Effect of Wool Porosity on Scouring and Drying Process. Part 1

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Abstract

It seems important that we have full knowledge of how far the efficiency of scouring and drying varies with the degree of the porosity of fed wool assemblies, opened or unopened.

The author has made experiments, analyses and measurements concerning the mechanism of porosity construction as a basic subject for inquiry. His findings are given in this article.

The author has also made experiments to inquire into the effect of wool porosity on the practical processes of steeping, scouring and drying, in the hope of offering a guide in actual operations. His findings will be published in later issues.

Introduction

The purpose of the scouring and drying process as a fundamental step in treatment in woolen and worsted spinning is to remove yolk (suint and grease), mud, sand, dust, etc. from greasy wool and, after drying and oiling, to supply scoured wool for the subsequent process, namely, carding.

The principal function of the scouring and drying process is, therefore, to enable wool to display its inherent characteristics fully without damage to, or the felting of, wool fiber. For this purpose, the right kind of scouring agent has to be selected and the degree of concentration of the solution, the temperature, the time for treatment, etc. must be properly fixed.

To increase the efficiency of scouring and drying under equal conditions, compressed assemblies of greasy wool have to be fed after adequate opening. The mechanism and efficiency of treatment vary with the degree of opening—compactness or openedness—of a wool assembly treated in a washing and a drying machines.

It seems important, therefore, to have full knowledge of how far the efficiency of scouring and drying varies according to the degree of the porosity of a wool assembly, opened or unopened. Wool supplied in the highest possible degree of porosity increases efficiency, requires fewer washing bowls, consumes less scouring agent and heating calories, and helps prevent damage to fiber—to mention the major advantages. The present article reports the results of experimental measurements and analyses of porosity construction as a basic subject for study.

1. How to Make and Calculate Porosity

To obtain a variety of states of porosity artificially, three methods were used in the

experiments under review.

(1) Porosity of constant bulk (P_c)

Various quantities of wool fiber are uniformly stuffed into a tube of a uniform diameter and length. The smaller the amount of fiber, the higher the degree of porosity.

(2) Porosity of vertical extension (P_v)

Equal quantities of wool fiber are uniformly stuffed into several tubes of different heights but of the same diameter. The taller the pile of fiber in the tube, the higher the porosity.

(3) Porosity of horizontal extension (P_h)

Equal quantities of wool fiber are uniformly stuffed into several tubes of different diameters but of the same height. The larger the diameter, the higher the porosity.

P_v or P_h gives the advantage of keeping the quantity of wool constant. Assemblies of wool are previously opened in a uniform state with a handcard, and then stuffed into a tube as uniformly as possible.

Porosity is calculated by the following formula:

$$\left. \begin{aligned} V_o &= \frac{M}{S} \\ P_o &= \frac{V_s - V_o}{V_s} \times 100\% \end{aligned} \right\} \dots\dots\dots(1)$$

P_o : wool porosity

S : specific gravity of wool fiber

M : weight of wool fiber

V_o : actual volume of wool fiber

V_s : apparent volume of wool assemblies

Several examples of calculation by this method are given in Table 1.

2. Constitution of Porosity

The question of how the number n , radius r , and length l of capillaries differ according to the degree of the porosity of wool assemblies

Table 1 Example of Calculation of Porosity

	Diameter of tube (cm)	Bottom area of tube (cm ²)	Height of filling-up (cm)	Apparent Volume of wool assemblies V _s (cm ³)	Weight of wool fiber M (g)	Actual Volume of wool fiber V _o (cm ³)	Porosity P _o (%)
Porosity of constant bulk (P _c)	3.00	7.07	5.00	35.33	16.08	12.37	65
	"	"	"	"	13.78	10.60	70
	"	"	"	"	11.48	8.83	75
	"	"	"	"	9.19	7.07	80
	"	"	"	"	6.89	5.30	85
	"	"	"	"	4.59	3.53	90
Porosity of vertical extension (P _v)	"	"	"	"	2.30	1.77	95
	2.00	3.14	4.29	13.50	7.00	5.38	60
	"	"	5.70	17.90	"	"	70
	"	"	8.50	26.70	"	"	80
Porosity of horizontal extension (P _h)	"	"	16.80	52.75	"	"	90
	1.84	2.66	5.0	13.29	7.00	5.38	60
	2.12	3.53	"	17.64	"	"	70
	2.62	5.39	"	26.94	"	"	80
	3.70	10.74	"	53.74	"	"	90

Table 2 Results of Measurement by "Pour-down" Method

Porosity P _c (%)	Time required for passage through wool assemblies t (sec)	Time required for outflow until quantity is 50 cc t' (sec)	t' - t (sec)	Quantity of outflow per unit time Q (cc/sec)	Electric resistance by filling-up of 1N KCl solution R (Ω)
65	200.0	1200.0	1000.0	0.05	1500
70	108.0	608.0	500.0	0.10	950
75	38.0	228.0	190.0	0.26	480
80	18.0	92.6	74.6	0.67	325
85	8.0	43.0	35.0	1.43	260
90	4.5	14.5	10.0	5.00	165
95	2.0	5.5	3.5	14.28	105

Fig 1 Experimental apparatus of flowing-down method

shown in Figure 1. Porosity in the experiment under discussion was made by the porosity of constant bulk P_c shown in Table 1. A quantity of distilled water ($18 \pm 1^\circ\text{C}$, 100 cc) was poured on the upper surface of the test piece to descend through the assemblies. The time required for passage through the wool assemblies, t (sec), and the quantity of water which descended per unit time, Q (cc/sec), were measured with the results given in Table 2.

The apertures in the wool assemblies in various states of porosity were filled with a 1 N KCl solution, and electric resistance between the edges of the tube was measured with the results also shown in Table 2.

With these results as a guide, each factor in the capillary system was presumed by the following formula under Hagen-Poiseuille's law⁽¹⁾ (the sections of capillary tubes being assumed to be circular in shape):

$$\left. \begin{aligned} Q &= \frac{n\pi r^4 p}{8\eta l} \\ R &= \frac{l}{n\pi r^2 \lambda} \\ \frac{l}{t} &= \frac{r^2 p}{8\eta l} \end{aligned} \right\} \dots\dots\dots (2)$$

Q : quantity of water descending per unit time (cc/sec)

p : total water pressure given to the upper

has been considered on the assumption that a wool assembly is a multiplex capillary system.

Merino type wool of grade 64's was used as a sample. The experimental apparatus used is

- surface of the test piece (14.14 g/cm^2)
 λ : relative conductivity of 1 N KCl solution at 18°C (0.09822)
 R : value of electric resistance (see Table 2)
 η : coefficient of viscosity of water at 18°C ($0.0115 \text{ g/sec}\cdot\text{cm}$)

The results of the presumption are shown in Table 3. The higher the degree of wool porosity is, the wider the radius r of the capil-

Table 3 Values Converted by Presumption of Capillary System Various States of Porosity

Porosity P_c (%)	Radius r (cm)	Length l (cm)	Number n (/cm ²)
65	0.098	46.2	11.8
70	0.093	31.8	12.6
75	0.106	21.4	12.7
80	0.140	19.6	9.9
85	0.183	17.1	6.3
90	0.273	19.1	5.0
95	0.369	17.1	3.9

Fig. 2 Experimental apparatus for measuring the curve of outflow of liquids by adding pressure

Fig. 3 Curve of outflow of liquids in various states of porosity

laries, the shorter their length and the smaller their number per unit area.

For a more minute presumption of the state of distribution of the radius r of capillaries in each state of porosity, a curve of the outflow of water by adding pressure was measured and analysed. The experimental apparatus used is shown in Figure 2. Sample wool fibers were stuffed into a glass tube 0.65 cm in diameter and 3.00 cm in height. Water was dropped from a reservoir into a compressed tank at the rate of 40 cc/min, and compressed air was sent into the water vessel by adding pressure. Just then, the water which penetrated and passed through the wool assemblies began to spout from one end of the glass tube. The value of pressure and the quantity of the outflow of water were measured simultaneously after the passage of each constant length of time. The curve of outflow of liquid (water) measured by this method is given in Figure 3.

The curve of outflow from one capillary tube is shown in Figure 4 as the most fundamental case. At the instant liquids begin to move by an increase in pressure, Cantor's law [2] forms itself:

$$p = \frac{2\sigma}{rg} \quad \dots\dots\dots (3)$$

σ : interfacial tension between water and air (69.2 dyne/cm)

g : acceleration of gravity (980 cm/sec²)

When the value of p exceeds the value shown in this formula, the relation of $p \sim Q$ is a straight line according to Poiseuille's law.

In a complex structure built of capillaries of various diameters, like wool assemblies, the r_{max} section corollary opens first. As pressure increases gradually, the section corollaries of smaller r open in order of the smallness of r , and eventually liquids spout from all section corollaries.

Assuming that the distribution function of a capillary tube is $n(r)$, the number existing between r and $r + dr$ is $n(r) dr$ and the quantity of outflow is $\pi r^4 n(r) dr / 8 \eta l$. Therefore, the following equation forms itself:

$$\frac{Q}{p} = \int_r^{r_{max}} \frac{\pi r^4 n(r) dr}{8 \eta l} \quad \dots\dots\dots (4)$$

if $[n]_{r_{max}} = 0$

Fig. 4 Curve of outflow in one capillary tube

$$= \frac{-\pi n(r)}{8\eta l} \cdot \frac{r^5}{5},$$

$$\therefore \frac{d}{dr} \left(\frac{Q}{p} \right) = \frac{-\pi r^4 n(r)}{8\eta l},$$

and
$$\frac{d}{dr} \left(\frac{Q}{p} \right) = \frac{(dQ/dr)p - Q(dp/dr)}{p^2},$$

$$= \frac{(dp/dr)[(dQ/dp)p - Q]}{p^2},$$

and from the equation (3)

$$\frac{dp}{dr} = \frac{-2\sigma}{r^2 g}, \quad r = \frac{2\sigma}{pg},$$

$$\therefore n(r) = \frac{8\eta l p^4 g^5}{\pi (2\sigma)^6} \left(p \frac{dQ}{dp} - Q \right) \quad \dots\dots\dots (5)$$

In an ideal multiplex capillary system, like a thin film, the $p \sim Q$ curve is like the solid line

Fig. 5 Curve of outflow in ideal multiplex capillary system

in Figure 5. Point B is the point at which equation (3) forms itself in the r_{max} section corollary. When pressure reaches this value, the r_{max} section corollary opens for the first time and outflow begins. The r_1 section corollary opens with a further increase in pressure, and the quantity of outflow increases gradually. The opening of the r_{min} section corollary ends at point C. Thereafter, the relation of $p \sim Q$ is proportional and a straight line. AD is a tangent at spontaneous point D on the BC curve. AO corresponds to $[p(dQ/dp) - Q]$. If these operations are made at a spontaneous point on the curve of the outflow of liquids, $n(r)$ of the section corollary which opens at that point can be diagrammatically drawn.

Figure 6 is a magnified diagram of the curve section in Figure 3. p_{min} and p_{max} are obtained from the measured values. From formula (3) r_{max} and r_{min} are calculated. The range of $r_{max} \sim r_{min}$, equally divided into k parts, gives $\Delta = (r_{max} - r_{min})/k$.

$$(p_{max} [= p_0], p_1), (p_1, p_2), \dots\dots\dots (p_{k-1}, p_{min} [= p_k])$$

which corresponds to $r_{min} + (\Delta/2)$, $r_{min} + (3/2)\Delta$, $r_{min} + (5/2)\Delta, \dots r_{min} + [(2k-1)/2]\Delta [= r_{max} - (\Delta/2)]$, as follows:

$$p_x = \frac{k p_{max} p_{min}}{k p_{min} + x(p_{max} - p_{min})}, \quad \dots\dots\dots (6)$$

where $x = 0, 1, 2, \dots\dots\dots, k$.

The pressure value at the moment when each section corollary opens can be calculated by equation (6). The range of $r_{max} \sim r_{min}$ in

Fig. 6 Magnified diagram of curve of outflow

Figure 6 is divided into five equal parts, and $[p(dQ/dp) - Q]$ that corresponds to each r is measured in the figure. The values of l calculated by the ratio of the conjectural value in Table 3 are shown in Table 4. Equation (5) is substituted into the following equation:

$$n(r) = cp^4 \left(p \frac{dQ}{dp} - Q \right) \quad \dots\dots\dots(7)$$

The values of c in various states of porosity are also shown in Table 4. $n(r_x)$ in each state of porosity is calculated by equation (7). Take the number of capillaries in the $r_{1+(\Delta/2)}$ section corollary to be $\bar{n}_{r_{1+(\Delta/2)}}$. Then:

$$\bar{n}_{r_{1+(\Delta/2)}} = \int_{r_1}^{r_{1+\Delta}} n(r) dr$$

Therefore, the ratio in percentage of the number of the $r_{min+[x+(1/2)\Delta]}$ section corollary to the total number of the sections is:

$$Z = \frac{\bar{n}_r}{\sum \bar{n}_r} \times 100 \quad (\%) \quad \dots\dots\dots(8)$$

Calculations by this method are given in Figure 7.

When porosity is small, the absolute value of r distributes in the range of a small value. The smaller porosity is, the smaller the range of the distribution of the capillary radius (the difference between $r_{max} \sim r_{min}$). The common part of the absolute value of the capillary

Table 4 Values of c in Various States of Porosity (Eq. 7)

Porosity P_c (%)	60	70	80	90
l (cm)	9.5	5.0	3.1	3.0
c	0.509	0.268	0.168	0.167

Fig. 7 Ratio of distribution of radius of capillary tube in various states of porosity

radius in each state of porosity (the part shown in an oblique line in Figure 7) is the largest when $P_c = 70 \sim 80\%$ (the range of $70r_{max} \sim 80r_{min}$). The ratio of concentration to r_{min} is smaller when $P_c = 80\%$, than in other states of porosity. Judging from these findings, it is thought that the standard constructive state of wool assemblies is $P_c = 70 \sim 80\%$.

3. Comparison of Osmosis Accompanying the Difference in Porosity

It is thought that, as a means to analyze the effect of wool porosity on the efficiency of the steeping and scouring process, it is appropriate to measure and compare the osmosis of wool assemblies.

In the first of the author's experiments to

Fig. 8 Sectional diagram of steeping bath

that end, the process of the ascent of liquid through wool assemblies by adding pressure was analysed. In place of the water bath (shown in Figure 2) for adding pressure, the steeping bath shown in Figure 8 was installed. Pale-colored distilled water was put in this bath. A glass tube 0.65 cm in diameter and 30 cm in height was used, and sample wool was stuffed to a height of 10 cm from the lower end of the tube. The velocity of pressure was 4.2g/cm² per minute and the temperature of liquid 20 ~ 22°C.

The results measured for each state of porosity are shown in Figure 9. The smaller the degree of porosity is, the longer the time required and the higher the pressure needed for the 10-cm ascent. Also the resistance of discharge of air in the first period of ascent and the resistance of the capillaries in the last stage appear the more clearly. The relation of $dh/dt \sim t$, calculated by these results, as shown in Figure 10. When the value of P_c exceeds 80%, a considerable difference exists in the velocity of ascent between the first stage of adding pressure and the last stage.

Fig. 10 Variations in velocity of ascent according to length of time spent

Fig. 9 Curve of ascent of liquids by continuous adding of pressure

This difference is small when the value of P_c is under 70%.

The ratio of the descent of pressure at a given height is calculated by the following equation: (3)

$$\left. \begin{aligned} \Delta p &= \frac{8\eta l}{gr^2} \cdot \bar{u} \\ \bar{p} &= \frac{p_1 - p_2}{p_1} \times 100 = \frac{\Delta p}{p_1} \times 100 \% \end{aligned} \right\} \dots\dots\dots (9)$$

$\bar{u}$: mean velocity in tube

Δp : difference in pressure at the two ends of tube

p_1 : value of pressure added to the face of the bottom of sample

p_2 : value of pressure at $h = 9$ cm

$\bar{p}$: ratio of pressure descent

The results calculated are shown in Table 5. The smaller porosity is, the larger the loss of pressure.

The results of measurement by a sudden, temporary increase in pressure are shown in Figure 11. The value of pressure added is, in

Table 5 Estimated Values of Descent of Pressure at $h=9$ cm in Continuous Adding to Pressure.

Porosity P_c (%)	50	60	70	80	90
Passed time, t (min)	14.3	10.7	7.6	5.4	3.7
Value of pressure added to face of bottom p_1 (g/cm ²)	54.0	42.5	31.0	22.7	16.3
Difference in pressure Δp (g/cm ²)	15.6	5.4	1.7	0.7	0.3
Value of pressure at $h=9$ cm, p_2 (g/cm ²)	38.4	37.1	29.3	22.0	16.0
Ratio of descent of pressure $\Delta p/p_1 \times 100$ (%)	35.8	16.1	6.4	3.1	1.7

Fig. 11 Curve of ascent by sudden, temporary increase in pressure

this case, 18.6 g/cm². The ability of liquid to reach a height—the faculty of ascent—differs fairly measurably according to the degree of porosity. The ratio of the descent of pressure at each height of ascent was measured with the results given in Figure 12. In every degree of porosity, the relation of $h \sim \bar{p}$ is a straight line.

An analysis was also made of the difference in the ascending action of capillaries by porosity. Greasy wool was stuffed into a glass tube 0.7 cm in diameter, and the last 1 cm of its root was steeped in a colored liquid. The values of a measurement taken after 100-hour steeping are shown in Figure 13. The height of ascent of liquid is the greatest when $P_c = 70 \sim 80\%$. This, it is thought, is because the constructive state of that porosity is the most suitable for capillarity.

4. Summing up

The author has made a few experiments and considered their results in an effort to analyse and presume the constructive state of the porosity of wool assemblies. We have also made measurements to see how far the osmosis of liquid for wool assemblies differs according to the degree of porosity.

Findings:

(1) The smaller porosity is, the smaller the range of distribution of the capillary radius. The common part of the absolute value of the capillary radius in each state of porosity is the largest when $P_c = 70 \sim 80\%$. Also the ratio of concentration to r_{min} is low when $P_c = 80\%$, compared with other states of porosity.

(2) The height of ascent of liquid by capillarity in the pillar of wool assemblies is the

Fig. 12 Presumed values of descent of pressure by sudden, temporary add in pressure

Fig. 13 Height of ascent by capillarity in various states of porosity

greatest when $P_c = 70 \sim 80\%$.

(3) Judging from these findings, it is thought that the standard constructive state of wool assemblies is $P_c = 70 \sim 80\%$.

The author has also made experiments as regards the effect of wool porosity on the practical processes of steeping, scouring and drying as a guide in actual operations. His findings will be published in future issues of this journal.

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