of work required to fold the samples to a minimum angle, determined by the thickness of the fabric, can be calculated, and this is taken as a measure of the stiffness of the material.

4. Planoflex

This method was developed by Dreby (9, 10) in connection with some work sponsored by the American Society for Testing Materials, ASTM Committee D-13. In the instrument, a three-inch wide strip of fabric is mounted in a frame which permits lateral displacement of one end of the fabric in the plane of the fabric. This movement distorts the fabric, and is carried on until diagonal wrinkles appear. The angle through which the frame has been moved at the appearance of the wrinkles is read off a scale on the instrument. The angle is determined on each side of the center, and the sum of the two angles so obtained is taken as a measure of the stiffness of the material.

5. M.I.T. Drapeometer

This instrument was designed at Massachusetts Institute of Technology (M.I.T.) to measure drape rather than stiffness. But insofar as the measure is based on simple bending under zero gravitational force, it was believed that it might correlate with other test methods designed specifically to measure stiffness (47).

On the basis of simplicity of apparatus and the ease and accuracy with which the test may be carried out, Abbott (11) selected cantilever test as a standard laboratory test for stiffness.

The ASTM Standards on Textile Materials (2) suggest two methods of test for determining the stiffness of fabrics.

1. Cantilever test

2. Heart Loop test

Both methods are applicable to fabrics of any fiber content, and are capable of giving results that are reproducible within reasonable limits. In general, they are more suitable for testing woven than for knitted fabrics.

The Cantilever test is the preferred method because it is simpler to carry out. It is, however, not suitable for testing very limp fabrics, or fabrics which have a marked tendency to curl at a cut edge, or when cut specimens have a tendency to twist excessively. In these latter cases, the Heart Loop test may often be used.

The two test methods may not give the same numerical values, but both give excellent rank correlation with a subjective evaluation obtained by feeling the fabric.

Grimes and Werman (14) studied the effect of four finishes on stiffness of white broadcloth. They measured the stiffness by Cantilever method and found that resin finish gave the greatest stiffness with starch and CMC nearly as stiff. The plastic finish was somewhat less stiff and the control had approximately half the stiffness of the fabric with the finishes. The differences among the finishes in drape stiffness was highly significant.

Tear Resistance

Tear resistance is defined as the force required to start or continue a tear in a fabric under specified conditions (ASTM D123-54) (6). It is dependent on such factors as strength and stretchiness of the yarns, the weave, and type of finish.

Two methods of test are common, the trapezoid and the so-called tongue, single-tear, or rip method (2). The tests differ essentially in the preparation of the test specimen and the method of mounting it in the tensile tester. In either test the force necessary to tear the cloth is observed, preferably by means of an autographic device. All machine attachments for determining maximum loads are disengaged during the test.

The Federal Specification (11) defines the tear resistance as the average of the five highest peaks of the curve, whereas the average load is observed according to the ASTM procedure. For research, the Instron tester equipped with an integrator provides a convenient means for obtaining the average load by integrating the area under the curve.

The Elmendorf tear-resistance tester, well known and widely used in the paper industry, is also applicable to fabrics (2). It provides a tongue-type test, the results of which are similar to those obtained by other methods except that they are usually somewhat higher since the tear takes place much more rapidly. The test is relatively rapid to perform, for readings are made directly from the instrument without the use of autographically recorded charts. The method is specially suitable for lightweight and heavily loaded or coated fabrics.

Painter and Chu (31) studied the magnitude of and variations in the speeds of tear obtained with the use of the Elmendorf machine.

CHAPTER III

THE EXPERIMENT

Introduction

Different starches and different concentrations of starches can affect many properties of cotton fabrics, and hence their serviceability. Determinations were made of five properties in which differences might exist between two white cotton fabrics treated with high and low concentrations of a solid starch, liquid starch and no starch in laundering. The properties were: air permeability, absorption, reflectance, stiffness and tear resistance.

Description of the Fabrics

The two cotton fabrics selected for the study were obtained from Pakistan. These cotton fabrics are widely used for shalwars and men's shirts which are usually starched. Both fabrics were white and differed in weight, closeness of weave and in the yarn size. Fabric No. 1, which had the brand name "Latha No. 1500" from Colony Textile Mills, Ismailabad, and a yarn count 85 x 75 was slightly heavier than fabric No. 2, whose brand name was "Latha No. 96000" from Dawood Cotton Mills, Karachi, with a count of 100 x 92. Fabric No. 1 was comparable to good quality bleached muslin and fabric No. 2 was comparable to percale. The fabrics were originally starched; no other information was avilable.

Selection of Starches

Two kinds of cornstarch were used: Faultless, a solid starch and Sta-Flo, a liquid starch containing blueing. In Pakistan generally corn, wheat and rice starches which are available in the market only in the solid state are used. However, the Pakistani homemaker often uses liquid starch for her laundry, which she gets as a by-product of her rice cookery. Liquid Sta-Flo starch was used in this study to replace the rice-extract, or home-made liquid starch used by the Pakistani homemaker.

Experimental Plan

The experiment was set up as a 2 x 2 x 2 factorial one, with three replications. Each replication was treated as a completely randomized block experiment. Starched and unstarched samples were laundered twenty times for each replication and tests were made at intervals of 5, 10, 15 and 20 launderings. The results were analyzed statistically.

Preparation of Swatches

The fabrics were torn from selvage to selvage into 14 inch sections. Each of these sections was then divided into two swatches approximately 18 inches wide. The edges of all swatches were machine overcast to prevent raveling.

Sixty such swatches were prepared from each fabric, out of which twenty swatches per fabric were used in each replication of the experiment. Swatches for the entire experiment were randomly numbered.

In order to simplify identification of the swatches according to fabrics and treatments, colour and number codes were assigned to the various swatches. In order to readily differentiate between the two fabrics, the edges of the swatches were stitched with different colour threads. Different colours of marking inks were used to number the swatches to facilitate rapid sorting of the swatches treated with different concentrations of starches, number of laundering as well as replications.

All the samples, for the various tests were cut from these swatches according to ASTM Standards on Textile Materials (3) specifications at the intervals of 5, 10, 15 and 20 launderings.

Laundering Procedure

The swatches to receive solid starching, liquid starching and no starching were laundered separately. A series of 20 launderings was done for each of the three kinds of treatments mentioned above. Swatches which were treated with solid and liquid starches were separated for high and low concentration treatment of the respective starches.

As the swatches were removed for testing after 5, 10, and 15 launderings, they were replaced by other swatches of the same size and fabric so that the wash load remained constant throughout the series of launderings. These replacement swatches were treated in the laundering as though they were test swatches.

An automatic, top loading, agitator type washer was used for the launderings. Each wash load was built up to two and one-half pounds by addition of extra swatches of white cloth. The water level for one-half of a machine load was used (approximately 8 gal. of water). The swatches were washed for ten minutes with a water temperature of $160 \pm 2^{\circ}F$.

The temperature of water was controlled thermostatically, and was higher than is ordinarily used in home laundering in the United States. This temperature was used purposely in an attempt to provide a temperature in laundering similar to that used by "dhobi" in Pakistan, who soaks the white cotton garments in almost boiling water with soap and bleach for some time before laundering. One-half cup of a synthetic detergent (Duz) and one-half cup of a chlorine bleach (Clorox), with 5.25 per cent available chlorine were used. After the wash period, the fabrics were rinsed twice and damp dried. After the final spin-dry period, the swatches were sorted. The untreated or control swatches were dried for ten minutes in a preheated electric dryer set at a medium heat setting. The swatches which were used to build up the specified weight of the wash load, were dried separately. The starched fabrics were treated as follows:

Solid Starch Treatment

One quart of high concentration starch solution was prepared by dissolving three tablespoons of powdered "Faultless" starch in one quart of boiling water. The solution was cooled to room temperature, and stirred occasionally to prevent scum formation. Similarly, low concentration of starch solution was prepared by dissolving one tablespoon powdered starch in one quart of boiling water and cooling to room temperature.

Since the liquid starch had blueing in it, blueing was added to the solid starch to give approximately the same degree of blueing to the solid starch solutions as the respective concentration of liquid starch. The amount of blueing to be added in these solid starch solutions was determined by preliminary testing in which visual comparisons were made of the blueing effect. Accordingly, two drops of blueing were added to the high concentration of starch solution and one drop was added to the less concentrated starch solution.

The sorted swatches, four each of fabric 1 and 2, which were to be treated with the lower concentration of solid starch solution, were immersed together in that starch solution. They were then put through an automatic wringer, two at a time. The swatches of the two starched fabrics were dried together in an electric dryer for ten minutes, at a medium heat setting.

Similarly, the other eight swatches, four per fabric, were treated with starch solution of high concentration, wrung and dried.

Liquid Starch Treatment

High concentration of liquid starch was prepared by taking one and one-half cups of liquid "Sta-Flo" starch and making the solution up to one quart with lukewarm water. The solution was allowed to attain room temperature. Low concentration of starch solution was obtained by diluting two-thirds cup of "Sta-Flo" starch with water up to one quart.

The starching procedure was the same as described under solid starch treatment. The swatches treated with high and low concentrations of liquid starch were also dried separately.

All the swatches, solid starch treated, liquid starch treated and untreated were dampened as nearly alike as possible and left for two hours before they were ironed. An automatic electric ironer set for the same speed and temperature was used to iron the swatches after each laundering.

Description of Test Procedures

The test samples for the determination of the properties under investigation were cut from the variously treated swatches, according to A.S.T.M. specifications where applicable. Three test samples were obtained from each swatch of fabric, for each treatment and for each property, except for absorption, for which only two test samples were cut. Air permeability and reflectance measurements were made directly on the variously treated swatches at the prescribed locations, before cutting the other samples, since these determinations do not produce any physical damage to the fabric. Test samples for stiffness determinations as well as for tear resistance were cut only in the warp-wise direction.

All tests were performed in a constant temperature and humidity laboratory where conditions were maintained at a temperature of $70 \pm 2^{\circ}F$. and a relative humidity of 65 ± 2 per cent.

1. Air permeability

The Frazier Air Permeometer was used to measure air permeability. The apparatus consisted of a suction fan which draws air through a known area of the fabric, a circular orifice over which the fabric to be tested is clamped, a device for regulating the drop in pressure across the fabric, and a means of measuring the amount of air passing through the fabric.

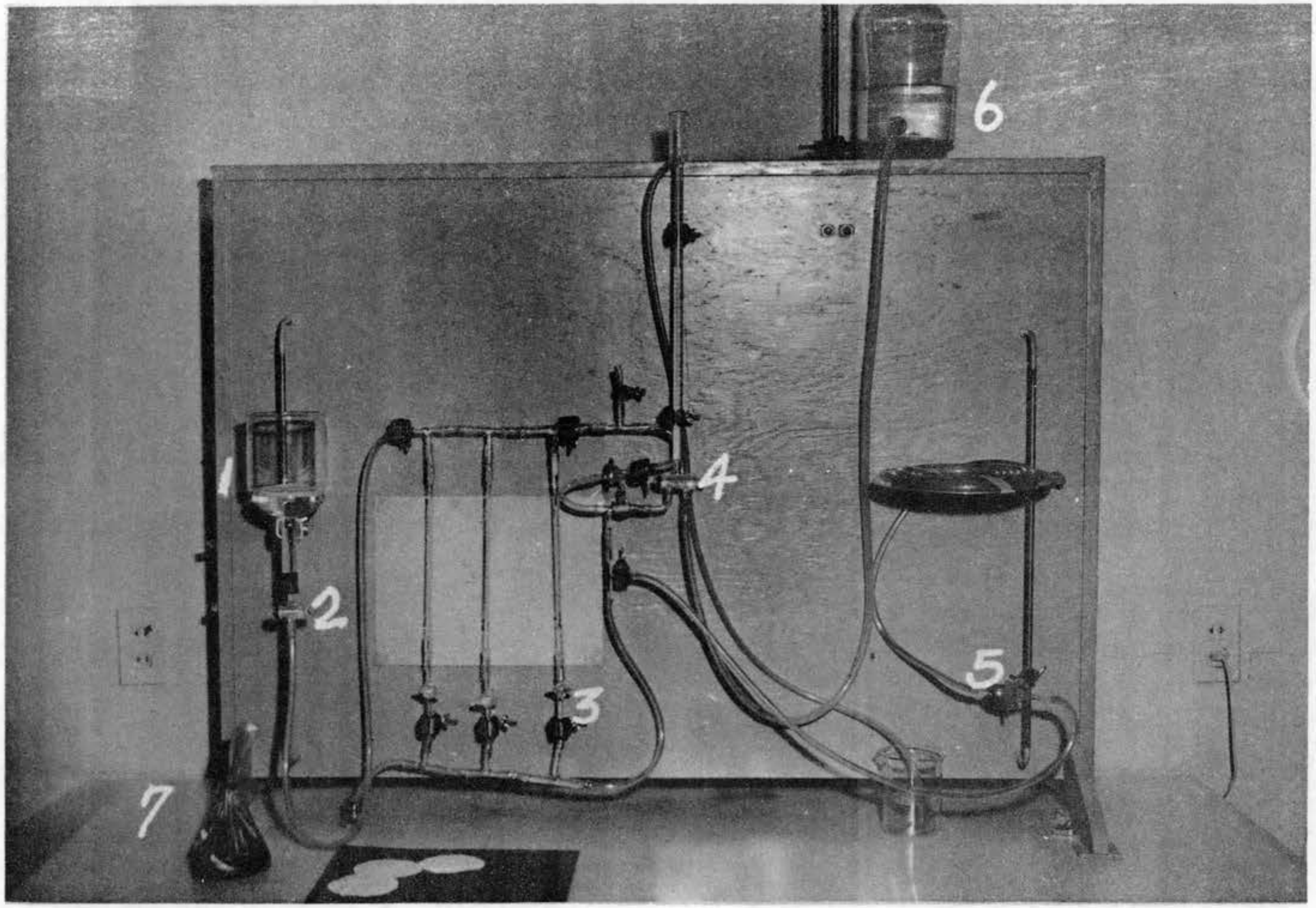
The test sample was clamped smoothly over the orifice and the pressure drop across the fabric was maintained at a predetermined value, and the reading on the flow meter was recorded. The air permeability of the fabric was expressed as cubic feet of air per minute per square foot of fabric at a stated pressure drop.

2. Absorption

An apparatus similar to that used by Buras, Goldthwait, and Kraemer (5) was used to determine the rate and total absorption of the variously treated fabrics. The apparatus (See Plate I) consisted of a fritted glass funnel 2 with a porous plate 1 connected by a plastic tubing to a series of three flow meters 3 of which one flow meter was actually used. The flow meters were connected to a concentrically coiled plastic tubing 5 which was in turn connected to a graduated burette 4 and the supply bottle or reservoir 6 for refilling the burette. A polyethylene bag filled with lead shot 7 was used as weight for bringing the test sample uniformly in contact with the porous plate.

The apparatus was filled with distilled water and was so adjusted that when the entire system of tubing and flow meters was filled with

PLATE I



Absorption Apparatus

distilled water the surface of the porous plate was just moist. The porous plate of the funnel was placed approximately one-fourth inch lower than the coiled length of tubing to compensate for the capillary action which tended to retard the flow of water from the tubing through the plate. However, the difference in the heights of the porous plate and the tubing was not great enough to allow water to stand on top of the plate (45).

Test samples, the same diameter as the porous plate ($3\frac{1}{4}$ inches), were used to determine the absorbency of the cloth. The test sample was placed on the porous plate, and the bag of lead shot was immediately placed on the sample to insure even contact with the plate. At the same time the stopcock that opened and closed the flow meter was turned so that water could pass from the "head" (coiled tubing) through the open flow meter, through the porous plate, and into the fabric. The flow meter reading was taken when the float reached its highest point. From this reading and from calibration curves that had been plotted for each flow meter in an earlier work by Mary Walsh (45) it was possible to determine the maximum rate of absorption in cubic centimeters per minute. The total amount of moisture absorbed was determined by reading on the burette the number of millilitres of water required to refill the coiled tube to the initial mark.

3. Reflectance

A Gardner Multipurpose Reflectometer was used to measure reflectance, which is based on the same principles of construction and operation as described by Hunter (19). Three coloured filters, green, blue, and amber were employed in this apparatus along with a photoelectric cell which measured the amount of light reflected by the surface being tested. The apparatus was adjusted with enameled ceramic standard plate which was provided with the instrument. The reading obtained from the instrument gave the percent of light reflected with each filter by the surface being tested.

Because it was desirable to measure the yellowness of the white fabrics, an equation supplied by Hunter (18) was employed to give a scale of yellowness. Values increased from zero for magnesium oxide standard to positive values for yellowish surfaces and negative values for bluish surfaces.

4. Stiffness

The Cantilever method of measuring stiffness was used (2). Four measurements were made for each of the three test samples, two with the face side up and two with the reverse side up. From the length of overhang in centimeters, the bending length was determined by dividing the length of overhang by two.

5. Tear Resistance

The Elmendorf (falling pendulum) apparatus was employed for the determination of tear resistance. The average force or energy required to continue a tongue-type tear in a fabric is determined by measuring the energy consumed in tearing through a fixed distance. The tester consists of a sector shaped pendulum carrying a clamp which is in alignment with a fixed clamp when pendulum is in the raised, starting position with maximum potential energy. A rectangular test sample (2.5 x 4 inches) was fastened in the clamps and the tear was started by cutting a slit in the test sample between the clamps. The pendulum was then released and the sample was torn. The energy in grams required to tear the sample was obtained by multiplying the instrument scale reading by the appropriate factor.

Analysis of Data

The entire experiment was repeated three times with maintenance of all the conditions as nearly alike as possible, thus representing three true replications. The means of the readings of the test samples for every treatment in every property determined, were used for each replication. The totals of the means of the three replications were analyzed statistically. Analysis of variance and orthogonal comparisons were made for each property at each time interval, ie; after 5, 10, 15 and 20 launderings.

CHAPTER IV

INTERPRETATION AND DISCUSSION OF RESULTS

Laundering the fabrics with a solid and a liquid starch, each at two concentrations, produced some differences in one or more of the five fabric properties under investigation and also some differences between fabrics.

Results of the evaluation of data by analysis of variance (A.O.V.) and of orthogonal comparisons for the five properties studied at four intervals over a period of 20 launderings are shown in tables I to XXIV. The significant differences at .5%, 1%, 5% and 10% levels as shown by $P > .005$, $P > .01$, $P > .05$, $P > .10$ are indicated in the analysis of variance tables. The orthogonal comparison tables give the magnitude and the direction of change. In a certain comparison, the positive value for factor Q indicates the change to be in favour of the factor or factors having positive coefficients and vice versa. That is, the property shows an increase in magnitude for a specific treatment if the sign of the factor Q corresponds with the sign of the coefficients used for that specific treatment in the orthogonal comparison table.

The results of each property investigated are discussed in this chapter.

Air Permeability

Results of the effect of the various treatments on air permeability at 5, 10, 15 and 20 launderings for both fabrics are shown in tables I, II, III, and IV.

Air permeability of both fabrics increased with the number of launderings. Air permeability of the starched fabrics was significantly higher than unstarched fabrics after 5 launderings and also at all following laundering intervals. No significant difference was found in the air permeability of unstarched (control) fabrics, indicating that fabrics 1 and 2 were not different in this respect. Although when starched, fabric 1 was more permeable than fabric 2.

Both fabrics showed greater air permeability with liquid starch than with solid starch although the difference was not significant. Liquid starch made the fabrics more permeable than solid starch at both low and high concentrations. However, there was a highly significant interaction between fabrics and concentrations, indicating that both low and high concentrations of solid and liquid starches increased the air permeability of fabric 1; but in the case of fabric 2, permeability decreased with the increase in concentration of solid starch and only slightly increased with the high concentration of liquid starch. The results after 10 launderings were similar to those after 5 launderings except that the fabric-starch interaction was highly significant, indicating that liquid starch increased the air permeability of fabric 1 but not that of fabric 2. The effect of low and high concentrations of starches was more pronounced and showed a greater increase in air permeability at high concentrations. A

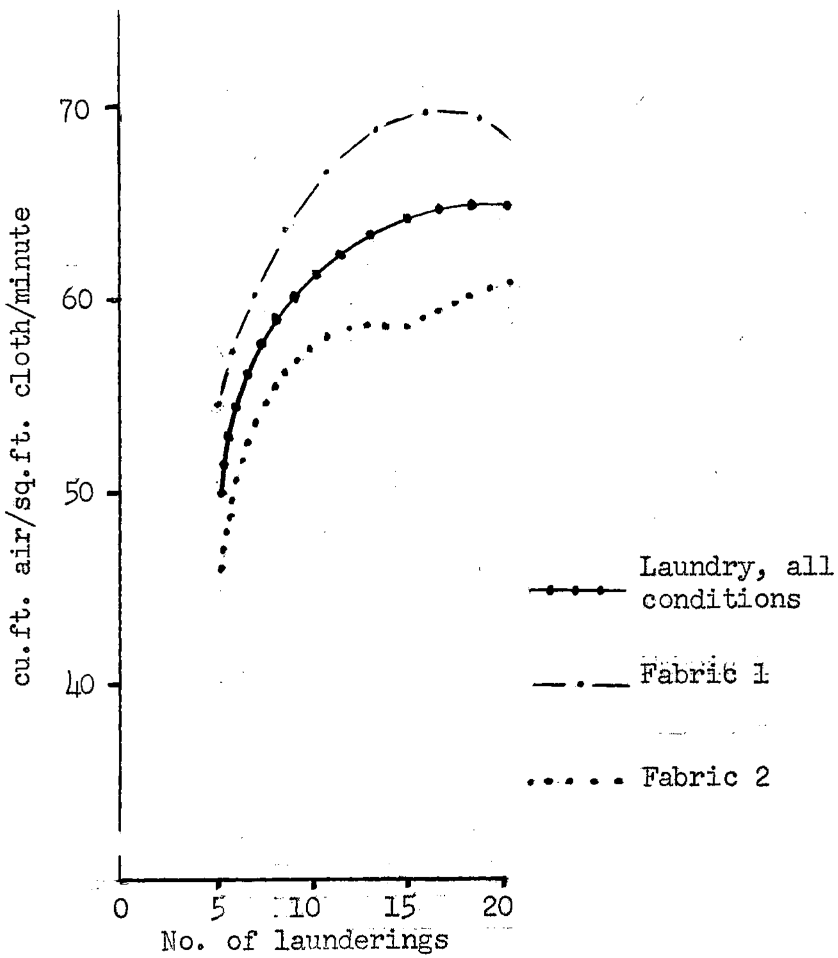


Fig. 1. Air Permeability

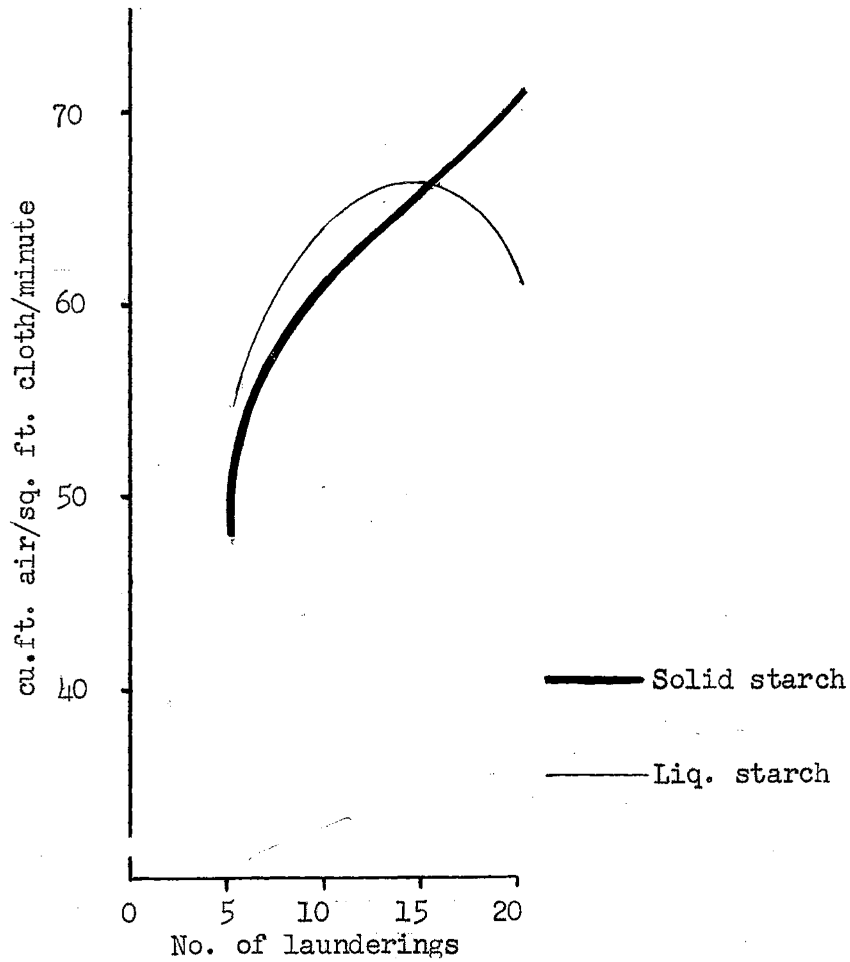


Fig. 2. Air Permeability

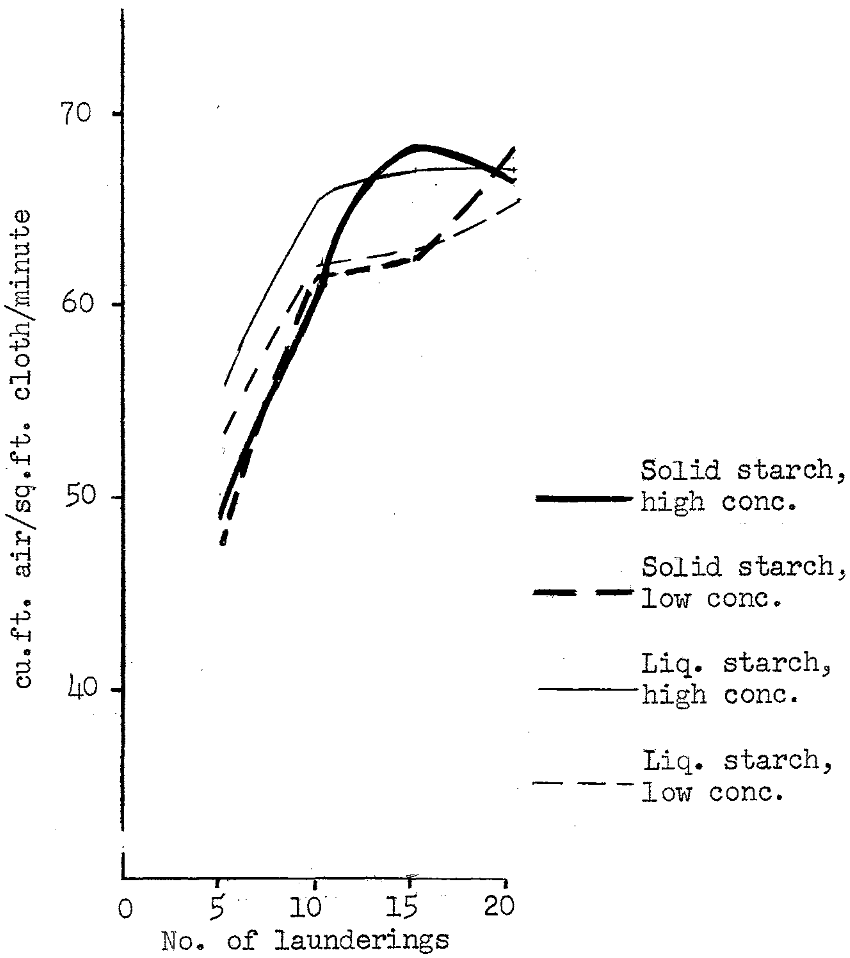


Fig. 3. Air Permeability

highly significant interaction between starch and concentration, after 20 launderings, showed that high concentration of solid starch decreased the air permeability of both the fabrics as compared to low concentration of liquid starch.

Figures 1, 2 and 3 give an overall view of the effect of the treatments on air permeability of fabrics over a period of 20 launderings.

Absorption

a. Maximum Rate of Absorption

The maximum rate of absorption of the two fabrics, for various treatments are summed up in tables V, VI, VII and VIII, at the interval of 5, 10, 15 and 20 launderings respectively. Fabrics showed an increase in their rate of water absorption with an increase in the number of launderings.

After 5 launderings fabrics 1 and 2 did not differ significantly in their rate of water absorption when they were not starched. However, when starched, fabric 1 showed slightly but not significantly higher rate of water absorption with both solid and liquid starches.

Starched fabrics had a higher rate of absorption than unstarched fabrics. Also, liquid starch increased the rate of absorption more than solid starch. Higher concentrations of both the starches increased the rate of absorption of both fabrics, significantly.

After 10 launderings, the fabrics behaved the same way in all treatments as after 5 launderings, but the increase in rate of absorption of fabric 1, when starched was much more pronounced. The

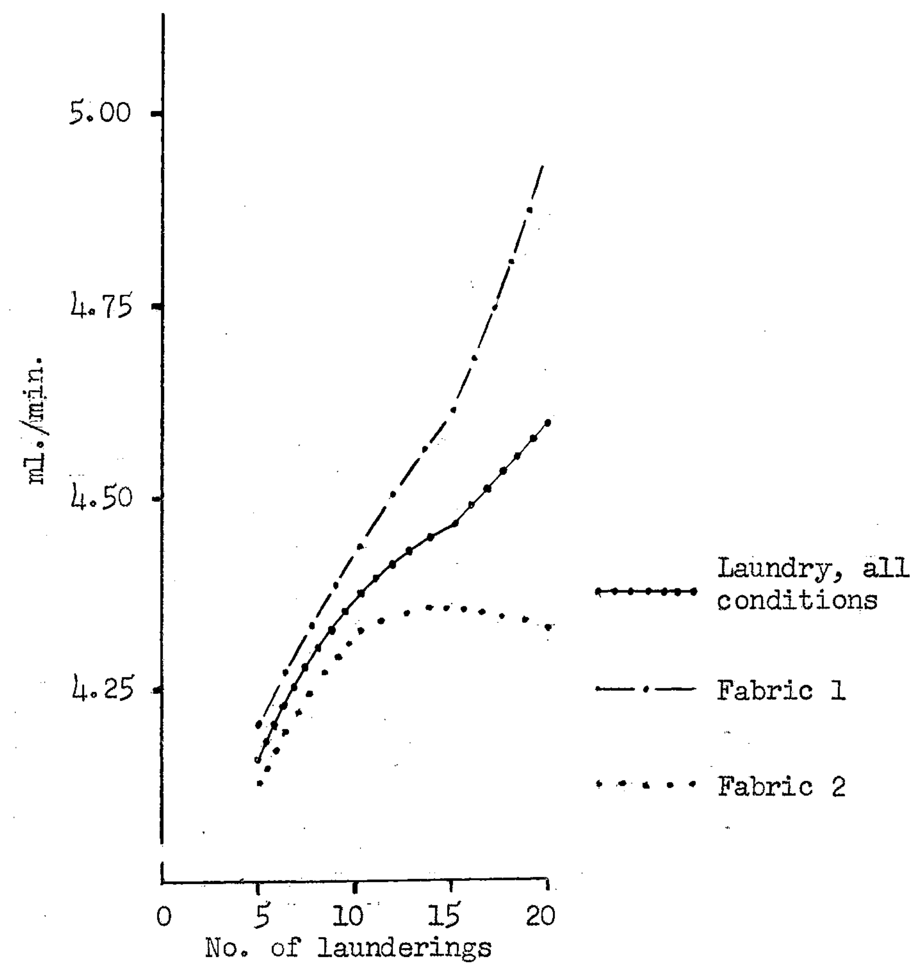


Fig. 4. Max. rate of Absorption

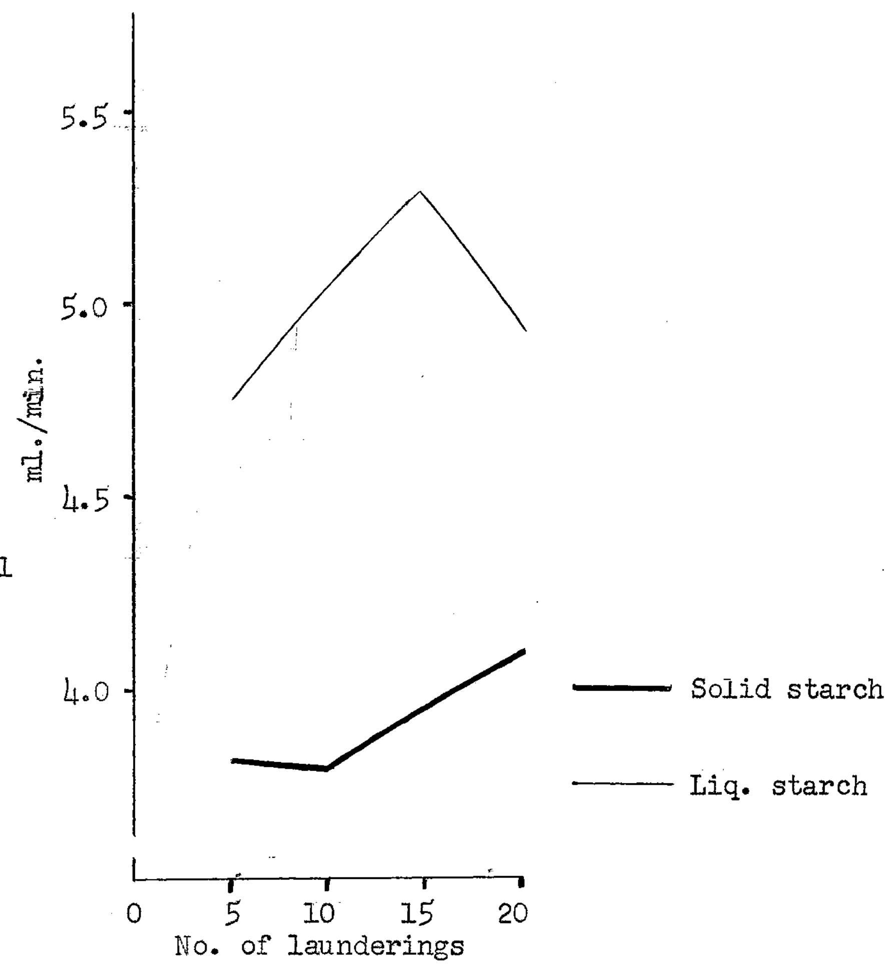


Fig. 5. Max. rate of Absorption

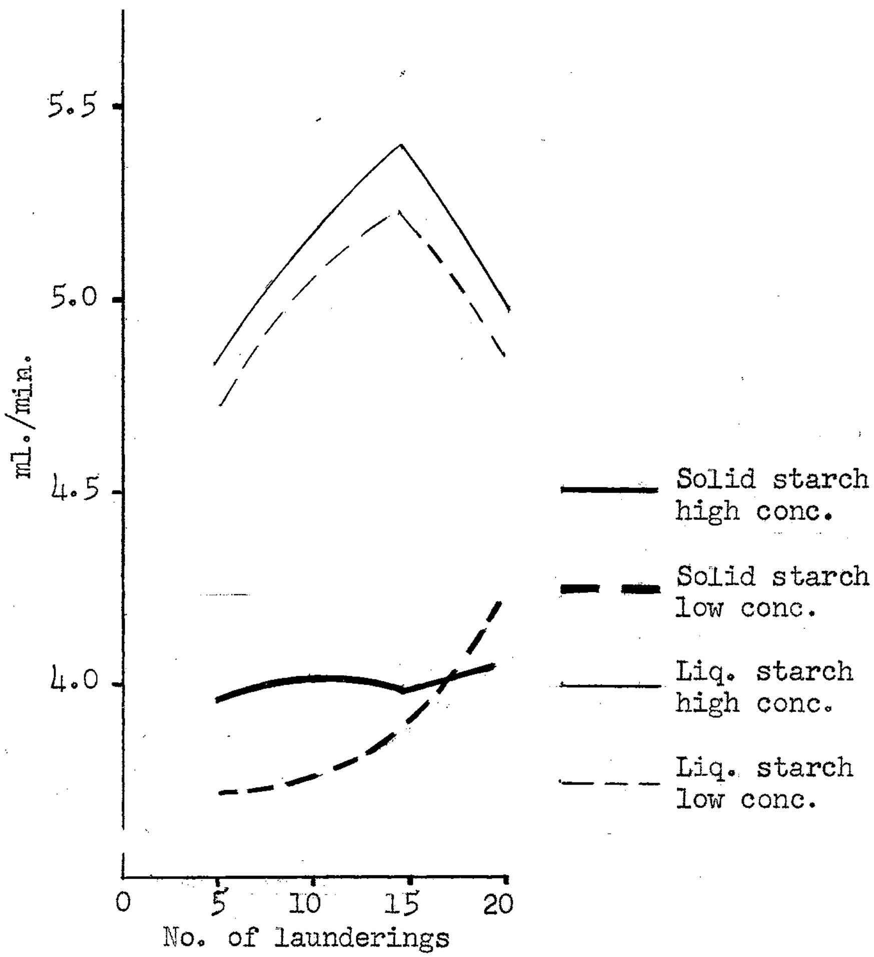


Fig. 6. Max. rate of Absorption

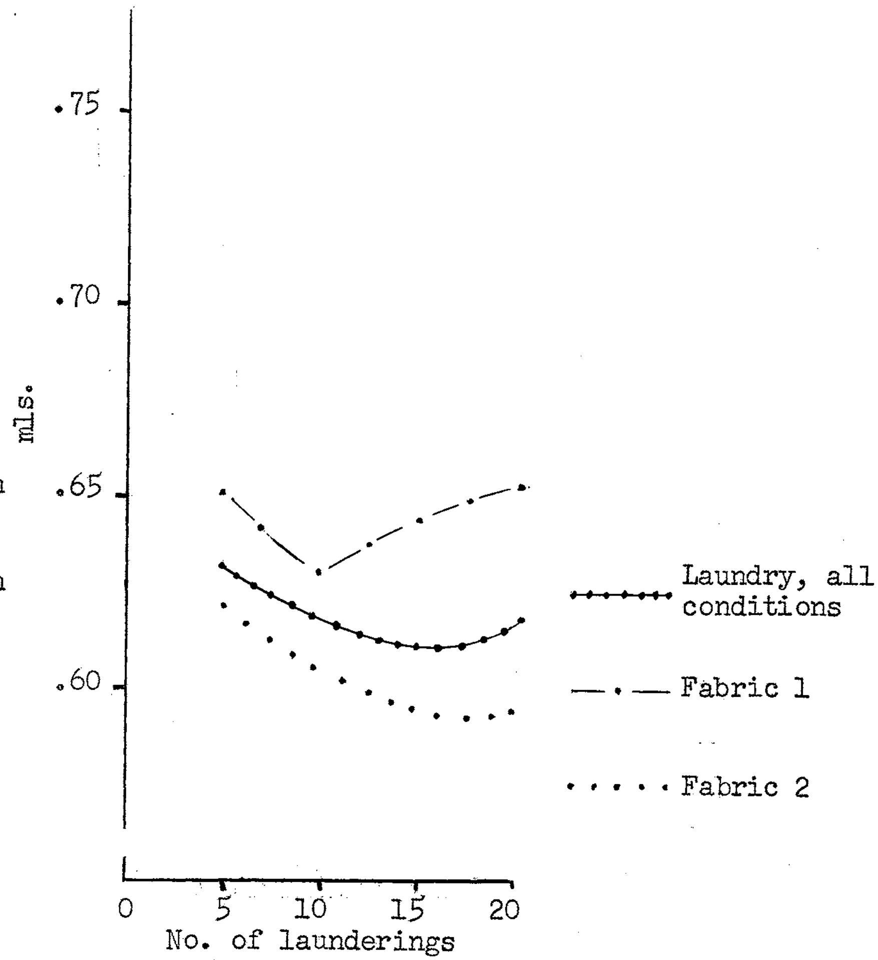


Fig. 7. Total Absorption

increase in rate of absorption due to liquid starch was significantly higher than that due to solid starch as shown in table VII. Results in table VIII, were similar to those in table VII, but after 20 launderings the effect of different concentrations of starches was not as pronounced as in previous laundering intervals. Figures 4, 5, and 6 show the changes in rate of absorption due to the different treatments over a period of 20 launderings.

b. Total absorption

Tables IX, X, XI and XII give the A.O.V. for total amount of absorption in millilitres of water by the variously treated samples, at the intervals of 5, 10, 15 and 20 launderings respectively. Total amount of absorption decreased with an increase in the number of launderings, up to 15, after which it increased slightly.

Unstarched fabric 2 had greater absorption than unstarched fabric 1, but when they were starched, fabric 1 showed greater total absorption. Starched and unstarched fabrics differed greatly in their absorptive power; starched fabrics absorbed a greater quantity of water than unstarched fabrics. Liquid starch showed much higher absorption than solid starch, and high concentration of both solid and liquid starches resulted in greater absorption than low concentrations. However, there was a significant interaction between fabrics and starches, indicating that fabrics behaved differently with different starches.

Results after 10 launderings were similar to those after 5 launderings. After 15 launderings results differed from those at previous launderings in that solid starch resulted in greater absorption

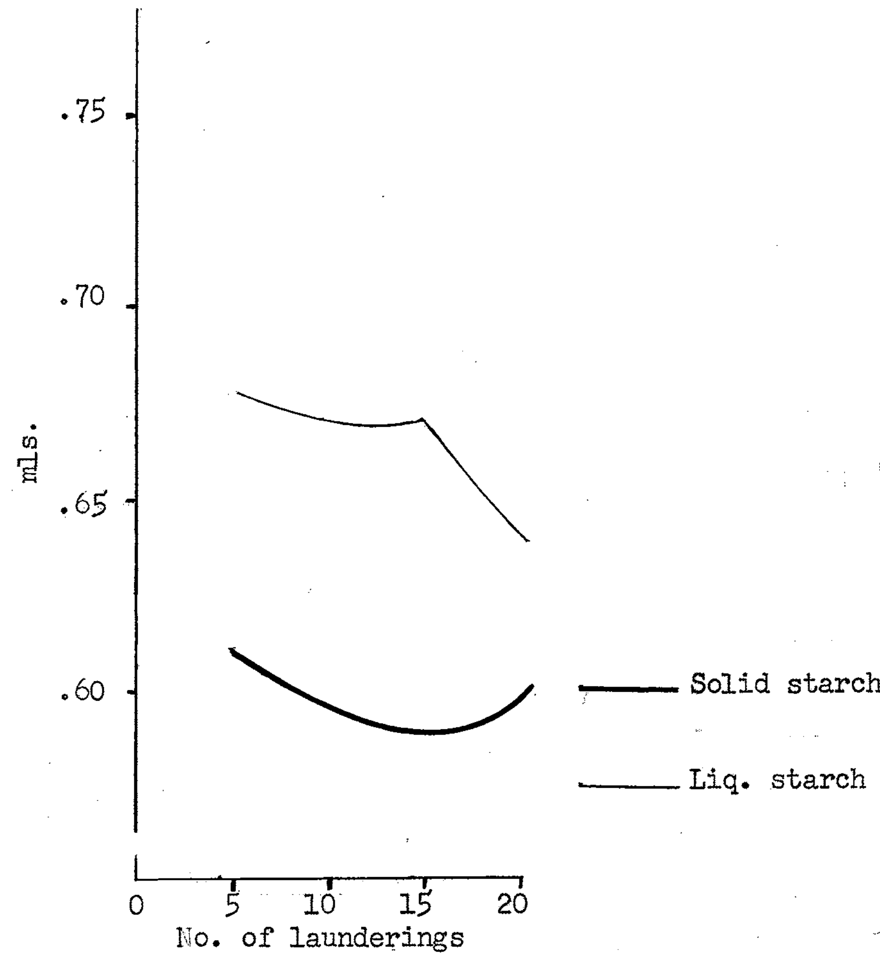


Fig. 8. Total Absorption

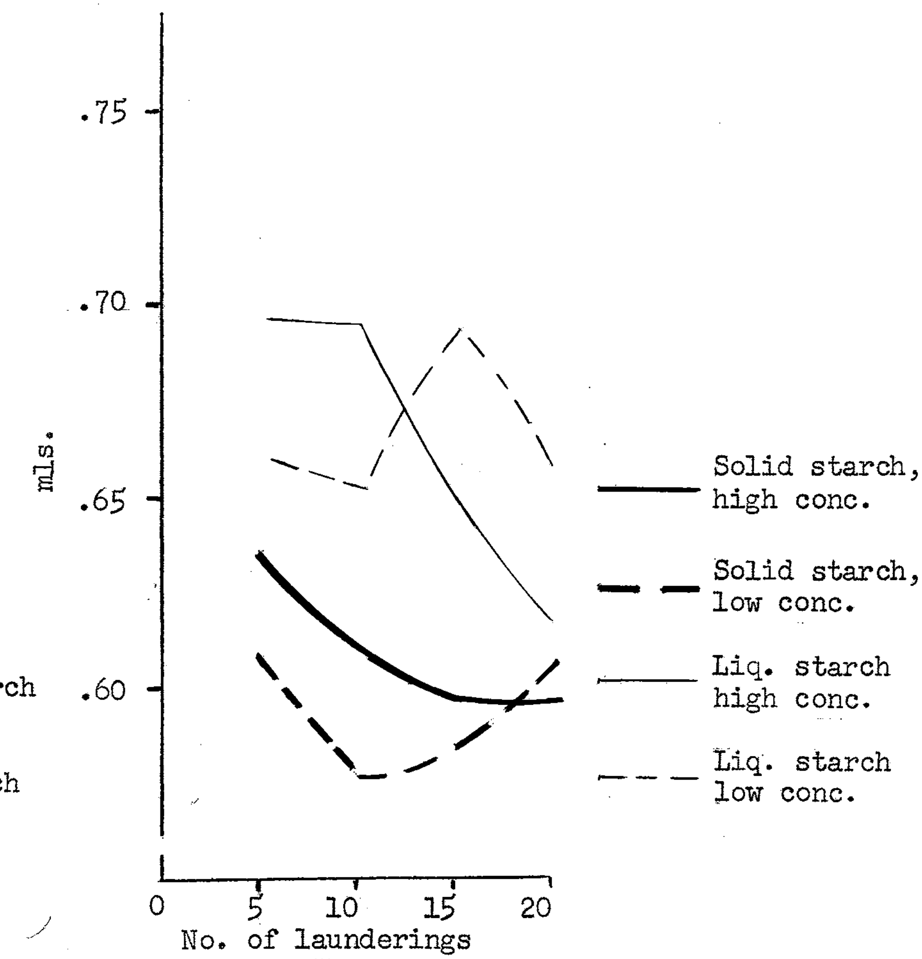


Fig. 9. Total Absorption

at high concentration, while liquid starch showed greater absorption at low concentration. After 20 launderings, the results were similar to those after 15 launderings.

The changes in total absorption of fabrics over a period of 20 launderings are given in figures 7, 8 and 9.

Reflectance

Reflectance was used as the measure of yellowness produced in the fabrics due to washing, starching and ironing. Yellowness decreased at 5 and again at 10 launderings after which yellowness increased gradually up to 20 launderings (See tables XIII, XIV, XV and XVI). The initial decrease in yellowness was probably due to the bleaching effect of the chlorine bleach which was used during the washings, and also to the blueing present in the starches. After 10 launderings the yellowing effect of starching, drying and ironing was greater than the whitening effect of the blueing and bleaching, hence an increase in yellowness of the fabrics.

The A.O.V. (table XIII) shows no significant differences after 5 launderings between:

Starched and unstarched fabrics;

Fabric 1 and 2 without starch and with starch;

Low and high concentrations.

However, slight differences did exist as shown in the orthogonal comparison table where the sign of the factor Q shows differences in favour of the positive or negative sign corresponding to the sign of the coefficients used in the table. According to this explanation,

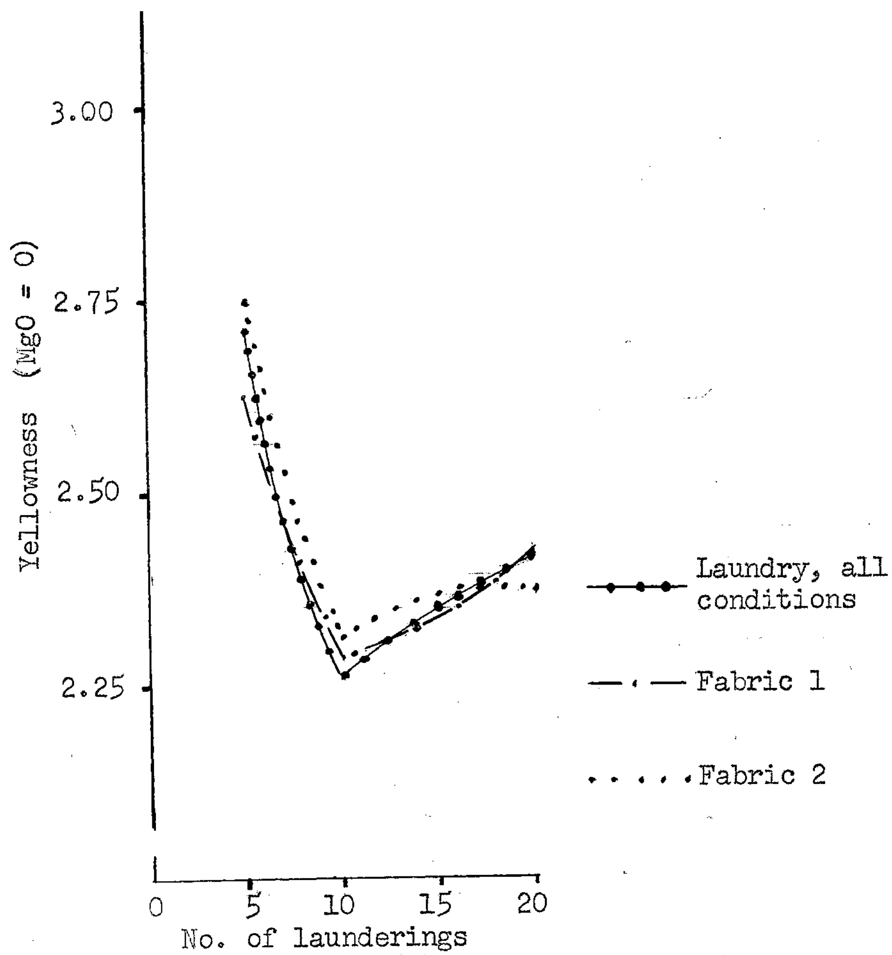


Fig. 10. Reflectance

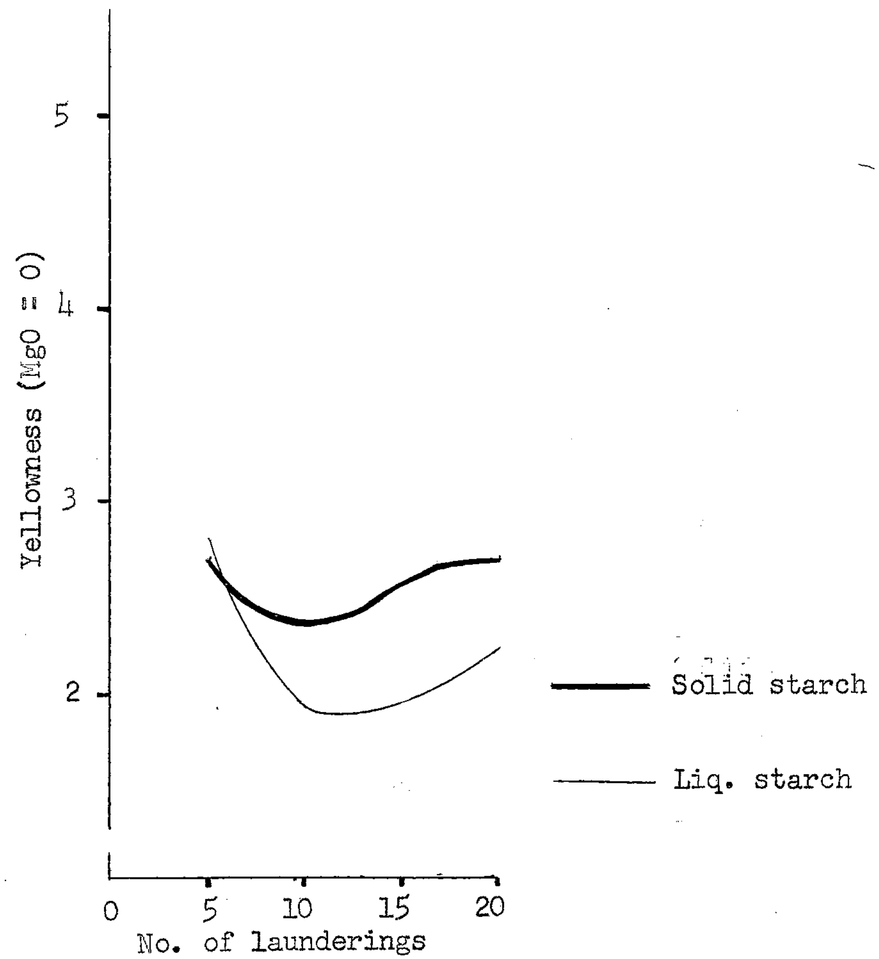


Fig. 11. Reflectance

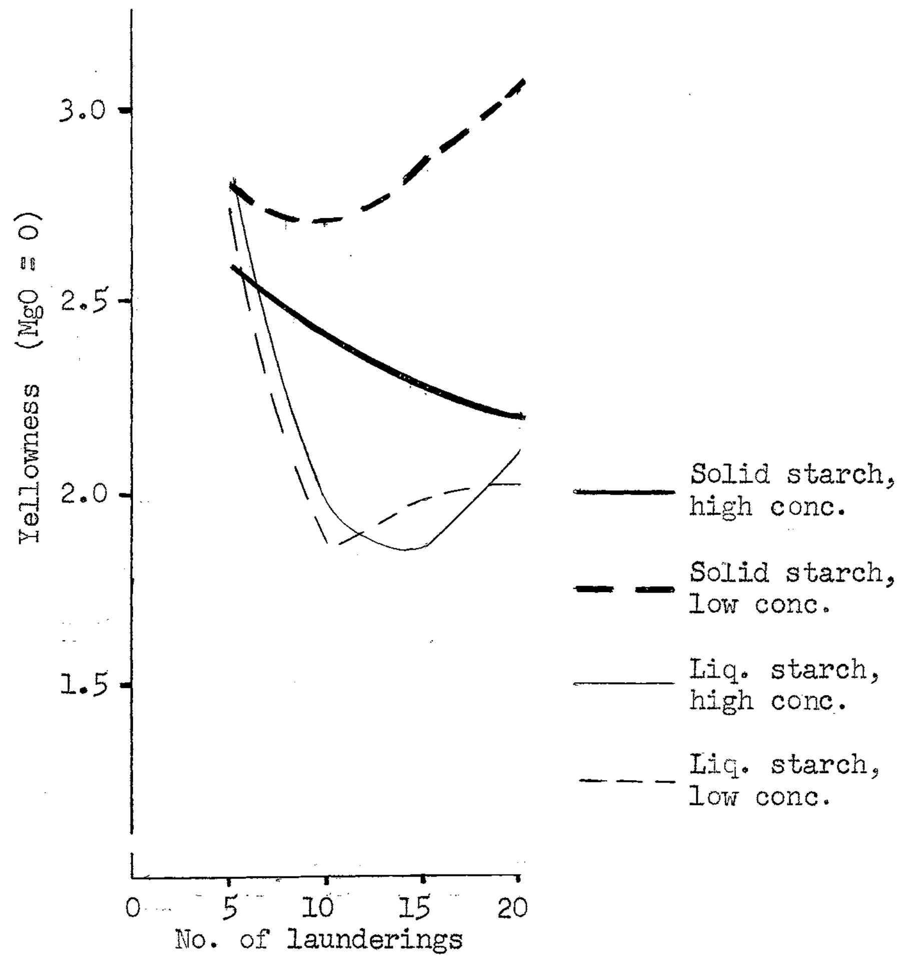


Fig. 12. Reflectance

starched fabrics showed slightly higher yellowness than unstarched fabrics. Fabric 2 showed more yellowness than fabric 1 when unstarched, as well as when starched. Liquid starch produced greater yellowness than solid starch; high concentration of liquid starch and low concentration of solid starch produced greater yellowness.

With the increase in the number of launderings from 5 to 10, 15 and 20, the differences became more highly significant. After 10 launderings, as shown in table XIV, the yellowness of starched fabrics increased over that of unstarched fabrics. Other results after 10 launderings were the same as those at 5 launderings except that solid starch showed a greater yellowing effect than liquid starch, and that unstarched fabrics showed greater yellowness than starched fabrics. Since blueing was present in the liquid starch but was added to the solid starch, the effectiveness of the blueing in the two starches may not have been the same.

Results at the 15 and 20 launderings, as shown in tables XV and XVI, were the same as those at the 5 and 10 launderings except that at 15 and 20 launderings lower concentration of both starches produced a greater degree of yellowness than higher concentrations. This might be explained by the fact that starches had blueing in them, and obviously the higher concentration of starches had the greater amount (although not greater degree of blueness) of blueing in them. More blueing may have been absorbed from the higher concentration of starch solution by the same area and weight of samples. An increase in the blueing of a sample would increase the reflectance of the fabric and therefore decrease the degree of yellowness.

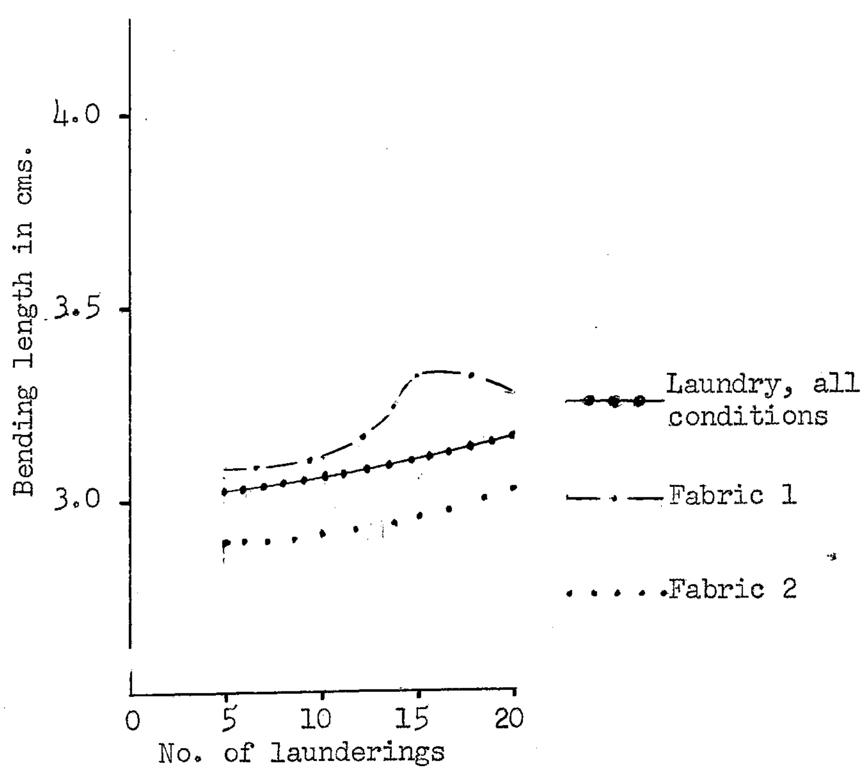


Fig. 13. Stiffness

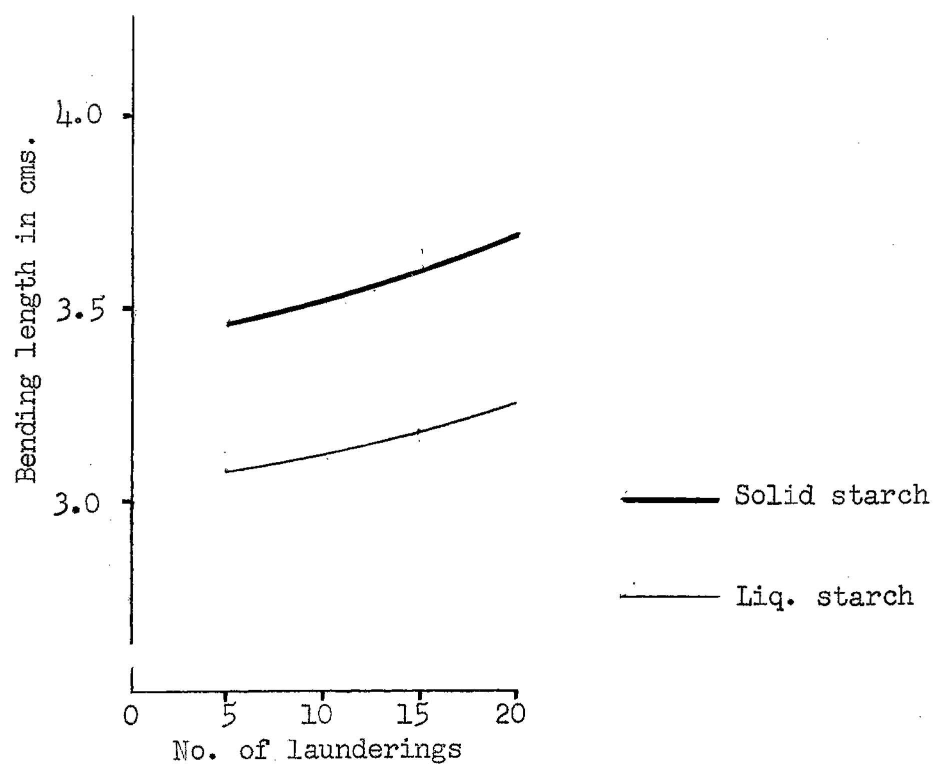


Fig. 14. Stiffness

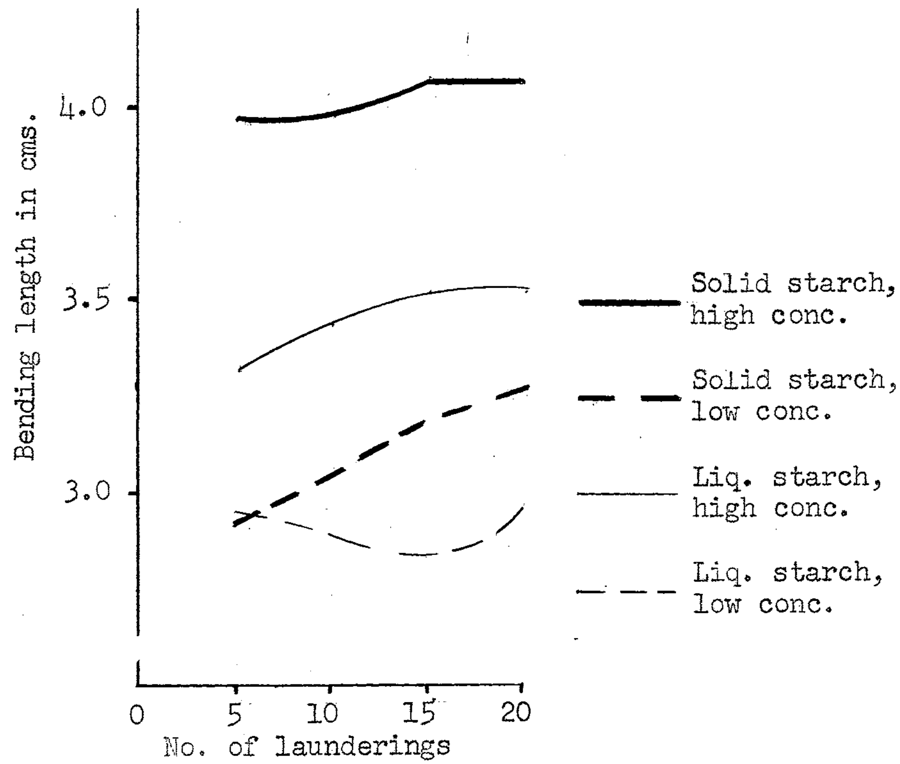


Fig. 15. Stiffness

Figures 10, 11 and 12 give results on the yellowness of the fabrics over all the launderings.

Stiffness

Tables XVII, XVIII, XIX and XX give the analysis of variance after 5, 10, 15 and 20 launderings for stiffness measurements.

Fabrics 1 and 2 did not differ significantly in their stiffness, and both starches increased the stiffness of the fabrics after 5 launderings. The two starches differed significantly in the stiffness produced in the two fabrics. Solid starch produced a significantly higher degree of stiffness than the liquid starch. Also the higher concentration of both solid and liquid starches increased the stiffness of both fabrics. However, there was a significant interaction between starches and concentrations, showing that the degree of stiffness produced by high and low concentrations differed with starches.

Results after 10, 15 and 20 launderings were similar to that after 5 launderings, except that stiffness decreased with the low concentration of liquid starch for both the fabrics from 5 to 10 to 15 launderings and then increased slightly.

The changes in stiffness are show in figures 13, 14 and 15 over a period of 20 launderings.

Tear Resistance

Analysis of variance for tear resistance of the two fabrics with various treatments is given in tables XXI, XXII, XXIII and XXIV. As

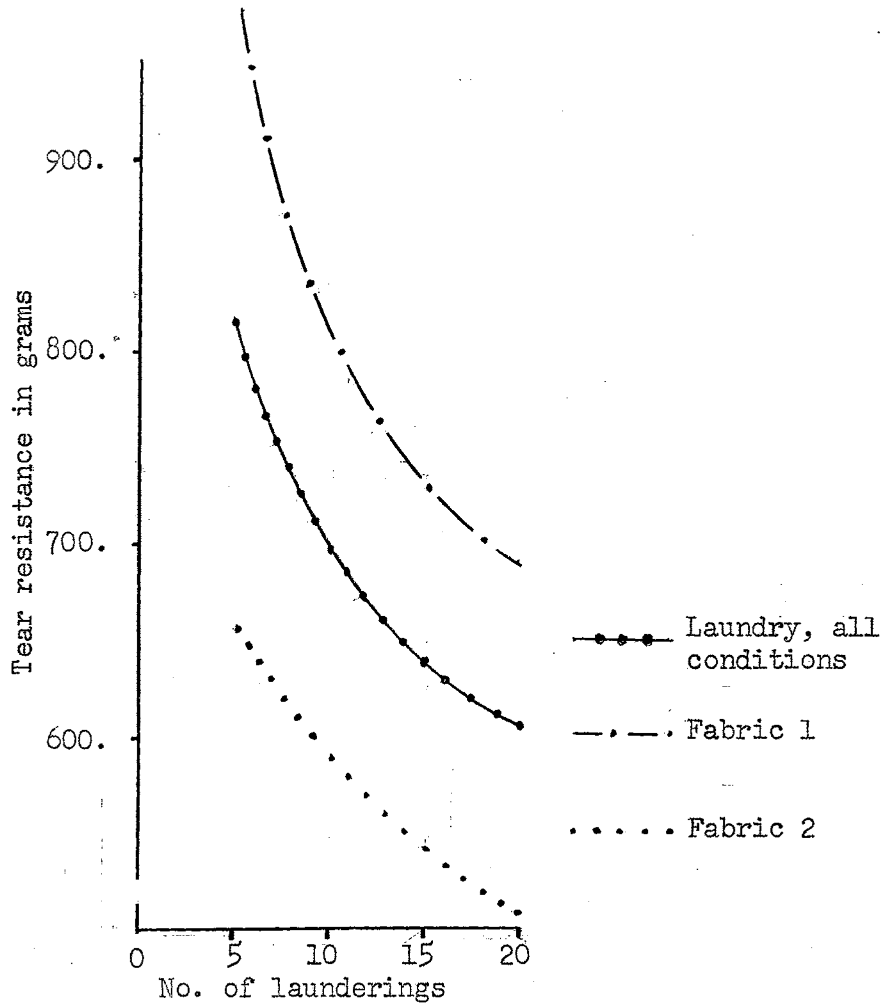


Fig. 16. Tear Resistance

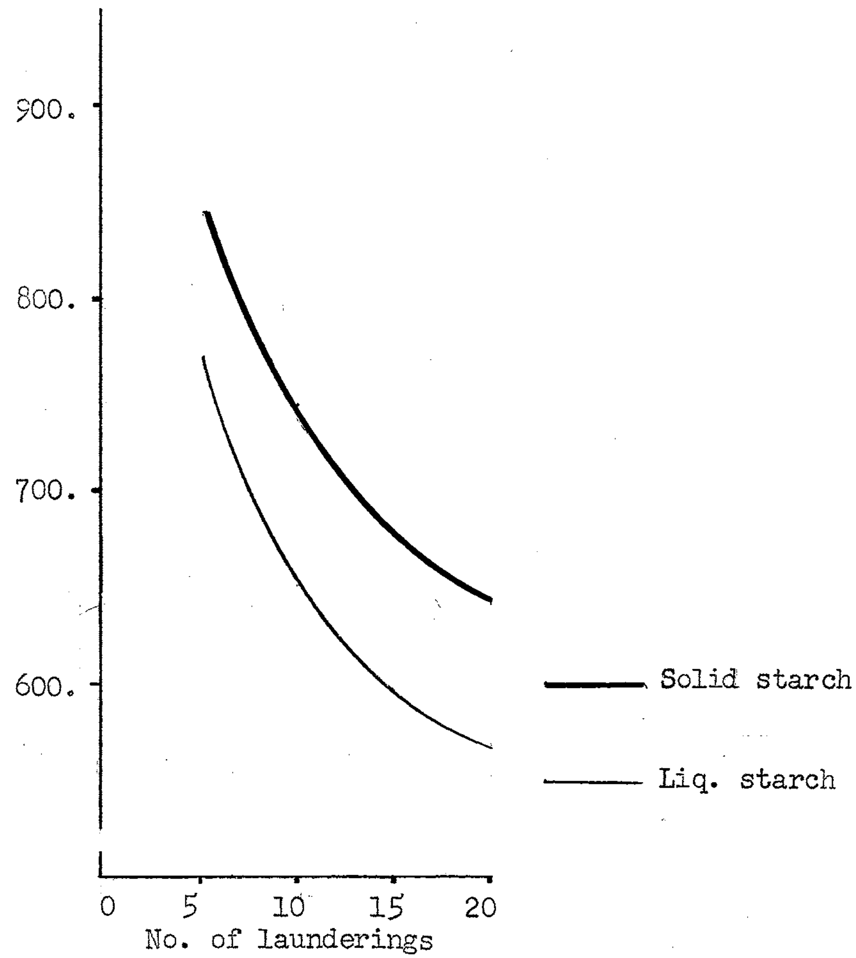


Fig. 17. Tear Resistance

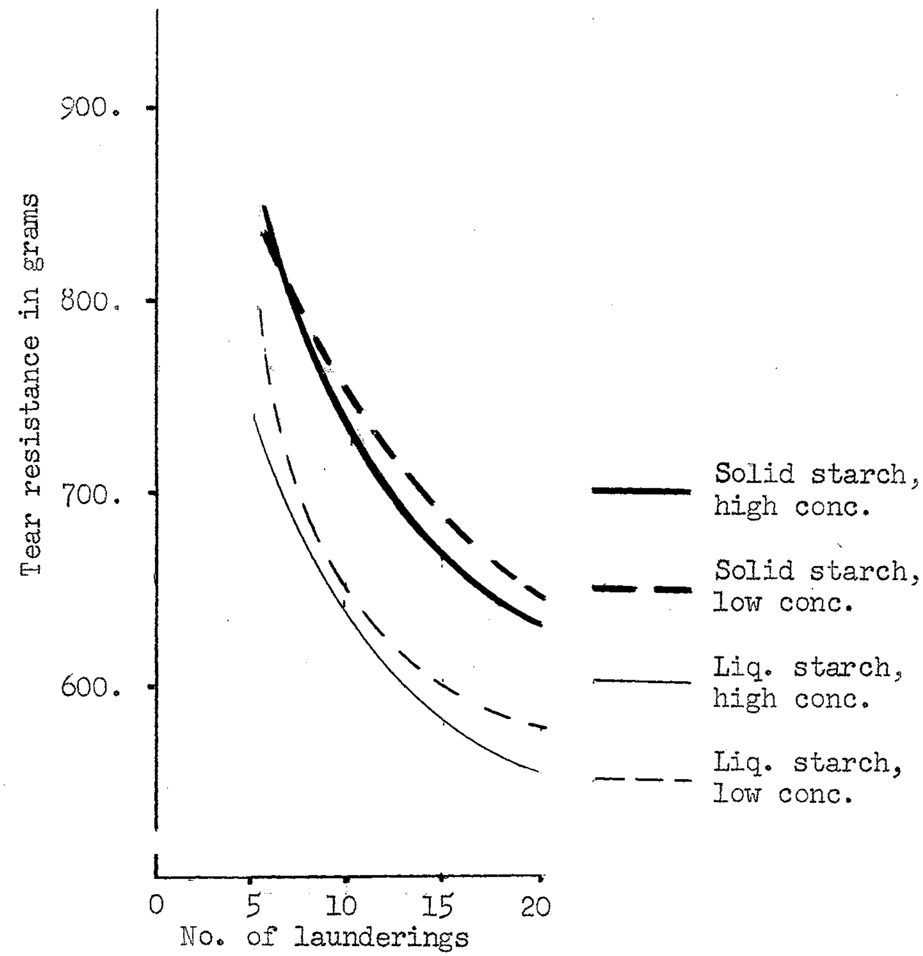


Fig. 18. Tear Resistance

shown in all of the four tables, fabric 1 had higher tear resistance than fabric 2 at the 5, 10, 15 and 20 laundering intervals. Starched fabrics were lower in tear resistance than the unstarched fabrics, and liquid starch reduced the tear resistance more than the solid starch. The high concentration of both solid and liquid starches lowered the tear resistance of the fabrics more than low concentration of starches, except at 5 laundering interval; where low concentration of solid starch decreased the tear resistance of both the fabrics more than high concentration.

The results are shown in figures 16, 17 and 18.

Relationship Between Stiffness and Air Permeability, Absorption, Reflectance and Tear Resistance

In general, as the stiffness increased with the number of launderings from 5 to 20, air permeability, maximum rate of absorption, and yellowness increased, while total absorption slightly decreased, and tear resistance decreased significantly.

Stiffness, air permeability, maximum rate of absorption, total rate of absorption and tear resistance of fabric 1 were higher than fabric 2, but yellowness was vice versa.

Solid starch was more effective in producing a higher degree of stiffness, but liquid starch showed greater air permeability, maximum rate of absorption, and total amount of absorption. Solid starch produced more yellowness than liquid starch and higher tear resistance than liquid starch.

High concentration of solid starch produced higher stiffness as compared to high concentration of liquid starch. High concentration of liquid starch showed greater air permeability, maximum rate of absorption, more yellowness and lower tear resistance.

Low concentration of solid starch produced greater stiffness than that of liquid starch. Low concentration of liquid starch had higher air permeability, higher rate of absorption and higher total absorption but less yellowness and lower tear resistance. Low concentration of solid starch had higher yellowness and tear resistance than high concentration of solid starch.

Relation of Five Properties to Appearance, Comfort and Durability

Starching improved stiffness and produced less yellowness than laundering without starch, thus enhancing the appearance of the white fabrics. Solid starch was superior to liquid starch.

Starching increased the air permeability, rate of absorption and total absorption of cotton fabrics. Liquid starch increased the air permeability and rate of absorption of water more than solid starch, but solid starch produced greater total absorption. These properties have an important effect on comfort of fabrics, and liquid starch showed more favourable qualities for comfort.

Tear resistance of the fabrics was decreased significantly by starching indicating reduction in durability of the fabrics.

Reasons for Experimental Design

The experiment was done in three true replications which involved more time and effort. The main reason for repeating the entire experiment three times was to have a means of determining experimental error, which would reduce the chances of making misleading statements to a greater extent than would otherwise be possible.

In order to determine the differences among the treatments, the experimental error must be taken into consideration. Differences in replications indicate experimental error and therefore help in giving a truer measure of differences among the treatments. The statements hold true over a wider range of conditions than would otherwise be the case had the experiment not been done in replications.

CHAPTER V

SUMMARY AND CONCLUSIONS

The effect of a solid and a liquid cornstarch on five selected properties of two white cotton fabrics from Pakistan were determined from the results of tests performed on starched and unstarched fabrics. The unstarched fabrics provided a control for the experiment. The starching of fabrics consisted of a low concentration treatment and a high concentration treatment for each starch and each fabric.

The swatches of fabrics from which the test samples were cut at definite intervals of launderings, were assigned to various treatments at random, so that statistical analysis could be used to determine causes of variation among fabrics due to starches.

The swatches were laundered separately for no starching, solid starching and liquid starching. An automatic agitator type washing machine using water at $160 \pm 2^{\circ}$F., a synthetic detergent, and a 5.25 percent chlorine bleach were used. Fabrics were dried separately in an automatic tumbler type drier.

Starching and ironing were done after each laundering. Swatches of fabric were removed after 5, 10, 15 and 20 launderings for various tests. These swatches were replaced by the same size and kind of swatches to keep the wash load constant.

Test samples were cut from the swatches according to A.S.T.M. specifications. The tests performed were:

a. air permeability

b. absorption

c. reflectance

d. stiffness

e. tear resistance

The entire experiment was repeated three times maintaining all the conditions as nearly alike as possible, thus representing three true replications.

The results obtained from analysis of variance and orthogonal comparisons of the data showed:

1. Laundering increased air permeability in both the fabrics. Air permeability of starched fabrics was much higher than of unstarched fabrics. Liquid starch increased the air permeability of the fabrics more than solid starch. High concentration of liquid starch increased the air permeability most.

2. Measurements of the rate of absorption showed an increase with an increase in the number of launderings. Starching also increased the rate of absorption. Liquid starch accelerated the rate of absorption more than solid starch. Also, higher concentration of both the starches increased the rate of absorption of the two fabrics.

3. Total amount of absorption decreased with an increase in the number of launderings up to 15, after which it increased.

Starched fabrics absorbed a greater quantity of water than unstarched fabrics. Solid starch showed greater amount of absorption as compared to liquid starch, and high concentration of solid starch absorbed greater amount of water than low concentration. However, liquid starch showed the reverse behaviour.

4. Yellowness of the white fabrics first decreased with laundering and then increased. Liquid starch produced more yellowness than solid starch. Low concentrations of both liquid and solid starches produced greater yellowness.
5. Starching increased the stiffness of both the fabrics. Stiffness also increased with the increase in the number of launderings. Solid starch produced greater stiffness in fabrics as compared to liquid starch. High concentrations of both the starches increased stiffness, although stiffness decreased with the low concentration of liquid starch over a period of 20 launderings.
6. Laundering decreased the tear resistance of both the fabrics, also starched fabrics had lower tear resistance than unstarched fabrics. Liquid starch reduced the tear resistance more than solid starch, and high concentrations of both the starches decreased the tear resistance of the fabrics to a greater extent than low concentrations.
7. Comparison of stiffness with other properties showed:
    a. As the stiffness increased with the number of launderings from 5 to 20, air permeability,

maximum rate of absorption and yellowness increased, while total absorption and tear resistance decreased.

b. Fabric 1 showed greater stiffness, air permeability, rate of absorption, total absorption, and tear resistance than fabric 2.

c. Solid starch produced greater stiffness, yellowness and higher tear resistance than liquid starch, which showed greater air permeability and rate of absorption.

d. Higher concentration of solid starch produced greater stiffness, yellowness and tear resistance than that of liquid starch--which showed greater air permeability and rate of absorption.

8. Liquid starch showed advantageous qualities over solid starch in the fabric properties which would have greatest effect on comfort.

9. Tear resistance which was the only test performed representing durability, was highest for unstarched fabric and was reduced more by liquid starch than by solid starch.

10. Solid starch showed superior qualities in regard to appearance of the fabrics. The properties in favour of solid starch were greater stiffness and less yellowness as compared to liquid starch.

Recommendations for Further Research

1. In this experiment liquid corn starch was used to represent the rice extract which the Pakistani homemakers frequently use. The assumption that liquid corn starch is nearly like rice extract is only partially true. It is well known that the granule size and shape, the gelatinization temperature, and the paste characteristics of various starches differ according to their origin.

   Therefore a research project involving the actual use of corn starch, wheat starch and rice starch (rice extract) which are commonly used in Pakistan, would give a truer picture of the effect of these starches on various fabric properties.

2. The liquid starch available in the market at the time when this research was carried out, contained blueing. The nature and the concentration of this blueing was not known. The blueing which was added in solid starch to make both the starches look more nearly alike might have been of a different nature, therefore, it could have had different affinity for being absorbed on the fabrics. Starches having no blueing in them might give results for reflectance more truely comparable.

3. The results from this experiment may not be true indication of the extent of change in the five properties of similar fabrics laundered by the procedure generally used in Pakistan. Studies involving the usual conditions would give results more parallel to those obtained in actual practice.

4. The results of this experiment might be used for developing more standard procedures for home laundering.

5. A cooperative class project might be worked out to evaluate by objective and subjective means the results of the effect of different kinds and concentrations of starches on cotton fabrics. The variously treated shalwars could be worn by the students themselves, while the variously treated men's shirts could be worn by their family members. The treatments could be rated subjectively for the properties as related to comfort, appearance and durability. At the same time, the properties could be determined by laboratory methods and compared with the subjective evaluation with the help of the class participants.
6. Cotton is a big industry in Pakistan, and fortunately there are textile mills around Lahore where the College of Home and Social Sciences is located. Research projects in cooperation with the industry could be mutually beneficial for the College and industry. The industries might provide the equipment and some of the finances to carry out projects for the betterment of the cotton industry. For instance, the results of this experiment could be employed to determine if starching affected the dyeing and block printing of cotton fabrics, which is a big industry in Pakistan.

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A P P E N D I X

DESCRIPTION OF SYMBOLS AND CODES

	Symbols
Fabric 1	F_1
Fabric 2	F_2
Solid starch	S_1
Liquid starch	S_2
No starch	S_o
Low concentration	C_1
High concentration	C_2

No.	Fabric	Starch	Concentration
1	1	0	0
2	1	1	1
3	1	1	2
4	1	2	1
5	1	2	2
6	2	0	0
7	2	1	1
8	2	1	2
9	2	2	1
10	2	2	2

TABLE I

AIR PERMEABILITY AFTER 5 LAUNDERINGS

	Treatments										
	1	2	3	4	5	6	7	8	9	10	
Reps	$F_1S_0C_0$	$F_1S_1C_1$	$F_1S_1C_2$	$F_1S_2C_1$	$F_1S_2C_2$	$F_2S_0C_0$	$F_2S_1C_1$	$F_2S_1C_2$	$F_2S_2C_1$	$F_2S_2C_2$	Total
R_1	35.1	51.1	57.0	56.3	62.2	48.9	36.1	41.6	43.9	42.9	475.1
R_2	52.1	47.7	58.6	57.7	56.6	44.6	46.6	37.0	48.2	50.5	499.6
R_3	55.7	53.3	52.9	59.7	65.0	49.7	50.3	41.1	53.5	56.4	537.0
Total	142.90	152.10	168.5	173.70	183.80	143.20	133.0	120.0	145.6	149.8	1512.6

AOV

	df	SS	MS	F	
Total	29	1706.0080			
Reps	2	200.3660	100.183	4.5966*	$P > .01$
Treatments	9	1113.3210	123.702		
S_0 vs (S_1+S_2)	1		56.170	2.577**	$P > .10$
F_1 vs F_2/S_0	1		0.015	< 1	
F_1 vs F_2/S	1		700.920	32.159*	$P < .005$
S_1 vs S_2	1		262.020	12.022*	$P < .005$
C_1 vs C_2	1		13.053	< 1	
S x C	1		4.950	< 1	
F x S	1		1.260	< 1	
F x C	1		52.510	2.409**	$P > .10$
Error	18	392.3210	21.795		

TABLE I (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	142.90	152.10	168.5	173.7	183.80	143.2	133.0	120.0	145.6	149.8			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	82.1	120	56.170
F_1 vs F_2/So	+1	0	0	0	0	-1	0	0	0	0	-0.3	6	0.015
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	129.7	24	700.920
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-79.3	24	262.020
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-17.7	24	13.053
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	10.9	24	4.950
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	5.5	24	1.260
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-35.5	24	52.510

TABLE II

AIR PERMEABILITY AFTER 10 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	46.4	63.1	61.0	72.2	73.1	59.1	56.6	50.1	51.3	52.9	585.8
R_2	55.7	56.6	83.6	72.9	78.5	51.8	73.2	66.1	58.6	59.7	656.7
R_3	63.7	65.0	61.7	64.7	70.4	60.7	55.9	40.2	57.2	56.5	596.0
Total	165.80	184.7	206.3	209.8	222.0	171.60	185.7	156.4	167.10	169.10	1838.5

AOV

	df	SS	MS	F	
Total	29	2680.7617			
Reps	2	293.8447	146.9223	2.8372*	$P > .05$
Treatments	9	1454.8217			
S_o vs (S_1+S_2)	1		191.2687	3.6936*	$P > .05$
F_1 vs F_2/S_o	1		5.6066	< 1	
F_1 vs F_2/S	1		870.0104	16.8010*	$P < .005$
S_1 vs S_2	1		50.7504	< 1	
C_1 vs C_2	1		1.7604	< 1	
S x C	1		19.9837	< 1	
F x S	1		90.8704	1.7548**	$P > .10$
F x C	1		155.5504	3.0038**	$P > .10$
Error	18	932.0953	51.7830		

TABLE II (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	165.8	184.7	206.3	209.8	222.0	171.6	185.7	156.4	167.10	169.10			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	151.5	120	191.2687
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-5.8	6	5.6066
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	144.5	24	870.0104
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-34.9	24	50.7504
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-6.5	24	1.7604
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	21.9	24	19.9837
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-46.7	24	90.8704
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-61.1	24	155.5504

TABLE III

AIR PERMEABILITY AFTER 15 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	53.9	81.0	94.7	76.8	80.1	63.2	56.8	67.6	57.2	57.6	688.9
R_2	65.4	62.9	76.9	70.1	83.4	59.1	66.9	56.7	66.6	61.5	669.5
R_3	58.0	58.9	58.8	58.1	64.3	54.6	52.3	51.4	52.4	54.4	563.2
Total	177.3	202.8	230.4	205.00	227.80	176.90	176.00	175.70	176.20	173.50	1921.6

<u>AOV</u>

	df	SS	MS	F	
Total	29	3325.6547			
Reps	2	915.8847	457.9423	9.4024*	$P < .005$
Treatments	9	1533.0880			
S_o vs (S_1+S_2)	1		189.0030	3.8806*	$P > .05$
F_1 vs F_2/S_o	1		0.0266	< 1	
F_1 vs F_2/S	1		1128.8816	23.1781	$P < .005$
S_1 vs S_2	1		0.2400	< 1	
C_1 vs C_2	1		93.6150	1.9221**	$P > .10$
S x C	1		2.1600	< 1	
F x S	1		0.1066	< 1	
F x C	1		118.8150	2.4395**	$P > .10$
Error	18	876.6820	48.7045		

TABLE III (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	177.3	202.8	230.4	205.0	227.8	176.9	176.0	175.7	176.2	173.5			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	150.6	120	189.0030
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	0.4	6	0.0266
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	164.6	24	1128.8816
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	2.4	24	0.2400
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-47.4	24	93.6150
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-7.2	24	2.1600
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-1.6	24	0.1066
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-53.4	24	118.8150

TABLE IV

AIR PERMEABILITY AFTER 20 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	55.4	71.8	72.2	74.9	78.4	65.2	69.5	65.0	63.5	61.9	677.8
R_2	58.8	68.8	67.3	71.00	72.7	56.5	62.9	60.4	59.3	62.1	639.8
R_3	60.4	69.1	66.33	68.9	71.4	56.1	65.7	65.3	53.3	53.9	630.43
Total	174.6	209.7	205.83	214.8	222.5	177.8	198.1	190.7	176.10	177.90	1948.03

AOV

	df	SS	MS	F	
Total	29	1227.8096			
Reps	2	125.8571	62.9285	7.8143*	$P < .005$
Treatments	9	957.0003			
S_o vs (S_1+S_2)	1		288.3000	35.8007*	$P < .005$
F_1 vs F_2/S_o	1		1.7066	< 1	
F_1 vs F_2/S^o	1		504.1666	62.6068*	$P < .005$
S_1 vs S_2	1		7.0416	< 1	
C_1 vs C_2	1		0.1350	< 1	
S x C	1		18.0266	2.2385**	$P > .10$
F x S	1		133.4816	16.5755*	$P < .005$
F x C	1		3.6816	< 1	
Error	18	144.9522	8.0529		

TABLE IV (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	SS = $\frac{Q^2}{Kr}$
	174.6	209.7	205.8	214.8	222.5	177.8	198.1	190.7	176.1	177.9			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	186.0	120	288.3000
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-3.2	6	1.7066
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	110.0	24	504.1666
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	13.0	24	7.0416
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	1.8	24	0.1350
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	20.8	24	18.0266
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-56.6	24	133.4816
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-9.4	24	3.6816

TABLE V

ABSORPTION AFTER 5 LAUNDERINGS
Maximum Rate in ml/min.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	3.65	4.28	4.70	5.30	5.40	3.45	4.00	4.20	5.00	5.00	44.98
R_2	2.95	3.1	3.65	4.00	4.1	3.38	3.55	3.65	4.00	4.20	36.58
R_3	4.1	3.45	3.90	5.1	5.2	4.7	3.72	3.55	4.70	5.1	43.52
Total	10.70	10.83	12.25	14.40	14.70	11.53	11.27	11.40	13.70	14.30	125.08

AOV

	df	SS	MS	F	
Total	29	14.0610			
Reps	2	4.0285	2.0142	15.0876*	$P < .005$
Treatments	9	7.6282			
S_o vs (S_1+S_2)	1		1.6170	12.1123*	$P < .005$
F_1 vs F_2/S_o	1		0.1148	< 1	
F_1 vs F_2/S	1		0.0950	< 1	
S_1 vs S_2	1		5.3676	40.2067*	$P < .005$
C_1 vs C_2	1		0.2501	1.8734**	$P > .10$
S x C	1		0.0176	< 1	
F x S	1		0.0198	< 1	
F x C	1		0.0408	< 1	
Error	18	2.4043	0.1335		

TABLE V (Continued

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	10.70	10.83	12.25	14.40	14.70	11.53	11.27	11.40	13.70	14.30			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	13.93	120	1.6170
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.83	6	0.1148
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	1.51	24	0.0950
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-11.35	24	5.3676
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-2.45	24	0.2501
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-0.65	24	0.0176
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-0.69	24	0.0198
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.99	24	0.0408

TABLE VI

ABSORPTION AFTER 10 LAUNDERINGS
Maximum Rate in ml/min.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	4.1	4.37	5.4	5.30	5.90	4.28	4.6	4.48	5.00	5.10	48.53
R_2	3.45	3.05	3.30	4.48	4.40	3.45	3.20	3.37	4.60	4.70	38.00
R_3	3.62	3.65	3.90	5.80	5.50	4.3	3.72	3.82	5.10	5.20	44.61
Total	11.17	11.07	12.60	15.58	15.80	12.03	11.52	11.67	14.70	15.00	131.14

AOV

	df	SS	MS	F	
Total	29	19.0416			
Reps	2	5.6647	2.8323	22.6947*	$P < .005$
Treatments	9	11.1302			
S_o vs (S_1+S_2)	1		1.9101	15.3052*	$P < .005$
F_1 vs F_2/S_o	1		0.1232	< 1	
F_1 vs F_2/S	1		0.1945	1.5584**	$P > .10$
S_1 vs S_2	1		8.4253	67.5104**	$P < .005$
C_1 vs C_2	1		0.2016	1.6153**	$P > .10$
S x C	1		0.0560	< 1	
F x S	1		0.0600	< 1	
F x C	1		0.0704	< 1	
Error	18	2.2467	0.1248		

TABLE VI (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	11.17	11.07	12.60	15.58	15.80	12.03	11.52	11.67	14.70	15.00			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	15.14	120	1.9101
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.86	6	0.1232
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	2.16	24	0.1945
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-14.22	24	8.4253
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-2.20	24	0.2016
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-1.16	24	0.0560
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-1.20	24	0.0600
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-1.30	24	0.0704

TABLE VII

ABSORPTION AFTER 15 LAUNDERINGS
Maximum Rate in ml/min.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	4.10	4.20	4.70	5.60	6.00	3.72	4.00	4.28	5.40	5.20	47.20
R_2	3.90	3.90	3.55	5.10	5.20	3.82	3.55	3.55	5.10	5.00	42.67
R_3	4.30	3.62	4.00	5.30	5.50	3.65	3.82	3.82	4.90	5.40	44.31
Total	12.30	11.72	12.25	16.00	16.70	11.19	11.37	11.65	15.40	15.60	134.18

AOV

	df	SS	MS	F	
Total	29	16.6060			
Reps	2	1.0521	0.5260	10.3339	$P < .005$
Treatments	9	14.6364			
S_o vs (S_1+S_2)	1		2.3324	45.8231*	$P < .005$
F_1 vs F_2/S_o	1		0.2053	4.0333*	$P > .05$
F_1 vs F_2/S^o	1		0.2926	5.7485*	$P > .025$
S_1 vs S_2	1		11.6343	228.5717*	$P < .005$
C_1 vs C_2	1		0.1218	2.3929**	$P > .10$
S x C	1		0.0003	< 1	
F x S	1		0.0234	< 1	
F x C	1		0.0234	< 1	
Error	18	0.9175	0.0509		

TABLE VII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	12.30	11.72	12.25	16.00	16.70	11.19	11.37	11.65	15.40	15.60			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	16.73	120	2.3324
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	1.11	6	0.2053
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	2.65	24	0.2926
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-16.71	24	11.6343
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-1.71	24	0.1218
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	0.09	24	0.0003
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-0.75	24	0.0234
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.75	24	0.0234

TABLE VIII

ABSORPTION AFTER 20 LAUNDERINGS
Maximum Rate in ml/min.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	4.50	4.38	4.60	6.2	6.32	4.10	3.80	3.72	5.50	5.60	48.72
R_2	5.40	3.55	3.45	5.6	5.20	4.90	3.82	3.55	5.00	5.10	45.57
R_3	5.40	5.80	5.90	3.65	3.55	5.40	4.06	3.20	3.20	4.00	44.16
Total	15.30	13.73	13.95	15.45	15.07	14.40	11.68	10.47	13.70	14.70	138.45

AOV

	df	SS	MS	F	
Total	29	26.6670			
Reps	2	1.0901	0.5450	<1	
Treatments	9	7.7853			
S_o vs (S_1+S_2)	1		0.8551	<1	
F_1 vs F_2/S_o	1		0.1350	<1	
F_1 vs F_2/S	1		2.4384	2.4670**	$P > .10$
S_1 vs S_2	1		3.4428	3.4832*	$P > .05$
C_1 vs C_2	1		0.0057	<1	
S x C	1		0.1080	<1	
F x S	1		0.4788	<1	
F x C	1		0.0001	<1	
Error	18	17.7916	0.9884		

TABLE VIII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	K.r	$SS = \frac{Q^2}{Kr}$
	15.30	13.73	13.95	15.45	15.07	14.40	11.68	10.47	13.70	14.70			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-10.13	120	0.08551
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	0.90	6	0.1350
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	7.65	24	2.4384
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-9.09	24	3.4428
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	0.37	24	0.0057
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	1.61	24	0.1080
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	3.39	24	0.4788
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.05	24	0.0001

TABLE IX

ABSORPTION AFTER 5 LAUNDERINGS
Total Absorption in mls.

Reps	Treatments 1	2	3	4	5	6	7	8	9	10	Total
R_1	.65	.70	.70	.75	.75	.70	.60	.70	.70	.75	7.00
R_2	.55	.65	.60	.60	.65	.50	.50	.60	.62	.55	5.82
R_3	.50	.60	.60	.70	.75	.65	.60	.60	.60	.70	6.30
Total	1.70	1.95	1.90	2.05	2.15	1.85	1.70	1.90	1.92	2.00	19.12

AOV

	df	SS	MS	F	
Total	29	0.1636			
Reps	2	0.0704	0.0352	18.5263*	$P < .005$
Treatments	9	0.0596			
S_o vs (S_1+S_2)	1		0.0156	8.2105*	$P > .01$
F_1 vs F_2/S_o	1		0.0037	2.0526**	$P > .10$
F_1 vs F_2/S^o	1		0.0117	6.1578*	$P > .01$
S_1 vs S_2	1		0.0187	9.8421*	$P > .005$
C_1 vs C_2	1		0.0045	2.3684**	$P > .10$
S x C	1		0.0001	< 1	
F x S	1		0.0001	< 1	
F x C	1		0.0022	1.1578**	$P > .10$
Error	18	0.0336	0.0019		

TABLE IX (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	1.70	1.95	1.90	2.05	2.15	1.85	1.70	1.90	1.92	2.00			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	1.37	120	0.0156
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.15	6	0.0037
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	0.53	24	0.0117
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-0.67	24	0.0187
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-0.33	24	0.0045
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	0.03	24	0.0001
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.03	24	0.0001
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	0.23	24	0.0022

TABLE X

ABSORPTION AFTER 10 LAUNDERINGS
Total Absorption in mls.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	.65	.65	.60	.70	.80	.65	.65	.60	.65	.70	6.65
R_2	.50	.50	.65	.60	.60	.50	.50	.55	.60	.65	5.65
R_3	.55	.60	.70	.70	.70	.60	.55	.60	.65	.70	6.35
Total	1.70	1.75	1.95	2.00	2.10	1.75	1.70	1.75	1.90	2.05	18.65

AOV

	df	SS	MS	F	
Total	29	0.1535			
Reps	2	0.0526	0.0263	15.4705	$P < .005$
Treatments	9	0.0701			
S_o vs (S_1+S_2)	1		0.0163	9.5882*	$P > .005$
F_1 vs F_2/S_o	1		0.0004	< 1	
F_1 vs F_2/S^o	1		0.0067	3.9411*	$P > .05$
S_1 vs S_2	1		0.0337	19.8235*	$P < .005$
C_1 vs C_2	1		0.0104	6.1176*	$P > .01$
S x C	1		0.0000	< 1	
F x S	1		0.0004	< 1	
F x C	1		0.0004	< 1	
Error	18	0.0308	0.0017		

TABLE X (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	1.70	1.75	1.95	2.00	2.10	1.75	1.70	1.75	1.90	2.05			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	1.4	120	0.0163
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.05	6	0.0004
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	0.40	24	0.0067
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-0.90	24	0.0337
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-0.50	24	0.0104
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	0.00	24	0.0000
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.10	24	0.0004
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.10	24	0.0004

TABLE XI

ABSORPTION AFTER 15 LAUNDERINGS
Total Absorption in mls.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	.65	.60	.65	.75	.75	.60	.55	.60	.70	.60	6.45
R_2	.50	.60	.55	.65	.60	.50	.55	.55	.70	.55	5.75
R_3	.60	.60	.65	.70	.75	.55	.60	.55	.65	.65	6.30
Total	1.75	1.80	1.85	2.10	2.10	1.65	1.70	1.70	2.05	1.80	18.50

AOV

	df	SS	MS	F	
Total	29	0.1417			
Reps	2	0.0272	0.0136	9.0666*	P $<$ .005
Treatments	9	0.0882			
S_o vs (S_1+S_2)	1		0.0187		
F_1 vs F_2/S_o	1		0.0017	1.1333**	P $>$ .10
F_1 vs F_2/S^o	1		0.0150	10.0000*	P $>$ .005
S_1 vs S_2	1		0.0417	27.8000*	P $<$ .005
C_1 vs C_2	1		0.0016	1.0667**	P $>$ .10
S x C	1		0.0037	2.4667**	P $>$ .10
F x S	1		0.0004	<1	
F x C	1		0.0037	2.4667**	P $>$ .10
Error	18	0.0263	0.0015		

TABLE XI (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	1.75	1.80	1.85	2.10	2.10	1.65	1.70	1.70	2.05	1.80			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	1.50	120	0.0187
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	0.10	6	0.0017
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	0.60	24	0.0150
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-1.00	24	0.0417
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	0.20	24	0.0016
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-0.30	24	0.0037
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-0.10	24	0.0004
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.30	24	0.0037

TABLE XII

ABSORPTION AFTER 20 LAUNDERINGS
Total Absorption in mls.

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	.65	.60	.70	.75	.70	.55	.55	.55	.70	.65	6.40
R_2	.70	.55	.55	.65	.70	.50	.60	.55	.65	.60	6.05
R_3	.60	.75	.70	.65	.50	.75	.60	.50	.55	.55	6.15
Total	1.95	1.90	1.95	2.05	1.90	1.80	1.75	1.60	1.90	1.80	18.60

AOV

	df	SS	MS	F	
Total	29	0.1780			
Reps	2	0.0065	0.0033	< 1	
Treatments	9	0.0480			
S_o vs (S_1+S_2)	1		0.0002	< 1	
F_1 vs F_2/S_o	1		0.0037	< 1	
F_1 vs F_2/S	1		0.0234	3.3913*	$P > .05$
S_1 vs S_2	1		0.0084	1.2173**	$P > .10$
C_1 vs C_2	1		0.0051	< 1	
S x C	1		0.0009	< 1	
F x S	1		0.0026	< 1	
F x C	1		0.0009	< 1	
Error	18	0.1235	0.0069		

TABLE XII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	1.95	1.90	1.95	2.05	1.90	1.80	1.75	1.60	1.90	1.80			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-0.15	120	0.0002
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	0.15	6	0.0037
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	0.75	24	0.0234
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-0.45	24	0.0084
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	0.35	24	0.0051
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-0.15	24	0.0009
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.25	24	0.0026
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.15	24	0.009

TABLE XIII

REFLECTANCE AFTER 5 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	2.62	3.18	3.32	2.70	2.60	3.04	3.31	3.20	3.04	2.81	29.82
R_2	2.55	2.95	2.59	3.16	4.00	3.12	2.47	2.35	3.43	3.58	30.20
R_3	2.47	2.09	2.18	1.97	1.86	2.20	2.59	2.18	2.09	1.85	21.48
Total	7.64	8.22	8.09	7.83	8.46	8.36	8.37	7.73	8.56	8.24	81.50

AOV

	df	SS	MS	F	
Total	29	8.7071			
Reps	2	4.8579	2.4289	12.3357*	$P < .005$
Treatment	9	0.3041			
S_o vs (S_1+S_2)			0.0187		
F_1 vs F_2/S	1		0.0864	<1	
F_1 vs F_2/S^o	1		0.0037	<1	
S_1 vs S_2	1		0.0308	<1	
C_1 vs C_2	1		0.0088	<1	
S x C	1		0.0486	<1	
F x S	1		0.0216	<1	
F x C	1		0.0888	<1	
Error	18	3.5451	0.1969		

TABLE XIII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	7.64	8.22	8.09	7.83	8.46	8.36	8.37	7.73	8.56	8.24			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	1.5	120	0.0187
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-.72	6	0.0864
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	-0.30	24	0.0037
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	-0.86	24	0.0308
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	0.46	24	0.0088
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	1.08	24	0.0486
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.72	24	0.0216
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-1.46	24	0.0888

TABLE XIV

REFLECTANCE AFTER 10 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	2.35	2.84	2.73	1.76	2.23	2.21	3.21	2.62	1.76	1.88	23.59
R_2	2.42	2.40	2.29	1.87	2.03	2.42	2.60	2.36	1.98	2.10	22.47
R_3	2.20	2.69	2.23	1.86	1.74	2.45	2.59	2.47	1.85	1.74	21.82
Total	6.97	7.93	7.25	5.49	6.00	7.08	8.40	7.45	5.59	5.72	67.88

AOV

	df	SS	MS	F	
Total	29	3.9988			
Reps	2	0.1603	0.0802	2.2093**	$P > .10$
Treatments	9	3.1848			
S_o vs (S_1+S_2)	1		0.0468	1.2892**	$P > .10$
F_1 vs F_2/S_o	1		0.0020	< 1	
F_1 vs F_2/S	1		0.0100	< 1	
S_1 vs S_2	1		2.8222	77.7465*	$P < .005$
C_1 vs C_2	1		0.0491	1.3526**	$P > .10$
S x C	1		0.2147	5.9146*	$P > .025$
F x S	1		0.0301	< 1	
F x C	1		0.0176	< 1	
Error	18	0.6537	0.0363		

TABLE XIV (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	6.97	7.93	7.25	5.49	6.00	7.08	8.40	7.45	5.59	5.72			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-2.37	120	0.0468
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.11	6	0.0020
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	-0.49	24	0.0100
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	8.23	24	2.8222
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-0.99	24	0.0491
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	2.27	24	0.2147
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-0.85	24	0.0301
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.65	24	0.0176

TABLE XV

REFLECTANCE AFTER 15 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	2.93	2.47	2.49	1.76	1.64	2.34	2.48	2.14	1.76	1.64	21.65
R_2	3.20	3.20	1.91	2.19	1.76	3.04	3.11	2.88	2.22	1.99	25.50
R_3	2.40	2.80	2.47	2.09	1.86	2.56	2.93	2.35	1.97	2.09	23.52
Total	8.53	8.47	6.87	6.04	5.26	7.94	8.52	7.37	5.95	5.72	70.67

AOV

	df	SS	MS	F	
Total	29	6.7480			
Reps	2	0.7413	0.3707	5.6855*	$P > .01$
Treatments	9	4.8316			
S_o vs (S_1+S_2)	1		1.1368	17.4355*	$P < .005$
F_1 vs F_2/S_o	1		0.0580	< 1	
F_1 vs F_2/S^o	1		0.0352	< 1	
S_1 vs S_2	1		2.8428	43.6012*	$P < .005$
C_1 vs C_2	1		0.5890	9.0337*	$P > .005$
S x C	1		0.1261	1.9340**	$P > .10$
F x S	1		0.0013	< 1	
F x C	1		0.0416	< 1	
Error	18	1.1751	0.0652		

TABLE XV (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	8.53	8.47	6.87	6.04	5.26	7.94	8.52	7.37	5.95	5.72			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-11.68	120	1.1368
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	0.59	6	0.0580
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	-0.92	24	0.0352
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	8.26	24	2.8428
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	3.76	24	0.5890
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	1.74	24	0.1261
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	-0.18	24	0.0013
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	1.00	24	0.0416

TABLE XVI

REFLECTANCE AFTER 20 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	2.71	2.49	2.14	1.76	1.64	2.10	2.68	2.14	1.76	1.76	21.18
R_2	2.46	4.39	2.14	2.03	2.97	1.95	2.95	2.47	2.17	2.34	25.87
R_3	2.73	2.93	2.35	2.21	1.97	2.57	3.04	2.70	2.32	2.44	25.26
Total	7.90	9.81	6.63	6.00	6.58	6.62	8.67	7.31	6.25	6.54	72.31

AOV

	df	SS	MS	F	
Total	29	8.4203			
Reps	2	1.3004	0.6502	4.3520*	$P > .025$
Treatments	9	4.4297			
S_o vs (S_1+S_2)	1		0.0007	< 1	
F_1 vs F_2/S_o	1		0.2730	1.8273**	$P > .10$
F_1 vs F_2/S	1		0.0026	< 1	
S_1 vs S_2	1		2.0709	13.8614*	$P < .005$
C_1 vs C_2	1		0.5612	3.7563*	$P > .05$
S x C	1		1.2195	8.1626*	$P > .01$
F x S	1		0.0187	< 1	
F x C	1		0.0975	< 1	
Error	18	2.6902	0.1494		

TABLE XVI (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	K.r	$SS = \frac{Q^2}{Kr}$
	7.90	9.81	6.63	6.00	6.58	6.62	8.67	7.31	6.25	6.54			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-0.29	120	0.0007
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	1.28	6	0.2730
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	0.25	24	0.0026
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	7.05	24	2.0709
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	3.67	24	0.5612
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	5.41	24	1.2195
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.67	24	0.0187
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	1.53	24	0.0975

TABLE XVII

STIFFNESS AFTER 5 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	1.69	2.70	3.70	3.02	3.78	1.76	2.51	3.17	2.55	3.23	28.11
R_2	2.27	3.00	4.25	2.64	3.69	2.30	2.92	3.85	2.75	3.16	30.83
R_3	1.87	3.41	4.53	4.07	2.90	1.87	2.87	3.98	2.60	3.55	31.65
Total	5.83	9.11	12.48	9.73	10.37	5.93	8.30	11.00	7.90	9.94	90.59

AOV

	df	SS	MS	F	
Total	29	16.6209			
Reps	2	0.6867	0.3433	2.5581**	P > .10
Treatments	9	13.5183			
S_o vs (S_1+S_2)	1		8.4217	62.7548*	P < .005
F_1 vs F_2/S_o	1		0.0016	< 1	
F_1 vs F_2/S^o	1		0.8626	6.4277*	P > .01
S_1 vs S_2	1		0.3626	2.7019**	P > .10
C_1 vs C_2	1		3.1901	23.7712*	P < .005
S x C	1		0.4788	3.5678*	P > .05
F x C	1		0.0001	< 1	
F x C	1		0.0222	< 1	
Error	18	2.4159	0.1342		

TABLE XVII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	5.83	9.11	12.48	9.73	10.37	5.93	8.30	11.00	7.90	9.94			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	31.79	120	8.4217
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.10	6	0.0016
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	4.55	24	0.8626
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	2.95	24	0.3626
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-8.75	24	3.1901
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-3.39	24	0.4788
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.03	24	0.0001
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	0.73	24	0.0222

TABLE XVIII

STIFFNESS AFTER 10 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	1.72	2.78	3.44	2.91	3.79	1.81	2.63	3.33	2.83	3.36	28.60
R_2	1.79	3.16	4.00	2.84	3.25	1.75	2.82	3.61	2.56	2.87	28.65
R_3	1.92	3.74	5.1	3.33	4.02	1.84	3.00	4.44	3.04	3.26	33.69
Total	5.43	9.68	12.54	9.08	11.06	5.40	8.45	11.38	8.43	9.49	90.94

AOV

	df	SS	MS	F	
Total	29	19.8206			
Reps	2	1.7104	0.8552	9.3566*	$P < .005$
Treatments	9	16.4642			
S_o vs (S_1+S_2)	1		11.2792	123.4048*	$P < .005$
F_1 vs F_2/S	1		0.0001	< 1	
F_1 vs F_2/S^o	1		0.8855	9.6881*	$P > .005$
S_1 vs S_2	1		0.6633	7.2571*	$P > .01$
C_1 vs C_2	1		3.2487	35.5437*	$P < .005$
C x S	1		0.3151	3.4474*	$P > .05$
F x S	1		0.0012	< 1	
F x C	1		0.0301	< 1	
Error	18	1.6460	0.0914		

TABLE XVIII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	5.43	9.68	12.54	9.08	11.06	5.40	8.45	11.38	8.43	9.49			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	36.79	120	11.2792
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	0.03	6	0.0001
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	4.61	24	0.8855
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	3.99	24	0.6633
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-8.83	24	3.2487
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-2.75	24	0.3151
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.17	24	0.0012
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.85	24	0.0301

TABLE XIX

STIFFNESS AFTER 15 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	1.73	2.95	4.28	3.12	3.89	1.71	2.66	3.29	2.82	3.26	29.71
R_2	1.78	3.22	4.54	2.98	3.73	1.78	2.99	3.91	2.62	2.95	30.50
R_3	1.90	4.05	4.60	2.89	4.13	1.93	3.46	4.16	2.68	3.37	33.17
Total	5.41	10.22	13.42	8.99	11.75	5.42	9.11	11.36	8.12	9.58	93.38

AOV

	df	SS	MS	F	
Total	29	21.6514			
Reps	2	0.6575	0.3288	5.6592**	$P > .01$
Treatments	9	19.9473			
S_o vs (S_1+S_2)	1		12.8249	220.7383*	$P < .005$
F_1 vs F_2/S_2	1		0.0000	<1	
F_1 vs F_2/S_o	1		1.6069	27.6574*	$P < .005$
S_1 vs S_2	1		1.3396	23.0567*	$P < .005$
C_1 vs C_2	1		3.8962	67.0602*	$P < .005$
C x S	1		0.0631	1.0860**	$P > .10$
F x S	1		0.0007	<1	
F x C	1		0.2110	3.6316*	$P > .05$
Error	18	1.0466	0.0581		

TABLE XIX (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	5.41	10.22	13.42	8.99	11.75	5.42	9.11	11.36	8.12	9.58			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	39.23	120	12.8249
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.01	6	0.0000
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	6.21	24	1.6069
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	5.67	24	1.3396
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-9.67	24	3.8962
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-1.23	24	0.0631
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.13	24	0.0007
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-2.25	24	0.2110

TABLE XX

STIFFNESS AFTER 20 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	1.65	3.32	4.17	2.84	3.62	1.78	2.75	3.42	2.79	3.08	29.42
R_2	1.84	3.56	4.36	2.98	4.08	2.80	3.27	4.21	2.96	3.21	33.27
R_3	2.07	3.73	4.54	3.33	3.87	1.95	3.08	4.08	2.66	3.43	32.74
Total	5.56	10.61	13.07	9.15	11.57	6.53	9.10	11.71	8.41	9.72	95.43

AOV

	df	SS	MS	F	
Total	29	18.0082			
Reps	2	0.8708	0.4354	9.7187*	$P < .005$
Treatments	9	16.3304			
S_o vs (S_1+S_2)	1		10.2025	227.7343*	$P < .05$
F_1 vs F_2/S_o	1		0.1568	3.5000*	$P > .05$
F_1 vs F_2/S	1		1.2376	27.6250*	$P < .005$
S_1 vs S_2	1		1.3207	29.4799*	$P < .005$
C_1 vs C_2	1		3.2193	71.8593*	$P < .005$
C x S	1		0.0759	1.6941**	$P > .10$
F x S	1		0.0035	< 1	
F x C	1		0.0396	< 1	
Error	18	0.8070	0.0448		

TABLE XX (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	5.56	10.61	13.07	9.15	11.57	6.53	9.10	11.71	8.42	9.72			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	34.99	120	10.2025
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	-0.97	6	0.1568
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	5.45	24	1.2376
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	5.63	24	1.3207
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	-8.79	24	3.2193
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-1.35	24	0.0759
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	0.29	24	0.0035
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-0.97	24	0.0392

TABLE XXI

TEAR RESISTANCE AFTER 5 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	1138.56	1066.72	965.28	936.00	842.72	693.28	688.00	666.72	645.28	634.56	8277.12
R_2	1008.00	1136.00	1034.00	933.28	864.00	634.72	661.28	682.72	688.00	618.28	8260.28
R_3	1024.00	758.40	1013.28	954.72	901.28	672.00	709.28	714.72	624.00	592.00	7963.68
Total	3170.56	2961.12	3012.56	2824.00	2608.00	2000.00	2058.56	2064.16	1957.28	1844.84	24501.08

<u>AOV</u>

	df	SS	MS	F	
Total	29	894411.589			
Reps	2	6216.659	3108.3295	< 1	
Treatments	9	791784.469			
S_o vs (S_1+S_2)	1		15226.2246	2.8427**	$P > .10$
F_1 vs F_2/S_o	1		228368.4522	42.6367*	$P < .005$
F_1 vs F_2/S_2	1		504843.6294	94.2551*	$P < .005$
S_1 vs S_2	1		30980.2832	5.7840*	$P > .025$
C_1 vs C_2	1		3069.0816	< 1	
S x C	1		6191.4512	1.1559**	$P > .10$
F x S	1		2036.5152	< 1	
F x C	1		138.8166	< 1	
Error	18	96410.461	5356.1367		

TABLE XXI (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	3170.56	2961.12	3012.56	2824.00	2608.00	2000.00	2058.56	2064.16	1957.28	1844.84			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-1351.72	120	15226.2246
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	1170.56	6	228368.4522
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	3480.84	24	504843.6294
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	862.28	24	30980.2832
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	271.40	24	3069.0816
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-385.48	24	6191.4512
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	221.08	24	2036.5152
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	57.72	24	138.8166

TABLE XXII

TEAR RESISTANCE AFTER 10 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	549.28	874.72	816.00	746.72	720.00	800.00	565.28	592.00	533.44	474.72	6672.16
R_2	842.72	922.56	880.00	709.28	826.56	576.00	618.72	592.00	570.56	560.00	7098.40
R_3	853.28	938.72	874.56	789.28	778.72	592.00	613.28	608.00	592.00	522.72	7162.56
Total	2245.28	2736.00	2570.56	2245.28	2325.28	1968.00	1797.28	1792.00	1696.00	1557.44	20933.12

AOV

	df	SS	MS	F	
Total	29	571708.208			
Reps	2	14209.640	7104.820	1.3114**	P > .10
Treatments	9	459984.603			
S_o vs (S_1+S_2)	1		148.0296	< 1	
F_1 vs F_2/S_o	1		12814.0330	2.3653**	P > .10
F_1 vs F_2/S	1		383649.3066	70.8174*	P < .005
S_1 vs S_2	1		47868.3744	8.8359*	P > .005
C_1 vs C_2	1		2190.3882	< 1	
S x C	1		524.1610	< 1	
F x S	1		6672.0010	1.2315**	P > .10
F x C	1		142.1066	< 1	
Error	18	97513.965	5417.4425		

TABLE XXII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1 2245.28	2 2736.00	3 2570.56	4 2245.28	5 2325.28	6 1968.00	7 1797.28	8 1792.00	9 1696.00	10 1557.44	Q	Kr	$SS = \frac{Q^2}{Kr}$
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-133.28	120	148.0296
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	277.28	6	12814.0330
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	3034.40	24	383649.3066
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	1071.84	24	47868.3744
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	229.28	24	2190.3882
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	112.16	24	524.1610
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	400.16	24	6672.0010
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-58.4	24	142.1066

TABLE XXIII

TEAR RESISTANCE AFTER 15 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	512.00	848.00	784.00	688.00	634.72	757.28	522.56	554.72	506.72	437.28	6245.28
R_2	752.00	736.00	757.28	666.72	704.00	544.00	517.28	554.72	490.72	480.00	6202.72
R_3	789.28	880.00	805.28	736.00	741.28	565.28	592.00	554.72	549.28	528.00	6741.12
Total	2053.28	2464.00	2346.56	2090.72	2080.00	1866.56	1631.84	1664.16	1546.72	1445.28	19189.12

AOV

	df	SS	MS	F	
Total	29	458757.783			
Reps	2	17918.108	8959.054	1.8891**	$P > .10$
Treatments	9	355476.545			
S_o vs (S_1+S_2)	1		1401.3800	< 1	
F_1 vs F_2/So	1		5810.7264	1.2252**	$P > .10$
F_1 vs F_2/S	1		302239.8816	63.7314*	$P < .005$
S_1 vs S_2	1		37118.0810	7.8268*	$P > .01$
C_1 vs C_2	1		1621.6416	< 1	
S x C	1		30.4650	< 1	
F x S	1		4699.5210	< 1	
F x C	1		145.2380	< 1	
Error	18	85363.1300	4742.3961		

TABLE XXIII (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1 2053.28	2 2464.00	3 2346.56	4 2090.72	5 2080.00	6 1866.56	7 1631.84	8 1664.16	9 1546.72	10 1445.28	Q	Kr	$SS = \frac{Q^2}{Kr}$
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-410.08	120	1401.3800
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	186.72	6	5810.7264
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	2693.28	24	302239.8816
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	943.84	24	37118.0810
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	197.28	24	1621.6416
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-27.04	24	30.4650
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	335.84	24	4699.5210
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	59.04	24	145.2384

TABLE XXIV

TEAR RESISTANCE AFTER 20 LAUNDERINGS

	Treatments										
Reps	1	2	3	4	5	6	7	8	9	10	Total
R_1	480.00	736.00	741.28	645.28	618.56	704.00	517.28	480.00	448.00	442.56	5812.96
R_2	698.72	752.00	778.56	693.28	682.72	538.72	528.00	560.00	490.72	458.72	6181.44
R_3	736.00	768.00	752.00	677.28	656.00	517.28	554.56	506.72	512.00	485.28	6165.12
Total	1914.72	2256.00	2271.84	2015.84	1957.28	1760.00	1599.84	1546.72	1450.72	1386.56	18159.52

AOV

	df	SS	MS	F	
Total	29	374516.412			
Reps	2	8668.683	4334.3415	1.2563**	P > .10
Treatments	9	303750.947			
S_o vs (S_1+S_2)	1		381.918	< 1	
F_1 vs F_2/S_o	1		3989.713	1.1301**	P > .10
F_1 vs F_2/S	1		263995.545	76.5244*	P < .005
S_1 vs S_2	1		31104.000	9.0161*	P > .005
C_1 vs C_2	1		1066.666	< 1	
S x C	1		304.166	< 1	
F x S	1		2510.033	< 1	
F x C	1		231.633	< 1	
Error	18	62096.782	3449.8212		

TABLE XXIV (Continued)

ORTHOGONAL COMPARISONS

Treatments

Comparisons	1	2	3	4	5	6	7	8	9	10	Q	Kr	$SS = \frac{Q^2}{Kr}$
	1914.72	2256.00	2271.84	2015.84	1957.28	1760.00	1599.84	1546.72	1450.72	1386.56			
S_o vs (S_1+S_2)	-4	+1	+1	+1	+1	-4	+1	+1	+1	+1	-214.08	120	381.918
F_1 vs F_2/S_o	+1	0	0	0	0	-1	0	0	0	0	154.72	6	3989.713
F_1 vs F_2/S	0	+1	+1	+1	+1	0	-1	-1	-1	-1	2517.12	24	263995.545
S_1 vs S_2	0	+1	+1	-1	-1	0	+1	+1	-1	-1	864.00	24	31104.000
C_1 vs C_2	0	+1	-1	+1	-1	0	+1	-1	+1	-1	160.00	24	1066.666
S x C	0	+1	-1	-1	+1	0	+1	-1	-1	+1	-85.44	24	304.166
F x S	0	+1	+1	-1	-1	0	-1	-1	+1	+1	245.44	24	2510.033
F x C	0	+1	-1	+1	-1	0	-1	+1	-1	+1	-74.56	24	231.633

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