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# Wettability and wicking phenomenon in scoured cotton fibre

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**ABSTRACT:** There are various factors affecting wetting and wicking of fibrous assemblies; micronaire value of cotton. Fibre has been an important parameter governing the wetting and wetting of cotton fibres. The present study deliberates on the fibre properties and their effect on wetting and wicking of a fibrous assembly. An attempt has been made to calculate the contact angel of the fibre, using the powder cell method, and compared it with the fineness of cotton fibres. Three categories of the cottons are prepared depending on their fineness which are further grouped into 3 based on the coarse, fine and super fine varieties. It is found that within the group the contact angle depends upon the micronaire value of the cottons.

**Key words :** Absorbtion, adhesion, fibre, luricity, phenomenon, scoured cotton, wettabilty

The wetting and wicking phenomenon in cotton fibre is of great importance as these influence the processability and ultimate performance of the textiles made from cotton. Fibre wetting most commonly finds its application in dye uptake and water affinity/repellency of fabrics, which in turn is usually found to depend on the surface characteristics of the fibre. The behaviour of fibre with respect to the phenomenon of wetting is characterized by the ratio of surface to volume.

Measurement of contact angle and surface tension provides a better understanding of the interactions between solids and liquids or liquids/liquids, that play a key role in adhesion, wettability, biocompatibility, lubricity of solid surfaces as well as washability, spreading and adsorption of liquids.

Molecules inside (bulk) a liquid/solid are in every direction affected uniformly by attraction forces, whereas those at the surface lack a neighbor towards the air phase and therefore have larger attraction forces towards the liquid/solid (Fig.1). This leads to a situation where the liquid air interface has excess free energy. This excess free energy is characteristic of any liquid or solid and for liquids, a spontaneous contraction of the surface would take place and the surface tension of a liquid is a direct measure of it. Chemical bonds are the attractive forces between atoms in a molecule and between adjacent molecules in a substance. These are the forces that hold things together. When molecules exist in close proximity in a liquid or solid, the atoms arrange themselves to optimally satisfy the bonding forces with nearby neighbors (Fig.1). Depicts an atom in the interior has satisfied bonds in all directions: 4 in this 2 D drawing and 6 in the real 3 D world. But atoms in the top row do not have one bond satisfied, because there is no neighbor above. These unsatisfied bonds constitute surface energy, a potential energy in the sense that another object brought up close might be able to satisfy some of these “dangling” bonds**.** These bonds are the source of wetting and much of adhesion. Contact angle gives estimate of the nature and strength of these bonds, mainly because we lack a direct-reading meter the way we have a thermometer for temperature or a voltmeter for voltage. The interaction between bonds of surfaces brought together is not the same as two substances reacting to form a new chemical compound (*e.g.,* hydrogen oxidizing to form water). With adhesion or wetting, one can, with effort, separate the constituents as no compound is formed. Due to the imbalance in the forces acting at the surface/interface, the structure and composition

of the surface/interface is different than in the bulk. Interactions at surfaces/interfaces therefore result in special orientations of molecules, accumulation of certain types of molecules at the interface, separation of positive and negative charges. Combined analysis of surface tension and contact angle gives information about the properties of the outer most layer of a surface in a simple way.

In the case of solids, the contraction is hardly ever seen, but still this free energy is present at the interface of air/solid. However, now it is called surface free energy (instead of surface tension as for liquids) can be computed by measuring the contact angle of a series known liquids placed on the solid surface. Contact angles are an easy to visualize and measure manifestation of surface energy, which in turn

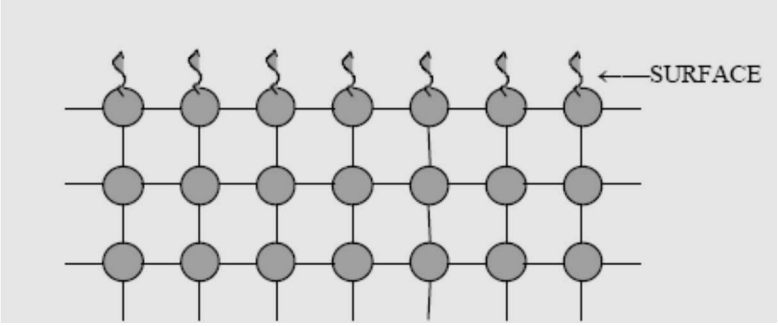



**Fig.1.** Schematic of idealized solid surface. Circles represent atoms, straight lines satisfied chemical bonds of electrons, and wiggly lines unsatisfied bonds of top layer of atoms at surface.

is a characteristic of chemical bonding. Contact angles, *per se*, describe the shape of a liquid drop resting on a solid surface. The dimension of both surface tension and surface free energy is mN/m.

Since the wetting of a fibrous material (fabric) is a complex process and various mechanisms *viz.,* spreading, immersion, adhesion, and capillary penetration may operate simultaneously. Wetting of fibres is a displacement of a fibre air interface with a fibre liquid interface and primarily depends upon the surface characteristics. Textile fibres do not have ideal surfaces, their wetting phenomenon are complicated by heterogeneity, and adsorption of liquids or surfactants with a consequent change of surface energy. The wettability of fibres (Miller, 1975 and 1985) depends on the chemical nature of the fibre surface and fibre geometry, especially surface roughness (Cazabat, 1986, Dettre, and Johnson, 1964).

The micronaire reading on a bundle or plug of cotton fibres is a measure of resistance of air flow; it is a result of the combined influence of fibre fineness and fibre maturity. Fibre fineness may be directly measured either by the weight/unit length or by the circumference of the individual fibres. Maturity may be directly measured by the ratio of cell wall thickness to fibre circumference.

According to Harnet and Mehta, 1984, "wickability is the ability to sustain capillary flow," whereas wettability "describes the initial behavior of a fabric, yarn, or fiber when brought into contact with water." While wetting and wicking are still argued to be separate phenomena, they can be described by a single process – liquid flow in response to capillary pressure (Ghali *et al.,* 1994). More completely, in the absence of external forces, the transport of liquids in a porous media is driven by capillary forces that arise from the wetting of the fabric surface.

## MATERIALS AND METHODS

To study the influence of fibre properties, with main thrust on fineness, on the contact angle with distilled water, 9 cotton varieties having different micronaire values, were selected from coarse to fine. The fibre properties were evaluated along with mature fibre per cent by NaOH method. The fibre properties are given in Table 1. The samples were divided into 3 groups on the basis of their micronaire values. The first group was made of cottons which are having micronaire value 3.6 or lower and second group having micronaire value between 3.7 and 5.0 and third group having micronaire value 5.1 and above. Broadly they may be classified as fine, medium and coarse cottons.

Cotton fibres were treated, at boil for 90 min in absence of air, with 4 per cent sodium hydroxide on the weight of the fibres with 1:20 material to liquor ratio. Fibres were thoroughly washed with demonized water to achieve a neutral pH, and allowed to dry at room temperature.

The primary parameter reported to characterize wetting is contact angle. Wetting is thus characterized by a contact angle representing the degree of spreading of the drop. Fig. 2 defines the contact angle, which is nothing more than the angle between a tangent drawn on the drop's surface at the resting or contact point and a tangent to the supporting surface. The important concept is that the shape of the drop reveals information about the chemical

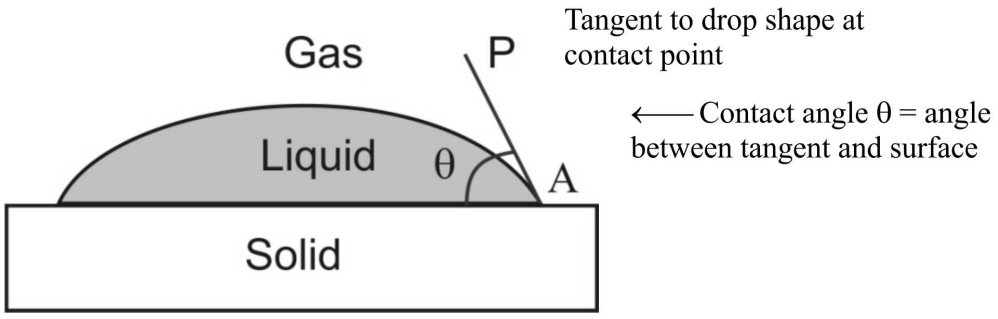



**Fig. 2** Measure of Contact Angle

bonding nature of the surface. This bonding will determine its wettability and adhesion. The relationship of drop shape to bonding is contact angle's utility. It is accepted that this angle is measured inside the liquid.

The contact angle can vary between 0° and 180°, and conventially 3 situations can be schematized in the following way:

Typically contact angles are measured using a goniometer. This requires a drop of the test liquid, be placed on the surface of the solid tested. Placement of a drop of liquid on fibers of

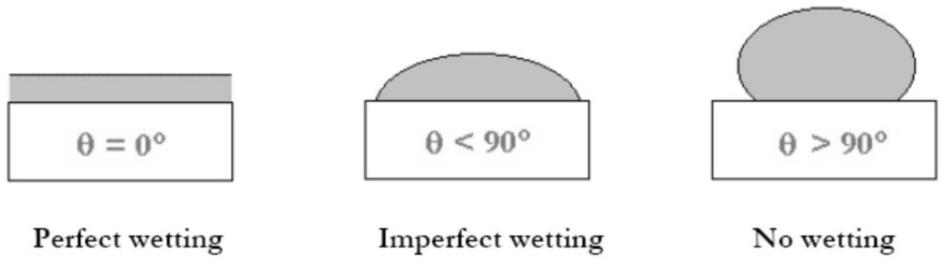



**Fig. 3** Wetting and Contact Angle

small dia may be quite difficult. Measurements of contact angle is carried by depositing small droplets, in the 2 to 3m ml volume range, the sample by positioning the dispense tip just above the surface and growing the pendant drop until its bottom touched the sample and the drop detached. The image is captured by means of high speed camera and the contact angle is measured with the help of software associated with Goniometer (Fig. 3).

It is not very easy to determine contact angle between a fibre and a liquid because in order to put a drop on the surface of fibre one need to prepare very small drops and very high magnifying camera to capture the image, therefore, it is not practical to put a drop on the fibre surface and measure the angle directly. Washburn developed a technique to determine the contact angle between a powder material and a liquid with liquid capillary rise in powder. The following Washburn equation is applied to calculate the contact angle between a powder material and a liquid. The powder granules are also very small in size; therefore, a drop cannot be placed on the surface of single granule. In the present study, because of very small surface size available, to determine contact angle between fibres and water, the following Washburn equation is applied.

$$\frac{m^2}{t} = \frac{C\rho_L{}^2\gamma_L \cos\theta}{\eta_L}$$

m: mass of liquid with capillary rise (g)
t: time (s)
$r_L$: liquid density ($g/m^3$)
$g_L$: liquid surface tension (N/m)
C: cell constant ($m^5$)
$h_L$: liquid viscosity (Pa.s)

This equation contains two unknown quantities *viz.,* angle q and cell constant C. The cell is nothing but a glass container having a very porous bottom with markings on its surface to help fix the height of material (fibres) to be filled in and preparing a column of fibres within cell (Fig. 4). Cell constant is dependent on the height of the material (fibres) and density of the material (fibre plug) in the cell. The GBX tensiometer cum goniometer was used to carry out the test. The density of the fibre plug in the cell can be controlled with the control on height to which fibres are filled in the cell. It was achieved by keeping the mass and height to which fibres were filled in the cell, constant for all the specimens, 200 mg of cotton was weighed and compressed to 20 mm in the cell provided. To calculate cell constant C, a low surface tension liquid, hexane, was used. The cell containing fibre plug was hooked on the balance of the tensiometer with hexane in the small beaker kept in the designated bracket of the instrument. The platform containing the beaker was raised at 100mm/sec speed, as the platform starts raising the balance resets to zero. The automatic contact detection between cell and water was effected by the instrument. As contact was detected instrument went into measurement mode and amount of water being absorbed with time was measured. Since the Washburn equation needs the value of $m^2/t$ on the left side, a real time graph of $m^2$ $\upsilon/s$ time t (sec.) was recorded and slope was calculated by the software associated. The software associated also calculates the cell constant with the help of slope and other parameters which were fed into at the start of the test. The readings of increase in mass were recorded with the time till saturation point occurred *i.e.* $m^2$ values become constant with the time t. Since the surface tension of Hexane (18.4) significantly lower than water (72.8), it rises through the cell rapidly and gives rise to perfect wetting; therefore, the contact angle with fibre is zero. Same procedure is repeated with the liquid with which the contact angle is desired to be determined, replacing the value of cell constant with the value obtained while testing with Hexane as liquid. So, in the first time, using a wetting liquid hexane having low surface tension (q=0°), the cell constant C was determined. In the second time, with the cell constant already known, the capillary rise with

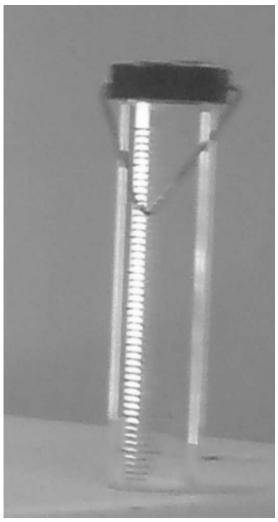


**Fig.4** Cell

the liquid was measured. The software associated also calculates the rate of amount of water rise in the fibre plug with respect to time (mg of water/sec) and total amount of water gained by the fibre plug at saturation point.

## RESULTS AND DISCUSSIONS

It can be seen from the the data in Table 1 that the contact angle between water and fibres does not seem to be influenced by the span length, UR (Uniformity ratio) and tenacity of the fibres. Since contact angle depends more on the interaction between the outer surface of the material and the liquid, finer cottons are having contact angle value more as compared to coarse cottons. It means that coarse variety of cotton wets better than fine cottons. The correlation coefficients between contact angle, MIC (Micronarire value) and mature fibre per cent are as follows: $r_{mic, A}$ = -0.864, $r_{M\%, A}$ = -0.530 and partial correlation between MIC and A (Contact angle) suppressing mature fibre percentage is r = -0.841**.

Capillarity describes the phenomenon when liquids in narrow tubes, cracks, and voids take on motion caused by the surface tension of the liquid. Capillarity is based on the intermolecular forces of cohesion and adhesion. If the forces of adhesion between the liquid and the tube wall are greater than the forces of cohesion between the molecules of the liquid, then capillary motion occurs. This flow is similar to other types of hydraulic flow in that it is caused by a pressure difference between two

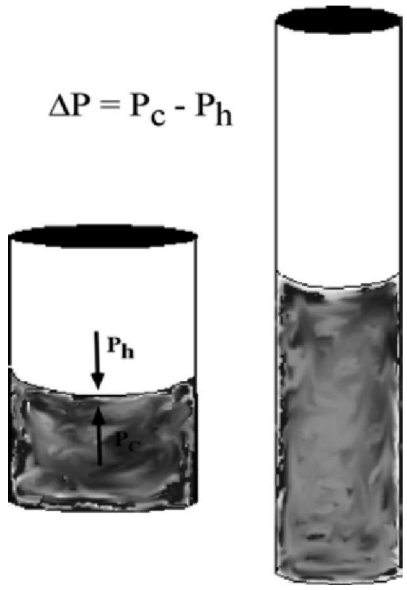



**Fig. 5** Illustration of capillary rise in different size pores

hydraulically connected regions of the liquid mass. The direction of flow is such as to decrease the pressure difference. Flow would cease when the pressure difference became zero. According to the laws of capillarity, fluid flow would be faster in a void with a large capillary radius than that in one with a small radius. Though that may be true, the smaller radius capillary can transport moisture to a greater height as illustrated in Fig. 5 below.

In general, the moisture begins in all the pores, but can travel only to certain heights in the larger pores where it then migrates to the smaller pores. If the pores or capillaries do not fill, then they do not contribute in the transport or wicking of the moisture.

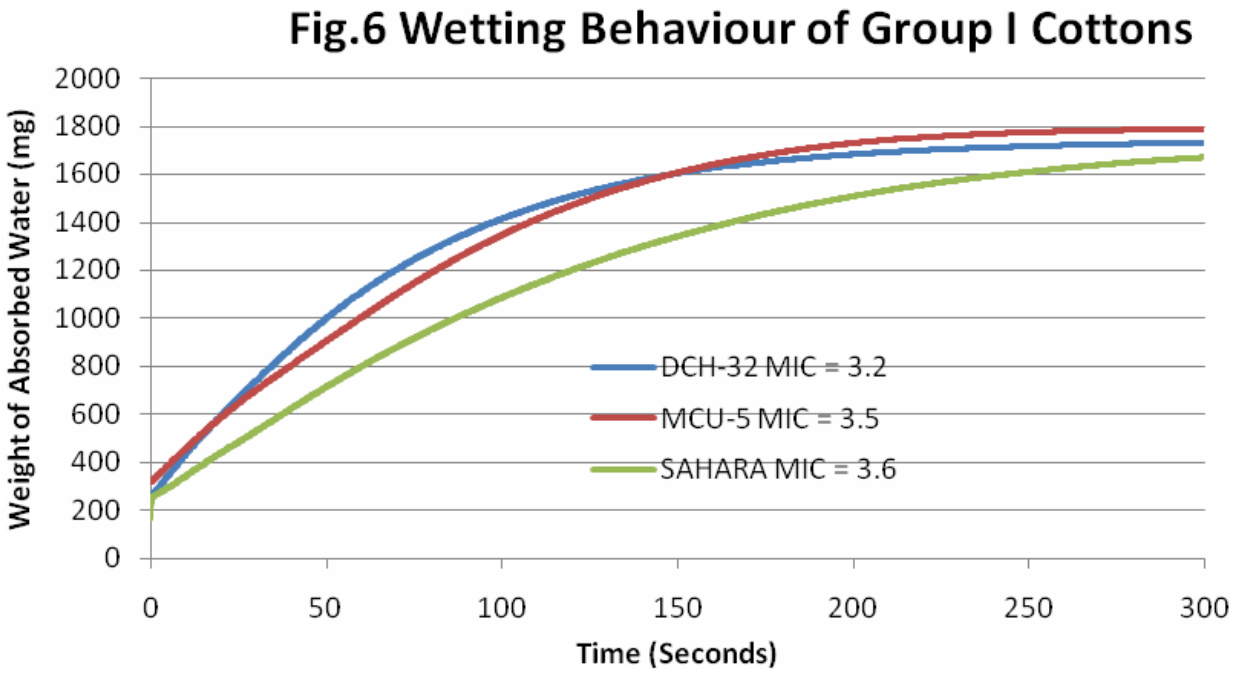
The rate of travel of liquid /water is governed by the fiber arrangement in yarns which control capillary size and continuity. Changes in fiber properties when wet can

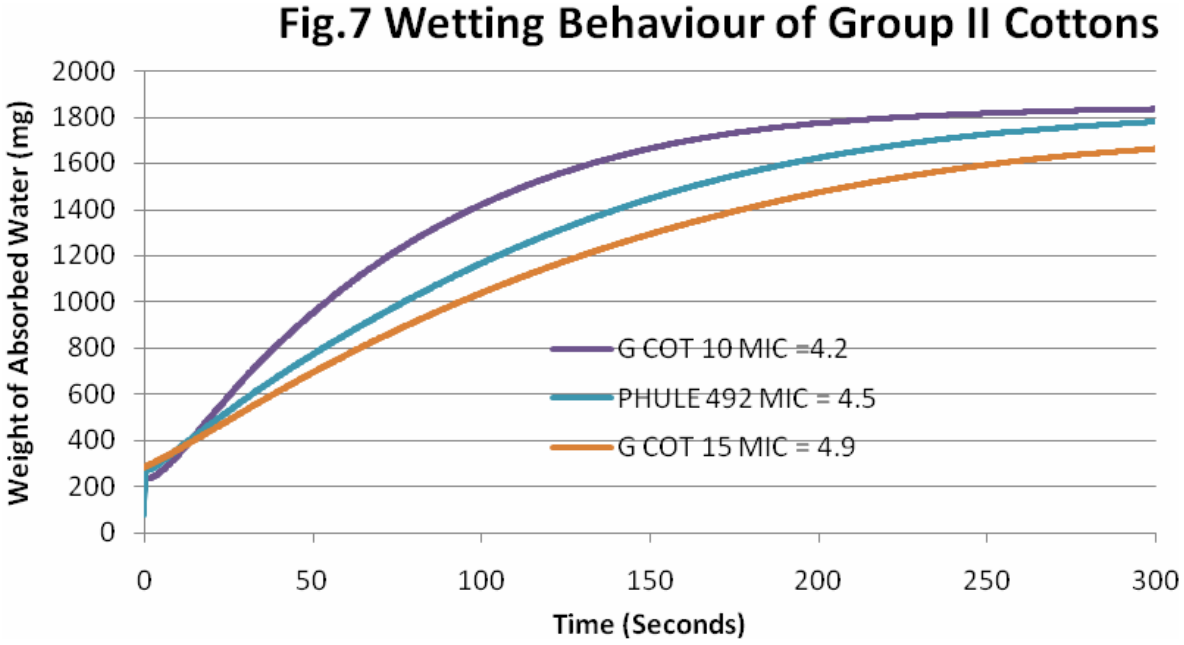
**Table 1.** Fibre properties, contact angle and wetting behavior of samples

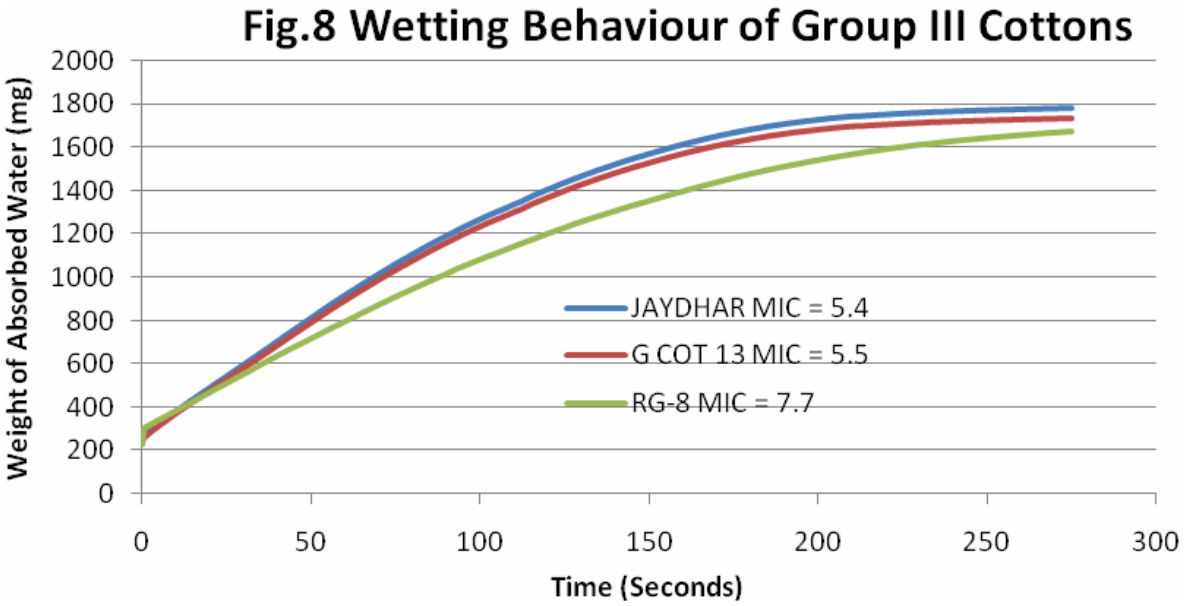
| | Variety | 2.5 per cent span length | UR (Uniformity ratio) | MIC (Micronaire value) | Tenacity | Mature fibre (%) | $A^0$ (contact angle) | Water slope (mg/s) | Water gain (mg) |
|---|---|---|---|---|---|---|---|---|---|
| **Group I** | | | | | | | | | |
| | DCH 32 | 35.1 | 48 | 3.2 | 31.6 | 66 | 80.8 | 143 | 1757 |
| | MCU 5 | 28.9 | 45 | 3.5 | 22.5 | 59 | 79.4 | 139 | 1828 |
| | SAHARA | 26.3 | 48 | 3.6 | 18.0 | 70 | 84.0 | 115 | 1716 |
| **Group II** | | | | | | | | | |
| | G COT 10 | 25.2 | 48 | 4.2 | 19.7 | 78 | 78.6 | 139 | 1846 |
| | PHULE 492 | 25.3 | 51 | 4.5 | 18.9 | 68 | 80.6 | 119 | 1783 |
| | G COT 15 | 24.7 | 49 | 4.9 | 21.4 | 79 | 80.4 | 112 | 1745 |
| **Group III** | | | | | | | | | |
| | JAYDHAR | 22.8 | 50 | 5.4 | 18.1 | 77 | 75.7 | 145 | 1780 |
| | G COT 13 | 24.5 | 48 | 5.5 | 18.6 | 75 | 73.7 | 146 | 1737 |
| | RG 8 | 17.8 | 54 | 7.7 | 13.6 | 84 | 70.5 | 122 | 1671 |

significantly affect liquid movement and retention behaviors through fiber swelling. Fiber swelling not only increases liquid retention in the fibers at the expense of the capillary liquid capacity in inters fiber pores, but also complicates the pore structure (Hsieh, 1995). This swelling of the fibers can cause bottlenecking or the closing off of capillaries, which in turn causes the flow in those capillaries to be slow or even stop. It is well known that this type of response to moisture is prevalent in yarns made of cellulosic fibers (Tortora, 1997). Cotton fibers, with their flat, lima bean shaped cross section and ribbon like appearance, would produce very irregular capillaries within a yarn that could inhibit fluid flow.

Within a given variety, fibres with low micronaire values have less cellulose deposition than those with high micronaire values; therefore, there is more empty space, *i.e.* larger cavities in low micronaire cotton than in high micronaire cotton. As explained above according






to the laws of capillarity, fluid flow would be faster in a void with a large capillary radius than that in one with a small radius. In cotton plug of same density, cotton with low micronaire value will have capillaries with larger diameters. Within a group of cottons, higher the maturity of fibres betters the absorbency. Within a group of cottons, the higher MIC values indicates higher maturity since MIC value is a combination of fineness and maturity. The rate at which water is getting absorbed within a cotton plug does not depict any particular trend if seen from overall angle. But

it has definite trend when we look at it group wise. As explained above within a group of cottons, cotton having a higher MIC value indicates better matured cotton. The swelling of fibres of higher MIC value cotton, within a group of cotton, will be higher compared to one which has got lower MIC value. Therefore, as explained above the bottlenecking or closing of capillaries in such cotton, after swelling, will be higher hence lower rate of water getting absorbed. The data of rate of water absorbed within a group of cotton can give a very good idea of maturity and MIC of fibres because the rate of water absorbed varies to larger extent though the difference in MIC values is not much.

From the data in Table 1,. it can be seen that cotton with lower micronaire has high rate of rise of water compared to one with higher micronaire value within a group of varieties (Fig.6, 7 and 8).

The amount of water gain in the given variety depends upon the available space within the fibre. The higher the maturity of the fibre lowers the available space within it. The data from the Table 1 shows that the variety with highest mature fibre percentage has lowest amount of water gain and *vice versa* within a group.

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