CHAPTER III

METHODOLOGY AND STANDARDISATION
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3.1 Natural and Synthetic Soils

There are, in general, three types of soils, particulate; oily and their mixtures. The overall composition of a soil depends upon the environmental conditions and upon the textiles put in use. Dust deposited from the air on textiles makes up a large part of solid particulate soil. Sanders and Lambert analyzed natural particulate soil. They found that the major part of the soil was made up of inorganic oxides. Their relative amounts were similar in the soils collected from various places. The problem of natural oily soiling is usually more at places such as the kitchen, the workshop, the automobiles etc. However, a mixture of a particulate soil embedded in an oily soil is usually observed. The characteristics of the resulting mixture depends on the physical and chemical properties of the constituents as well as on their relative amounts in the mixture. Therefore, its precise duplication in controlled laboratory studies is a difficult task. For generalised comparisons of soil removal, Florio and Mersereau proposed a standard synthetic soil mixture as shown in Table 3.1.

Analysis of many workers have shown that the garment in contact with human skin picks up measurable amounts of greasy human sebum as a soil. Brown found that the sebum contained fatty acids, triglicerides, fatty alcohols, hydrocarbons and other oils in minor
TABLE 3.1
COMPOSITION OF FLORIO-MERSEREAU SYNTHETIC SOIL

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humus</td>
<td>38</td>
</tr>
<tr>
<td>Portland cement</td>
<td>17</td>
</tr>
<tr>
<td>Georgia clay</td>
<td>17</td>
</tr>
<tr>
<td>Silica (200 mesh)</td>
<td>17</td>
</tr>
<tr>
<td>Carbon black (furnace)</td>
<td>1.75</td>
</tr>
<tr>
<td>Red Iron oxide</td>
<td>0.5</td>
</tr>
<tr>
<td>Light Domestic Mineral oil</td>
<td>8.75</td>
</tr>
</tbody>
</table>

quantity. During a day about one per cent of the human sebum gets deposited on the garment. This indicates that a sensitive method is required for quantitative analysis of this soil.

The majority of studies have been done with one or more particulate solid mixed with one or more liquids. Byrne has discussed problems of soiling with synthetic soils. He showed that the soils do not simulate natural soil and the soils are applied at very high levels on test samples. Moreover, the selection of the solid component is difficult because various particle shape, sizes and surface properties are involved. A general classification of soils is formulated in Table 3.2
### TABLE 3.2
#### CLASSIFICATION OF SOILS

<table>
<thead>
<tr>
<th>Particulate soils</th>
<th>Oily soils</th>
<th>Mixed soils</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siliceous soils</td>
<td>Aliphatic acids</td>
<td>Mixtures of particulate and oily soils</td>
<td>Vegetable matter</td>
</tr>
<tr>
<td>Clays</td>
<td>(saturated and unsaturated)</td>
<td></td>
<td>Food products</td>
</tr>
<tr>
<td>Silicates</td>
<td>Alcohols</td>
<td></td>
<td>Dyes</td>
</tr>
<tr>
<td>Carbonaceous soils</td>
<td>(aliphatic and cholesterol)</td>
<td></td>
<td>Cosmetics</td>
</tr>
<tr>
<td>Carbon black</td>
<td>Hydrocarbons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td>(pure and partly oxidized)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural dust</td>
<td>Triglycerides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-borne dust</td>
<td>(saturated and unsaturated)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal oxides</td>
<td>Natural products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferric oxide</td>
<td>(olive oil, tallow)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium oxide</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Particulate soils
- Siliceous soils
  - Clays
  - Silicates
- Carbonaceous soils
  - Carbon black
  - Graphite
- Natural dust
  - Air-borne dust
- Metal oxides
  - Ferric oxide
  - Calcium oxide

### Oily soils
- Aliphatic acids
  - (saturated and unsaturated)
- Alcohols
  - (aliphatic and cholesterol)
- Hydrocarbons
  - (pure and partly oxidized)
- Triglycerides
  - (saturated and unsaturated)
- Natural products
  - (olive oil, tallow)

### Mixed soils
- Mixtures of particulate and oily soils

### Miscellaneous
- Vegetable matter
- Food products
- Dyes
- Cosmetics
3.1.1 Selection of Synthetic Soils

The important criteria for the selection of synthetic soils suitable for basic studies on soiling and soil release of textiles are as follows:

(1) The soil should be simple, easily available in large quantity and be pure.

(2) It should be easy to apply on textiles.

(3) The dry soil should possess small particle sizes of narrow range, preferably below five microns.

(4) It should not react chemically with the fabric.

(5) It should be preferred if it possesses a colour or if it is possible to dye the soil.

(6) It should be preferred if it can be detected accurately by a suitable quantitative analysis.

(7) The coloured soil should possess good light-fastness.

(8) The soil should be selected on the basis of its physical and surface chemical properties for specific studies.

(9) It should be sufficiently difficult to remove from fabric after laboratory washing i.e. some portion should be retained by the fabric so that a gradation among a set of samples subjected to a specific treatment is obtained for comparison.

(10) A synthetic soil is suitable if the rate equation
for removal differs only in slope from that for natural soils.

3.1.2 Concept of a Model Soil

The naturally occurring soil is a mixture of a number of particulate substances with varying proportions. Usually, multicomponent synthetic soils have been used in laboratory tests. Use of heterogeneous soil mixtures raises several problems: 1. It complicates interpretation of results. 2. It is difficult to prepare it reproducibly. 3. Its activity may change with time. 4. It may not be truely representative of all soils that come in contact with textiles in actual use.

The main objective of a laboratory soiling test is not the close duplication of natural soiling. The intention is to predict correctly the relative soil resistance of a fabric in use by the tests. Another objective of laboratory test is to elucidate soiling and soil release mechanisms to define the governing parameters.

Based upon the above concepts Kissa showed that simple singular or binary model soils can represent complicated natural soil in relative soil resistance evaluation, and he introduced ferric oxide powder as a model particulate soil. He stressed that the model soil should represent the soiling characteristic of the soil encountered in use, although a duplication of the soiled
fabric is not very essential.

On the basis of the above logic, ferric oxide was chosen as a model particulate soil. Moreover, it is available in consistent quality, suitable particle size and is convenient to analyze on fibres.

Similarly, used lubricating oil (a composite mixture of carbon particles suspended in oil) and synthetic sebum (a mixture of organic ingredients found in the human sebum) have been selected as representative oily soils.

The unused lubricating oil was dyed with 0.2% w/w Milling Blue BL Base for the purpose of spectrophotometric determination. The dye possesses adequate light-fastness and is readily soluble in oils. It has no chemical affinity towards untreated or crosslinked cotton fabrics. No preferential diffusion either of dye or of oil on fabric has been noticed. These observations justify the use of the dye in colouring the oil.

3.2 Test Methods for Soil Application

The natural soiling of fabric takes usually a long time. In addition, the level of the soiling is difficult to reproduce and the type of components is difficult to govern precisely. Therefore, the employment of use-soiling procedures in laboratory is impracticable.

The soiling process of textiles are of two types:
static and dynamic, depending upon the soil transport to the fabric. In static soiling, the soil is transported to the fabric by gravity, air currents, or electrostatic attraction. In dynamic soiling, the soil is deposited by contact transfer. During the former process the fabric remains essentially stationary but the latter one puts the fabric under mechanical force.

The most important factor affecting soiling and soil removal of soil-fabric system is the procedure used for the soil application to the fabric. Various methods reported so far can be divided into two categories depending upon their mode of soil application, namely, direct and transfer (Table 3.3).

**TABLE 3.3**

**METHODS FOR APPLICATION OF SOILS ON TEXTILES**

<table>
<thead>
<tr>
<th>Mode of Soil Application</th>
<th>Particulate Soils</th>
<th>Oily Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric floating, both sides soiled</td>
<td>Accelerator$^{28}$</td>
<td>Rotating disk$^{1,27}$</td>
</tr>
<tr>
<td>Tumbler$^{29-32}$</td>
<td>Reciprocal abrader$^{34,35}$</td>
<td>Wicking$^{11}$</td>
</tr>
<tr>
<td>Transfer</td>
<td>Tumbler with felt cubes$^{33}$</td>
<td>FIRA tumbler with felt cubes$^{39,40}$</td>
</tr>
</tbody>
</table>
In the methods designed for particulate soils the fabric either is floating and both the sides are soiled or it is mounted and only one side is soiled. In the soiling devices of direct application, the soil comes in direct contact with the fabric. In transfer application, the fabric is soiled by a soiled substrate, usually felt cubes.

Transfer of soils from soiled to unsoiled fabrics can be carried out by pressing both the samples together or by washing them together. The latter approach is referred to as soil redeposition, that is deposition of soil in the wash medium. Compton and Hart suggested to soil chopped fibres with soil solution or dispersion.

Oily soils are applied in quantities measured by burettes or syringes, or, less accurately, by a medicine dropper. The application of viscous fatty soils by these techniques is difficult, unless the soil is molten or dissolved in a volatile solvent. Such soils are usually applied by transfer methods, which also have the advantages of simulating natural soiling of apparel fabrics with sebum or "hand soiling" with upholstery fabrics.

3.2.1 Selection of Soiling Methods

The evaluation of soil release agents (finishes) requires a meaningful soil release test. Natural soiling of textiles usually involves mechanical action.
Kissa showed that soil release during laundering depends on mechanical work performed during soiling. This means that soiling and washing procedures are interrelated. Therefore, this aspect should be incorporated in a particulate soil detergency test. The criteria of a meaningful soiling method are as follows:

1. The soiling method should be related to the mechanism of soiling during use.
2. It should permit the evaluation of two factors: the ability of a fabric to resist soiling and its ability to release soil by laundering.
3. It should provide a uniform distribution of soil on fabric.
4. It should provide reproducible variation of soiling levels. That is, it should provide the option to vary soiling conditions.
5. It should enable the operator to control the amount of soil applied accurately.
6. It should provide a reasonably quick application of soils on fabric.
7. It should not result in excessive damage to the fibre surface which may, in turn, alter the soiling characteristics of the original fabric.
8. It should provide a soiled area of fabric large enough for several reflectance measurements.
(9) Particulate soiling should be followed by a cleaning method. The method should remove the "loose" soil, but leave the soil adhered to the fabric.

Two methods of soiling - one for the application of particulate soil and the other for the application of oily soil on fabric were required. An appropriate soiling method can be found by studying salient features like principle of soil application, speed, uniformity, reproducibility and other advantages of soiling on comparative basis. With this concept, for particulate soils two representative methods (Table 3.2), namely, the Tumbler and the Accelerator, and for oily soils AATCC Test Method 130-1977 and the wicking method have been compared.

3.2.2 Comparative Studies on Soiling Methods for Particulate Soils

The working principle of the Accelerator method is the direct application of soil on fabric whereas that of the FIRA tumbler method is the transfer one. Both are representative of dynamic soiling process, in which the fabric is subjected to mechanical action. The fabric in the Accelerator undergoes flexing, friction, abrasion; the FIRA tumbler causes collision of felt cubes with the fabric. Various features of the two methods are discussed below.
(a) Speed of Soiling

The Accelerator requires only 1 minute to soil a pair of fabric swatches whereas for the same purpose the tumbler requires at least 220 minutes. This fact shows that the Accelerator provides rapid soil application relative to the tumbler.

(b) Uniformity and Reproducibility

The uniformity and reproducibility of soil application is shown in Tables 3.4 and 3.5 respectively. The uniformity of the soiled fabric is indicated by the standard deviation of Kubelka-Munk values calculated from reflectance of different areas of a soiled sample.

**TABLE 3.4**

<table>
<thead>
<tr>
<th>Soiling method</th>
<th>Mean soiling value V</th>
<th>Standard deviation</th>
<th>Confidence limits(95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator</td>
<td>5.20</td>
<td>0.05</td>
<td>± 0.03</td>
</tr>
<tr>
<td>Tumbler</td>
<td>4.80</td>
<td>0.42</td>
<td>± 0.26</td>
</tr>
</tbody>
</table>

The reproducibility is shown by the standard deviation of Kubelka-Munk values calculated from reflectance of replicate samples.
TABLE 3.5

REPRODUCIBILITY OF SOILING WITH PARTICULATE SOIL

<table>
<thead>
<tr>
<th>Soiling method</th>
<th>Mean soiling value V</th>
<th>Standard deviation</th>
<th>Confidence limits (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator</td>
<td>5.20</td>
<td>0.07</td>
<td>± 0.04</td>
</tr>
<tr>
<td>Tumbler</td>
<td>4.80</td>
<td>0.56</td>
<td>± 0.34</td>
</tr>
</tbody>
</table>

The data show that the Accelerator applies soil more uniformly and reproducibly than the tumbler. The Accelerator attains these characteristics at any soiling level. The poor reproducibility of the tumbler method may be attributed to its nonuniformity of soiling. This may be caused by accumulation of the soil on one side of the fabric which is mounted in the sample holder and does not flex during soiling.

(c) Adsorption Isotherm of Soiling

Kissa\textsuperscript{14} showed a quantitative relationship between the amount of soil used for soiling ($s, \% \text{owf}$) and the amount of soil adsorbed ($c_s, \% \text{owf}$) on the fabric in analogy with Freundlich adsorption isotherm as

$$c_s = c_0 s^A, \; \text{Eq. 3.1},$$

where $c_0$ is the soilability of the fabric and $A$ is a constant having the value $2/3$ for direct soiling. The plot of $c_s$ against $s$ on logarithmic scales is reported to be linear up to the saturation.
concentration of the fabric. The slope of the straight line gives the value of the exponent $A$.

Direct soiling is a one-step process, which can be written as:

\[
\text{SOIL} \xrightarrow{k/A} \text{FABRIC}
\]

Soiling values $V$ (Chapter II) are linearly related to the soil content $c_s$ of the fabric. Hence,

\[
V = k s^A, \text{ Eq. 3.2},
\]

where $k$ is a coefficient. The soiling values $V$ of fabric samples soiled in the Accelerator gave a straight line when plotted on logarithmic scales against the $s$ values (Fig. 3.1). The exponent $A$ was found to be 0.66 from the plot and 0.67 from the regression.

Transfer soiling is a two-step process, which can be written as:

\[
\text{SOIL} \xrightarrow{k_1/A} \text{FELT CUBES} \xrightarrow{k_2/B} \text{FABRIC}
\]

The soiling values of fabric samples soiled in the tumbler cannot be plotted in a similar manner because the soil content of the felt cubes, used to transfer soil, is not known accurately. However, it can be assumed that the soil content of the cubes is about the same. Therefore, the soiling values can be plotted against the number of cubes.
FIG. 3.1: APPLICATION OF FERRIC OXIDE ON FABRIC BY THE ACCELERATOR

SOILING VALUE

SLOPE 0.65

s % owf

V

FIG. 3.1: APPLICATION OF FERRIC OXIDE ON FABRIC BY THE ACCELERATOR
in the tumbler. The plot yields a straight line with the slope 0.66 (Fig. 3.2) when the tumbler is rotated until the soil transfer is completed (14 or 18 cycles). Rotation for only 9 cycles yields a line with a slightly higher slope, 0.81.

When the soiling values are plotted against the amount of soil supplied for soiling cubes, then the slope of the resulting curve is smaller, 0.23, than that of the Accelerator soiling. (Fig.3.3). If $s_c$ is the amount of soil applied to the cubes, then

$$c_s = k_1 k_2 s_c^A B$$  \hspace{1cm} \text{Eq. 3.3}

where $k_1$ and $k_2$ are transfer coefficients of each step and $B$ the exponent of the second (soil-deposition on fabric) step. If $A$ and $B$ both have the value of 0.67, then the exponent of the whole soiling process is 0.45. The data obtained suggest that either $A$ is less than 0.67 or $B$ is equal to $0.23/0.67 = 0.33$. It is also possible that the cubes become saturated with soil at higher values of loading and could not absorb all of the soil supplied. Saturation, either of the cubes or the fabric is indicated in Fig.3.3 by the horizontal position of the line at higher soil loadings.

Therefore, it is apparent that with the tumbler method it is difficult to reproduce exactly the same degree of soiling or develop quantitative
FIG. 3.2: APPLICATION OF FERRIC OXIDE ON FABRIC BY THE TUMBLER
FIG. 3.3: APPLICATION OF FERRIC OXIDE ON FABRIC BY THE TUMBLER
relationships between soiling conditions and detergency.

With the help of the Accelerator, the amount of soil used for soiling, the soiling time, and the rotational speed can be varied instantly. For the same purpose the tumbler required a long time. Moreover, the cubes used for soil transfer in the tumbler are a part of the soiling system. Their physical properties and chemical composition affect soiling, thus complicating soiling and detergency studies. Their physical properties are not constant because the cubes are resoiled and used repeatedly until they become too hard or worn.

3.2.3 Comparative Studies on Methods for Oily Soils

The principle of the AATCC method 130-1977 is that an oily spot on a test specimen is produced by using a metallic cylinder to force a given amount of the oily soil into the fabric. The wicking method is based on the principle that a measured amount of oil is allowed to wick itself into the fabric. Wicking changes the soil density (% owf) according to (i) the amount of oil placed on the fabric, (ii) rate of wicking, and (iii) time of wicking. For a particular oil with its known quantity, the time required for almost complete wicking can be determined.
(a) Time Required for Soiling

The forceful wicking by the AATCC Method is subjected to 1 minute and approximately 15-30 minutes after removing the force. The self wicking method is found to require about 15-18 hours for near completion. In spite of the long time required for soiling, the latter method seems to simulate natural soiling of fabric with oils.

(b) Accurate Quantity of Oil on Fabric

In the AATCC Method, the fabric sample during soiling remains in close contact with the blotting paper on one side and the glassine paper on the other. As a consequence, some of the oil applied on the fabric gets transferred. In the Wicking method, the sample is mounted on an embroidery hoop eliminating any contact with the oil spot.

(c) Reproducibility of Soiling

As stated earlier, the precision of the two methods in terms of the Kubelka-Munk values has been shown in Table 3.6. The data indicate that the wicking method is superior to the AATCC method in achieving reproducible soiling level. The inferior reproducibility of the latter method may be attributed to transfer of oil to the intimate surfaces during soiling. The wicking
TABLE 3.6

REPRODUCIBILITY OF SOILING WITH OILY SOIL

<table>
<thead>
<tr>
<th>Soiling method</th>
<th>Mean soiling value S</th>
<th>Standard deviation</th>
<th>Confidence limits (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wicking</td>
<td>3.65</td>
<td>0.03</td>
<td>± 0.025</td>
</tr>
<tr>
<td>AATCC 130-1977</td>
<td>8.00</td>
<td>0.31</td>
<td>± 0.23</td>
</tr>
</tbody>
</table>

The method is studied further for the following aspect.

(d) Effect of Oil Concentration on Fabric

The area of the soiled spot does not increase proportionally with the amount of soil applied. Hence the soil concentration usually increases with the increasing amount of soil applied depending upon the nature of the substrate. The soiling of cotton poplin with increasing amount of used lubricating oil is indicated by soiling value $S$ in Fig. 3.4. Similarly, the soiling of cotton poplin with increasing amount of particulate matter in oil is shown in Fig. 3.5. Both the results confirm the increase in density of oil as well as particulate matter per unit mass of the fabric.

3.3 Assessment of Soil on Fabric

The amount of soil on fabric, in general, can be determined by the following ways:
FIG. 3.4: EFFECT OF INCREASING AMOUNT OF OIL ON FABRIC SOILING VALUE, S.
CARBON PARTICLES CONCENTRATION (% w/w) IN USED LUBRICATING OIL

FIG. 3.5: EFFECT OF INCREASING CONCENTRATION OF CARBON IN OIL ON FABRIC SOILING VALUE, S
a. Qualitative assessment.
b. Quantitative assessment.
c. Optical assessment.
d. Modern techniques.

These four approaches involve different methods. The selection of a particular method depends usually on the type of soil and fabric used and the precision of the data required. The methods are listed in Table 3.7.

The human eye is obviously the ultimate judge of the appearance of a soiled fabric inspite of its subjective assessment. Soiled test samples after washing can be graded visually or by visual comparison of the residual oily spot with photographic standards. Standard viewing conditions are described by Reese. Although the eye is quite sensitive in detecting relative visual differences among a few test samples, it can neither store nor reproduce the information. Another deficiency of the eye is the inability to handle a large number of examinations. Therefore, the visual is rather quick but a crude method of soil assessment.

In quantitative analysis, the results are expressed as the mass of soil determined gravimetrically. However, frequently a marked visible soiling is produced by minute quantities of certain soils which make the gravimetric method an impracticable one. Moreover, the analyses require relatively long time. Similarly, the modern techniques require a skilled hand and are rather expensive.
<table>
<thead>
<tr>
<th>Table 3.7</th>
<th>METHODS OF DETERMINATION OF SOIL CONTENT OF FABRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative method</td>
<td>Visual rating</td>
</tr>
<tr>
<td>Quantitative methods</td>
<td>Gravimetric analyses</td>
</tr>
<tr>
<td></td>
<td>Solvent extraction</td>
</tr>
<tr>
<td></td>
<td>Weighing the dirt</td>
</tr>
<tr>
<td></td>
<td>Ashing fabric</td>
</tr>
<tr>
<td></td>
<td>Millipore filtration</td>
</tr>
<tr>
<td></td>
<td>Coulter counter</td>
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<tr>
<td></td>
<td>Chemical analysis</td>
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<tr>
<td></td>
<td>Radiotracer technique</td>
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<tr>
<td></td>
<td>Neutron activation analysis</td>
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<tr>
<td></td>
<td>X-ray fluorimetry</td>
</tr>
<tr>
<td></td>
<td>Microscopic examination</td>
</tr>
<tr>
<td>Optical assessments</td>
<td>Light reflectance measurement</td>
</tr>
<tr>
<td></td>
<td>Light transmission measurement</td>
</tr>
<tr>
<td>Modern techniques</td>
<td>Gas liquid chromatography</td>
</tr>
<tr>
<td></td>
<td>Infrared spectroscopy</td>
</tr>
</tbody>
</table>
As regards the optical methods, the light transmission measurements have been made on soiled fabric as well as on wash liquor. The difficulty with the soap turbidity and various degrees of agglomeration of the soil are main drawbacks of transmission techniques.

Colour-measuring instruments can be divided into two classes, namely, the spectrophotometers and the colorimeters. Their function is to express colour differences or the colour of materials in terms of what eye perceives. They have three essential parts, namely, a light source, a sample holder, and a detector. Spectrophotometers give complete information about the colour of a specimen and give it in absolute terms. Colorimeters, on the other hand, yield limited information, and give it only in relative terms.

In domestic and commercial laundering, if washed clothes look clean and smell clean, they are clean; appearance and not the soil content is the principle standard by which such laundering is judged. Thus, based upon this philosophy, a convenient method for assessing soil on fibres is an optical one in which the intensity of light reflected by the test sample is compared with that reflected by a standard white surface. Therefore, spectrophotometers equipped with reflectance measuring assembly are usually employed for this purpose.

Asnelin et al. reported that the visual ratings correlate reasonably with the spectrophotometric assessment
of residual spot,

It is important to differentiate the two terms, namely, whiteness and brightness. Whiteness is a quantity to which the eye is sensitive with consequent preference tendency and brightness is an entity measured by reflectance of light. Hemmendinger and Lambert have illustrated the chromaticity aspects encountered with both the concepts.

3.3.1 Concept of Spectrophotometric Assessment of Soil on Fabric

In the visual rating for the evaluation of relative soil release of fabrics, the samples are rated between 1 and 5 (in increasing soil removal with the accuracy of 0.5 rating unit) by a visual examination and comparison with a standard stain release replica. Because of the narrow range of rating and the deficiency of the eye for reproducible evaluation, the method is not an accurate one.

The spectrophotometric reflectance technique provides a quick and sensitive method of estimation of soil on fabric. It is well established that per cent reflectance value is not linearly related to the amount of soil present on the fabric. Hence, it is necessary to convert the reflectance data into a suitable function. The various systems for the analysis of the reflectance and various expressions derived from the systems are listed in Table 3.8.
TABLE 3.8
REFLECTANCE ANALYSIS

Systems
- Kubelka-Munk function
- Modified Kubelka-Munk function
- Scattering and Absorbing power
- Tristimulus values
- Florio-Mersereau functions
- U,V,W (CIE) functions

Expressions
- Soiling values
- Percent soil retained/removal
- Soil additional density
- Graying additional density
- Percent whiteness

The systems can best be compared by the correlation coefficient. The correlation coefficients between pairs of various systems for particulate (ferric oxide) and oily (used lubricating oil) soils are given in Table 3.9.

The data indicate that the various functions are in reasonably good agreement with each other up to the saturation concentration of the soiling level on the fabric.
TABLE 3.9
CORRELATION OF THE KUBELKA-MUNK FUNCTION WITH TRISTIMULUS FUNCTIONS

<table>
<thead>
<tr>
<th>Correlation between</th>
<th>Correlation coefficient, ( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Particulate soil</td>
</tr>
<tr>
<td>K/S and X</td>
<td>0.99</td>
</tr>
<tr>
<td>K/S and Y</td>
<td>0.97</td>
</tr>
<tr>
<td>K/S and Z</td>
<td>0.98</td>
</tr>
</tbody>
</table>

3.3.2 Effect of Spectrophotometric Variables on Assessment of Soil

In the interest of improved precision of reflectance readings, a number of variables in the technique of presenting soiled fabric swatches to the reflectometer have been recognized and studied. These factors comprise orientation of fabric, type of backgrounds, thickness of fabric, etc. Such variables are studied for the two selected soils on cotton polishing, and the results are shown in Figs. 3.6 and 3.7, respectively.

In Fig. 3.6 is depicted soiling values \( V \) as a function of ferric oxide concentration on fabric under the conditions illustrated above. The soiling values for identical background and also for warp (original) and fill (90° rotated) directions of the fabric swatch are the same. The geometry of the optical system is of great
FIG. 3-6: EFFECT OF SPECTROPHOTOMETRIC PARAMETERS ON SOILING VALUE FOR PARTICULATE SOIL
FIG. 3.7: EFFECT OF SPECTROPHOTOMETRIC PARAMETERS ON SOILING VALUES FOR OILY SOIL
importance in measuring reflectance. Since the spectrophotometer studied here involves \(0^\circ/\text{diffuse}\) type of optical system it eliminates the effect of the construction of the substrate. However, 0.1 to 2.6\% change in reflectance has been reported by Hunter\(^{25}\) for \(45^\circ/0^\circ\) type of an optical system.

The soiling values obtained using a white background are slightly less than those obtained with a black background.

When the soiled samples are covered with a cover glass, the soiling values are reduced probably due to the increased scattering of light by the glass.

Similar studies for used lubricating oil are presented in Fig.3.7. It can be inferred that the soiling values are significantly higher with the black background than with the white background, and they are intermediate of the two with the identical background.

Physically considering, the used lubricating oil is a two component mixture, that is, carbon particles suspended in oil. With the increasing amount of oil on the fabric, the concentration of carbon particles per unit mass of fabric is increased and subsequently the opacity of the fabric is decreased. As a consequence, the adsorption of the incident light by carbon particles in oil and also by the black background is increased. However, the latter
adsorption is decreased when the black background is replaced by identical and white backgrounds respectively. Thus, the respective levels of soiling values are lowered.

In addition, the soiling values are independent here also of the direction of the soiled sample and comparatively lower level of soiling values is obtained with the cover glass, as observed in earlier case.

In general, it can be inferred that the best resolution of reflectance measurement of soiled fabric is obtained with the black background of approximately zero reflectance. Kissa\textsuperscript{11} reported that the highest contrast and consequently the best visibility are provided by a background which absorbs in a spectral region where the fabric is transparent. He added that the precision and sensitivity are relatively higher with coloured soils than with colourless one, and relatively higher with a dyed fabric than with a white one. Use of black backing cloth is also recommended by Ashcraft.\textsuperscript{26}

Rees\textsuperscript{27} studied the effect of white against black background and degree of openness of fabric with respect to the optical soil assessment of fabric. He found that measurement made against a black background showed an increased soiling with increasing openness of the fabric. While corresponding results employing a white background gave an erroneous impression that the most open fabric soil less than the reasonably close fabrics. Therefore, he
preferred a background of black velvet.

Hunter proposed the use of a cover glass over the fabric sample in order to make the fabric surface plain with the uniform pressure. However, this technique has not been found helpful in the present investigations since lower levels of soiling values are obtained.

3.3.3 Validity of the Kubelka-Munk Function in Soil Assessment

Figs. 3.8 and 3.9 show the relationship between the Kubelka-Munk function and the soil content (% owf) of fabric. For particulate soil the relationship is quite linear (Fig. 3.8) but for oily soil it is linear only to a certain extent (Fig. 3.9). The slight deviation found at higher concentration of oily soil may be due to the saturation of the fabric with the oil.

3.4 Intercomparison of Particulate Soils

In tropical countries like India, soiling of garments, with particulate soils is a major problem. Natural particulate soil (NPS) is a heterogeneous mixture of various compounds. Such a soil when carried by air-currents is called air-borne NPS. It contains mainly small particles.

A typical NPS was collected locally during dry weather and was analysed. The analytical data are shown in Table 3.10. The high ash-content of the soil indicates
FIG. 3.8: RELATIONSHIP BETWEEN THE KUBELKA-MUNK FUNCTION AND THE SOIL CONTENT OF FABRIC (PARTICULATE SOIL)
FIG. 3.9: RELATIONSHIP BETWEEN THE KUBLER-KA-
MUNK FUNCTION AND THE SOIL CONTENT OF
FABRIC (OILY SOIL)
a higher percentage of inorganic compounds. An aqueous slurry of the soil is mildly alkaline. The NPS was passed through four sieves of various pore-sizes and five fractions obtained were weighed. A large percentage of the soil is found to contain particles below 37 microns.

TABLE 3.10
ANALYSES OF THE NATURAL PARTICULATE SOIL

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Colour :</td>
<td>Greyish Black</td>
</tr>
<tr>
<td>2. Odour :</td>
<td>Odourless</td>
</tr>
<tr>
<td>3. Water-soluble fraction :</td>
<td>9.7 %</td>
</tr>
<tr>
<td>4. Ether-soluble fraction :</td>
<td>0.3 %</td>
</tr>
<tr>
<td>5. Ash content:</td>
<td>75.4 %</td>
</tr>
<tr>
<td>6. pH of 10 % slurry :</td>
<td>8.0</td>
</tr>
<tr>
<td>7. Particle-size distribution:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particle range (micron)</th>
<th>% Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 210</td>
<td>0.1</td>
</tr>
<tr>
<td>105-210</td>
<td>8.0</td>
</tr>
<tr>
<td>53-105</td>
<td>16.3</td>
</tr>
<tr>
<td>37-53</td>
<td>9.7</td>
</tr>
<tr>
<td>&lt; 37</td>
<td>62.4</td>
</tr>
</tbody>
</table>

Various amounts of the NPS were employed in the Accelerorot to soil fabric samples keeping other soiling conditions constant. Soiling value V of soiled samples plotted against amount of the NPS used for soiling S on a log-log scale is shown in Fig. 3.10. The straight
FIG. 3-10: ADSORPTION IsoTHERM OF NATURAL PARTICULATE SOIL
line thus obtained yields a slope value of 0.656 which is close to 2/3. Thus, adsorption of ferric oxide and of the NPS are essentially similar for the direct soiling process.

Representative micrograph of the NPS and of ferric oxide are shown in Figs. 3.11a and 3.11b, respectively. The NPS contains particles of various sizes and shapes with rough surfaces. On the other hand, the particles of ferric oxide are relatively fine and the size distribution is narrow. Owing to its consistency in particle size and chemical composition, ferrix oxide is used as a model particulate soil.
FIG. 3.11(a): NATURAL PARTICULATE SOIL (240X)

FIG. 3.11(b): FERRIC OXIDE (1800X)
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