THE DEVELOPMENT OF VISCOSE RAYON FOR NONWOVEN APPLICATIONS

This Paper is reprinted from the text of a talk given at the Tappi Non Woven Fibres Seminar at Myrtle Beach in 1979. It has not been edited in any way, and the following points should be noted:-

1. "Fibroloft" was the U.S. name for the "Viloft" hollow rayon.
2. Spun laid viscose was not commercialised, and the development has stopped.
3. The development of lower cost routes to binderless viscose rayon non wovens (fibre entanglement, thermally bonded blends) will probably provide the pure, absorbent fabrics for the future.
4. The improvement in demand for short-cut fibre for wet laid non-wovens has occured, and Courtaulds Viscose Europe will be adding the necessary products to their range.

ABSTRACT

The development of the viscose rayon process is reviewed in general terms and also with particular reference to the dry, wet, and spun laid rayon non woven routes. The versatility of the technology is emphasised, and the scope for developing new forms of rayon designed especially to suit the needs of the nonwoven market is assessed. The applicability of the newly introduced modified cross section rayons and the improved absorbancy varieties is discussed, as are environmental factors, energy consumption and raw material considerations.

HISTORICAL BACKGROUND

The development of man-made fibres commenced with the early attempts to extrude natural gums, moved on through the discoveries of how to dissolve natural polymers, and continues today with the synthesis of thermoplastic polymers and their extrusion. As early as 1664 Robert Hooke predicted that man would learn how to extrude natural gums to make textile fibres, but it was not until 1842, when Louis Schwabe first extruded molten glass, that the prediction began to look realistic. In 1846 Friedrich Schönbein made the first nitrocellulose, and in 1855 George Audemars found that an ether/alcohol solution of nitrocellulose, could be drawn into filaments which hardened in the air as the solvent evaporated. These soft strong flexible fibres were convertible into textiles, but their explosive nature prevented their use. It was Sir Joseph Swan who, as a result of his quest for a carbon fibre for lamp filaments, learnt how to convert nitrocellulose filaments back into harmless cellulose. In 1885 he exhibited the first textiles made from the new "artificial silk", but carbon fibres were his main theme and he failed to follow up the textile possibilities. Meanwhile, Count Hilaire de Chardonnet was following the same route and exhibited his first artificial silk fabrics at the Paris exposition in 1889. There he got the necessary financial backing, and the first Chardonnet silk factory was built in 1890 in Besançon. Although the route was simple in concept and had a stable spinning dope, it proved slow in operation and difficult to scale up safely. The fibre was produced sporadically until 1949, when the last factory operating in Brazil closed down after a major fire.

The second cellusosic fibre process to be commercialised was invented in 1890 and involved the dissolution of cellulose in cuprammonium liquor followed by spinning into water prior to regeneration in sulphuric acid solution. It was safer and less costly than the nitrocellulose process and proved capable of producing unusually fine and lustrous filament or staple. The process is still in use today producing speciality products, but like nitrocellulose route, it never achieved the really large scale manufacture that the next invention, the viscose process, did.

The dissolution of cellulose via its conversion to the sodium cellulose xanthate form was discovered in 1892 by Cross and Bevan. The xanthate could be dissolved in water and the resulting dope or viscose could be extruded into an ammonium sulphate solution where the polymer coagulated. The fibres could then be regenerated in dilute sulphuric acid prior to purification. Stearns and Topham perfected the spinning and yarn collection processes, and in 1904 Courtaulds Ltd. acquired the British rights. The first factory began production in Coventry in 1905, and the rapid commercial success encouraged Courtaulds to set up the American Viscose Corporation at Marcus Hook in 1910.

A fourth process based on the preparation of the acetate derivatives was developed between 1906 and 1921 and commercialised by British Celanese. Unlike the other three processes this one yielded a cellulose acetate fibre as the final product. The dope was dry spun and the fibres coagulated as the acetone solvent evaporated. Acetate fibres could be converted into cellulose and this was done commercially to make the Fortisan high tenacity rayons. Similarly, viscose rayon can be acetyalted to give a secondary acetate fibre with a higher strength than conventionally prepared acetate. Acetate rayons are thermoplastic, and exhibit many of the characteristics of synthetic fibres whilst retaining some of the advantage of cellulosics. Their relatively low strength restricts the range of applications in conventional textiles.

VISCOSE PROCESS DEVELOPMENT

GENERAL

Before considering the nonwoven applications for viscose in more detail it is worth reviewing the basic process and some of the technical developments made for the conventional textile market.

The chemistry of dope manufacture has remained substantially the same since its conception; only the scale of the operation has changed, and continuous processes have largely replaced the early batchwise ones. The key steps are as follows:

Steeping. Wood pulp or cotton pulp in sheet, roll, or flock form is soaked in caustic soda and the excess is removed by pressing.

Alkcell Preparation. The soda saturated pulp is ground up into fine crumbs and stored under controlled conditions to allow oxidative depolymerisation to occur as necessary. The ageing or "mercerising" time controls the viscosity of the final solution.

Xanthation. The alkcell is reacted with carbon disulphide to form the bright yellow sodium cellulose xanthate derivative:

$$\text{CELL O}^{-}\,\text{Na}^{+} + CS_2 \rightarrow \text{CELL O CS}_2\,\text{Na}$$

At this stage side reactions occur between the CS_2 and the soda and result in the formation of a variety of contaminants which are removed during spinning and washing.

Dissolution and Ripening. The xanthate crums are dissolved in dilute caustic soda to give the unstable "viscose" solution. At room temperature, the decomposition of the xanthate would result in a solidification of the viscose in one or two weeks, and in practice, the ageing is controlled at around one to two days to yield the beneficial redistribution of xanthate groups which improves spinnability.

Filtration and Deaeration. The viscose is filtered to remove any particulate matter and deaerated to remove the small bubbles which would disrupt the spinning.

Spinning. A wide variety of different spinning conditions have been used depending on the fibre properties required. In early days, an ammonium sulphate coagulation bath was used because spinning directly into the sulphuric acid regenerating bath proved difficult. Muller later discovered that sulphuric acid plus sodium sulphate was an improvement on ammonium sulphate, and Napper later added zinc sulphate to the bath to get tougher fibres. The basic process in spinning is the regeneration of cellulose:

$$2\ \text{CELL OCS}_2\text{Na} + H_2SO_4 \rightarrow 2\ \text{CELL OH} + 2\ CS_2 + NA_2SO_4$$

The viscose is extruded through small (50 micron for 1.7 dtex fibres) holes in precious metal spinnerettes and begins to coagulate instantaneously forming a semi-permeable membrane through which the spin bath ions diffuse inwards and the reaction products diffuse outwards. Zinc ions, when present, form an intermediate zinc cellulose xanthate derivative which takes longer to regenerate and hence renders the filaments more stretchable.

Stretching. The first viscose rayon fibres were produced without stretch. Stretching during spinning was developed by Wilson in 1914, and coupled with the acid/zinc/sodium sulphate bath it raised the fibre tenacity from the original 1.1 gms/den to 1.8 gms/den. The first really high tenacity rayon fibres came in 1926 as a result of the very high stretches possible following spinning into a strong sulphuric acid spin bath (Lilienfeldt Process). Unfortunately the dry tenacity of 5 gms/den was accompanied by an extension of only 7% and the fibre proved to be too brittle for all but the most gentle conversion processes. The quest for high tenacity with high extensibility led to the development of the present rayon tyre yarn process based on high zinc spin baths and modified viscoses, and with the all important hot acid stretching bath.

Such processes can yield the same tenacities as the Lilienfeldt process but with double the extensibility and using a less corrosive spin bath. The highest stretch levels and hence the highest tenacities were achieved as a result of using formaldehyde to delay the regeneration process. High Modulus Industrial yarns with tenacities around 9 gms/denier were made in the mid sixties using such processes.

Aftertreatments. Of the three main viscose rayon processes, the tyre yarn process has the simplest aftertreatment. It is water washed to a controlled pH, lubricated with an oil finish, dried and wound onto bobbins. Desulphurisation is not necessary for a rubber reinforcement yarn, whiteness is unimportant, and therefore acid removal (to prevent degradation) and lubrication (to assist the tyre manufacturers processes and to improve the yarn to rubber adhesion) are the only steps. Textile continuous filament yarns are generally desulphurised and bleached as well as being neutralised and lubricated. The desulphurising is generally carried out in two stages, the first involving a dilute soda bath which solubilises the sulphur contaminants, and the second being a water wash which removes them. Bleaching generally means a conventional hypochlorite treatment followed by water washing. All these processes are carried out in a predetermined sequence on large scale machines for both the textile and the staple fibre processes. (See below.) It is perhaps worth noting that one of the proprietary textile yarn washing processes does not desulphurise on the grounds that the sulphur will be removed

TABLE 1 The Properties of a Variety of Commercially Available Rayon Fibre

Type	Dry Tenacity gms/den.	Wet Tenacity gms/den.	Dry Extension %	Wet Extension %	Water* Imbibition %	Density gms/ml.
VISCOSE RAYON:						
Standard	1.9-2.5	0.9-1.3	18-30	20-40	90-100	
Improved Strength	2.5-3.0	1.3-1.5	17-25	20-30	85- 95	
Crimped	1.7-2.4	0.8-1.4	18-40	25-54	90-100	1.5 -1.52
Polynosic	3.0-5.0	2.0-4.0	6-12	9-15	55- 75	
Modal	3.5-4.5	2.2-3.2	12-15	17-21	70- 80	
High Tenacity (Tyre Yarn)	4.0-7.5	3.0-5.5	4.5-17	6.5-33	68- 76	
Hollow	2.2-2.6	1.0-1.5	13-15	16-19	120-140	
CUPRO RAYON:	1.7-2.3	0.9-1.4	10-17	17-33	100-110	1.52-1.54
ACETATE RAYON:						
Primary	1.1-1.4	0.7-0.8	25-35	30-40	10- 11	1.3
Secondary	1.1-1.4	0.6-0.8	20-30	35-45	20- 25	1.32

* For comparitive purposes the value for cotton is 40%, nylon is 12%, polyester is 3% and polypropylene is zero.

TABLE 2 A Comparison of Textile Fibre Characteristics

	Strength	Extension at Break	Elastic Recovery	Bulk Density	Water Imbibition	Equilibrium Regain	Abrasion Resistance	Crease Shedding
STAPLE FIBRE								
Cotton	2	1	1	1	2-3	3-4	2-3	1*
Wool	1	5	1	2-3	2	5	4	5
Std. Rayon	1-2	2-3	1-2	1	4	5	1*	1*
Modal Rayon	3	2	1	1	3	5	2-3	1*
Hollow Rayon	2	2	2-3	3-4	5	5	2	1*
Acetate Rayon	1	4	2-3	2-3	1-2	3	2-3	1*
Polyester	4-5	5	4-5	2	1	1	4	5
Acrylic	3	5	2-3	3-4	1-2	1-2	3	4-5
Modacrylic	3	5	2-3	3-4	1-2	1	3	4-5
Nylon	5	5	5	3-4	1	2	5	4
Polypropylene	1-2	3	5	5	1	1	4	3

N.B. On the 1 to 5 scale 1 represents a low test result and 5 a high test result
* **Can be improved by resin finishing**

in the fabric scouring step prior to dyeing, or, if the fabric is not dyed, in the first domestic wash. While such arguments are valid, it is fair to say that such yarns have only limited appeal in today's market!

On the staple route the output of a large number of spinnerettes are collected together for cutting prior to washing and drying. The acid tufts leaving the cutters are sluiced in hot dilute acid and wet-laid onto an endless conveyor belt which takes them through a washing process similar to that described for textile yarn. The evolution of CS_2 and H_2S during sluicing helps to separate the filaments and disintegrate the tufts thereby assisting even washing and bleaching.

FIBRE DEVELOPMENTS

In the 1920's and early 1930's, waste textile yarn was chopped into short lengths and disposed of in blend with cotton in various carding processes. Increasing demand for this product led to deliberate large scale production in 1935, and the low cost and versatility of the product led to its rapid acceptance as one of the major raw materials of the world's textile industry. It could be produced in various lengths and deniers to be processable on conventional cotton or woollen spinning machinery either alone or in blend with the natural fibres. Although the basic process differed little from the coninuous filament processes, new varieties were developed to suit the new markets. One of the most significant was the creation of a chemically crimped fibre which in the 1960's attained widespread acceptance as a carpet fibre, and is still in demand today in various surgical and apparel markets. At the same time attempts to correct the poor wet performance of rayon textiles led to the development of the polynosic type of high wet modulus for cotton blending. Intermediate wet modulus fibres, which used to be known as high elongation polynosics and are now called modal fibres, were developed later in response to a need for a fibre better able to withstand the easy-care finishing techniques. These fibres are made by a modification of the tyre yarn process and have proved particularly suitable for blending with polyester.

Coming right up to date, the bulk and handle of rayon blend fabrics is being improved by the creation of fibres with novel cross-sectional shapes. In 1976, Courtaulds commercialised "Fibroloft", an improved strength rayon, with a hollow cross-section, and more recently Avtex have introduced Avril III with an E shaped section.

Table 1 summarises the key properties of the various types of rayon mentioned above, and Table 2 gives a semi-quantitative comparison of the main synthetic fibres with rayon. Qualitatively, the main advantages of rayon are well established. The processes convert the most abundant and rapidly renewable natural polymer, cellulose, into a wide variety of fibres with precisely known physical and chemical characteristics. The resulting yarns, tows, or staples can be made suitable for use in almost all the known conversion processes either alone or in blend with any of the other natural or synthetic fibres. They are easy to process, low in cost, and because of their unique water absorption characteristics, they are the most comfortable of fibres to be worn next to the skin.

RECENT DEVELOPMENTS IN VISCOSE RAYON FOR NONWOVENS

DRY LAID NONWOVENS

The increasing sophistication of the nonwoven market has led to the introduction of several variations on the basic rayon fibre. They can be regarded as a further enhancement of the main advantages of rayon fibre, and are considered here under those headings.

PROCESSABILITY

The main requirement has been for staple fibre with either a lower or a higher cohesion than that which suits conventional cotton spinning. The need for low cohesion comes from either the older, slower, dry lay processes where a more easily opened fibre gives a clearer web and a more even fabric, or from the newer air laying processes where the webs are created on a supporting conveyor and not on the card wire. The need for high cohesion arises from the new high speed processes where the card webs have to withstand substantial air turbulence in the chutes and on the conveyors prior to bonding.

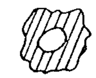
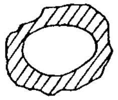
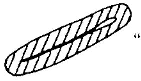
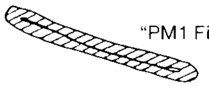
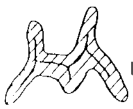
The rayon manufacturer has a wide variety of ways in which he can comply with the desired changes, and these are summarised in Table 3. Unfortunately the most suitable technique for one customer is not necessarily the best for another, and the details of the processes are not made available to the fibre manufacturer. As a result each development exercise tends to be unique, and conclusions which would benefit future developments are often difficult to draw with any confidence.

Generalising, it is possible to say that variables 1 through 4 are most frequently used to lower the cohesion, and variables 4 through 7 are used to increase it.

TABLE 3 Methods of Varying the Cohesion of Standard Viscose Staple (Web Tests)

PARAMETER	TO INCREASE COHESION	TO DECREASE COHESION
1. Fibre Denier	Decrease	Increase
2. Fibre Length	Increase	Decrease
3. Fibre Moisture	Increase	Decrease
4. Fibre Finish-Level	Decrease	Increase
Fibre Finish-Level – soap/Oleic Ratio	Decrease	Increase
Fibre Finish-Level – Special Finishes	Manufacturer Advises	Manufacture Advises
5. Fibre and shape	Blunt Cut	Sharp Cut
6. Stretch Level	Increase	Decrease
7. Regeneration Parameters	Move towards higher strength conditions or towards higher crimp conditions	Move towards lower strength conditions or towards lower crimp conditions

TABLE 4 Inflated Viscose Rayons and Their Properties

Cross Section	Name	Water Imbibition %	Dry Tenacity gms/den.	Dry Extension %	Comments
	Standard Rayon	90 -100	1.9-2.5	18-30	Uninflated Rayon for Comparison
	-	110	-	-	Not commerical
	"Fibroloft"	120-140	2.2-2.5	13-15	High bulk cotton-like Textile Fibre
	"PM2 Fibre"	150-160	1.8-2.0	20-25	Self Bonding Fibre for Wet Laid Non-wovens. Not commerical
	"PM1 Fibre"	160-180	1.4-1.8	20-25	Self Bonding Fibre for Quality Papers. Not commerical
	Super Inflated Fibre	190-350	1.0-1.4	30-50	Highly absorbent, opaque and bulky textile fibre feasibility of scale-up to commercial production currently being reviewed

It is interesting to note that there seems to be some sort of synergism between the newer high speed carding processes and the newer improved tenacity rayons. The changes made to the basic process to enable the production of improved strength fibre also increase the fibre cohesion by a factor of around 2. In a lightweight nonwoven production process this type of rayon was used following the manufacturer having difficulty in meeting the wet cross directional strength specification for diaper top-sheet. (The strength problem was initially thought to be due to some incompatibility between the fibre finish and the binder system, and the fibre change was only made after a series of different finishes had been evaluated in the production process without benefit. A thorough analysis of the combined fibre and fabric production data suggested that the best correlation was between fibre strength and nonwoven strength.) The change to the improved rayon was recommended, and the wet cross directional strength improved. The unexpected benefit of the change was the way in which the improved cohesion enabled the line speed to be raised from 80 to 120 metres/minute.

ABSORBENCY

One of the major advantages of rayon fibres is their high level of water absorption compared with other fibres, and in recent years much development effort has gone into increasing the effective absorbency in a wide variety to nonwoven products.

The effective absorbency of a fibrous product depends in practice on the rate of wetting out, the amount of water taken up between the fibres and the amount of water imbibed or held firmly within the fibre and on its surface. In the majority of structures, the testing is carried out with little or no compression, and under these circumstances the interstitial absorption dominates the total absorption. As the compression is increased, water is expressed in quantities which depend on the ability of the fibre mass to resist the compression, and under these conditions fibres which are more rigid when wet are able to retain more moisture. At very high pressures, when the mass is completely collapsed, the remaining moisture content is that contained within the molecular structure of the fibre plus the small quantities trapped within crevises on the fibre surface. Typically, this latter value is assessed after centrifuging the saturated fibre mass at 1000'g' for 5 minutes. As seen from Table 1, ordinary rayon has the highest value of all the fibres. This arises from the natural affinity between the cellulose molecule with its 6 hydroxyl groups per anhydroglucose unit and water, but the large difference between cotton and the various rayons indicates that the situation is not simply a direct effect of the polymer type. Rayon fibres have two distinct interior regions which can be revealed by staining techniques as a skin and a core. On an even smaller scale these regions are made up of crystalline bundles where the polymer chains have locked themselves firmly together with hydrogen bonds, and amorphous regions where the chains are randomly disposed. It is the amorphous form of cellulose that has the high affinity for water, and this form predominates in the core of the fibre. The skin contains more crystalline regions, and these tend to be more oriented along the fibre axis as a result of the stretching process. Cotton is very much more highly ordered than rayon and is made up of much longer polymer chains.

There is considerable scope for changing the absorbency of rayon by altering the structure of the fibre both at the molecular level and at the "cross-sectional" level. The early rayons made without stretch and without zinc baths had a higher imbibition than do the present day fibres. Their tenacity was of course, substantially lower as a result, but there are indications from the nonwoven industry that in the areas where absorbency is at a premium, the fibre tenacity could be lowered without detrimental effect.

The inflation process provides a further way of increasing the imbibition without resorting to non-cellulosic additives. In this case it is the increased surface area of the fibre which plays the main part in increasing the imbibition figure. Table 4 illustrates the fibre types isolated to date using the inflation technique. 'Fibroloft', the hollow fibre with the large hole down the middle is the first of the range to be commercialised. The imbibition increases up the range and the commercial significance of the most absorbent form, 'Superinflated Fibre'[3] or simply 'S.I.' is now being re-examined. Fibre with an imbibition of 250% has been produced on a pilot scale and is now being evaluated in a variety of end uses. Table 5 illustrates how some of the improved absorbency rayons perform in laboatory scale tampon tests, and it is in this market, where the alloy rayons have already had a significant success, that the 100% cellulose S.I. types are expected to prove attractive.

"Fibroloft" was developed to improve the bulk, handle and comfort factor of conventional textiles expecially in blend with polyester or cotton, and the early trials suggest that the same benefits could be expected to appear in nonwoven constructions.

TABLE 5 Results from a Series of Laboratory Tests on Tampon Fibres

Fibre Type	Plug Density gms/cc.	Liquid Absorbed	Water Absorption cc/gm
Dull Crimp Rayon	0.33	Water	5.6
	0.73	Water	4.4
S.I. Fibre	0.35	Water	7.3
	0.72	Water	6.8
Fibroloft	0.32	Water	6.0
	0.58	Water	4.3
Alloy Fibres (1)	0.48	Water	6.9
	0.64	Water	6.7
Alloy Fibres (2)	0.48	Water	6.1
Alloy Fibres (3)	0.37	Water	5.6
	0.72	Water	5.3
Dull Crimp Rayon	0.35	1% Saline	4.6
	0.58	1% Saline	4.8
S.I. Fibre	0.32	1% Saline	7.2
	0.74	1% Saline	6.8
Fibroloft	0.59	1% Saline	4.8
Alloy Fibres (1)	0.64	1% Saline	6.2
(2)	0.43	1% Saline	5.4

- All tests carried out in a Syngina type apparatus with 170mm head.
- In general, the 100% Cellulose fibres are unaffected by the change of saline whereas the alloy fibres which contain poymeric additives are.
- All fibres appear to be sensitive to the pressure used in tampon manufacture (as indicated by density) with alloy fibres being least affected and Fibroloft most.

In the first trial, "Fibroloft" was fed to a full scale disposable wipe production line both in blend with, and instead of, the normal rayon feedstock. No processing difficulties were encountered but there were several problems which were caused by the unusual properties of the fibre:-

a. The basis weight of the fabric fell from 47 to 30 g.s.m. reflecting the high bulk of the "Fibroloft".

TABLE 6 A Comparison of Fibroloft and Ordinary Rayon in a Dry Laid Wipe Fabric

	Standard Dry Laid Rayon Wipe	Fibroloft Wipe
Basis Weight (g/m^2)	47	40
Thickness (mm)	0.26	0.36
Total absorbency (cc/g)	8.3	13.9
Cover (% light transmission)	17.0	15.3
Tensile Dry (daN) M.D.	5.5	3.8
X.D.	1.6	0.9
Tensile Wet (daN) M.D.	2.5	2.1
X.D.	0.9	0.6
Burst Strength (10k Pa) Dry	89	71
Wet	52	65

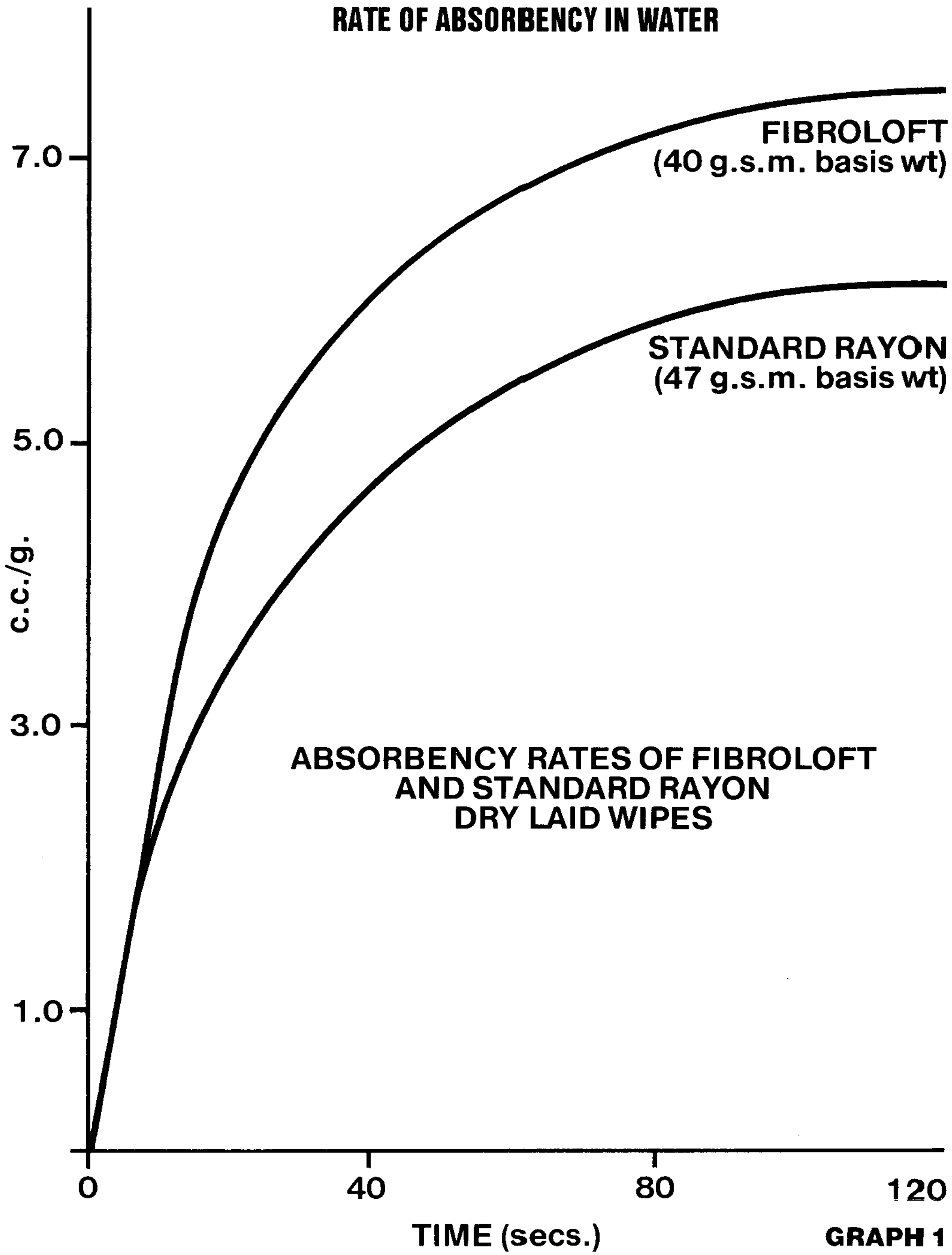
b. The fabric was significantly stronger and stiffer than the conventional rayon wipe, and this was thought to be due to the higher surface area of "Fibroloft" giving both er a higher latex uptake and more efficient interfibre bonding.

c. The wiping performance of the finished fabric was inferior to the control product, and this was also thought to be due to the effects described in b.

In a subsequent trial, the level of prebond was reduced to an unusually low level without adversely affecting the performance in drying prior to print bonding. The very high wet cohesion of "Fibroloft" coupled with its slight self bonding tendency (see also the Wet Laid section) gave the virtually upbonded sheet a significantly greater coherence than is obtainable from standard rayon. The basis weight was deliberately raised to give the end product a tangibly increased bulk and thickness than the control, and the results given in Table 6 and Graph 1 were obtained. Quantitative evidence of the improved thickness opacity and absorbency of the "Fibroloft" is seen to be obtained even at a basis weight 17.5% lower than that of the control fabric.

The reduced strength probably indicates that the optimum bonding conditions remain to be found and in future trials steps to improve the strikethrough of the print latex may have to be taken. It is possible that a less viscous binder mix is needed to penetrate the increased thickness of the more absorbent "Fibroloft" product.

"S.I. fibre" has yet to be tried in dry laid non-woven processes. It is bulkier than "Fibroloft" and is a significantly more absorbent and opaque product. Its wet cohesion is higher and its highly convoluted surface could be expected to give



GRAPH 1

more efficient bonding. On the other hand, it could prove to be more difficult to process on certain systems, and will inevitably be more difficult to dry after wet processing.

Where additives can be tolerated, rayon fibre imbibition can also be raised by adding a variety of highly swellable polymersto the viscose. The resulting products have been called alloy fibres and they are now offered commercially by manufacturers in both the U.S.A. and Europe. They are currently finding applications in tampons.

Finally, one of the consequences of rayons affinity for water is its limpness in the wet state, and this is regarded as the main disadvantage of the fibre in many conventional textile applications. Towels made of rayon have a sleazy texture when wet, and apparel fabrics have poor dimensional stability. Efforts over the years to overcome this fault have been partially successful. The development of the high wet modulus rayons have given improved wet dimensional stability. The modified cross section rayons have a better wet handle, and the use of cross linking or partial acetylation gives improved resilience. In additon, surface wettability can be adjusted to the levels of synthetic fibres simply by changing the finish. However, a target of synthetic fibre levels of wet resilience coupled with normal rayon strength and full absorbency is probably unrealistic. In conventional textiles, the absorbence of the ideal fibre has been overcome by the use of synthetic/cellulosic blends in those areas where 100% use of either fibre type is unsatisfactory, and the same could happen in dry laid nonwovens.

In nonwovens, the wet limpness of rayon is an advantage in latex bonding and in those processes where the fibres are hydrodynamically entangled, but as in conventional textiles, it is a disadvantage in those markets where a firm wet handle is desirable. Latex bonding can be made to give considerable improvements, but with adverse effects on the rate of absorbency. Development work with specific nonwoven applications in mind continues, and there are, in addition to new ideas, several techniques rejected for the conventional textils market which are worth reappraising in the dry laid fabric context.

COST EFFECTIVENESS

Traditionally, rayon has been the cheapest of the man made fibres, but in recent years the U.S. manufacturers of polyester have offered their fibre at low prices below those of rayon. One school of thought would argue that this is a temporary distortion of values arising from surplus capacity and suggests that polyester prices will rise faster than rayon prices in both the short and long terms. The other school of thought has been thoroughly aired elsewhere! The long term argument for rayon having the advantage is related to the renewability of the basic raw material and the lower dependence of the rayon processes in oil. This is discussed in more detail in a later section.

The other school of thought would also argue that rayon having been around for three quarters of a century has reached the end of its learning curve, and that there is little fresh scope for further advances. This is untrue in a general sense, and particularly untrue for a new and growing nonwoven industry. It is perfectly clear that the ideal fibre for cotton or woolen spinning processes is not necessarily the best for nonwovens. If for the sake of discussion the assumption is made that the nonwoven manufacturer could, in some of his major markets, successfully process a fibre with reduced fibre tenacity, more variable denier and staple length, but with no compromises on purity, processability, appearance or absorption. The rayon manufacturer would then in principle be able to operate with cheaper pulps, lower levels of soda and carbon disulphide, reduced filtration and cheaper, zinc free, spin baths. Even without the qualification of a relaxed fibre specification, processes are being developed which operate on two thirds of the normal carbon disulphide charges, three quarters of the normal soda levels, and with consequential savings in regeneration, purification, and pollution control[4].

One of the perennial problems of translating such concepts into reality is a direct result of the economy of scale already reached in the modern rayon plants. Any new fibre has to overcome the very large initial hurdle of the cost and the production tonnage involved in the first factory trial. In the past, the nonwoven market has not been able to provide the attractive volume necessary to ease the speciality from research to production. The situation is changing, and the larger the nonwoven industry gets, the more likely it becomes that its special needs will be met.

WET LAID NONWOVENS

The very high growth rates predicted for wet laid nonwovens in the mid sixties led rayon manufacturers to begin to develop specialities for these products. Much effort was expended, several new varieties of fibre were introduced but the market did not live up to the preduictions.

Courtaulds' efforts were linked with the inflated fibre developments described in the last section, and the work had commenced with attempts to create a fibre capable of being processed into a high quality security paper on existing paper machines. The inflation process was progressively modified until consistent pilot scale production of the powerfully self bonding "P.M.1." type of collapsed tube rayon was achieved. Then the width, thickness and length of the flat fibres were adjusted to give the desired handle, strength appearance and water marking characteristics. Several tons of the fibre were produced and converted into paper on a production scale paper machine in 100% form and without serious difficulty. The fibre could be dispersed simply by slurrying in the stock chest and was then fed directly to the headbox.

TABLE 7 The Energy Requirements of the Main Staple Fibre Routes

Fibre Production	Polypropylene	Acrylic	Viscose	Polyester
Form	Bale Staple	Staple or Tow	Bales Staple	Bales Staple
Raw material	Polypropylene	Acrylonitrile	Pulp, CS_2, NaOH, H_2SO_4	T.P.A., E.G.
Energy required ** TFOE/T fibre/yarn	1.2	1.6	1.3	0.5 (0.8)*
Raw material prod. Energy TFOE/T fibre/yarn	1.6	2.6	1.1	2.1
Total:	2.8	4.2	2.4	2.6 (2.8)*

*** Batch polymerisation ** TFOE = Tonnes of fuel oil equivalent**

At the same time, other flat fibres with higher and lower surface areas (and hence higher and lower and self bonding tendencies), were being developed and it was the lower bonding product which aroused the most interest in the wet laid nonwovens field. A 6mm/1.5 denier version of this P.M.2[5] fibre gave a soft, bulky paper or nonwoven either on its own or in blend with wood pulp or ordinary rayon. The 100% product showed the unusual effect of being coherent when wet, but completely dispersible in flowing water. Similar products were developed by A.V.C. and Kurashiki Rayon, and all three fibres were used for a time as a wet laid flushable coverstock for sanitary towels and diapers. The market fizzled out for reasons which are not too clear, but to quote a leading coverstock maker, 'flushability is no longer an issue'.

Out of the flat fibre developments came a project aimed at maximising the fibre length that could be processed into an even sheet on the newer Rotiformers and Hydroformers[6]. It was shown that high dilution factors and increased fibre rigidity helped, and that the quality of fibre cutting was of paramount importance. Traces of overlength fibres arising from poor alignment of the filaments in the tow prior to cutting or from faulty cutter blades could not be tolerated. Fibre end shape was also important and the hooked and which has since proved beneficial in improving web cohesion in dry lay processes caused entanglement and poor formation on the wet route. Precision cutting had to be carried out off-line and even then the cutter fault downgrading levels were high, waste was difficult to dispose of, and the costs of the exercise were unattractive to both the user and the producer. Courtaulds opted out of the short cut fibre market, but still supplies tow to producers with in-house cutting facilities. Needless to say, any of the routes using off-line cutting add substantially to the fibre costs, and this clearly affects the viability of rayon in this market.

For the future, the development of special on-line cutting techniques coupled perhaps with the use of finishes providing improved wet rigidity and hence a reduced tendency to entangle could be worth consideration. Short cut "Fibroloft" has, in small scale trials given indications that its high wet cohesion and slight self bonding tendency enable it to be formed into a soft paper without the need for processing aids. Furthermore, its tubular structure makes it rather more rigid in water than a comparable denier ordinary rayon. Short cut "Fibroloft" is not available commercially, and its further development like all the developments relating to the wet laid sector are awaiting a significant improvement in demand.

SPUN LAID VISCOSE

Although the wet laid developments proved generally disappointing, one of the offshoots of the work is still a real issue. Attempts were made to overcome the problems of handing long fibres on paper machines by laying endless tows. When commercially available tows were used, it was impossible to achieve acceptable web quality, and a decision was taken to design and build the necessary specialised tow making and tow laying equipment. Thus the first Spun Laid viscose pilot plant came on stream.

THE VISCOSE PROCESS

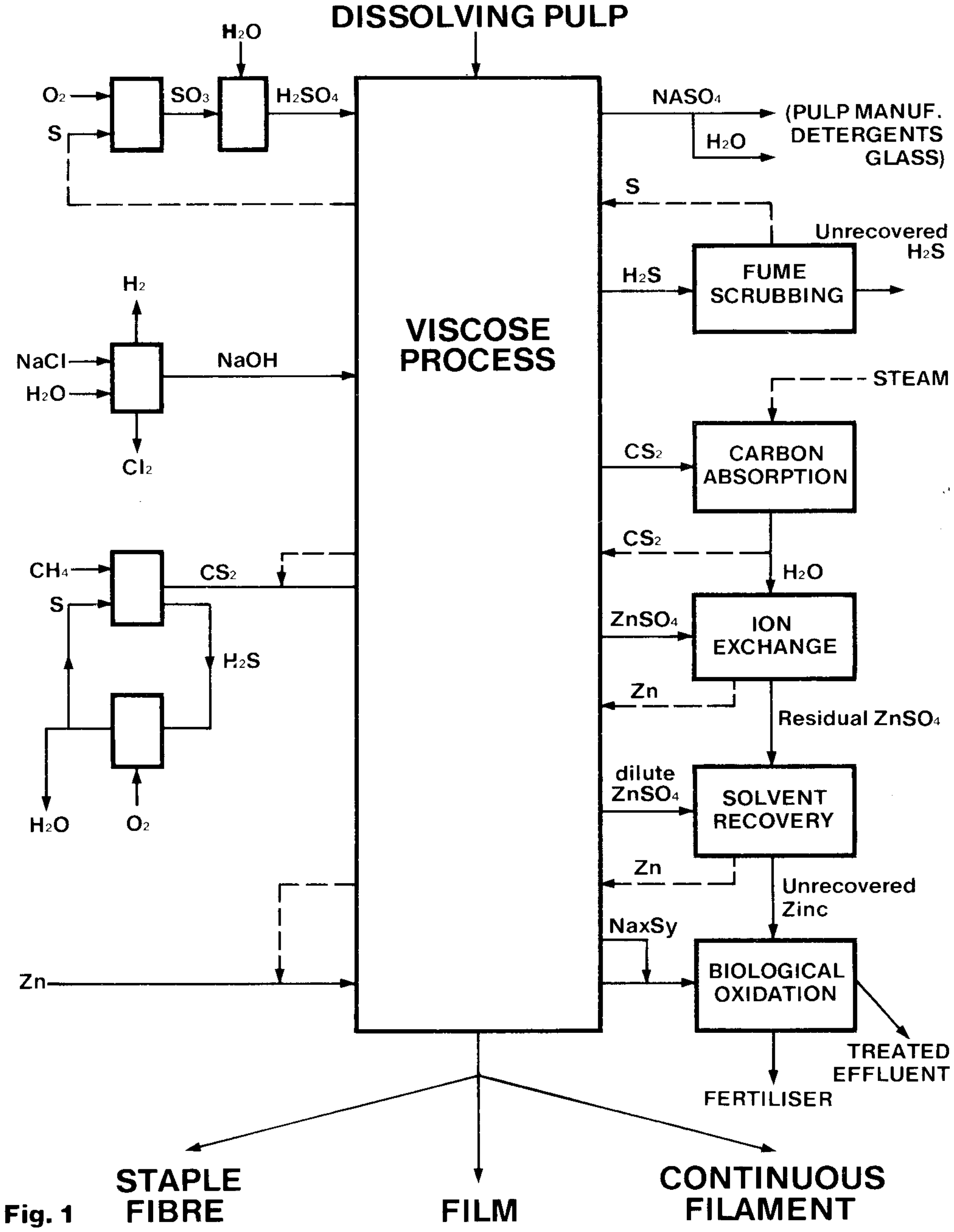


Fig. 1

By 1972 the technical problems were largely solved and the feasibility of an immediate scale up to commercial operation was investigated. Unfortunately it became apparent that the nonwovens market was not growing at the explosive rates predicted at the out-set of the project and the immediate future looked relatively bleak for a major new process. The exception was perhaps the coverstock market, but at that time the low basis weights needed, coupled with low selling prices made the spun laid process as it was then look uncompetitive with wet layed pulp/rayon mixtures or the fabrics from the newer dry lay machines. A major investment in spun bonded could not be justified and the project was shelved.

The spun laid viscose question was reopened in 1976. The nonwoven market had expanded since 1971 and the future was beginning to look brighter after the lean years of 1974 and 1975. Even so, the original spun laid route did not look right. One of the problems of linking fibre production to a nonwovens machine was the very disparity of scale which makes the launching of a new fibre in the nonwovens market a difficult business. The synthetic fibre spun bonded processes appeared in some instances to be suffering from this problem. The fibre end of the machines needed to run at high rates for long periods on one product to achieve the best economics, whereas the nonwoven end of the machine needed to make a variety of products for a diversity of nonwoven outlets. The older dry lay processes may have appeared inelegant and overcomplicated, but they were very versatile compared with the spun bonded route.

The key issue with respect to spun laid viscose was whether or not the 1970 approach could be modified to meet the demands of a wider range of nonwoven markets without losing efficiency. On paper the answer was that it could, and to help to prove it the design and construction of a new pilot plant line was commenced. The first phase of the line has now been commissioned and product development has begun. The highly flexible line is designed to be capable of handling any of the rayon fibre types currently made either in the factories or in the laboratory. It will be capable of latex bonding in the conventional manner, but will also be able to produce 100% cellulosic nonwovens by a range of techniques form spin bonding (sticky fibres) through hydrogen bonding ("P.M." and "Fibroloft" fibres) to autogenously bonded standard rayon. it will also be capable of producing continuous filament webs at a variety of basis weights and M.D./X.D. strength ratios. The early results from the new machine show considerable promise, and the line is now being extended to enable the preparation of quantities of fabric for market evaluation. The questions of how, when and where the process will be commercialised are currently under review. At present the development work is expected to continue through 1979 and a scale up to commercially viable widths in one of the Group's rayon factories could yield fabric in quantity at the end of 1980. Several new techniques are being developed within the main project, and spin offs of value to the production of the other viscose fibres are anticipated.

Two Japanese rayon producers are also working along similar lines. Asahi are using the cuprammonium process to make 100% cellulose surgical disposables, and Mitsubishi have used a modified viscose process to make their 'T.C.F.' spun laid products.

ENVIRONMENTAL ASPECTS OF THE VISCOSE RAYON PROCESS[7]

In the early days of rayon production there were few pressures, economic or otherwise, to encourage the manufacturers to conserve materials or recycle the by-products. Since the war, economic factors have dictated the use of sophisticated chemical engineering solutions to problems of wastage, and more recently the anti-pollution pressures have added impetus to the changes. Figure 1 illustrates the flowsheet of the modern viscose process and indicates the extent to which a "closed box" approach has been achievable. The majority of the major chemicals are recovered and re-cycled. Sodium sulphate, the main reaction product from the regeneration step is extracted from the spin bath and sold either as Glaubers salts or in the anhydrous form. Further improvements continue to be sought, particularly in removing the last traces of contaminants from both the liquid and gaseous effluents.

Disposability aspects of the used nonwovens is an environmental issue which can be expected to grow in importance as the disposable market grows. Viscose rayon fibres, like cotton and wood pulp, are completely and rapidly biodegraded following burial in the soil. The fibres are converted into natural humus in a matter of months, and waste fibres could even have applications as soil conditioners. The biodegradation results from the activities of soil based bacteria which utilise cellulose in their food chain, in much the same way as cows do. The ultimate degradation products are of course carbon dioxide and water, and these can be reconverted back into cellulose by the photosynthesis process in living plants. Figure 2 illustrates this point, and also draws attention to

THE NATURAL CYCLES OF RAYON AND SYNTHETIC FIBRES

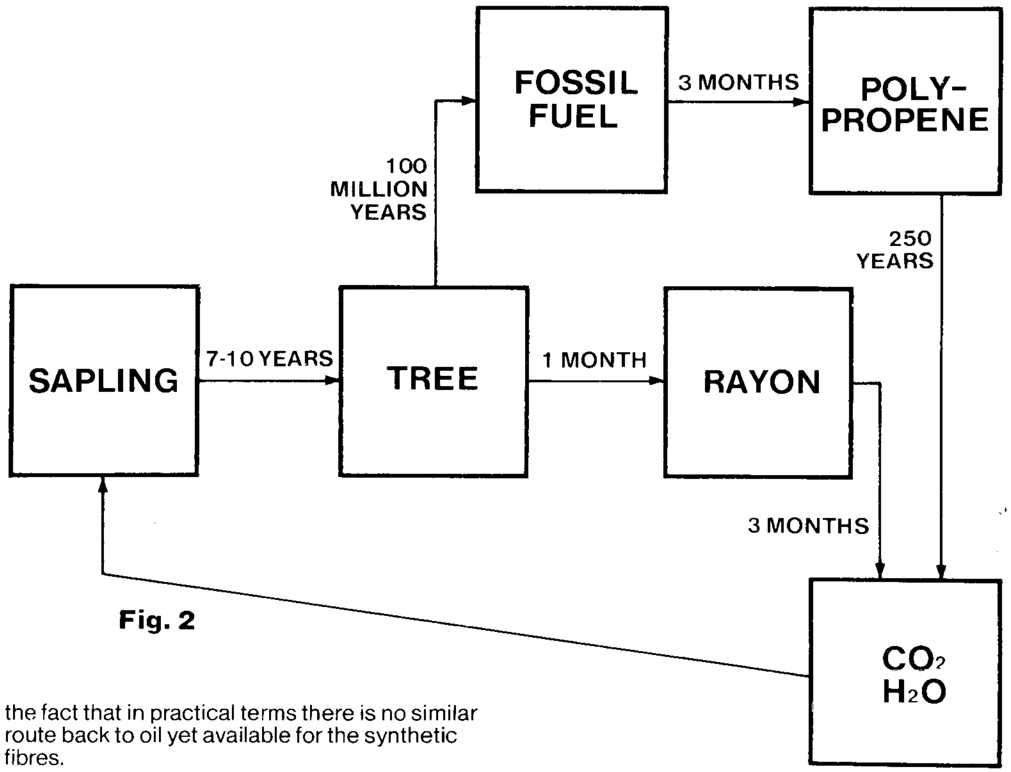


Fig. 2

the fact that in practical terms there is no similar route back to oil yet available for the synthetic fibres.

RAW MATERIAL SUPPLY CONSIDERATIONS AND ENERGY ASPECTS[7]

As indicated above, viscose rayon has a significant long term advantage over the synthetic fibres in that its basic raw material is the tree, and the tree is a rapidly renewable resource. Caustic soda is readily and cheaply obtainable by the electrolysis of brine, and the only other major raw material, sulphur, is in abundant supply and is recoverable in the process itself. With planned silviculture, and the increase in fast growing hardwood plantations, the future supply of wood pulp seems assured. In any event, the rayon industry represents only a small proportion of pulp demand. Consumption of fibre pulp in 1975 for instance, accounted for only 3m. tonnes of the 70 million tonnes of chemical pulp produced in that year. Put into perspective, the conversion of only *one* of the large chemical pulp mills to the manufacture of rayon pulp could increase the availability of dissolving pulp by 13%.

There are sensible reasons too for the feeling that the tree as a source of cellulose fibres is a more attractive long term resource than the cotton plant. The argument that cotton wastefully uses valuable food production acreage whilst trees grow in relatively poor agricultural areas, has already been widely advanced. What is perhaps less well known is that trees offer a significantly higher cellulose yield per acre. In the bumper cotton harvest of '73 – 74, the average cellulose yield/acre was between 150 and 200 kg compared with a 300 kg/acre yield for slow growing softwoods, and an astonishing 2500 kg/acre/annum yield from fast growing hardwoods.

In energy resource too, the situation is healthy. Despite suggestions from some sources, a complete balance sheet of energy requirements for the major staple fibre types shows that rayon overall is a lower energy consumer than polyester, polypropylene or acrylic fibre.

The energy balance sheet offers consolation to the rayon producer and user when the impact of energy prices on the long term future of a process and on product prices is realised.

MARKET TRENDS

Rayon has dominated the nonwoven market since the war but does not owe this success to any major attempt to tailor the fibre and process to the nonwoven manufacturers needs. In a sense the reverse is true. Nonwoven processes were developed using textile cards at a time when rayon and cotton were the only abundant and cheap raw materials for plant designers to consider. The fact that rayon had evolved with precisely controlled physical properties was of little consequence to the nonwoven man, a point which was adequately illustrated by the high demand for the lower cost second quality fibres. Denier and staple faults which would have stopped the average cotton mill were consumed without difficulty in the nonwoven processes of the fifties and early sixties. However, as the industry grew, and the market became more sophisticated, the demand for first quality fibres increased. Carding speeds were raised, or new higher speed processes were installed, and the nonwoven industry began to seek variants on the basic fibre which would enable even more efficient conversion. In the seventies the increased availability of lower cost synthetic fibres enabled the nonwoven manufacturer to begin to develop fabrics with characteristics which could not be matched by viscose rayon, and as a result, the synthetics in general, and polyester in particular, enjoyed the lions share of the growth in the tonnage consumed. The situation is till in a state of flux, and there are several views as to how the trends will continue. It is hoped that this paper will provide further information on which future speculations can be based. In the opinion of the author, the situation is in some ways analogous to that in conventional textiles about ten years ago. The synthetics offered new and interesting properties which led to their acceptance in 100% form in apparel markets where factors such as comfort were initially ignored. It soon became apparent that a blend of synthetics and cellulosics offered the best all round performance with the rest that the polyester/cellulosic blend became the most widely used man made fibre fabric. The same could happen in dry and wet laid nonwoven processes, where the ability to handle blends is a major advantage. Where the 100% synthetic character is required it will probably be obtained most efficiently from the spun laid routes. Similarly, there are indications that where purity and disposability are the key issues, 100% cellulosics will be needed, and these too would be produced mostt efficiently on a spun laid route.

ACKNOWLEDGEMENTS

The author wishes to thank the directors of Courtaulds for permission to publish this paper, and Bonded Fibre Fabric Ltd. for permission to discuss the "Fibroloft" wipe trial.

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THE DEVELOPMENT OF VISCOSE RAYON FOR NONWOVEN APPLICATIONS

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