A STUDY OF THE SOILING AND SOIL RETENTION PROPERTIES OF THREE SELECTED NYLON TRICOT FABRICS

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ABSTRACT

A STUDY OF THE SOILING AND SOIL RETENTION PROPERTIES OF THREE SELECTED NYLON TRICOT FABRICS

by Katherine E. Burgess

The general purpose of this study was to learn more about retention of soil on fabrics, and to compare soiling and soil retention characteristics of three types of nylon tricot fabrics. One fabric studied was manufactured from regular filament nylon yarn (Fabric I), one from a crimped (Textralized) yarn (fabric known as Ban-Lon, Fabric II), and one from a false-twist, torque (Saaba) yarn (Fabric III).

Specific objectives were: to compare the soiling characteristics of three types of nylon tricot fabrics; to compare their soil retention characteristics; to compare the relative effectiveness of one light-duty soap and one light-duty synthetic detergent as cleaning agents.

Specimens were soiled with a standard artificial soil, and laundered twenty times in an Atlas Launder-Ometer, under controlled conditions. Reflectance readings were taken originally, and before and after the first, fifth, tenth, fifteenth, and twentieth launderings. Specimens were also microscopically examined at the above mentioned intervals, and photomicrographs were taken of the fabrics originally and after the twentieth soiling.

An analysis of variance of the reflectance readings taken after soilings and launderings was carried out. Differences between means which met or exceeded the 95% level of confidence were reported as significant.

The light-duty soap and water conditioner used under this set of conditions were more efficient cleaning agents than the light-duty synthetic detergent. Little of the decrease in reflectance of the fabrics was caused by the detergents. The soap and water conditioner appeared to have a slightly greater effect on reducing the reflectance than did the synthetic detergent.

The fabrics did not accumulate soil at the same rate. Regular filament nylon (Fabric I), unlike the other two fabrics, did not soil heavily originally, but by the twentieth laundering with soap, it had decreased the greatest amount in reflectance of the specimens which were laundered with the soap. The Saaba (Fabric III), although it lowered considerably at the first soiling, changed little in reflectance thereafter. The Ban-Lon (Fabric II), laundered with synthetic detergent, soiled most heavily and retained the most soil of the three fabrics when laundering with both detergents was considered.

The fabrics made of textured yarns (Fabrics II and III), did not seem to soil more or less heavily than the one made of regular filament nylon (Fabric I). However, a difference in rate of soiling was seen, the textured yarn fabrics (Fabrics II and III), taking on considerably more soil initially than the regular filament nylon (Fabric I). With twenty soilings and launderings, soil retention of the three fabrics became

severe enough to make them unsatisfactory to the discrimina-
ting consumer.

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By

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CHAPTER I

INTRODUCTION

"Many of the basic factors in soiling of textile fibers and fabrics, and in cleaning of the soiled materials, are not yet fully recognized and satisfactorily understood (45)." The majority of research which has been done in this area has dealt mainly with the soiling of cotton, and more recently with wool fabrics. Very little work has been done on nylon or on the even newer nylon fabrics made of textured nylon fibers.

Because of nylon's superior strength, abrasion resistance, chemical resistance, dimensional stability, draping qualities and ease of care, it has had a wide acceptance in the few years it has been on the market. With the development of texturization, an additional boon was given to the synthetic fabric market.

Texturization is the mechanical deformation of filament yarns to obtain a permanent voluminous effect (12). The result is a change in texture and an increase in the bulk and often stretch characteristics of the yarn. This can be obtained by putting a permanent crimp, loop, coil or curl into otherwise smooth, parallel, continuous filaments.

Textured yarns belong to either one of two large classifications, the torque or torque-free groups (8). Under each of these groups there are three main types, the stretch, modified stretch and bulk types. Textralized yarn[1] is a crimp type of torque-free bulk yarn, which has a wavy, irregular zig-zag crimp. Bulk yarns are continuous filament yarns which have been modified to give a greatly increased mass or bulk per unit length (7). The bulk obtained is permanent and the degree of stretch varies depending on the method used. Saaba is a torque, modified stretch yarn. It is a false twist type of stretch yarn which has been modified to remove some of the stretch, yet retain maximum bulk. Saaba has been labeled false-twist because unlike the conventional process for making torque-type yarns, it is a continuous twisting process, which reduces the number of operations and increases the speed of production.

In the last few years textured yarns have improved man-made fibers and extended their uses. These fibers are being used in place of regular filament and staple nylon to simulate the characterisitcs of fabrics constructed from hi-bulk spun yarns and also obtain certain other advantages. Some of these advantages are:

1. soft, warm hand,
2. high moisture take-up,
3. increased air space for improved thermal qualities,
4. durability and low pilling propensity,
5. variety of textures,
6. greater covering power with less weight, thereby re-

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[1]Textralized is a trade name for a crimped yarn, and Ban-Lon is the trade name for fabrics made of Textralized yarns.

ducing fabrication costs,

7. "stretch-to-fit" characteristis, which enable the manufacture of one-size items (7).

The greying or yellowing of white nylon in repeated launderings has been a common and frequent consumer complaint. According to Kaswell (25), any soil which is deposited on hydrophobic fibers, which do not swell in water or dye, must remain on the surface of the fibers. If this were the case, it follows that nylon fibers should give up soil more readily in laundering than the hydrophilics. Nylon, however, does not perform this way, and with the greater surface area of textured yarns, the question of soiling potentiality of the textured yarn as compared with the regular filament nylon yarn arises. Removal of soil and whiteness retention of nylon fabrics are important considerations for the consumer. This investigation of nylon fabrics was proposed because of the need for research in this particular area.

The general purpose of this study was to learn more about retention of soil on fabrics, and to compare soiling and soil retention characteristics of three types of nylon tricot fabrics. One fabric was manufactured from regular filament nylon yarn, one from a crimped (Textralized) yarn, and one from a false-twist, torque (Saaba) yarn.

Specific objectives of this study were:

1. to compare the soiling characteristics of three types of nylon tricot fabrics,
2. to compare the soil retention characteristics of the

three fabrics,

3. to compare the relative effectiveness of one soap and one synthetic detergent as cleaning agents on the three fabrics.

CHAPTER II

REVIEW OF LITERATURE

A. Introduction

"Care of fabrics, to achieve the most effective soil removal with the least damage to the fiber used in the fabrics, is of constant interest to commercial establishments and to homemakers (34)." In the finishing or laundering of white fabrics, one of the main objectives is to render them as white as possible; the ultimate basis of judgment is the visual appearance of the treated or laundered cloth (22).

The retention of soil and the removal of soil from textiles is a large and complex subject. Work which has been done has dealt mainly with the soiling and removal of soil from cotton fabrics, and until quite recently little mention has been made of wool and the synthetics. The literature on detergency contained many references to the preparation of artificial soiling compounds; most of the studies were concerned with methods of soil removal for cotton, rather than soil acquisition (52). For studying soiling, Brown (6) stated, and it is generally agreed, that the amount and nature of the soiling material should be similar to that present on articles soiled by actual use. Little quantitative information however, was available on fabrics soiled by the skin; realistic methods for accumulating and evaluating this type of soil were lacking (14).

Another factor which added to the complexity of this particular area of investigation was reproducibility of results. Crowe (10) found that the reproducibility of results among laboratories left much to be desired. In order to obtain reproducible results, careful attention must be given to many factors, for example: preparation of soiling mixture, storage of cloth prior to soiling, temperature and humidity of atmosphere at the time of soiling, and the mechanical details of the soiling procedure (45). Differences in any of these may cause misleading variations in soil content of treated pieces of cloth.

In studying the soiling and removal of soil from nylon, some of the factors which may add to its greying should be kept in mind. The greying of white nylon may be due to an accumulation of dirt or lint due to static or it may be simply caused by aging---a type of discoloration which cannot be overcome (13). Discoloration may also be partly due to improper use or care, high ironing temperatures, drying in sunlight, or near heat as on a radiator.

B. Soiling

According to Masland (33) dirt was defined as a small, solid particle whose presence on the fibers may be detected visually; ink, wine, and other liquid stains of similar nature were not considered as normal dirt. Dirt on domestically soiled articles was of two main constitutents, oily material, and solid particles of mineral and carbonaceous material (6). Domestic dirt varied greatly in composition and also in the way it got onto the fabric (10). It could vary from a mixture of lime and grease found on sheep's wool, to ground in carbon dirt on a soiled shirt, from a pigment-pitch blend on optical lenses to an acid inert dirt mix found on pickled metal. No one or two soiled fabrics can duplicate the variety of soils found in practice. Frishman, et. al. (14), stated that garments are subject to soil from the atmosphere, contact with soiled objects in surroundings, and contact with the skin itself. Utermohlen and Ryan (49) concluded that pigment soil, which is more easily seen and more objectionable, was more difficult to remove than was oily soil.

Appreciable amounts of foreign matter may be present in fabrics without constituting a soil, according to Reich, et. al. (39). For example, starch and sizing improved the feel and appearance of fabrics. Insofar as solid soil was concerned, unless it was present in excessive amounts, this soil was objectionable only if it differed markedly from the fabric in color. The extreme and also the most common example was black soil on white fabric. The amount of soiling from a practical point of view, was the extent to which the fabric was darkened. If, because of the small amount of soil present or the lightness of the soil, no darkening was visible, the fabric would usually be called clean.

1. Oil from actual wear

Brown (6) found that the amount of oil on articles soiled by actual use varied from 0.25% on shirts to 1.20% on soft collars. The oils were found to contain very appreciable portions of long-chain free fatty acids. The nature of these varied in different oils, but figures indicated they were mixtures of saturated and unsaturated 18-carbon acids in approximately equal proportions. Other major constituents: long-chain neutral fat (tallow type), long-chain partly unsaturated fatty alcohols, partly unsaturated hydrocarbons, and a very small amount of short-chain fatty acids.

Sebum excreted from the human body has been found to consist of the following, according to Macleod and Muendo:

1. fats: oleic, palmitic, and stearic glycerides,
2. fatty acids: oleic, palmitic and stearic acids,
3. occasionally: butyric and caproic acids, together with cholesterol, chlorides and phosphates of alkaline earths, organic salts, albuminoids, water and epidermal debris (32).

2. Artificial soil and soil of actual wear

One investigator devised a method whereby a collar was designed to be worn under the regular shirt collar and thus he was able to study soiling of textile materials in contact with the skin (14). Koch (27) has suggested that samples be sewn onto slips where they would be given an average amount of wear. By far, the majority of work in this area has been done with the use of artificially prepared soil mixtures. Some of the methods and mixtures are described later.

Utermohlen and Ryan (49) stated that although the artificial soils were prepared to simulate the soil of actual wear, light natural soils were frequently easier to remove than were some heavy artificial soils, and full-scale tests may indicate that a certain detergent will remove these natural soils satisfactorily when it was not a preferred detergent on the basis of laboratory cleaning of artificially soiled cloth. Nevertheless, there were certain advantages. The artificial soil could be standardized and applied under controlled conditions. It was often more reproducible than the soil of actual wear, as well as being a relatively quick method of soiling.

The apparent visual degree of soiling produced by a given soil content was influenced by the opitcal properties of the fibers themselves, that is by the S or scattering coefficient, according to Weatherburn and Bayley (52). In general, other things being equal, the higher the scattering coefficient of the fiber, the lower would be its apparent soilability as judged visually. The scattering coefficient of synthetic fibers could be controlled to some extent by addition of a delustering pigment, such as titanium dioxide.

3. <u>Soil retention of fiber types</u>

According to Kaswell (25), any soil which was deposited on hydrophobic fibers, which did not swell in water or dye, must have remained on the surface. Because of this, hydrophobic fibers may resist soiling more than hydrophilic. Because of the tendency towards surface soiling, it was logical to suppose that surface soiling would therefore be more obvious to the eye. On the other hand, hydrophobics probably resisted soiling so that under equivalent exposure conditions, the total amount of soil accumulated would be less. Which effect predominated and whether the synthetic hydrophobics actually soiled more or less than the hydrophilics, was a subject which needed more study.

Frishman, et. al. (14) have suggested that oily soils actually "dissolve" within the fiber much as a disperse dye does in acetate. According to their study, this was found to be the case; some of the oily soil did penetrate the hydrophobic fibers and was therefore not easily removed in an aqueous medium.

4. Mechanisms of soil impingement

According to Kaswell (25), the mechanisms whereby particles suspended in air impinged on the fibrous structure were as follows:

1. *direct interception of a particle in an airstream by a fiber,*
2. *inertial effect whereby air flowing through the structure contained large particles (1-2 microns) which had sufficient inertia to leave the stream lines bending around a fiber and making contact with it (in-*

creasing the velocity favored this mechanism of filtration),

3. kinetic diffusion was very effective for particles under 0.1 micron. These particles exhibited Brownian movement which increased the probability of impingement on fibers. Filtration was favored by low velocity.

Dirt particles then, may be brought into contact with fibers by diffusion or deposition from quiet or slowly moving air, by interception or inertial effects from more rapidly moving air, by direct transfer from another surface, or by electrostatic attraction. Having been brought in contact, the particles may adhere to the fibers by mechanical forces or occlusion in pits and crevices of fiber surfaces, by "oil" bonding and possibly electrical forces.

Soil pick up was a function of particle size, distribution of the pigment and the distribution and availability of roughness sites on the fabric for entrapment of pigment, according to Reich, et. al. (39). The mechanisms of impingement and of retention were separate factors in soiling, independent of one another, with the possible exception of electrostatic forces which could both attract and hold particles (25). Retention was a function of the fibers; impingement a function of the service or test condition. The degree of soiling was a result of both functions.

a. Particle size

Apparent soiling or "dirtiness" depended not only on the weight of soil retained, but also on the specific absorbance of the soil, according to Weatherburn and Bayley (52). The latter, in turn, depended on the particle size distribution and also in the case of a heterogenous soil, on the distribution of particle types. It cannot be assumed that each fiber will retain the various components of the soil in the same proportions. It was also probable that small particles were more readily retained by the fiber than were larger particles.

According to Kaswell (25), Masland estimated retained particles to be in the range of 0.2-4.0 microns. Compton and Hart (9) found that the smaller particle size had the greatest darkening power and was the most difficult to remove in detergency.

b. Electrostatic forces

Rees (38) experimented and found there was an electrostatic attraction on soil. On the other hand, Schappel (41) found no correlation between soiling characteristics and electrostatic properties in carpets made from various fibers and fiber blends. The New York Section of the American Association of Textile Chemists and Colorists (35) stated that electrostatic effects were not so important as may have heretofore been believed, and that a simple synthetic soil, rather than a complex composition could equally well be used to evaluate soiling properties. Some conclusions which Kaswell (25) had drawn are as follows: Most soil particles were uncharged and were not drawn to fabrics by virtue of their own electrostatic conditions. Frictional forces and other naturally occurring conditions could probably induce static charges of short duration on many soil particles. If these particles came close to a textile before charges were dissipated, they may be drawn into direct contact where mechanical forces and oil bonding could come into play. Uncharged soil particles may be strongly attracted to fabrics which have become charged, for example, nylon in processing.

5. Factors influencing degree of soiling

Various factors influenced the degree of soiling and the resistance to the removal of soil. For example, open weaves permitted dirt to penetrate, which hindered cleaning; close even surfaces with a tight layer of starch were resistant to contamination (35). Reich, et. al. (39) warned that care must be taken when clothes were soiled by the deposition from solvent, as accretion of soil may occur largely by growth of flocs rather than by uniform distribution of fresh soil particles.

Weatherburn and Bayley (52) found that the amount of soil retained by the fibers increased with increasing time of contact with the soil. It was probable that nylon contained fewer surface irregularities than other fibers studied in the previously mentioned piece of research, and once these soil-holding sites had become occupied, further time of contact with soil resulted in only a small increase in soil retention.

a. Moisture content

In this study by Weatherburn and Bayley (52), all yarns showed increasing soil retention with decreasing moisture content. Moisture present in very damp cloth resisted displacement by the soil-dispersing liquid. It was possible that the film of moisture on fibers conditioned at high relative humidities may tend to repel the hydrophobic soil particles, with a resulting decrease in soil retention. Textiles which were processed in dry conditions often built up static charges resulting in excessive soiling and many other processing difficulties. Nylon was particularly susceptible to this effect due to its low moisture absorption and low electrostatic conductivity. To what extent the influence of moisture content on soil retention could be attributed to an electrostatic effect was not known. Bacon (3) suggested that the soiled material should be prepared on days when the relative humidity was below 50%. Material prepared on a rainy or humid day would not give significant brightness when scoured.

b. Storage

If cloth was to be stored after soiling and before washing, it should be kept in a dry atmosphere (47). If oil-pigment soil was to be used, Utermohlen and Wallace suggested that the oil should not be mineral oil alone, despite its constant aging behavior, as resulting pigment dispersion would floculate and soil cloth unevenly. Neither should an oil with linoleic or other acid groups with multiple unsaturation be used, because of the polymerizing oxidation which such groups undergo, causing pigment soil to be held to the fabric. The preferred oil mixture was a mixture of mineral oil and a non-oxidizing vegetable oil of relatively low degree of unsaturation, for example, coconut oil and Snowdrift. This general soil was recognized as being useful because it simulated the type of oily soil acquired by textile fabrics and by clothing in normal use. Should the soiling mixtures be made with more unsaturated oils, they would display strong tendencies to bind the pigment soil to the cloth. According to Bacon (3), if the soil mixture was to be kept, it should not be exposed to the atmosphere more than a week, especially in humid weather.

Weatherburn and Bayley (52) found that the oil content of the soil had little, if any, influence on soil retention of acetate and nylon yarns. This was surprising in view of the known effect of oil bonding on soil retention. It might be expected that the effect of oil bonding would be similar whether the oil was initially on fiber or in the soil.

c. Other factors

Weatherburn and Bayley (53) suggested that the chemical type of the fiber may have a greater influence on soil retention than has the physical shape of the filament.

Irregular cross-section of fibers provided a greater surface area for a given weight of fiber and so had a greater area to take on soil (53). However, as long as the cross-section of the fiber was smooth and approximately circular, the soil retention per gram of fiber was proportional to the total surface area, according to Masland (33). In order to avoid excessive dirt retention, a synthetic fiber should be of sufficient size, regardless of cross-sectional contour, and of smooth, round cross-sectional outline, since two prime factors in soil retention of a fiber are the fiber diameter and cross-sectional outline or contour. These two factors are mutually dependent, if either was improperly chosen, high soil retention would result.

Masland (33) stated that the length of the fiber was not a factor in soil retention; therefore, low soil retention may be obtained in staple fiber and continuous filament.

He also suggested that with oriented dirt particles along a channel in a translucent fiber, it was possible an optical action occurred, somewhat like that of the red line on the back of a thermometer tube. The translucent fiber would then seem to magnify the dark line of the oriented dirt particles (33).

Weatherburn and Bayley (52) felt there was a possibility that percussion with steel balls during soiling might result in some abrasion of fiber surface, with a resulting increase in the number of soil holding sites, therefore a fiber which was easily abraded may soil more readily. The extent to which such mild abrasion affected the soil retention of fibers was not known.

In another study, Weatherburn and Bayley (54) found that as the amount of twist in yarn increased from zero twist, the soil retention increased rapidly at low values of twist due to entrapment throughout the whole interior of the yarn. With further increase in twist, the soil retention reached a maximum and then gradually decreased as the interior of the yarn became inaccessible to the soil particles, and soil holding sites became limited to those located on the external surface of the yarn.

Kaswell (25) pointed out that a fabric which was loosely woven from coarse threads should be more easily penetrated by solid soil than finely woven fabrics. However, it was easier to remove soil from a loosely-woven fabric than a tightly-woven one.

6. Methods for soiling fabrics

The following are three laboratory methods for soiling fabrics which the American Association of Textile Chemists and Colorists have set up (35):

1. Blower test.-Air permeable fabrics are exposed to impingement of suspended particles, chiefly by direct interception, and inertial effects. Air is drawn through test fabrics until they soil to a degree which permits observation of soiling visually or by instruments.
2. Tumbler test.-Soil impingement occurs principally by deposition and direct transfer. Test samples are tumbled in a Launder-Ometer jar with soil and steel balls.
3. Floor soiling.-Direct transfer and deposition--for floor coverings. Here the samples are inserted into

a small rug and exposed to foot traffic until soiled when observed visually or by instrument.

The Tumbler test was less sensitive to differences in fabric construction than the Blower test (35). It was therefore useful in evaluating soiling tendencies of fiber types. The Tumbler test had the advantage of the greatest potential reproducibility among the three test methods, since test conditions as well as test procedure could be standardized. However, the mechanisms of soiling are not yet sufficiently well established in all their details to permit preference of a single test method.

Modifications of methods have been used. Weatherburn and Bayley (52) have used a chopped-fiber technique in order to obtain a more uniform distribution of soil. Wagg and Britt (51) in their investigation into detergency have used radioactive isotopes and the chopped-fiber technique.

Some studies have used vacuum cleaner sweepings as the soil mixture. According to Masland (33), vacuum cleaner dirt is fairly constant across the country.

Utermohlen and Wallace (45) stated that a more uniform soiling was obtained by use of a volatile, inert, water-insoluble solvent, such as carbon tetrachloride, ether, Stoddard Solvent, etc., than by use of water. This was particularly true if mixed oil and pigment soil were to be applied; with dry soil, no dispersing medium would be required.

On the following page will be found a chart compiled by Brown (6) on selected soiling mixtures.

CHART 1.-Selected references to soiling mixtures

Worker	Reference	Soil Used
Schiewe, S., and Stiepel, C.	Seifenfabrikant 36 (1916) 737 (through Chem. Abstr. 11, (1917) 1551)	mineral oil and wood charcoal, or a mixture fatty acids, fatty oil and wood charcoal
Brauner, K.	Chem. Ztg. 47 (1923) 551 (through Chem. Abstr. 17 (1923) 2967)	various oils with cocoa, coffee, wine, milk, blood, rust and ink
Bergell, C.	Seifen Ztg. 51 (1924) 627	wood, charcoal and fat
Hoyt, L. F.	Oil Fat Indust. 3 (1926) 156	lubricating oil, tallow and lampblack
Hoyt, L. F.	Ibid. 4 (1927) 29	lubricating oil, tallow and lampblack
Hill, E. A.	J. Agric. Res. 39 (1929) 539	Oildag, olive oil, tallow, and mineral oil
Rhodes, F. H., and Brainard, S. W.	Industr. Eng. Chem. 21 (1929) 60	lampblack, lubricating oil and tallow
Morgan, O. M.	Canad. J. Res. 6 (1932) 292	tallow, Nujol, and lampblack
Snell, F. D.	Ind. Eng. Chem. 25 (1933) 1240	carbon black, cottonseed oil and mineral oil
Gehm, G.	Seifen Ztg. 68 (1941) 159	oil, lanolin, egg yolk, egg albumin, milk, cocoa soot, starch and sugar
Vaughn, T. H., Vittone, A., and Bacon, L. R.	Ind. Eng. Chem. 33 (1941) 1011	Norit C., No. 30 lubricating oil and "Crisco"

CHART 1.-Continued.

Worker	Reference	Soil Used
Crowe, J. B.	Am. Dye. Reptr. 32 (1943) 237	cotton.-Oildag and Wesson oil wool.-lampblack, edible tallow and Nujol
Holland, V. B., and Petrea, A.	Am. Dye. Reptr. 32 (1943) 534	Norit C, "Vaseline", paraffin wax, stearic acid and oleic acid
Van Zile, B. S.	Oil and Soap 20 (1943) 55	carbon black, mineral oil and vegetable oil

Different research workers have used different methods for soiling fibers and various sets of conditions. A few of these are mentioned as follows:

Holland and Petrea (23) used 100 grams of soil mixture, ten ½-inch steel balls, and rotated the jars for 60 minutes in the Launder-Ometer.

In another study five grams of dry soil and fifty ¼-inch steel balls were rotated 15 minutes. Specimens were then transferred to a dusting cage and rotated another 15 minutes (35).

Utermohlen and Wallace (45) placed the dispersion in a Nussbaum photographic tray. The fabric strip was then passed through the dispersion and through hand-driven wringer rolls.

Another worker used cotton soiled samples which were added to the different washes (27).

The following is a soil composition listed by Jackson (24): 89.0% Stoddard Solvent, 2.5% each of Vaseline, paraffin, stearic and oleic acids, and 1.0% Norit C. Many other soil compositions may be found in the literature, all somewhat similar.

C. Laundering

"A good home laundering detergent is a substance which is capable of removing many types of soil from fabrics of highly varied fiber content, and which can then hold the removed soil in emulsion or suspension in the washing water during the remainder of the laundry time (18)." According to Utermohlen and Ryan (49), the two main objectives of detergency are to obtain a satisfactory quality of cleaning, and to achieve this quality at a minimum cost. Holland and Petrea (23) suggest that the purpose of a detergent may be divided into two parts: first, in the textile industry for the removal of oil or fatty matter from a yarn or fabric, or more specifically, a fiber; secondly, in laundry processes for the removal of a general class of substances that may be classified as "dirt". The dirt is usually bound to the fabric by means of oil or some fatty matter, which reverts the purpose of the detergent back to its principal objective of removing oil.

According to Robinson (40), the initial stage of detergent action was the displacement of the oil on the fiber by the detergent solution. Hartley (21) stated that the solutions of soaps, and of the newer synthetic detergents had a solvent action on organic substances which was quite distinct from the emulsifying action which they may also possess. It was further suggested that this solvent action may have a direct function in detergency, namely the solution of part of the oily matter of "dirt" by the soap or synthetic detergent solutions. The efficiency of any one detergent would depend upon its chemical composition, concentration, the temperature of the washing solution, and nature of the mechanical treatment applied (30). Considering the many variables involved, the mechanism of detergent action is a complex one.

1. Soaps and synthetic detergents

The sharp rise in the use of synthetic detergents has been due to improving the level of performance and the relatively favorable cost, according to Utermohlen and Ryan (49). Also, Galbraith (18) stated, that because soaps do form precipitates and lose cleaning efficiency in hard water, the synthetic detergents have recently claimed a major portion of the home laundry market. We have now more than 4,000 commercial brands of synthetic detergents on the market (5).

According to Crowe (10), soap products are used either as neutral soap or built with alkali, whereas synthetic detergents can be used in almost any degree of alkalinity or acidity, with or without neutral salts, or with various organic agents. This complicates the problem for a detergent may appear good when used in an alkaline solution, but be poor in an acid one. In contrast, another synthetic detergent may show the opposite behavior.

Galbraith (18) found soaps to be superior to synthetic detergents in the prevention of graying, for all fabrics except cotton. This was seen most of all with wool, Dacron and nylon. Heavy-duty soaps and synthetic detergents were found superior to the light-duty ones.

Jackson (24) found soaps to be more effective than synthetic detergents in the removal of artificial soil from Dacron-and-cotton, and similar all-cotton fabrics. Keeney, et. al. (26) also found soaps to be more effective than synthetic detergents in their work.

Lund (31) found that in softened water and in tap water of 30 grains of hardness, the soap was more effective, but at higher levels of hardness the synthetic detergent was more effective.

It is interesting to note that the differences in detergency effectiveness differ from advertising claims, for although the synthetic detergents are rapidly replacing soaps in consumer usage, the soaps still appear to be more effective in the removal of soil (26).

2. Additives

According to Hemmendinger and Lambert (22), "it is essential in the search for the best detergents to first evaluate them in the absence of any additives and to employ bleaches, blueing, or fluorescent dyes only to minimize their limitations." Frishman, et. al. (14) gave a formula for the preparation of a synthetic detergent to avoid use of an optical brightener or other additives.

Legg (30) found the presence of a builder in the detergent was a definite aid in removing soil from wool and spun nylon fabric. When the water contained 300 ppm. of calcium and magnesium ions, the efficiency of the built detergents in removing soil from the spun nylon was reduced so that it was below or just equal to that of the unbuilt detergents. Galbraith (18) found the built detergent to be definitely superior to the unbuilt. However, according to Keeney, et. al. (26), it seemed to make little difference whether the synthetic detergent or soap used was considered light or heavy-duty. Also, the addition of brighteners or builders had little effect on whiteness of either cotton or the cotton-Dacron blend.

Hermmendinger and Lambert (22) found that the use of blueing in the wash counteracted the initial yellowness, therefore increasing the subjective impression of whiteness though the reflectance was simultaneously reduced.

There was disagreement in the literature over the part fluorescent whiteners play in the retention of whiteness. Furry, et. al. (16) concluded that fluorescent whiteners contribute to whiteness of cotton. However, in another study by Keeney, et. al. (26), it was concluded that additives such as builders or brighteners had little effect on either whiteness retention or the removal of soil from all-cotton and cotton-and-Dacron fabrics.

3. Other factors influencing detergency

a. Time

There was a limit to the amount of soil which a given detergent solution may remove and retain under specified conditions, according to Vaughn, Vittone, and Bacon (50). If the wash time was short there would be less tendency for the redeposition of the soil concentration in suspension. Frishman et. al. (14) found that the greatest amount of soil was removed during the first minute of the wash cycle, and after four minutes the rate of removal became very small.

b. Mechanical action

Experimental work applying standard washing procedures has shown that mechanical action alone frequently did a third to a half the scouring (11). Twenty-two per cent of dirt could be removed by water alone, 31% could be removed with water and alkali, 10% with a neutral soap, and 50% removed with a soap and alkaline builder (43).

According to Crowe (10), the type of agitation and mechanical action greatly affected the relative detergency of cleaning agents. Bacon (3) suggested a speed of 60 rpm. instead of the customary 42 rpm., and stated that the Launder-Ometer may not give perfect duplication of mechanical action of washing machines, but checks were close enough to warrant its use to obtain a large number of test results in a short time.

c. Rinses

Koch (27) found that the amount of yellowing was greater for samples given only one rinse than those given two rinses. The lengths and number of rinses varied in different investigations. To mention only one, Boalch (5) used two 2-minute rinses in the Launder-Ometer, using a 300 ml. volume of water in each jar and keeping the temperature the same as that used in the wash cycle.

d. Detergent concentrations

Vaughn, Vittone, and Bacon (50) stated that a soap concentration of 0.10% is representative of usual commercial laundry practice. Legg (30) suggested a 0.30% optimum concentration in distilled water and 0.45% in hard water, for fabrics including nylon.

e. Water hardness

It is interesting to note, that according to Legg (30), built detergents lost a little more of their effectiveness in hard water than did the unbuilt detergents.

Furry et. al. (17) found that soaps removed considerably more soil at 120°F. in both distilled and hard water than at 84°F., and in hard water the synthetic detergents in a majority of cases were more effective than the soaps, especially at concentrations lower than 0.35%.

When white nylon is washed in hard water, a soap which softens the water should be used to prevent the deposit of curds of insoluble soap on fabrics which give white garments a grey cast, resulting from soil redeposition (37). Tests have shown that many detergents have poor soil suspending characteristics and permit retention of soil over a period of washings.

It has been found that for cotton the soil removal increased up to 140°F. (55, 2). With nylon, according to Galbraith (18), the soil removal was less dependent on temperature, especially in distilled water. In hard water, 100°F. was as effective as 120°F. or 140°F. In soft water, 70°F. increased to 100°F. removed slightly more soil. Davidson (11), in her study on nylon slips used a water temperature of 110°F., ± 5°F.

The exact combination of time, temperature, soap concentration and other conditions of test, have varied considerably in different investigations. A few are mentioned as follows:

A 10-minute wash, at 140°F. for cotton and 110°F. for wool, at a water hardness of 50 and 300 ppm., and at various concentrations of detergent was used by Crowe (10).

Utermohlen and Wallace (46) also used a 10-minute wash, at 120°F. (for cotton), a 0.25% concentration of Ivory Snow soap, and forty ¼-inch steel balls per jar.

Furry et. al. (15) used a 15-minute cycle, at 140°F. (for cotton), in distilled water, and with a detergent concentration of 0.10%.

A 20-minute wash, at 120°F. (six fabrics used including nylon), in distilled water at 300 ppm., and at varying detergent concentrations, was used by Legg (30) in the first part of her study.

Keeney et. al. (26) used a 30-minute wash at 105°F. (for all-cotton and Dacron-and-cotton fabrics). Morris et. al. (34) also used the 30-minute wash, plus a 0.50% neutral chip soap solution, and distilled water at 100°F. (for wool).

D. Reflectance

The most common measurement used in these investigations is reflectance. It is popular because the pigments found in many natural and almost all synthetic soils are carbonaceous and black, and thus are most practically estimated by optical measurements, according to Utermohlen and Ryan (49).

There are two methods to measure soil removal without reflectance (49). One is to measure light absorption of the detergent solution before and after washing, the other is to use a black iron oxide pigment in place of carbon black for the soiling agent, and determine the pigment of washed and unwashed samples of cloth by analysis. However, neither of these methods are as convenient to use or as generally accepted as reflectance.

1. Limitations of photometric procedure

The errors in the usual photometric procedure cannot be overlooked. Three were mentioned by Utermohlen and Ryan (49):

1. It is necessary to sort the test pieces before washing so all pieces in any one test have the same average initial reflectance, because differences in initial reflectance are partially carried over after washing.

2. With the Launder-Ometer, measurements must be made on a sufficient number of test pieces, drawn from several test jars, to reduce possible error due to uneven mechanical action.
3. Reflectance must be measured on a stack of test pieces thick enough to eliminate effect of extraneous background.

The number of samples which have been used in this stack has varied with different investigators. Four were used by Morris et. al. (34) in their study on wool, and also by Furry, Bensing and Kirkley (15) in their study on cotton. Eight thicknesses were used in two other studies on cotton (45, 46). No mention was found in the literature reviewed, on the number in the stack when nylon specimens were read.

2. Additives

According to Glarum (19), fluorescent dyes converted invisible ultraviolet rays into visible light causing the fabric to appear whiter. Because this affects the reflectance readings, specimens which have been washed with detergents containing these brighteners should be read with Nuviol Shade A filters. In this way the reflectometer could be modified to include or exclude ultraviolet from the light source (15). With these ultraviolet-absorbing filters in the incident beams of light, no ultraviolet light could reach the fabric, and therefore only nonfluorescent color would be measured.

3. Deviation from whiteness

The color of nearly-white samples may deviate from whiteness in two ways (22):

1. Grayish: specimens reflect the same fraction of the incident light at all wave lengths, and color properties are fully described by reflectance alone.
2. Chromatic: green, amber, and blue reflectance readings are necessary to measure color change. According to Frishman et. al. (14), soiling frequently involved this change of hue as well as reduction in reflection. This has been found to be especially true of fabrics which have been soiled by the skin.

There are a number of ways in which detergents may exert a selective influence on the removal or deposition of colored materials. According to Hemmendinger and Lambert (22), if any of the following existed, it would be helpful to determine chromatic characteristics:

1. Detergents may differ in their ability to remove the yellowing ingredients of common soils.
2. Detergents may differ in tendency to permit the gradual build-up of colored impurities present in the wash or rinse waters.
3. Detergents may differ with respect to the intrinsic yellowing tendencies of any detergent remaining on the cloth.

a. Use of blue filter

Blue reflectance was a practical simplified measure of whiteness, according to Furry et. al. (15). It combined in one figure, departures from ideal whiteness toward both grayness and yellow-blueness. Carbon black was usually the solid or predominant component in soiling mixtures, and because it was a neutral soiling agent, and therefore imparted no chromaticity, the blue reflectance readings were usually sufficient, stated Hemmindinger and Lambert (22). Increasing grayness with added amounts of carbon black was not accompanied by any build-up of color. When natural soils were used, decided yellowness was seen; degradation of whiteness arising from chromaticity was about two times as great as that arising from grayness.

b. Other factors influencing reflectance

Frishman et. al. (14) found that reflectance decreased rapidly at first and then more slowly; the accumulation of soil was linear over the entire period of wear. It has also been found that if much of the soil in a piece of cloth lies on its surface, the reflectivity will be lower than if the same total amount of soil was present, but was largely within the cloth (46). The influence of the distribution of pigment in a piece of cloth was also felt in the ease with which the reflectance may be kept high and the cloth may be cleaned.

Lambert and Sanders (29) pointed out that reflectance did not bear a linear relationship to the weight of soil retained by the fibers, that is, the decrease in reflectance produced by the addition of soil to fiber depended not only on the amount of soil added, but also on the initial reflectance of the fibers prior to the addition. Furthermore, the decrease in reflectance measured an all over effect, some of which was due to the physical characteristics of fibers, some to the characteristics of the soil, and some to the interaction between soil and fiber, that is to weight and particle-size distribution of the soil retained by the fibers. Even though this assumption of a linear relationship between reflectivity and soil content was not valid, it has been of practical usefulness in comparing variables like temperature, concentration, and chemical nature of detergents when washing specimens with the same initial type and amount of soil (46, 49, 39). Kubelka and Munk (28) derived a complicated formula to show the relationship between actual soil content and reflectance. Bacon and Smith (4) used this same formula, and Reich et. al. (39) demonstrated its validity, especially for low values of soil content. They felt it was applicable, with reasonable accuracy to washing studies, and a generalized form of the equation employed with soiling studies. This formula and its variations could be used to a certain extent, but at present there is still no completely accepted reflectance measuring method of determining, even approximately, the true soil removal value of a washing treatment (49). Nevertheless, despite all these difficulties, the evaluation of a detergent process by reflectance measurements remains a great value in laboratory work when relative rather than absolute soil removal values are sought, and when surface cleanliness is the principal criterion of soil removal.

E. Microscopic Work

Microscopic work in the area of soiling and removal of soil was not extensive. Weatherburn and Bayley (54) have done work on the soiling characteristics of textile fibers, including microscopic examination of these fibers. Yarns were mounted in glycerine, which increased the transparency of the yarn so that the soil particles were more readily seen. Due to the fiber transparency, it was possible to focus the microscope on different planes of the yarn. Results of the microscopic examination were as follows: A tightly twisted yarn (60 twists per inch), appeared to be completely free from soil particles in the interior of the yarn, whereas, a loosely twisted yarn (20 twists per inch), had soil particles which were visible throughout the whole field because the soil had penetrated to the very center of the yarn. Soil which penetrated to the interior of a twisted yarn was protected from external influences and was therefore not readily removed; with a loose twist however, the soil penetrated the yarn but was also easily removed. The examination was done with an electron microscope.

Reich et. al. (39) found that the average particle size of carbon on more heavily soiled cloth was greater than for lightly soiled cloth. This would then seem to confirm the theory that there was an agglomeration of carbon at high soil intensities. This observation was made at 100 magnifications.

CHAPTER III

METHOD OF PROCEDURE

A. Organization of the Study

1. Selection of fabrics

Three types of white nylon double-bar tricot panties were purchased for this study. One type was manufactured from regular filament nylon yarn, one from crimped filament (Textralized[1]) yarn, and one from a false-twist filament (Saaba) yarn. All three types were purchased from the J. C. Penney Company, Incorporated. An attempt was made to have the three as comparable in fabric structure as possible.

Fabric I[2] was sold as made of 20-denier yarn, Fabric II was reported to be made of 70-denier yarn, and Fabric III was sold as made of 100-denier yarn.

Half a dozen units of Fabric I and Fabric II were purchased, at a unit price of $0.98 for the former, and $0.79 for the latter. Two-thirds of a dozen of the third fabric type were purchased, at a unit price of $0.98. The largest size available in each case was bought. All garments of each

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[1]See page 2.

[2]Regular filament nylon, Ban-Lon (fabric of Textralized yarn) and Saaba fabrics will be referred to as Fabric I, II and III throughout the remainder of this study.

yarn type came from the same lot. Fabric I garments had received a special treatment, whereby the diameters of the yarns had been flattened to give a whiter appearance. This treatment had not been given to either Fabric II or Fabric III.

2. Sampling procedure

Fourteen specimens, each measuring four inches by four inches, were cut from each garment made from Fabric I and from Fabric II. Ten specimens, each four inches by four inches, were cut from each garment made from Fabric III.

Specimens from each type of fabric were sorted randomly into four groups of twenty specimens each. One group of twenty specimens was for the soap treatment, one for the soap control, one for the synthetic detergent treatment, and one for the synthetic detergent control. The controls were laundered only, and not soiled.

3. Fabric analyses

Analyses of the original fabrics included: fiber content, filament denier, filament count, yarn denier, course and wale count, fabric thickness, weight per square yard, and moisture regain.

All tests were performed under standard conditions of temperature (70°F., ±2°), and relative humidity (65%, ±2%), in accordance with standard procedure and instruments of test of the American Society for Testing Materials (1), unless otherwise stated.

4. Soiling procedure

An artificial soiling mixture which approximated the soil of normal wear was formulated. Norit A, a neutral carbon was used as the pigment, olive oil, Nujol Mineral Oil, and Stoddard Solvent were used because of the ease of obtaining and handling.

In past studies the number of $\frac{1}{4}$-inch steel balls varied from 10 (35) to 50 (23). For this investigation, 15 per jar were chosen.

A series of preliminary tests were run and some of the main conclusions are noted here. Because Fabric II soiled very heavily, the time in the Launder-Ometer was reduced to five minutes, the number of specimens per jar increased from three to four, and the soiling mixture was diluted to one part soiling mixture and three parts Stoddard Solvent. (In each jar was placed 150 ml. of diluted soiling mixture.) With these proportions all three fabric types soiled to a degree which more nearly approximated the degree of soiling in normal wear. It should be noted here that enough carbon for the complete study was ground with a mortar and pestle to obtain finer particles. Compton and Hart (9) worked with soils of various particle size and concluded that the finer particles had the greatest darkening power and were the most difficult to remove in detergency.

The following ingredients and proportions made up the artificial soil:[1]

0.25 grams of ground Norit A
4.30 grams of Nujol Mineral Oil
3.00 grams of olive oil
1.00 liter of Stoddard Solvent

Into each pint jar was placed: 38 ml. of the above soil mixture (approximately 0.0095 grams of carbon, 0.1643 grams of Nujol, and 0.1140 grams of olive oil), 112 ml. of Stoddard Solvent, fifteen ¼-inch steel balls, and four fabric specimens. Before specimens were added the soiling mixture was stirred well with a stirring rod to prevent any carbon from settling in one place and thus causing uneven soiling of the specimens.

The jars were then covered and placed in an Atlas Launder-Ometer, Style B-1; the jars being positioned in such a way as to be balanced. Specimens were rotated for five minutes in the Launder-Ometer, at 42 rpm., and with no water placed in the Launder-Ometer.

After the soiling, the specimens were removed from the jars and dried between two screens which had been covered with cheesecloth. The screens were placed between two laboratory work tables and one fan was placed above, another below them, thus shortening the drying time to approximately half an hour.

5. Laundering procedure

The laundering was also done in an Atlas Launder-Ometer, Style B-1, which had space for 20 pint jars. The number of steel balls per jar was kept at 15.

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[1]This mixture was not kept longer than four days.

A 0.10% soap or synthetic detergent concentration is used by most commercial laundries (50), however, some workers have used from 0.10% (15, 50), to 0.25% (46, 49), to 0.50% (34). A recommendation was made by Galbraith (18) to use a 0.30% concentration in hard water. In the preliminary testing, several concentrations were tried, and it was concluded that the 0.35% concentration appeared to be most satisfactory.

Crowe (10) used a temperature of 110°F. for laundering wool in his study. In the case of nylon, soil removal is less dependent on temperature in hard water and therefore 100°F. is as effective as 120-140°F. according to Galbraith (18). A temperature of 110°F., ±2°F. was used in this study.

The length of the wash also varied quite considerably in various studies: (10 minutes (46), 15 minutes (15), 20 minutes (3), and 45 minutes (23).) Vaughn, Vittone, and Bacon (50) concluded that if the wash was of short duration, the tendency for the soil concentration in suspension to redeposit on the fabric would be less. Because of this and some preliminary testing which showed that the 15-minute wash was as effective, if not more so than the longer washes, the 15-minute wash cycle was used in this study.

In one of the preliminary tests, some specimens were given two rinses and others three to determine which was more effective. Weights of the specimens were recorded both before and after laundering and it was found that specimens rinsed two and three times were so similar in weight that the slight difference was considered negligible. Two rinses were therefore considered sufficient.

A light-duty soap[1] and a light-duty synthetic detergent, to which no optical whiteners had been added were chosen as the cleaning agents. Because of the tap water being hard (17.9 grains per gallon), a water conditioner[1] was added when soap was used in the wash and for both rinses. None was added when the synthetic detergent was used. (The cleaning efficiency of soap is reduced in hard water; part of it combines with the calcium and magnesium in the water causing a precipitate to form; this does not happen when a synthetic detergent is used.)

The original specimens were rotated 15 minutes in the Launder-Ometer in distilled water at 110°F., ±2°F., then reflectance readings taken. The samples were then ready to be soiled and laundered using the following procedure: fifteen ¼-inch steel balls, four specimens, 300 mls. of 0.35% soap or synthetic detergent solution at 110°F., ±2°F., and 1.13 grams of water conditioner[1] (if soap was being used), were placed in each jar and rotated in the Launder-Ometer for 15 minutes. The Launder-Ometer was half filled with water at 110°F., ±2°F.

Each jar was then opened, specimens and steel balls removed, the jar thoroughly rinsed (44), and specimens and steel balls replaced in jar. The jar was then filled with 300 ml. of rinse water at 110°F., ±2°F., and replaced in the Launder-Ometer for a 2-minute interval.

The above procedure was repeated for the second rinse, except the water temperature was reduced to 75°F., ±2°F. (A water conditioner was added to both soap rinses.) The

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[1]See Appendix p. 81 for brands used.

specimens were removed and dried between two screens as previously described. Drying time was approximately 45 minutes.

B. Specification Tests

1. Verification of fiber content

Fiber content was verified by burning, the Texchrome stain test, solubility tests and microscopic examination. For the solubility tests, the fibers were first tested with acetone at room temperature, then boiling glacial acetic acid (42). Fibers were next placed in 6 N HCl for 10 minutes at room temperature, and in dimethyl formamide for 60 minutes at room temperature (36).

2. Filament denier

To find the filament denier, the average yarn denier was divided by the average number of filaments per yarn and recorded.

3. Filament count

To determine the filament count, a yarn was unravelled from the fabric; a 3-inch piece of this yarn was cut and the filaments carefully separated. The average for five yarn counts for each fabric was calculated and recorded (42).

4. Yarn denier

The Universal Yarn Numbering Balance was used to determine the denier of the yarns. Yarn specimens, 90 centimeters in length were measured and cut; a total of ten for each fabric type. The averages of ten readings were calculated and recorded.

5. Course and wale count

The courses and wales in a 2-inch space, on at least five different places were counted, with the use of a Lowinson Micrometer. The fabric was placed on the laboratory table, without tension, while the count was being made. No two areas counted included the same set of courses and wales. The average of the five determinations was calculated and recorded.

6. Thickness

A Cenco Thickness Gauge was used to measure the thickness of the three fabrics. The fabrics were placed on the table without tension, and the foot of the thickness gauge was carefully lowered. After a 10-second interval, the reading was taken and recorded in thousandths of an inch. Five such readings were taken in such a manner as not to include the same courses and wales in any two readings. The average of each set of five readings was calculated.

7. Weight per square yard

Five, 2-inch squares were cut from each fabric type in such a way as not to include the same courses and wales in any two specimens. Each specimen was weighed and the weight per square yard calculated for each fabric according to the following formula:

$$\text{wt./sq. yd. in oz.} = \frac{\text{total wt. in gms. of 5 readings} \times 1296 \text{ in.}}{\text{total sq. inches} \times 28.35 \text{ gms.}}$$

8. Moisture regain

Three specimens, each four inches by four inches, weighing approximately one gram each were cut from each fabric in such a way as not to include the same courses and wales in any two specimens. Moisture regain was calculated according to the following formula: $R = \frac{A-B \times 100}{B}$ (R is percentage moisture regain, A is the weight of the weighing bottle subtracted from the weight of the conditioned specimen and bottle, B is the weight of the weighing bottle subtracted from the weight of the dry specimen and bottle.) The average of the three readings for each fabric was calculated and recorded as the percentage moisture regain.

C. Measurement of the Treatment Effects

1. Reflectance

A Gardner Tri-Stimulus Reflectometer was used to measure the percentage light reflectance of the original specimens and after the first, fifth, tenth, fifteenth, and twentieth soilings and launderings.

A 3-pound circular weight, with a 3-inch inside diameter was placed over the specimens to prevent light leakage at specimen edges when readings were taken.

As a result of preliminary testing, it was determined that a stack of twenty specimens was needed before readings could be taken. (If fewer specimens were used, the light would pass through them.) A specimen measuring four inches by four inches was used. All reflectance readings were taken at standard conditions with a constant light source consisting of a fluorescent bank behind, and not shining directly on the reflectometer.

The Student's t-test revealed no significant differences between readings taken on the right and wrong side, parallel to the courses and wales of the fabric. Because of this, only one side and direction of the fabric was read throughout this investigation; the right side facing up and courses parallel to the front edge of the reflectometer.

Only blue filter readings were taken, since chromaticity was not an objective of this study. Green and amber filters were only used to standardize the reflectometer. Two groups of readings were taken before the reflectometer was re-standardized with the porcelain plates. (This was decided on the basis of a preliminary test.)

Since the difference in readings between specimens which had been conditioned for one hour and the specimens which had been conditioned overnight was negligible, specimens were conditioned for one hour in this study. (They were spread out on paper towels in stacks of not more than three specimens for the conditioning.)

The following is a brief summary of the procedure used in taking reflectance readings: Samples were conditioned one hour before reflectance was taken. The instrument was standardized with the porcelain standard which most closely resembled the specimens to be read. A group of twenty specimens was placed over the light source, with a 3-pound weight holding them in place. The specimens were placed right side up with courses parallel to the front edge of the instrument. One reading per specimen was taken, and five consecutive specimens were read using the blue filter. Two groups of specimens were read before the instrument was checked for the correction figures, and then re-standardized.

The five readings obtained were averaged and the correction from the standard calculated by the use of the following formula: $C = A \times \frac{R_1}{R_2}$, where A is the average reading, R_1 the reading on the standard, and R_2 the reading on the reflectometer after the two groups of specimens were read.

2. Microscopic procedure

The original specimens were examined under the microscope; yarns were also unravelled and examined.

After the first, fifth, tenth, fifteenth, and twentieth soilings and launderings further microscopic examinations were made.

Photomicrographs were taken of the original fabrics and after the twentieth soiling. For this four small specimens, each one-half inch by two inches were removed per group of specimens. Not more than one small section was removed per specimen, and this was done along one outside edge.

3. Statistical analysis

An analysis of variance was done on the data collected from the reflectance readings. Differences between means which met or exceeded the 95% level of confidence were reported as significant.

CHAPTER IV

DISCUSSION OF RESULTS

A. Specification Tests

The three fabrics were analyzed to determine fiber content and denier; filament count, yarn denier and twist; course and wale count, thickness, weight per square yard, and moisture regain.

1. <u>Fiber analyses</u>

a. Fiber content

Microscopic, burning, stain, and solubility tests were used to analyze fiber content.

The three fabrics were found to be of 100% delustered nylon.

b. Filament denier

The filament deniers of Fabric II and Fabric III were quite similar. Fabric II was made of 2.18 and Fabric III of 2.13-denier filaments (see Table 1, p.47). No value was found for Fabric I due to difficulty encountered in unravelling the fabric before yarn denier could be calculated.

Filament deniers calculated on the yarn deniers as purchased were as follows: Fabric I, 2.86, Fabric II, 2.06, and Fabric III, 1.47-denier filaments.

TABLE 1.-Specification tests on the three nylon tricot fabrics

Tests	Fabric I	Fabric II	Fabric III
Fiber analyses			
Fiber content	100% nylon	100% nylon	100% nylon
Filament denier	.....	2.18	2.13
Filament denier (as purchased)	2.86	2.06	1.47
Yarn structure			
Filament count per yarn	7	34	68
Yarn denier	.....[a]	74	145[a]
Yarn denier (as purchased)	20	70	100
Twist[a]	low	low	low
Fabric structure			
Course and wale count per inch	courses 70 wales 57	courses 48 wales 47	courses 43 wales 33
Thickness in inches	0.0066	0.0148	0.0216
Wt./sq. yd. in ounces	1.95	2.74	4.02
Percentage moisture regain	3.53	3.81	3.53

[a]Impossible to calculate accurately

2. Yarn structure

a. Filament count

Fabric I was found to have 7 filaments per yarn, Fabric II, 34, and Fabric III, 68.

b. Yarn denier

The yarn denier of Fabric II was 74, and Fabric III, 145. No value could be found for Fabric I, however, it was purchased as a 20-denier yarn.

Only a slight difference between what the denier of Fabric II was reported to be, and what it was found to be was seen. Fabric II, reported as being a 70-denier yarn, was found to be a 74-denier yarn. This was within the American Standards for Testing Materials variation tolerance for nylon filament yarns. Fabric III however, was reported to be a 2-ply yarn of two 50-denier plies, but was found to be a 145-denier yarn. According to a representative of the J. C. Penney Company Testing Laboratory, an error of 45 points in computing denier measured on yarn ravelled from a knit garment is not unlikely.

c. Yarn twist

The twist was very low in all yarns, and was removed by the time a yarn was unravelled from the fabric. It was therefore impossible to determine the twist and direction of twist accurately.

3. Fabric structure

Fabric I had received a special treatment whereby the diameters of the yarns had been flattened to give the fabric a whiter appearance. This had not been done to either of the other two fabrics.

Fabric III (Saaba) and Fabric II (Ban-Lon) were made of regular nylon yarns to which a special texturing process had been applied (7).

Ban-Lon fabric is made from Textralized yarn. In making Textralized yarn, filaments are fed into a stuffer-box at a faster rate than they emerge, causing them to crimp. The resulting yarn has a wavy irregular zig-zag crimp, which is produced by heat setting while the yarn is in the stuffer-box. The filaments are flattened somewhat in the area of the bends, making them irregularly shaped.

The Saaba yarn is a modified stretch yarn. In processing, a false-twist type stretch yarn is modified to remove some of the stretch, yet retain maximum bulk. The Saaba process thus produces a false-twist, torque-type, modified stretch yarn.

The three fabrics were found to be of double-bar tricot construction. Fabric I and Fabric II were knit with single-ply nylon yarns. Fabric III was purchased as made of 2-ply yarn. Low twist made it difficult to recognize the yarns had been plied because there was no distinct physical separation of the plies once the yarn had gone through the knitting machine.

a. Course and wale count

Fabric I had a count of 70 courses and 57 wales per inch. Fabric II had a count of 48 courses and 47 wales, and Fabric III had a count of 43 courses and 35 wales per inch (see Table 1, p.47).

b. Thickness

Fabric I had a thickness of 0.0066 inches, Fabric II 0.0148 inches, and Fabric III 0.0216 inches. Because of the texturing processes and variations in denier, the yarns of the latter two fabrics had greater bulk than Fabric I, hence the variation in thickness.

c. Weight per square yard

The weight per square yard of fabrics in this study varied from approximately two to four ounces. Fabric I was 1.95 ounces, Fabric II was 2.74 ounces, and Fabric III was 4.02 ounces per square yard.

Weight per square yard figures were in keeping with results obtained in thickness and denier measurements. Because the denier of Fabric III was much higher than the other two, the weight per square yard of this fabric would be expected to be the greatest of the three, with Fabric II next and Fabric I being the lightest of the three fabrics.

d. Moisture regain

There was little variation among the three fabrics in percentage moisture regain. The differences noted in thickness, weight per square yard, yarn structure, and texturization seemed to have little effect. The range of thickness measurements was from 0.0066 to 0.0216 inches, and weight per square yard ranged from approximately two to four ounces. Fabric I had a 3.53% moisture regain, Fabric II 3.81%, and Fabric III 3.53%

Moisture regain is partly dependent upon the amount of surface area per yarn. Because Fabric III yarns had a much higher filament count than yarns of the other two fabrics, it had the greater surface area per yarn to take up moisture. However, Fabric I had the highest course and wale count, therefore the greater volume of yarn per unit area must compensate for the lower amount of surface area per yarn.

It was found, that an increase in percentage moisture regain was only seen in the case of Fabric II, and this was actually slight.

Because of compensating factors, the data do not indicate any relationships between texturing processes and moisture regain.

B. Analyses of Soiling Effects

Reflectance readings were taken on the specimens originally and after the first, fifth, tenth, fifteenth, and twentieth soilings. With an increase in fabric soiling a decrease in reflectance readings was noted.

An analysis of variance of the reflectance readings was carried out. Differences between means which met or exceeded the 95% level of confidence were reported as significant.

1. Differences among fabrics

Significant differences in reflectance between Fabric I and Fabric II were noted at all soiling intervals (see Table 4, p.56). However, the original reflectance readings were not found to be significantly different from one another, indicating that these fabrics took on soil at different rates. It was interesting to note that the largest significant difference was at the first soiling, indicating that considerable soil was taken on initially by Fabric II. After the first soiling, the significant difference decreased progressively at the fifth and tenth soilings, only to increase a small amount at the fifteenth and twentieth soilings. Soil taken on at succeeding soilings appeared to be less than that taken on initially.

Significant differences in reflectance were also found originally and at all soiling levels between Fabric II and Fabric III. Because there was a significant difference between the originals, soil take-up cannot be as easily examined as it was in the previous case, since original differences between fabrics are included in the figures. Fabric II, however, was found to decrease in reflectance a greater amount from the original readings than was Fabric III, at all soiling intervals. For the most part, Fabric II laundered with synthetic detergent had the lowest reflectance readings of the three fabrics studied.

Significant differences in reflectance were also found at all soiling intervals between Fabric I and Fabric III. The differences increased from the first to the twentieth soilings.

Comparatively little difference was found at the first and fifth soilings, with differences at the tenth, fifteenth, and twentieth soilings increasing to values more comparable to those for the other fabrics. There was considerable difference among the original reflectance readings, but this difference narrowed at the first soiling due to the large drop in reflectance of Fabric III at this particular interval (see Table 2, p. 54).

Soil take-up at the first soiling was extensive for Fabric II and Fabric III, and slightly less for Fabric I. However, as the soilings progressed, the rate of soil take-up increased for Fabric I. The rate of soil take-up of Fabric III varied little from the first soiling to the twentieth. Generally speaking, the greatest change in reflectance occurred at the first soiling for Fabric II and Fabric III. This is in agreement with the work of Frishman, et. al. (14), who stated that reflectance was found to decrease rapidly at first, then more gradually.

TABLE 2.--Actual change in reflectance readings from originals for three nylon tricot fabrics after the first, fifth, tenth, fifteenth, and twentieth **soilings** (reflectance readings recorded in per cent)

Soil Intervals	Fabric I		Fabric II		Fabric III	
	o - s	o - d	o - s	o - d	o - s	o - d
1	8.6	9.3	30.3	31.1	22.6	22.7
5	24.0	26.5	29.5	36.3	23.8	24.6
10	32.8	33.2	32.1	41.9	21.8	28.1
15	34.2	[illegible].3	37.7	43.9	22.8	25.8
20	36.0	44.3	41.7	51.0	21.0	27.8

TABLE 3.-Actual change in reflectance readings from originals for three nylon tricot fabrics after the first, fifth, tenth, fifteenth, and twentieth launderings (reflectance readings recorded in per cent)

Laundering Intervals	Fabric I				Fabric II				Fabric III			
	o-s	o-sc	o-d	o-dc	o-s	o-sc	o-d	o-dc	o-s	o-sc	o-d	o-dc
1	1.5	+0.5	2.7	+0.7	4.9	2.1	10.0	1.1	8.6	2.1	7.4	1.4
5	11.9	0.7	19.0	+0.5	10.6	3.2	23.2	3.5	16.[illegible]	6.3	13.5	3.9
10	19.6	0.8	21.6	.9	15.0	4.4	31.2	3.6	1[illegible].5	10.3	21.1	[illegible]
15	15.4	2.2	32.2	1.4	16.8	4.4	35.7	[illegible].4	1[illegible].7	9.5	21.2	10.0
20	27.3	1.7	35.2	1.3	20.7	4.4	38.0	[illegible].4	1[illegible].7	11.5	22.2	10.5

+ increase in reflectance

o-s original reflectance of specimens - reflectance of soap laundered specimens = change in reflectance

o-d original reflectance of specimens - reflectance of synthetic detergent laundered specimens = change in reflectance

o-sc original reflectance of specimens - reflectance of specimens laundered with soap, but not soiled = change in reflectance

o-dc original reflectance of specimens - reflectance of specimens laundered with synthetic detergent, but not soiled = change in reflectance

2. Differences between detergents

No significant differences were found between the soap and synthetic detergent at the first and fifth soilings. At the first soiling the mean square for the fabric types times detergents interaction was extremely small and at the fifth soiling and non-soiling interaction (see Table 5, p. 56). That is to say, that up to the fifth soiling the synthetic detergent differed little in soil removal efficiency or in effect on soil take-up from the soap.

Significant differences between soap and synthetic detergent occurred at the tenth, fifteenth, and twentieth soiling intervals. At these intervals there was a steady increase in the size of the significant differences. The specimens laundered with the soap were consistently higher in reflectance than those laundered with the synthetic detergent.

3. Differences between soiling and non-soiling

As would be expected, significant differences were found in all cases between the soiled specimens and those which were not soiled (controls). The significant differences increased in size from the first to the twentieth soiling, the differences being highly significant.

Considering the reflectance change from the originals, for the specimens which were laundered with soap, Fabric II lowered the greatest amount in reflectance at all soiling intervals except at the tenth soiling when Fabric I showed a greater change. Fabric I did not soil as heavily originally, but by

TABLE 4.-Grand summary of F-values from analysis of variance of reflectance data

Intervals	$B_{.05}\sqrt{A}$	$F_I - F_{II}$	$F_{II} - F_{III}$	$F_I - F_{III}$	$d_1 - d_2$	$s_1 - s_2$
Originals	.775	0.27	4.74*	5.01*	0.11	0.16
1-W	.842	3.49*	5.08*	1.59*	1.11*	4.59*
5-W	.727	2.05*	5.40*	3.35*	2.70*	12.71*
10-W	.790	0.77	4.28*	3.51*	4.82*	17.20*
15-W	.805	1.01*	6.45*	5.44*	6.37*	18.20*
20-W	.877	0.51	7.11*	6.60*	5.45*	20.72*
1-S	.961	10.60*	8.75*	1.85*	0.36	20.92*
5-S	.737	5.12*	6.85*	1.73*	0.30	25.64*
10-S	.885	2.29*	8.16*	5.87*	3.43*	28.03*
15-S	.883	3.81*	11.81*	8.00*	3.89*	30.32*
20-S	.915	4.56*	12.66*	8.10*	4.04*	31.34*

X _ significant differences at the 95% level of confidence

$B_{.05}\sqrt{A}$ _ least significant difference at the 95% level of confidence (see Appendix)

$d_1 - d_2$ _ soap and synthetic detergent

$s_1 - s_2$ _ soiled and non-soiled specimens

F_I _ Fabric I; F_{II} _ Fabric II; F_{III} _ Fabric III

S _ a soiling interval; W _ a laundering interval

TABLE 5.-Interaction mean squares for fabrics times detergents and fabrics times soiling and non-soiling after the first and fifth soilings and after the first, fifth, and fifteenth launderings

Soiling and Laundering Intervals	Fabrics x Detergents Interaction	Fabrics x Soiling and Non-Soiling Interaction
1 - S	.7084	634.4864
5 - S	40.4882	64.6832
1 - W	2.0935	1.8500
5 - W	56.5080	39.7000
15 - W	27.7162	347.1335

the twentieth soiling it had a large soil take-up. Fabric III soiled fairly heavily at the beginning but changed little thereafter (see Table 2, p. 54).

For specimens laundered with the synthetic detergent, Fabric II lowered the greatest amount in reflectance at all soiling intervals.

In summary, it is apparent that Fabric II took up the most soil both when laundered with the synthetic detergent and with the soap. Fabric I took on little soil at the first soiling, but increased in soil take-up thereafter. Fabric III soiled fairly heavily initially and changed in reflectance only approximately five per cent in the twenty soilings. The specimens laundered with the synthetic detergent took on more soil than those laundered with the soap. This was found to be consistent at all soiling intervals.

Significant differences in soil take-up were found at all soiling intervals among the three fabrics, the only exception being no significant difference between Fabric I and Fabric II originally.

No significant differences were found between the soap and synthetic detergent at the first and fifth soilings, however significant differences were found at the tenth, fifteenth, and twentieth soilings.

Soil take-up is a function of particle size, distribution of pigment, and distribution and availability of roughness sites on the fabric for entrapment of pigment (39). Weatherburn and Bayley (52) have stated that smaller particles were more readily retained by the fiber than were larger particles. Because the soil used in this study was fairly small in particle size, this may explain in part why the soil take-up was rather heavy.

These same workers have suggested that percussion with steel balls might result in some abrasion and thus cause more soil to be picked up. Fifteen, ¼-inch steel balls were used by the writer, a low number compared with some studies which have used as many as fifty (23).

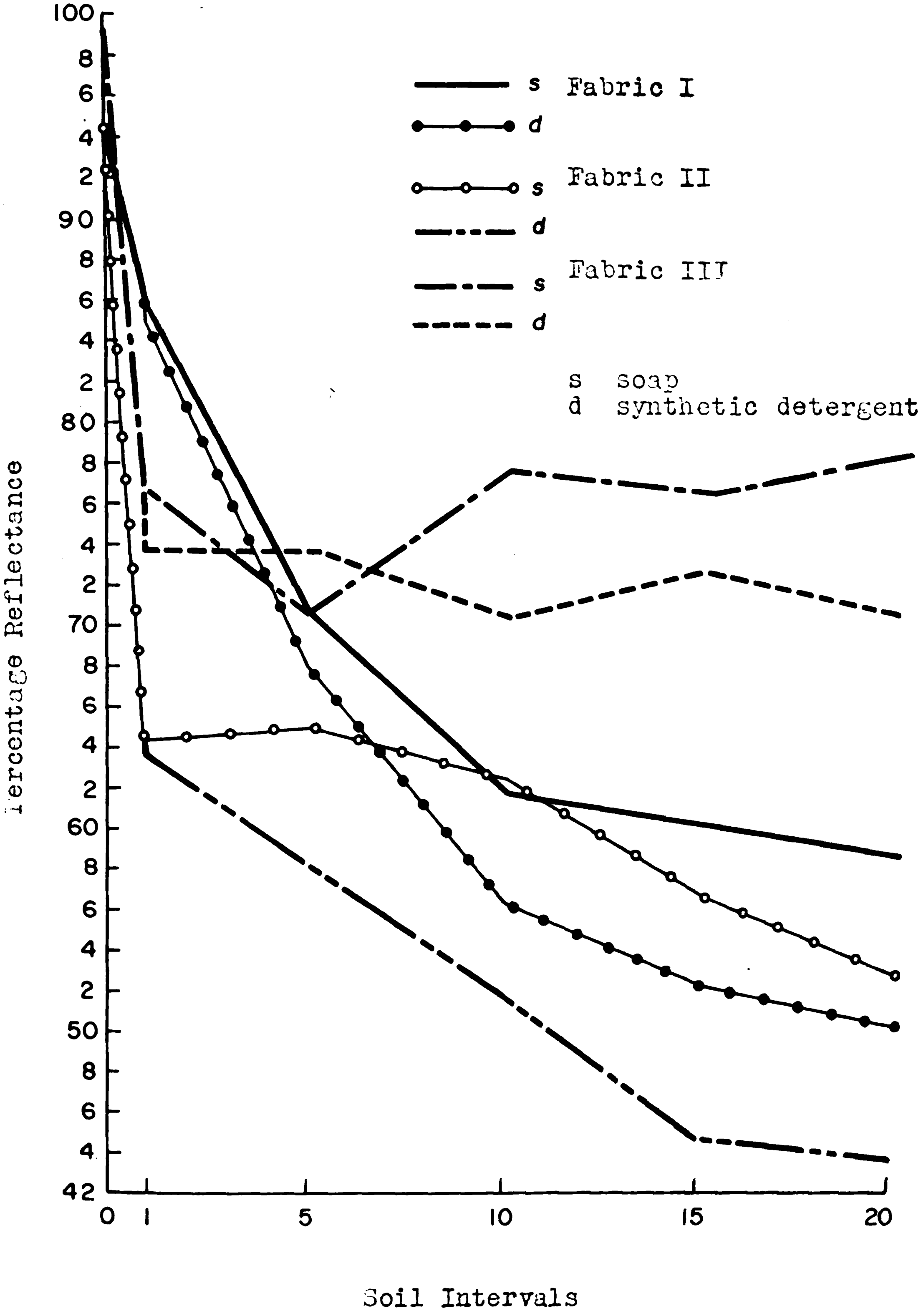
Weatherburn and Bayley (54) found that fairly high soil take-up occurred with low twists. The fabrics used in this study were all of low twist, so this might also be a partial explanation for instances of high soil take-up.

Other workers have found that soil is more easily removed from loosely woven fabrics. Fabric III had the lowest course and wale count and was found to retain the least amount of soil, whereas Fabric I had a very high course and wale count.

If much of the soil lies on the surface of the fabric, reflectivity will be lower than if the same amount of soil were present but largely within the cloth (46). It was evident upon microscopic observation that the carbon particles had penetrated to the center of the yarn in Fabric III. This was not as easy to detect for the other two fabrics.

A graph of the average reflectance readings taken at all soiling intervals will be found on the next page.

FIGURE 1.-Average reflectance readings for three nylon tricot fabrics originally and after the first, fifth, tenth, fifteenth and twentieth soilings



C. Analyses of Laundering Effects

Reflectance readings were taken on the specimens originally and after the first, fifth, tenth, fifteenth, and twentieth launderings.

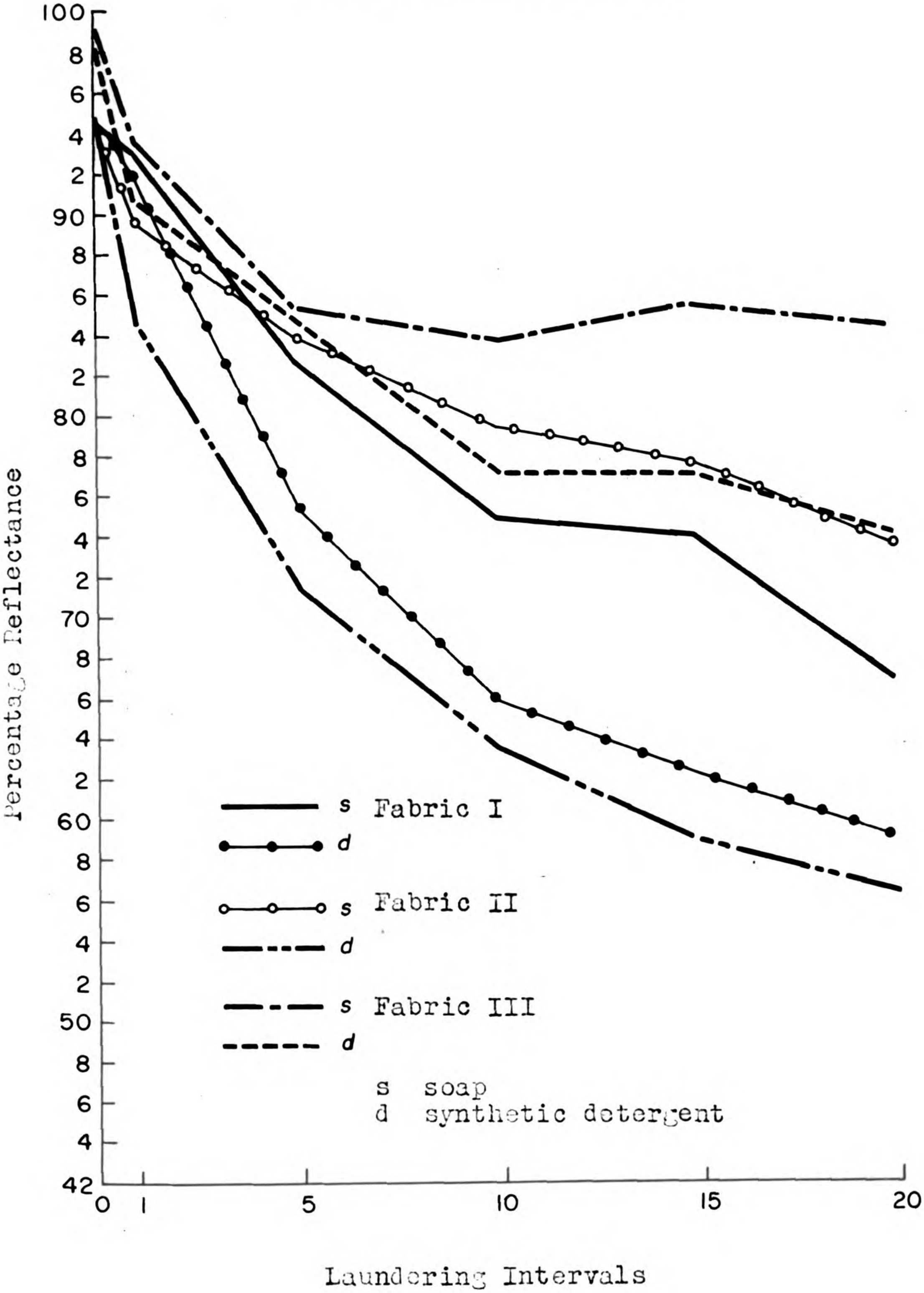
An analysis of variance of the reflectance readings was carried out. Differences between means which met or exceeded the 95% level of confidence were reported as significant.

Laundering procedures using soap cost approximately three times that of laundering the specimens with synthetic detergents. Since a non-precipitating water conditioner was used with the soap, it must be included with the soap when costs of the two launderings are compared. (The water conditioner cost slightly more than two times the cost of the soap).

1. Differences among fabrics

The changes in reflectance readings of the three fabrics subjected to a series of launderings followed similar patterns (see Figure 2, p. 61). Reflectance readings lowered quite sharply until the tenth laundering, then more gradually (see Figures 3, 4, 5, on pp. 63, 64). The reflectance readings of Fabric III laundered with soap were the exception, they tended to level off after the fifth laundering and changed only little thereafter. These patterns in reflectance readings for laundered specimens, generally speaking, were paralleled by the reflectance readings of the soiled specimens at the same intervals (see Figure 1, p. 59).

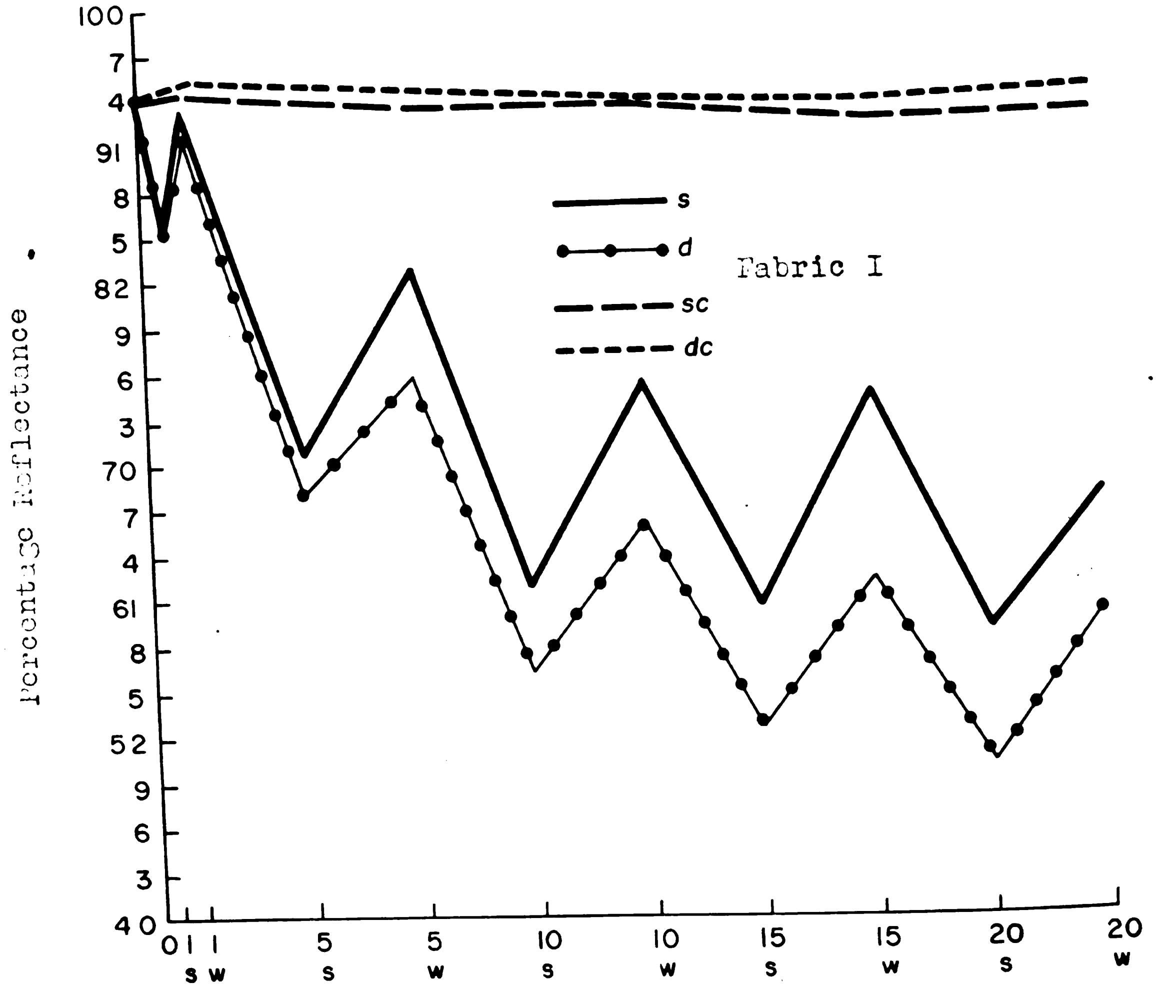
FIGURE 2.-Average reflectance readings for three nylon tricot fabrics originally and after the first, fifth, tenth, fifteenth and twentieth launderings



No significant differences in reflectance readings between Fabric I and Fabric II were found to exist originally and after the tenth and twentieth launderings. The original reflectance readings of these two fabrics were similar, however, significant differences were found after the first, fifth, and fifteenth launderings. This could be due to interactions between the fabric types times soiling and non-soiling and the fabric types times detergents (see Table 5, p. 56). The mean squares of these two interactions were similar at the first laundering. At the fifth laundering however, the fabric types times detergents interaction had a slightly higher mean square. The opposite was found to be true at the fifteenth laundering where the fabric types times soiling and non-soiling interaction was found to have a mean square approximately eleven times greater than the fabric types times detergents interaction. This can be explained by a comparison of the means (see Table 7, p. 85), which revealed a considerable loss in reflectance for Fabric I, Fabric II and Fabric III which had been soiled and then laundered with synthetic detergent as compared to the same fabrics soiled and then laundered with soap.

There were significant differences in reflectance at all laundering intervals between Fabric II and Fabric III. Originally Fabric III had the highest reflectance reading and it maintained this position to and including the twentieth laundering. The significant differences increased in size from the original to the twentieth laundering, with the only exception being the tenth laundering. The differences indicated both

FIGURE 3.—Average reflectance readings for Fabric I originally and after the first, fifth, tenth, fifteenth, and twentieth soilings and launderings



Soiling and Laundering Intervals

s soap
sc soap control
d synthetic detergent
dc synthetic detergent control
S soiling interval
W laundering interval

fabrics washed with both detergents were accumulating soil, but Fabric II at a higher rate than Fabric III.

There were also significant differences at all laundering intervals between Fabric I and Fabric III. Originally this was due to the differences in reflectance between the two fabrics. At the first laundering this difference was greatly reduced and then began to steadily increase up to the twentieth laundering. Fabric III took on more soil and retained more soil after laundering than did Fabric I, in order to reduce the difference in reflectance readings so greatly at the first laundering.

2. Differences between detergents

Significant differences were found to exist between the soap and synthetic detergent at each laundering interval. The significant differences increased progressively from the first to the twentieth launderings. The specimens laundered with soap were consistently higher in reflectance readings than those laundered with the synthetic detergent. The water conditioner may have had some effect here. Under the limited conditions of this study, soap was the most efficient cleaning agent especially in removing soil from Fabric III. Several workers (18, 24, 26), found that soaps were superior to synthetic detergents in removal of soil from fabrics, even though advertising claims often indicate the opposite. When expenditures were considered, the cost of laundering with soap was approximately three times that of synthetic detergent.

In Table 3, p. 54, may be found the differences between the original reflectance readings and the readings taken after the first, fifth, tenth, fifteenth, and twentieth laundering intervals. With one exception, the fifth laundering for Fabric III, there was a greater change between the original reflectance readings and those for the synthetic detergent specimens, than between the original reflectance readings and those for the soap specimens at each laundering interval.

After the first and fifth launderings with soap, Fabric III showed the greatest differences between original reflectance readings and readings taken after the first and fifth launderings. The great decrease in reflectance readings of Fabric III could be mostly due to retention of soil and partly due to reduction in reflectance caused by the soap and water conditioner used in the launderings.

After the tenth and twentieth launderings with soap, Fabric I showed the greatest differences between original reflectance readings and readings taken after the tenth and twentieth launderings. After the fifteenth launderings with soap, Fabric II showed the greatest change.

Though Fabric I remained fairly high in reflectance at the beginning, by the twentieth laundering with soap it had lowered the most in reflectance. Fabric III lowered more at first and little thereafter.

After the first, fifth, tenth, fifteenth, and twentieth launderings with the synthetic detergent, Fabric II showed the greatest difference between original reflectance readings and readings taken after each of the above mentioned intervals. The decrease in reflectance readings could be partly due to the retention of soil and a lowering of reflectance due to the detergent effect on the fabric, as has been already mentioned.

3. <u>Differences between soiling and non-soiling</u>

As would be expected, highly significant differences in reflectance were found at each laundering interval between soiled specimens and specimens which received no soil, but were laundered. It was again noted that significant differences increased from the first to the twentieth launderings.

The specimens which were laundered only (controls), did not change very much in reflectance with laundering. The greatest change was noted for Fabric III specimens laundered with soap, which lowered 11.5% at the twentieth laundering (see Table 3, p. 54). This indicated that the detergents caused very little yellowing or other change which would affect reflectance readings.

In nearly every case, the controls laundered with synthetic detergent and not soiled were higher in reflectance than the specimens laundered with soap. It would seem then, that the soap and water conditioner caused a greater yellowing or other change and thus reduced the reflectance slightly more than the synthetic detergent. However, the differences between the effects of the two detergents were not at all great. When the effect of the detergents was removed a clearer picture of the decrease in reflectance readings due to reten-

TABLE 6.-Changes in reflectance due to soiling (detergent effects removed) of three nylon tricot fabrics (reflectance readings recorded in per cent)

Intervals	Fabric I		Fabric II		Fabric III	
	sc-s	dc-d	sc-s	dc-d	sc-s	dc-d
1-W	1.5	3.1	2.6	9.0	4.1	7.3
5-W	10.7	19.2	7.2	20.0	8.2	10.9
10-W	13.3	27.4	10.4	27.7	5.8	13.6
15-W	17.7	30.5	12.2	31.4	4.8	12.5
20-W	25.1	33.6	16.1	32.7	3.8	13.0

sc-s soap control specimens - specimens soiled then laundered with soap = change in reflectance

dc-d synthetic detergent control specimens - specimens soiled then laundered with synthetic detergent = change in reflectance

W laundering interval

tion of soil remained (see Table 6, p.68). The trend of these results was comparable with those discussed in the previous section when detergent effect was not subtracted. For the specimens laundered with soap, generally speaking, Fabric I changed most in reflectance. For those laundered with the synthetic detergent, Fabric II was found to change the most in reflectance readings (also see Table 3, p. 54 for comparison).

In summary, when fabrics were compared, significant differences were found to exist between Fabric II and Fabric III, and between Fabric I and Fabric III, at all laundering intervals. Significant differences between Fabric I and Fabric II were found to exist with the exception of the tenth and twentieth launderings.

Change in reflectance from the original readings was also calculated. Considering specimens which were laundered with soap, Fabric III retained the most soil after the first and fifth laundering, however, by the twentieth laundering, Fabric I retained the greatest amount of soil. For specimens laundered with the synthetic detergent, Fabric II was found to have retained the greatest amount of soil at all laundering intervals.

When the effect of the detergents was removed[1], decrease in reflectance readings due to retention of soil remained. The trend here was found to be similar to change in reflec-

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[1]Calculated by subtracting the average reflectance reading for specimens soiled and laundered under given conditions, from the average reflectance reading for specimens laundered only, under corresponding conditions.

tance from originals, with Fabric I retaining the greatest amount of soil for fabrics laundered with soap and Fabric II retaining greatest amount of soil for fabrics laundered with the synthetic detergent.

Under the conditions of this study, the soap was found to be superior to the synthetic detergent as a cleaning agent. When the controls were examined(specimens laundered only and not soiled), specimens laundered with synthetic detergent were higher in reflectance readings than those laundered with soap. The soap and water conditioner therefore must have had a greater effect on lowering reflectance than the synthetic detergent. The differences between the two cleaning agents were not large, and the changes from the original reflectance readings were also relatively small.

Of the three fabrics, Fabric III was the whitest originally, both as seen visually and by reflectance readings. It regained this position at the twentieth soiling and laundering.

D. Gross and Microscopic Analyses

The three fabrics used in this study were examined under the microscope, both before and after the first, fifth, tenth, fifteenth, and twentieth launderings.

Upon microscopic examination, the three fabrics were found to be free of carbon particles originally. In appearance they were white and clean looking.

Gross observation of the specimens after the first soiling revealed that Fabric II and Fabric III took on more soil than Fabric I. As the soilings and launderings were repeated, a decided trend was evident. The specimens laundered with the synthetic detergent grew progressively darker in appearance. Although the specimens treated with the soap became greyer with each successive laundering, they did not appear to take on as much soil as those laundered with the synthetic detergent. These observations and the microscopic observations corresponded with the reflectance readings.

The size of the majority of the carbon particles on the fabrics was less than 15 microns, usually between five and 15 microns. However, some much larger particles were found, which ranged in size from 45 - 60 microns. These appeared to consist of several agglomerated carbon particles. Agglomeration of carbon can occur in oil-carbon-solvent soiling mixtures.

Size and location of the carbon particles were similar for the three fabrics for all launderings. It was noticed, however, that there appeared to be fewer "large" (45 - 60 microns) carbon particles present on the laundered specimens than before they were laundered. Compton and Hart (9) found that the smaller particle size had the greatest darkening power and was the most difficult to remove in detergency.

Carbon particles were found either on the filament surface or caught between two filaments in a yarn. It was particularly noticed in Fabric III that the carbon particles could be found even at the center of the yarn. This was probably because of the large number of filaments and low twist, as has been pointed out by Weatherburn and Bayley (54). The location of the carbon particles did not seem to vary with variation in size of the particles.

Oil globules on the fabrics were not visible with ordinary microscopic examination. This could be partly due to the fact that only a small amount of oil was present in the soiling mixture and therefore only a small amount could be deposited on the specimens. There is also the possibility that the oil may have penetrated into the filaments.

An attempt to stain the oil deposited on the specimens from the soiling mixture was made. The fat soluble dye used was D & C Green No. 6. It was dispersed in 95% alcohol, the specimens were left in the dye solution 20 minutes, then rinsed quickly in three concentrations of alcohol, 95%, 70% and 35%. Both mineral oil and olive oil were stained blue-green. With this procedure, only occasional traces of oil were found on the specimens. It would seem then, that there was not a strong and important carbon-oil association, since the specimens did take on carbon fairly heavily and remained grey in appearance after laundering, even with a low oil content soil. Weatherburn and Bayley (52) stated that the oil content of the soil has little if any influence on soil retention. This would seem to be the case in this particular study. Other factors than amount of oil present seemed to be influencing the relatively high soil retention of the three fabrics. (See photomicrographs pp. 33, 34).

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to learn more about retention of soil on fabrics, and to compare soiling and soil retention characteristics of three types of nylon tricot fabrics.

Specific objectives were: to compare the soiling characteristics of the three fabrics; to compare their soil retention characteristics; to compare the relative effectiveness of one light-duty soap and one light-duty synthetic detergent as cleaning agents.

From the data obtained, it would appear that the light-duty soap and water conditioner used under this set of conditions were more efficient cleaning agents than the light-duty synthetic detergent. Only two exceptions were found. These were for the fifth soiling and laundering of Fabric III.

Little of the decrease in reflectance of the fabrics was caused by the detergents. The soap and water conditioner appeared to have a slightly greater effect on reducing the reflectance than did the synthetic detergent.

The fabrics made of textured yarns (Fabrics II and III) did not seem to soil more or less heavily than Fabric I (made of regular nylon). However, a difference in rate of soiling was seen, the textured yarn fabrics taking on considerably more soil initially than Fabric I. With twenty soilings and launderings, soil retention of the three fabrics became severe enough to make them unsatisfactory to the discriminating consumer.

Although Fabric I did not soil heavily originally, with succeeding soilings and launderings, soil take-up increased markedly and eventually Fabric I had the greatest change in reflectance of the fabrics which were laundered with the soap.

Fabric II, laundered with synthetic detergent, soiled most heavily and retained the most soil of the three fabrics when laundering with both detergents was considered.

Both Fabric II and Fabric III dropped sharply in reflectance at the first soiling, however, Fabric III changed little in reflectance thereafter. Fabric III was the highest in reflectance originally, and after twenty soilings and launderings it had regained this position.

Upon microscopic examination, the size and location of carbon particles seemed to be similar for all three fabrics at all soiling intervals, although, fewer large carbon particles seemed to be present after laundering than before laundering. Due to loose twist, carbon particles were seen to have penetrated to the center of the yarn. This was particularly noticed for Fabric III.

Very little oil appeared to be present on the fabric surfaces upon staining and microscopic analyses. The carbon-oil bond did not appear to be an important means of soil retention in this study.

The soiling and soil retention properties of fabrics require further research. In dealing with nylon, many different conditions may be set up for study. Some possibilities are:

1. use water of varying degrees of hardness,
2. vary the temperature of the water in laundering,
3. use both light-duty and heavy-duty synthetic detergents and soaps, several belonging to each group,
4. vary concentrations of detergent,
5. use an artificial soil with a higher amount of oil,
6. run an actual wear study and compare findings with those of a laboratory study,
7. study fabrics made of other textured yarns,
8. use various deniers of yarns to determine if denier has an important effect on soiling and retention of soil,
9. use yarns of varying twist and direction of twist.

The results of this study indicate that variation in yarn twist, filament count and possibly denier may be associated with soiling and soil retention properties, and thus suggest important avenues for future investigations.

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APPENDIX

The light-duty synthetic detergent and soap used in this study were: Lux liquid detergent and Lux soap flakes. "Calgon" was used as the water conditioner for launderings with soap. The amount of "Calgon" placed in each jar was 1.13 grams. This was based on the Calgon Company recommendation of 12.6 grams of "Calgon" per gallon of water of 20 grains per gallon hardness. ("Calgon" is a sodium hexametaphosphate).

The three nylon tricot fabrics used were coded as follows: Fabric I, regular filament nylon; Fabric II, a crimped (Textralized) yarn (Ban-Lon is the trade name for the fabric); and Fabric III, a false-twist, torque (Saaba) yarn. Use of these products does not constitute the author's or the University's endorsement of the products, and conclusions reached were based on limited study under specified conditions.

Other codes which were used are as follows:

s - soap
sc- soap control (specimens laundered only, not soiled)
d - synthetic detergent
dc- synthetic detergent control (specimens laundered only)
S - soiling intervals
W - laundering intervals

Key to Table 4, p. 56.

$n = 5$
A = error mean square
$(q\ 1-.05)k_{12}$, d.f. 48 $= 4.87$
$B_{.05}\sqrt{A}$ = least significant difference at the 95% level of confidence
$B = (q\ 1-.05) \div \sqrt{n} = 2.18$

Fabric times detergents interaction includes all fabrics and both detergents. Fabric times soiling and non-soiling interaction includes both detergents and soiling and non-soiling.

PLATE I.-Photomicrographs of Fabric I originally and after the twentieth soiling

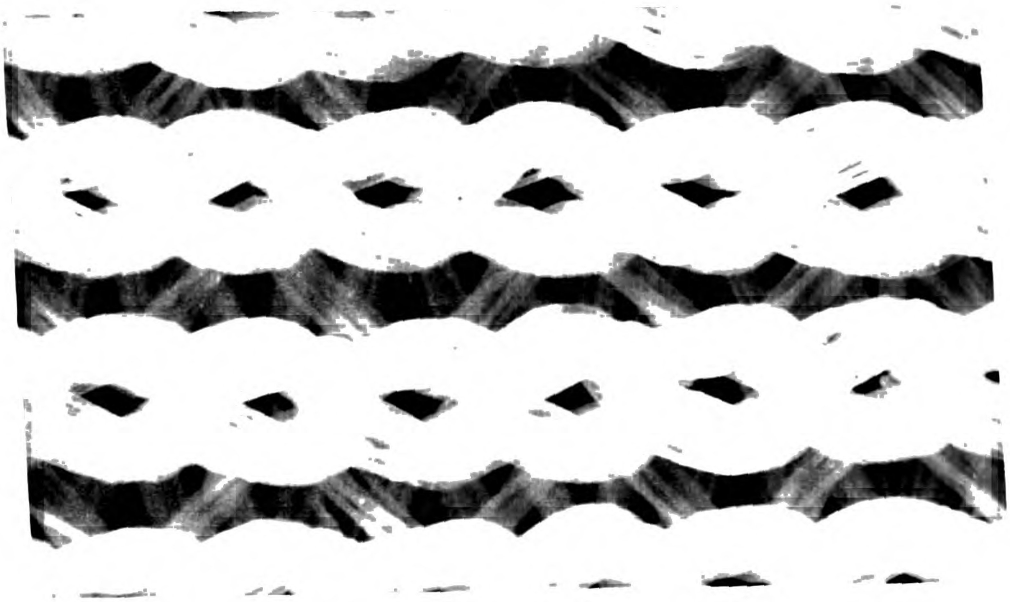

Fig. 1.-Fabric I originally

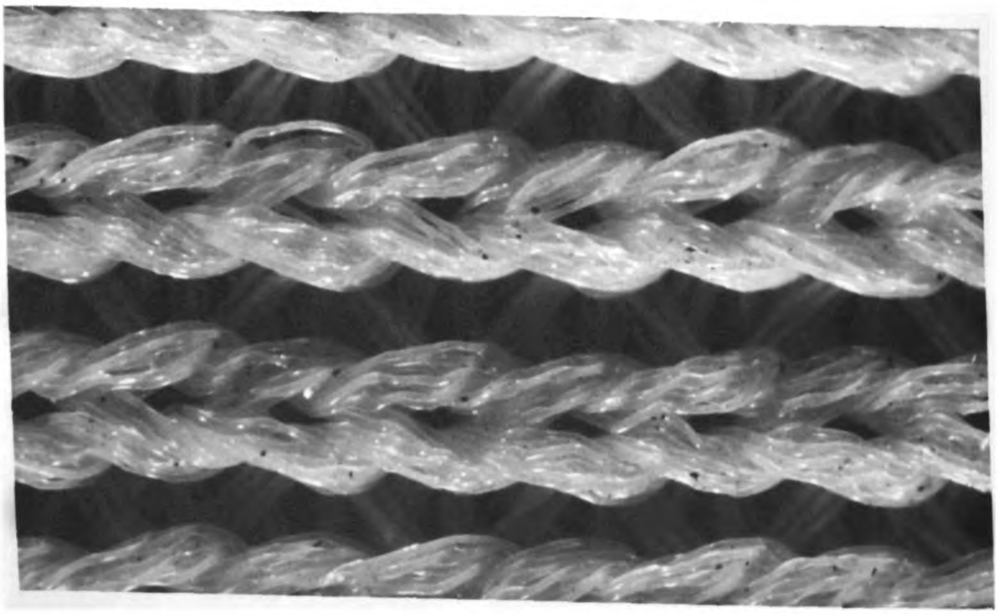

Fig. 2.-Fabric I after the twentieth soiling

	Originals			First					
	Fabric			Soiling			Laundering		
	I	II	III	I	II	III	I	II	III
Soap	94.9	94.3	98.8	85.7	64.2	76.3	93.4	90.0	93.3
	94.2	94.1	99.1	86.1	63.6	77.2	92.7	89.4	93.2
	94.6	94.3	99.6	85.6	65.1	76.1	92.8	89.2	93.8
	94.5	[illegible]	99.6	85.9	64.2	77.2	93.0	89.5	94.0
	94.2	95.0	99.6	86.1	63.8	76.9	93.2	89.8	94.4
ave.	94.5	94.5	99.3	85.9	64.2	76.7	93.0	89.6	93.7
Soap Control	94.6	94.0	100				94.5	91.8	97.2
	93.8	94.3	100				94.1	92.2	97.1
	93.6	93.8	100				94.3	92.4	97.9
	94.0	94.5	99.7				94.6	92.6	98.3
	94.1	94.7	100				94.9	92.0	98.4
ave.	94.0	94.3	99.9				94.5	92.2	97.8
Synthetic Detergent	94.4	95.1	98.4	85.2	62.9	75.0	92.2	84.9	90.4
	94.5	94.1	97.9	84.5	64.1	75.0	91.9	84.5	90.7
	94.8	94.2	98.8	85.4	63.0	75.8	91.4	84.4	91.1
	94.6	94.8	98.5	86.0	64.3	76.0	92.2	84.8	91.2
	94.0	95.1	97.9	84.8	63.8	76.1	91.4	84.9	90.9
ave.	94.5	94.7	98.3	85.2	63.6	75.6	91.8	84.7	90.9
Synthetic Detergent Control	93.8	95.3	99.3				95.2	93.2	97.5
	94.5	95.1	99.6				94.6	93.9	98.3
	94.2	94.2	100				94.3	93.5	98.6
	94.1	94.8	99.3				95.1	94.1	98.1
	94.2	94.4	99.6				95.2	94.0	98.3
ave.	94.2	94.8	99.6				94.9	93.7	98.2