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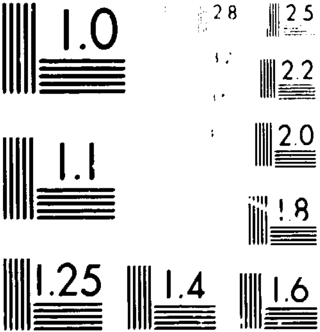
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N O N W O V E N S

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1. Introduction, definition and terminology of nonwoven fabrics.

Traditionally, fabrics are made by interlacing yarns in a woven or knitted form. But over the past 35 years a new category called nonwoven fabrics has developed as an important product of the textile and other industries, such as the paper industry.

What is a nonwoven fabric and how is it defined?

Definition of a nonwoven fabric:
Nonwoven fabrics are textile fabrics, consisting of fibrous layers, which are held together either mechanically or by means acting as or like adhesives; the fibrous layers may be combined with other flat structures such as conventional textile fabrics, paper, plastic film, foam layers, metal foils or threads.
Nonwoven fabrics can be classified - in principle - by the following aspects: (Table 1)

a) the starting materials
Starting materials for nonwoven fabrics are either commercial fibers as they are common in the textile industry, either of natural or synthetic origin, or fibers specifically engineered for the production of nonwoven fabrics.

b) the formation of the fibrous layer
From the just mentioned fiber types a flat fibrous layer is formed by different techniques, resulting in webs with properties sometimes typical for the particular technique. The fibers in the web may be oriented or just randomly laid.

c) the way of bonding
The fibrous layer or web formed by a particular forming technique is generally too weak to be used as formed and has to undergo a process step called bonding during which the strength of the web is increased. The bonding step can be performed during the formation process or afterwards. The type of bonding has an eminent influence on the structure and the properties of the final nonwoven product. Treatments of the fiber web after the bonding step are regarded as finishing processes and not used to classify nonwoven products.

Going now more into detail it can be said that the follow = ing fiber types are used in nonwoven fabrics:
Common, natural and synthetic fibers in staple or continuos filament form such as cotton, wood pulp, rayon, polyester, polyamide, polypropylene, polyethylene.
Filaments formed from a polymer just before the formation of the nonwoven web such as polypropylene, polyethylene, poly= ester and polyamide.
Filaments produced by slitting of polymer films from poly = ethylene, polypropylene, polyester and polyamide.
Specifically engineered staple fibers and continous filaments on the basis of cellulose,polyethylene,polypropylene,poly = amide and polyester.

For the formation of the fiber web from the starting fibers the following techniques may be employed:
Dry web formation: by mechanical
aerodynamic
and electrostatic means
Wet or hydrodynamic web formation

Nonwoven products can be classified by the method of bonding as follows:
Nonwovens whose bonding element consists of single fibers, bundles of fibers or of threads.
Nonwovens whose bonding elements are created at the fiber's cross-over sites by adhesives.
A third group could be defined when multiple layers of fiber webs are bonded either mechanically by bundles of fibers or by threads or by adhesives. Such nonwoven products are called composite nonwovens.
It can be seen, that the classification of nonwoven fabrics is a very complex task. The following schematic will hopefully give a good general view. (Diagram 1) In this schematic, non= woven fabrics are classified by the two aspects of the non= woven formation and the way of bonding.

2.Fields of application and end uses of nonwoven fabrics, market size.

As far as the end use of nonwoven fabrics is concerned we have to distinguish between durable and nondurable fabrics. The latter are also called disposables. Disposable nonwoven fabrics are determined to be used once or only a few times and then to be discarded.The following list reflects the wide range of application of nonwoven fabrics (Table 2 ,page 6), without claiming to be complete.
Some terms used in the list, which refer to certain production techniques will be explained later.

Table 2.

Disposable nonwoven products:

Baby diapers (cover material)
Sanitary napkins (cover material)
Sheets and underpads
Pillowcases
Tablecloth
Medical supply: operation room packages, medical gowns, caps and masks.
Filter material:
High loft, air laid webs in industrial air condition=ing
Carded webs for textile lint filters
Carded and air-laid webs for milk filters
Carded and air-laid webs for plate and frame filter=press application.
Spunbonded webs for the air and chemical filtration
Wet-laid webs for automotive oil and air filtration
Food and beverage filtration

Durable nonwoven products:

Carpets(needle felted)
Carpet backing (spunbonded)
Interlining in apparel
Furniture and bedding material
Coated fabric backing (synthetic leather)
Backing for abrasives
Durable papers (book covers)
Padding (automotives,furniture,pillows)
Backing for plastic floorcovering
Wall covering
Reinforcement in the construction industry
Electrical insulation

Market size: estimates for the production of nonwoven fabrics are both difficult to obtain and subject to error, because some products may be included and others not. Figures of the world's nonwoven production, quoted in the literature, which omitt heavy weight nonwoven products such as carpeting and also paper-like products containing a major percentage of wood pulp are charted in the following diagram (Diagram 2) and compiled in the table below (Table 3). These figures suggest a world consumption of nonwoven products of approximately 500,000 metric tons per year by the end of this decade, with current production running at approximately two thirds of this total.

Table 3. World production of nonwovens in metric tons, estimated.
US production of nonwovens in metric tons, estimated.

World production (excluding carpeting and products containing high percentages of wood pulp)		US production (excluding carpeting)	(including woodpulp)
1941	1500		
1961	60000		
1965	85000		
1967	122000		
1969	--	127000	197000
1970	180000	--	--
1971	--	--	260000
1973	280000	--	--
1974	--	222000	515000
1975	350000	--	--
1976	--	--	675000
1979	--	385000	969000
1980	500000	--	--

The diagram demonstrates the tremendous growth experienced in the past and also the growth potential of this industry in the future.

My own oppinion on the figures quoted for the world consumption of nonwoven products in Table 3 is, that they are very cautious underestimates. This view is supported by a market survey * published recently, which was performed for Western Europe and which quotes a yearly fiber consumption in nonwoven products including carpeting for 1972 Of 400000 metric tons just for Western Europe alone. The figures given in Table 3 for the US nonwoven market on the far right, which include woodpulp con= taining products but exclude nonwoven carpeting, support the view, that the actual figures for the world's nonwoven con= sumption and its future outlook must be much higher than anti= cipated. Consumption of nonwoven products has been always much more advanced and higher in the United States than in Europe. Therefor it can be said, that we have - with great probability - already surpassed the half million mark of consumption and are approaching a world consumption of almost one million metric tons of nonwoven products per year at the end of this decade.

3.Production methods.

It was mentioned earlier that nonwoven fabrics are produced in several, mostly seperated steps, namely forming of the fibrous layer, the basis web, which is bonded to give it strength. These two operations are in some cases followed by a finishing opera= tion. The whole sequence is shown in Figure 1.

First,forming methods for the basic web will be discussed.

Forming methods

Basic webs for nonwoven fabrics are produced by a number of methods which may be divided roughly into two main classes. (See also Diagram 1)

Dry formed webs (mechanic,aerodynamic,spin extrusion and elec= trostatic method)

Wet formed webs (hydrodynamic method)

* Study of the central market research of Farbwerke Hoechst AG, published in 1973.

Mechanic, aerodynamic, electrostatic web formation or as they are also called - web laying methods and spin extruding constitute the major methods of dry forming.Paper making related techniques constitute the wet forming or wet-laying or hydrodynamic method of making nonwoven fabrics.
The importance of each particular production method is reflected in the following table (Table 4),which lists the percentual share of nonwovens produced by each method.

Table 4. Percentage share,by production method, of total production of nonwoven fabrics.

Production method	Share in %	
	Forecast for the US, 1975	German Federal Republic, 1970
Dry formation	73,6	91
Wet formation	13,2	6
Spin extrusion	13,2	3

From the table it can be seen that dry formation is the dominating technique employed by the nonwoven industry.Dry formation of the basic web of a nonwoven fabric can be achieved by several approaches:
Mechanical opening of staple fibers on conventional textile machinery.
Mechanical opening of staple fibers, even with the help of air, air suspension of the opened fibers and deposition of the fibers on a screen.
Electrostatic deposition of fibers.

In conventional fiber processing for making yarns the staple fibers are blended and opened by a series of machines called blenders, openers, cards and garnetts. The latter consist principally of rotating rolls of large and small diameter equipped with needles, which perform a combing and spreading action.A typical example of the machinery in a forming process by carding is shown by the following schematic(Figure 2) The staple fibers are supplied in the form of bales, then divi= ded into smaller pieces , which are blended and fed to a fiber opening machine, which separates the compacted fibers from the bale into coarse lumps.The fibers are then transported to a card, which separates the fibers into single species and spreads them to a web, which is collected on a conveyor. The thickness of the web such formed is increased either by collecting it on an endless conveyor from which it is removed as soon as it has reached a certain desired dimension (Figure 3).This operation is called lapping. Another possibility of increasing the thick= ness of the web is by collecting thin webs from different card= ing machines.(Figure 4). The webs may be combined in a parallel fashion or by depositing webs crosswise to each other with spe= cial devices (Figure 5) . The latter method is called cross= lapping and has the advantage of producing a more isotropic web which means less oriented web with regard to the strength of the web. A web so formed has more strength in the width- and lengthwise direction than a straight carded web.

Figure 5 illustrates a simple method for crosslapping two webs on a conveyor. Web A runs forward continuously, while web B is fed onto it at a right angle.The moving conveyor reciprocates in a transverse direction above the lower conveyor and thus web B is laid in an alternating bias. A disadvantage of this method is that the diagonal lines can be detected in the finished non= woven fabric. A number of ways are used to avoid this defect. One such method involves feeding web B at an oblique angle and not at a right angle to the conveyor,another is to use two cards facing each other. This arrangement,however, requires a relatively large floor area as do other arrangements shown in the next figures (Figures 6,7 and 8).Improvements of the ordi= nary cross-lapped web can be accomplished by depositing anoth= er web parallel to the direction of the conveyors before the cross-lapped web is deposited and by placing a second longi= tudinally oriented web on top of the cross-laid web. Thus, the composite is a sandwich providing a fabric having a smooth, un= broken top and bottom surface with good strength in all direc=

tions.

Examples of major manufacturers of nonwoven production equipment by carding are:

Krupp Maschinenfabriken - Spinnbau
Hergeth KG Maschinenfabrik und Apparatebau
Davis and Furber
James Hunter Machine Co.
Procter and Schwartz, Inc.
Houget Duesberg Bosson

Random orientation of the fibers in the web is accomplished by another dry-forming technique, the deposition of the fibers on a screen from an air stream. This is what is called the aerodynamic method. Air dispersion equipment is particularly useful in processing specialty fibers, which are impractical to handle on garnetts or cards. Manufacturers of air laying or aerodynamic forming equipment are:

Dr. Fehrer, Linz, Austria
Dr. Angleitner, Linz, Austria
Curlator Corporation, USA
Birfield-Callaghan, England
Pneumat, Czechoslovakia

These machines work in principle as follows:
A feeder forms a continuous feed mat of fibers which has uniform density. A webbing machine combs the fibers from the feed mat, introduces them into a very high speed air stream, which conveys them to a so called condenser (a screen in the form of a roll or continuous belt), where a uniform, random web is formed. The air stream can be created by blowing or by suction. The strength ratio, machine-direction to cross-machine-direction, of webs produced on such machines is about 1.5, which compares very favorably with the one achieved on carding machines, which is normally 5. Examples of air laying equipment are given next in Figures 9, 10, 11, 12 and 13. These are examples of commercially available air laying equipment of different origin. The first example is the DOA nonwoven machine of the Austrian Dr. Angleitner Co.

This machine (Figure 9) works as follows:
Fibers are supplied from a large chest feeder by an elevating apron into a metering unit activated by three photocells arranged along the width of the unit.Feeding rolls deliver the fibers to an opening cylinder from where they are taken off by an air stream and deposited on a condensing cylinder.The final web is formed by passing another combination of opening and condensing cylinders.To increase the width of the web such formed, two units can be combined to give a total width of 5.8 meters (Figure 10).
Another well known type of air laying equipment is the Rando-Webber of the Curlator Corporation. It consists actually of a series of machines, the Rando-Prefeeder, the Rando-Opener-Blender and the Rando-Feeder and Webber. In the machinery before the Rando-Feeder an uniform pre-web is formed, which is combed off in the Rando-Webber and taken by an air stream to the suction cylinder and condensed there(Figure 11).
The nonwoven line V 21/K12 of the Austrian Dr.Fehrer Company consists of a feeding unit, where the fibers are pre-opened and deposited aerodynamically to give a primary web, which is transformed into the final web by a carding machine from which the fibers are taken off by air and condensed on a belt or cylinder(Figure 12).
Modified machinesof this type allow to even use short cellulose fibers in the form of wood pulp for the formation of fluffy webs for sanitary products. As an example of such a modified machine the Randomizer of the Curlator Corporation can be quoted (Figure 13).

Electrostatic fields can be used to produce fiber fleeces from very short fibers. This kind of nonwwoven materials consist in their final form of short fibers arranged vertically on a carrier (Figure 14). The short fibers are supplied to a moving belt, a carrier with a binder moves on top of the deposited fibers, which are attracted when the pass the electrodes.Fibers not attracted are collected f om the supplying belt.

Another way of forming a basis web for nonwoven fabrics is the wet-laying or hydrodynamic forming process, a technique developed from paper making methods and closely related to them. Paper is normally made from wood pulp, which consists of natural cellulose fibers of 1 to 4 mm length. This pulp mixed with water and treated mechanically - a step called refining - to soften up the fibers. This enables them to adhere to each other when they are in the sheet form.More water is added to bring the concentration of the fibers down to around 1 % and then this suspension is poured as uniformily as possible onto a moving, endless wire mesh. In this way a mat of fibers is formed on the wire mesh as the water from the suspension drains through the mesh. At the end of the wire mesh the fibrous web is transferred to an endless felt on which it is carried through aseries of presses and is subsequently dried on steam-heated cylinders and reeled up (Figure 15). A paper machine for making light weight tissue paper for hygienic purposes can run at speeds of 1000 meters per minute. It can be imagined that the output of such a machine is considerable. Machines of this type can be used in a modified form to produce textile like nonwoven fabrics. When one looks into ways of giving paper more textile-like characteristics, it is apparent that a more open and flexible structure has to be formed. This can be brought about by choosing a soft type of pulp, doing a minimum mechanic work on it, and replacing a proportion of the pulp with relatively long man-made fibers. In the extreme, all of the pulp may be replaced by man-made fibers.However , if either part or all of the pulp is replaced by relatively long fibers, it is found that the latter tend to entangle in the tanks, pipes and pumps of the production equipment and lumps and strings appear. The resulting web is therefor of very low quality. Two things must be done to avoid this- the proportion of water has to be increased considerably, and the length of the man-made fibers has to be severely limited, unless the fibers are of a special type exhibiting high degrees of dispersibility in water. Increasing the amount of water used gives rise to a number of practical problems.Larger pumps, pipes and tanks are required to handle the increased amount of water but more major difficulties are encountered at the web formation stage, in the so-called head box. To handle the large amounts of water there, the wire is inclined to form a pond (Figure 16) and suction is applied from under the wire to assist the removal of the water. Such machines equipped with special pumps to handle long fiber stocks are built for non=woven manufacture by three companies. Two of them are located in Germany, the J.M.Voith GmbH - Heidenheim, which produces the Hydroformer wet-laying machine and the Bruderhaus Maschinenfab=rik, which manufactures the NoWoformer. A third company, bas=ed in the United States, the Sandy Hill Corporation of Hudson Falls, N.Y., manufactures the Rotoformer (Figure 17), which has the wire mesh running around a perforated cylinder and for=ming so a pond of the fiber suspension. This company makes al=so a machine with an inclined wire, which is called Deltaform=er.

The webs formed on these machines are best dried on through-air-dryers, such as manufactured by Fleissner GmbH, Germany, where the wet web is dried on perforated drums through which air is sucked from the outside to the inside to give a loftier web. A similar dryer, but with a flat wire, is produced by the A&H Corporation,USA.

The last dry forming technique to be dealt with is the web formation by spin extrusion.Principally this type of web for=mation works by extrusion of a polymer melt or solution of a fiber forming polymer through a system of orifices into stream=ing air to give fibers,which are deposited on a moving support such as a continuous belt or screen or a perforated drum.

Quite a number of polymers can be transformed directly into fiber webs, for instance polyester, polyamide and polypropy=lene. One method of producing nonwoven webs directly from the polymer is the technique of blowing or spraying fibers formed from the polymer in a spraygun onto a moving and perforated screen (Figure 18).

Imposition of an electrostatic field on the fibers as they are formed helps to improve the web quality. The arrangement of such a web forming unit is shown in Figure 19. The spray gun forms one electrode, the fiber receiving screen the other electrode.

Another way of forming fibers and fiber web in one step is by utilizing centrifugal forces (Figure 20). A polymer melt is supplied to rotating jets which are surrounded by moving belts. The three methods just described lead to fibers which are not stretched. The optimum fiber properties normally achieved by fiberorientation are therefor not fully developed. That is the reason that methods of forming fiber webs by spin extrusion, where the fibers undergo an orientation are preferred over those just described. Two methods working with fiber orientation will be described now: (Figure 21) (Figure 22)

The polymer- for instance a polyamide - is extruded from a heated extruder into a manifold, which distributes the molten polymer to a system of orifices of about 0.2-0.4 mm width. The fibers formed by pressing the hot polymer melt through the orifices are caught by astream of hot air and led to a stretching channel, where the fiber orientation takes place. The hot air streams at velocities of about 270 m/sec, the diameter of the fibers changes from 0.3 mm to 0.006 mm. The fibers are collected on a perforated belt or drum after having passed the stretching channel and deposited by suction. Since the velocity of the fibers arriving on the drum surface is much higher than the speed with which the drum or belt moves, an extensive entanglement of the fibers is achieved. The covering effect of this method is improved , when the sets of orifices are moved to and fro.

A seperation of the fibers to improve the uniformity of the webs can here again be accomplished by applying an electro - static field (Figure 22). The fibers are formed by a system of orifices, removed and stretched by a number of rolls which are running at increasing speeds. The fiber tow passes a unit , where the filaments receive a uniform charge, from there they are transferred by streaming air to a grounded belt , where

the charge is neutralized and a random web is formed. The technique of spin forming of nonwovens is in Austria employed by Chemie Linz AG, where nonwovens for several purposes are produced from polypropylene.
Instead of extruding a polymer through a number of very small orifices it can be transformed into a film by pressing it through a narrow slot and the film can be slit into filaments by blades or sharp and narrow edges. The filaments can then be formed into nonwoven webs.

Bonding methods

Most of the web formation processes described so far result a mat of loose fibers, which is too weak for further processing not speaking about a particular end use. The fiber in the mat have to be bonded to each other to give strength to the web, which means in other words that they have to be linked to each other. This can be accomplished by a number of bonding methods, which are listed in the following table:

Mechanical bonding :	needle punching
	stitch bonding
Adhesive bonding:	impregnation with polymer solution or polymer dispersion
	coagulation of a polymer dispersion
	spraying of a polymer dispersion or solution
	printing of a polymer dispersion or solution
	bonding with foamed polymer dispersions or solutions
	bonding with polymer in powder form
Bonding with fibers:	by use of heat
	by use of solvents
	self bonding
Spin bonding	

One way of increasing the strength of a loose fiber mat is to form intensively entangled bundles of fibers. The distances between such single bundles of fibers have to be very close to get an even strength distribution. This formation of a close network of bundles is achieved by punching the loose fiber network with special needles, which are arranged in a very clo=se pattern on a board, which moves up and down. A single pun=ching needle is shown in Figure 23. The needle has a number of small hooks, which catch a bundle of fibers of about 10 - 20 single species and punches them through the fiber mat , ei=ther vertically or under an angle to the plain of the mat. The punching is performed on a machine called needle loom. The simple schematic of such a machine is shown next (Figure 24). A belt transports the loose fiber mat to two perforated pieces of sheet metal, through which the needles move up and down. A pair of rolls removes the densified fiber web, which can be even further strengthened by other bonding means such as fiber shrinking, a process resembling that of wool felting. (Figure 25).

Similar bonding techniques have been developed from stitch bon=ding processes mostly employed in Eastern Europe. As will be explained later in more detail, stitch bonding processes in-crease the strength of a basic web by stitching threads into the web with a number of needles. Not using a thread but just exploiting the increase in web strength resulting from looping fibers through the web by the action of the empty needles is very similar to needle punching. Two processes of this type exist, which are the Malifleece (German Democratic Republic) and the Arabeva process (Czechoslovakia). The first is derived from a stitch bonding process called Maliwatt, the latter from a stitch bonding process called Arachne.

In the Maliwatt process, a fabric is produced by stitching yarn longitudinally into a fibre web, with the finished fabric having a yarn content of 6 to 20 %. A full Maliwatt line consists of a hopper feeder, a breaker card, a finish card, a cross lapper, a transporter, a Maliwatt machine and a wind-up unit. The basic Arachne process is similar to the Maliwatt system. A third stitch bonding process has been developed in Russia-the ACHV system, which is related to the Maliwatt and Arachne processes.

The principle of stitch bonding is demonstrated by the following figure 26, showing the Arachne process.
Typical data of a Maliwatt and an Arachne machine are compiled in the next table:

Machine type	Maliwatt	Arachne
Width(mm)	2400	2400
Number of stitches/minute	1500	100
Minimal length of stitch(mm)	0,9	1
Maximal length of stitch(mm)	5,5	5,9
Web weight minimum(g/m^2)	100	100
maximum	1600	700
Needles/25 mm	14	12,5

Another way of increasing the strength of a web is by application of an adhesive to the web, which glues the fibers together. Several kinds of polymer materials in the form of solutions or better dispersions are available for this purpose:

Natural and synthetic rubber forming polymer latices
Dispersions of acrylic polymers
Dispersions and solutions of vinyl polymers

Most of the polymers are applied in the form of polymer dispersions, which are prepared by polymerizing an emulsion of a monomer in the presence of an initiator. For the preparation of rubber latices butadiene, acrylonitrile, styrene and 2-chlorobutadiene (chloroprene) monomers are used in different combinations. The so called NBR-latices consist of butadiene-acrylonitrile copolymers, whereas SBR-latices are styrene-butadiene latices. Polychloroprene dispersions are called CK-latices.
Dispersions of acrylic polymers are made from acrylonitrile, acrylamide, acrylic acid and its esters and the appropriate homologues of the methacrylic series by emulsion polymerization.

The third group of polymer compounds used as bonding adhesives for nonwoven fabrics are the vinyl polymers, which are prepared from vinyl esters of organic acids (vinyl acetate), vinyl [illegible], halogen containing vinyl derivatives (vinyl chloride and vinylidene chloride) and styrene. Water soluble vinyl polymers are polyvinyl alcohol and polyvinyl pyrrolidone, which can be employed in the form of their aqueous solutions.

Quite a number of methods of applying a polymer dispersion or solution to a nonwoven basic web are at hand.

The dispersion can be brought into contact with the basic web by dipping the web, supported by screens, into the dispersion. Two examples of such an application are represented by the next schematic drawings (Figures 27 and 28).
In the course of the hydrodynamic web formation process, binder dispersions can be added to the process water. The tiny polymer particles are attracted by the suspended fibers as the result of an electrokinetic effect caused by opposite charges on the fibers and on the particles.The polymer dispersion coagulates finally on the fibers, giving strength to the fiber web after a drying step. The method is known as the wet-end addition of the binder.
The Ciago-process forms fibrous coagulated polymers from binder dispersions just before applying them to the web during the web formation.This has the advantage that more of the binder is retained on the fibers, which means that the binder application is more effective and uniformm which in turn means that the increase in strength of the bonded web is much higher than with the conventional wet end addition of binder dispersions.
A simple method of applying binder dispersions to the basic web is by spraying them. It is possible to spray both sides of the web with appropriate equipment shown in the next figure 29, where the upper side of the nonwoven web is sprayed first, then dried, turned around, sprayed and dried again and reeled up. The polymer dispersion or solution can be applied in a cer-

tain pattern by printing instead of applying a continuous polymer film as by spraying and dipping. Several examples of the principle printing methods are illustrated by the sketches in figure 30.

One highly developed method of printing nonwoven webs is by rotaryscreen printing as developed by the Austrian firm Johannes Zimmer. A hollow roll of flexible screen (Figure 31) is held to the surface of the passing web by a bar and a magnet beneath the supporting conveyor.

The advantage of print bonding is that the resulting nonwoven fabrics have a much softer hand than the products from bonding by impregnation, spraying, coagulation and others.

To increase the strength of a nonwoven fabric bonded with a polymer binder even further and to improve its durability to washing and dry cleaning, it can undergo a heat treatment after the binder application, for instance during the drying step. The structure of the bonding polymer can be such that it crosslinks under the influence of heat, especially by the action of particular, mostly acidic catalysts, which are normally added to the polymer dispersions or solutions before application. Thus, a network of polymer molecules is formed.

One other way of applying the polymer dispersion or solution is to form a foam of it with the help of emulsifiers and to apply the foam witha blade as illustrated in figure 32.

Another alternative so far not dealt with is to use the polymer not as a dispersion or a solution but in the solid state as a bonding powder, in the form of bonding fibers, in the form of a network of bonding filaments or as film. Thermoplasticity or swellability in a solvent are the conditions for applying the bonding polymer in the solid state. A simple device for distributing a polymer powder on a web is chown in figure 33.

The powder is supplied from a storage chest to a vibrating screen by a ruffled roll. The vibrating screen distributes the powder evenly on the web, which is then heat treated and compressed.

Bonding fibers are processed with the basic fibers of the web

making up a small percentage of the total fibers. The bonding action of the fibers is activated by heat and pressure or by a solvent, which may be even present during the formation of the web. An example for this is the application of polyvinyl-alcohol fibers in the hydrodynamic web forming process.
The bonding fibers can be made of modified cellulose, such as the BAR fiber of American Viscose Corp.,a chemically modified cellulose fiber, or the RD 101 fiber of the same firm, which is a viscose fiber with a structural modification (hollow fiber), cellulose acetate and triacetate, polyvinyl alcohol, copolymers of vinyl chloride and vinylidene chloride, of vinyl chloride and vinyl acetate(MP-fiber of Wacker GmbH, Germany) Chlorinated polyvinyl chloride(PC-fiber) and mixed polymers of the polyester type (combinations of ethylene glycol and terephtalic and isophtalic acid)
The bonding fiber can be employed in still another form such as a network slit from polymer film.The film is cut by rotating knives in the form of discs, which are interrupted in intervalls of their circumference. The next figure (Figure 34) shows an arrangement to produce such a polymer network. A network of polymer filaments can be also created by extruding the polymer through spinnerets sitting on a hollow shaft, rotating counter-currently to each other (Figure35).
Spin extruded webs can be bonded by such common methods as dipping into dispersions, spraying or printing of polymers, but their own thermosensibility can be utilized to bond them immediately after formation by pressure or hot calandering.
Web formation and bonding technique have an influence on the production speed of nonwoven fabrics.The following table demonstrates (Table 5) that even the output of the slowest nonwoven process is much higher than the output of conventional textile processes such as knitting and weaving.
The very high output of paper machines has, in the past, given quite some impetus to the development of the hydrodynamic web forming methods .But so far the expectations in these processes have not been fulfilled because of the problems involved in handling long textile type fibers in the papermaking process.

Table 5. Comparison of typical rates of production of non-woven and woven fabrics.

Process	Production speed	Annual output/shift
Paper	300m/min	40,000,000m
Spin extrusion	75m/min	10,000,000m
Adhesively bonded nonwoven	30m/min	4,000,000m
Mechnically bonded nonwoven	10m/min	500,000m
Knitting	1,5m/min	200,000m
Weaving	1,2m/min	10,000m
Handweaving	0,3m/min	1,000m
Tapestry	3cm/day	10m

Finishing methods

Nonwoven fabrics may undergo a secondary treatment after web formation and bonding, leading to certain desired properties or products. The finishing methods can be divided roughly into mechanical and more or less chemical methods.

Mechanical finishing used on nonwoven fabrics are calandering and embossing to impose a smooth or patterned surface, shrinking in hot water or hot air to increase its strength, perforating by slitting or by air and water jets to increase the drapability and compacting to improve the softness of the nonwoven fabric. Abrasion treatment may be applied on nonwoven fabric intended to be coated to produce synthetic leather. Some nonwoven fabrics are coated with heat sensitive adhesives, which are used in the garment industry as interlinings to be fused to the garment rather than sewn to it. Other coating impart flame retardancy, water repellency or antistatic properties. Cleansing or polishing aids are applied to nonwovens for the household.

Thick coats of polyvinyl chloride and polyurethane are combined with nonwoven fabrics in the manufacture of synthetic leather.

4.Fibrous raw materials for nonwoven fabrics.

It was mentioned in the beginning of this lecture, that regul ar textile fibers and fibers especially engineered for non-wovens are used in the manufacture of such fabrics. The shares of particular types of fibers, differentiated by chemical struc-ture,are compiled in the next table 6:

Table 6.Share of fibers used in nonwovens, by chemical structure

Fiber type	Share in percent
Viscose fibers	45
Cotton fibers	8
Polyester	15
Polyamide	17
Polypropylene	7
Acrylic fibers	4
Others	4

A comparison of the amount of viscose rayon fibers used in nonwoven fabrics with the fully synthetic fibers reveals that they constitute the major part of the fibers used in the non-woven industry, surmounting the total of the synthetics by ca. 6 percent. But the share of the fully synthetic fibers is in-creasing constantly.

Typical fiber dimensions of viscose fibers, polyamide, poly-ester and polyolefine fibers for the different processes - web formation by mechanic, acrodynamic and hydrodynamic means and by direct spinning - are compiled next (Table 7)

The acrodynamic process requires a certain reduction of the fiber length and special fiber finishes to minimize the build-up of static electricity.Very fine continous filament is used for spun bonded webs, Fibers for the hydrodynamic process have to be short, very short when the fibers are fine, for instance of 1.7 dtex, to achieve good distribution and fiber separation in water.

Table 7. Dimensions of fibers used in nonwoven fabrics.

Fiber type	Process			
	mechanic	aerodynamic	spinextr.	hydrodyn.
Viscose fibers	1.3-56dtex 40-80mm	1.3-56dtex 30-50mm	--	1.7-40dtex 5-40mm
Polyamide	1.6-22dtex 40-80mm	1.6-22dtex 30-50mm	0.5dtex and up	1.6-22dtex 6-25mm
Polyester	1.3-44dtex 40-80mm	1.3-44dtex 30-50mm	1.0dtex and up	1.6-8.9dtex 6-25mm
Polyolefine	2.0-30dtex 40-80mm	- -	1.0dtex and up	--

As a rule it can be said that the fiber length in mm should not exceed the fiber fineness in dtex times three to four. A 1.7 dtex fiber should therefore be not longer than 5 to 6 mm to guarantee the formation of a uniform web in the hydrodynamic web forming process.Another criterion of fibers for the hydro= dynamic process is their exact cut. Only very small percentages of longer fibers spoil already the formation of an uniform web. The newest development in fiber cutting machinery, the tow cut= ting machines of Eastman Kodak Corp. and of Krupp Spinnbau AG with the name of Percut 2000 gives very good results to ful = fill this requirement.

Regenerated cellulosic fibers: Basically five types of viscose fibers are available, which are used in all of the different nonwoven processes:

regular	
crimped	
high wet tenacity	viscose fibers
polynosic	
high wet modulus	

These types are offered as dull as well as bright fibers. Crimped viscose rayon fibers result high loft webs in the dry forming processes. Polynosic fibers are suited for the hydro-dynamic process because they fibrillate during a process step taken over from the paper industry which is called refining. This process step helps to increase the strength of the final product.

At Chemiefaser Lenzing AG a new modified viscose rayon type is in development which offers good processibility in the hydrodynamic web forming process, even when long fibers are used, and good water absorption. The processibility of this fiber type can be demonstrated by a comparison of dispersions of the modified and regular viscose fibers having the same length.

Cotton fibers: The importance of cotton in nonwoven fabrics is decreasing more and more because of a better performance of the man-made fibers in processing. Cotton contains impurities from the seed shells and has the tendency to form small agglomerations of fibers called neps which show up in the nonwoven webs.

Polyolefine fibers: these fibers are used in nonwoven fabrics because of their reasonable price and their hydrophobic character. A considerable portion of polyolefine fibers goes into needle felted carpeting.

Polyester fibers: give nonwoven fabrics high performance and dimensional stability, which is the reason for their increasing use in nonwovens.

Polyamide fibers: perform best of all fibers used in nonwovens.

Polyacrylonitrile fibers: are of interest because of their bulkiness.

Scrap fibers: regained by mechanical disintegration of used fabrics and yarns are used in lower grades of nonwoven fabrics.

Synthetic fibers can easily be produced with different cross-sections resulting in certain properties such as stiffness, higher volume or glittering effects. Typical cross-sections of fibers are represented by the next figure(Figure 36)
Shrinking is in some cases a desirable property of fibers for nonwoven fabrics, because this ability of the fiber to shrink can be utilised to increase the bulkiness and the strength of the nonwoven fabric.Normally, shrinking is achieved by heating specially engineered synthetic fibers. Synthetic fibers of the regular type are stabilized fibers, which means that they retain their dimensions during a heat treatment. Unstabilized fibers may exhibit medium to high shrinkage when heated.
A shrinking effect and other effects, such as high crimp, bending ability combined with high strength may results of a special fiber construction. Two different polymers can be combined in one synthetic fiber in such a way that they form a more or less integral part of the fiber. These fibers, developed during recent years, are called bicomponent fibers.There are several ways conceivable for combining different polymers in a fiber:(Figure 37)side by side , core-sheath arrangement, distribution of one polymer component as short or continuous fibrills in the matrix of the other polymer. Figure 38 shows an example how a bicomponent fiber with a side by side structure can be made.

5. Newest developments in the nonwoven field

Of quite some interest are several processes which have been developed during recent years. One of them is the "spun-laced" process of Du Pont de Nemours, Inc. This process produces net-like nonwoven fabrics of high strength from dry or wet laid basis webs without any bonding agents. Polyester fibers are preferably used as the raw material for the basis web of this process. A schematic drawing can illustrate how this "spun - laced" process works(Figure 39): a fiber web is fed to the spun-lacing unit on a continuous screen and passes a series of water jets through which water is pressed at high velocities. The water jets act in a similar manner as needles in the needle-punching process causing intensive entanglement of the fibers. By choosing an appropriate design of the screen, perforated in a certain pattern, a nonwoven fabric can be formed having the same pattern. The products of this process are well suited to be used for home furnishing, such as curtains or bed spreads.

Earlier it has been mentioned that webs of loose fibers can be bonded together by networks of thermoplastic polymers. Such networks are produced and distributed by the Xiro AG . The nets are made from copolymers of ethylene, having a softening temperature of 82°C and a melting point of 102-103°C. The trade name of these products is "Xironet". A sketch illustrates the use of these nets(Figure 40). An infrared heater softens the network and by applying pressure to the nonwoven fabric layers can be glued together to form a composite.

A simple technique to form a high pile nonwoven fabric is also a recent development. This process of the Metzeler Schaum GmbH, German Federal Republic, allows to produce a fiber pile on a carrier, which may be a woven or nonwoven fabric. A molten fiber forming polymer is applied to the carrier, which is peeled off to form numerous fibers which are quickly cooled and thus stabilized. Polyethylene, polypropylene, polyamide or polyvinylchloride are the polymers, which can be used in this process(Figure 41)

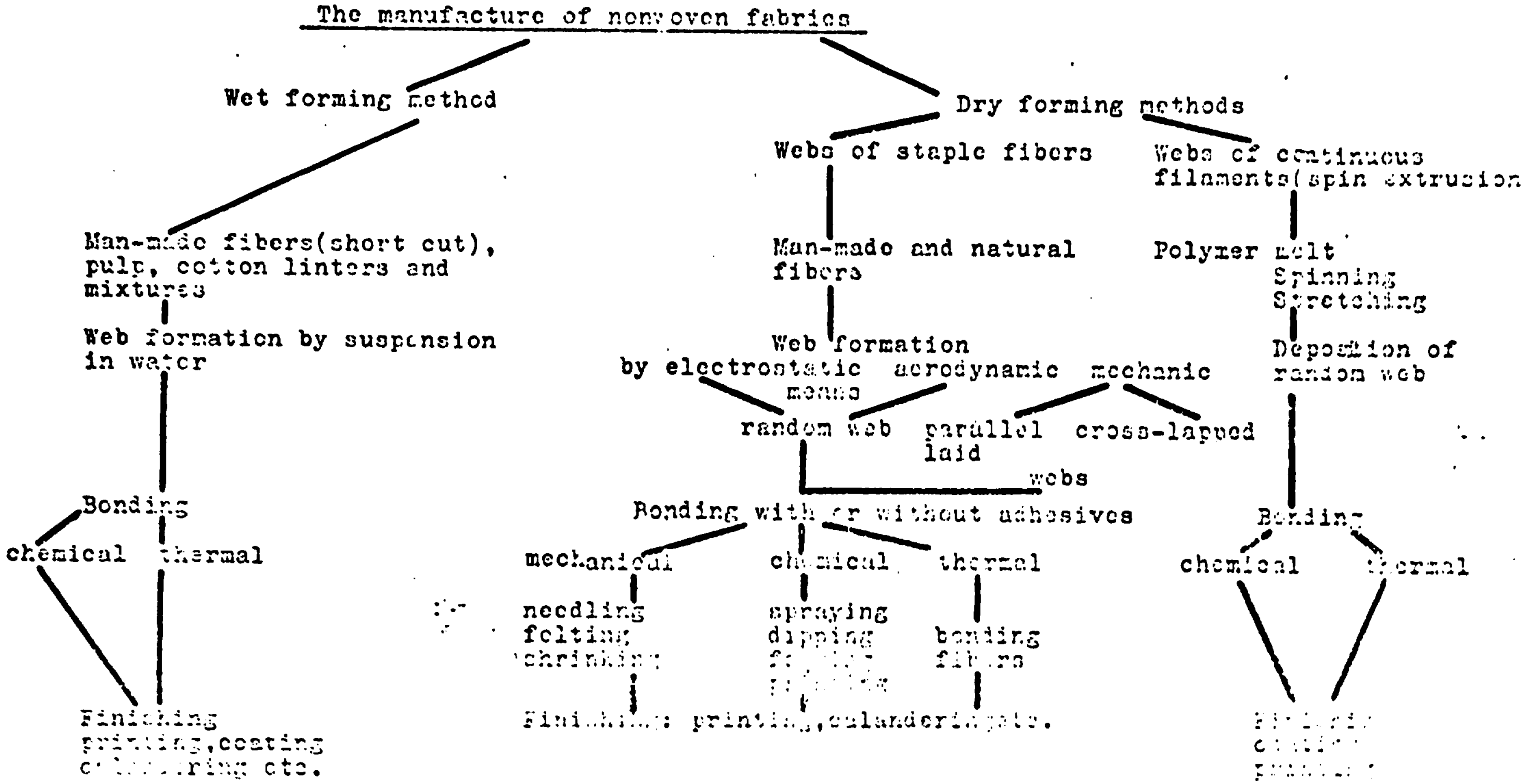
Table 1. Aspects of the classification of nonwoven fabrics:

The starting materials

The formation of the fibrous layer

The way of bonding

Diagram 1


The manufacture of nonwoven fabrics
Wet forming method
Dry forming methods
Webs of staple fibers
Webs of continuous filaments (spin extrusion)
Man-made fibers (short cut), pulp, cotton linters and mixtures
Web formation by suspension in water
Bonding
chemical
thermal
Finishing printing, coating calendering etc.
Man-made and natural fibers
Web formation
by electrostatic
aerodynamic
mechanic
means
random web
parallel laid
cross-lapped
webs
Bonding with or without adhesives
mechanical
chemical
thermal
needling
felting
shrinking
spraying
dipping
bonding fibers
Finishing: printing, calendering etc.
Polymer melt
Spinning
Stretching
Deposition of random web
Bonding
chemical
thermal

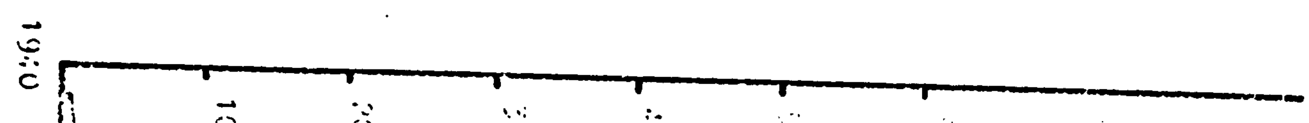


Diagram 2. The world's nonwoven production

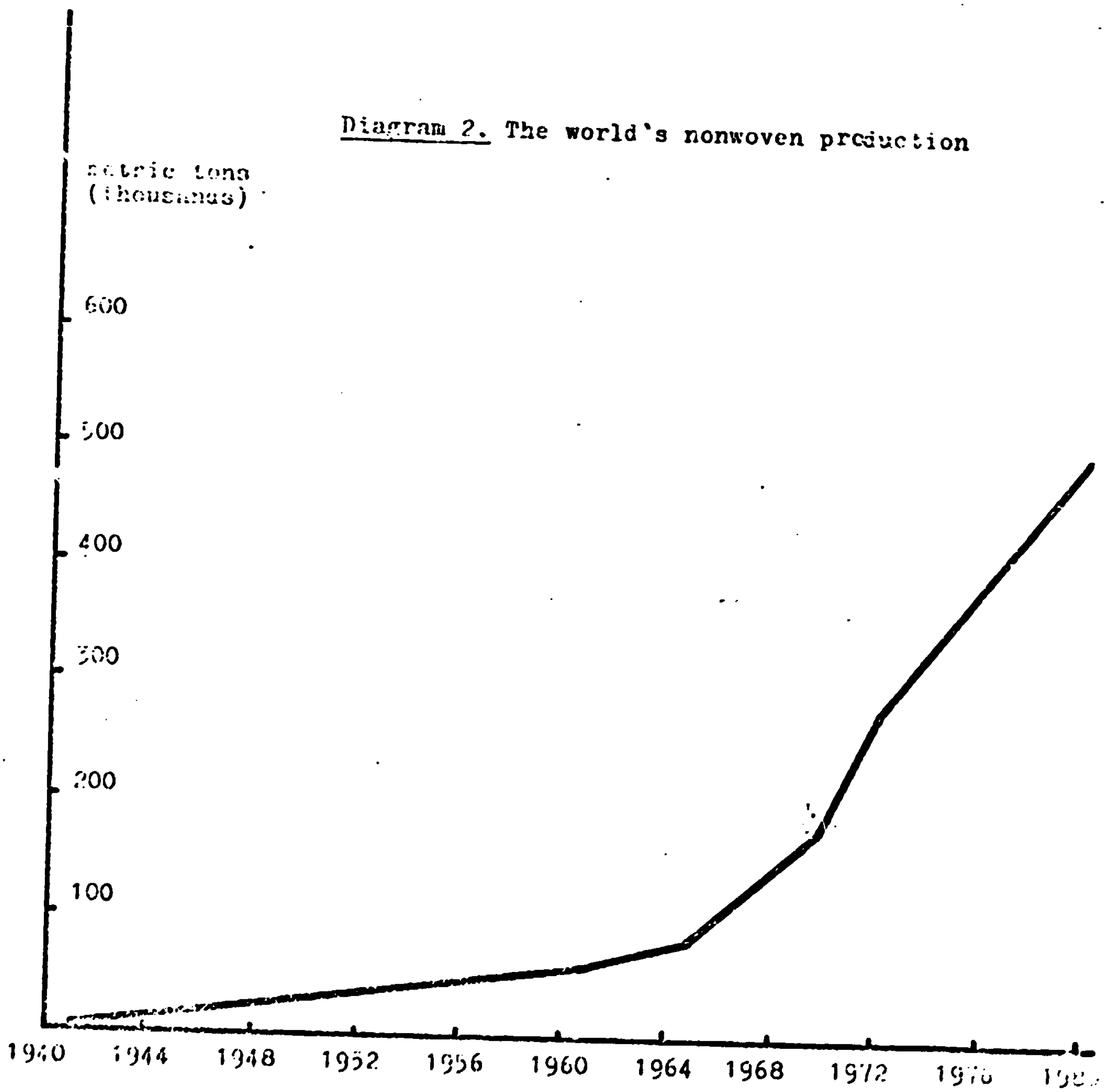
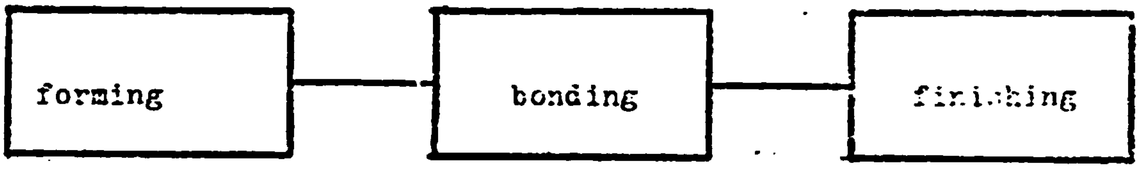


Figure 1. Production steps of nonwoven manufacture



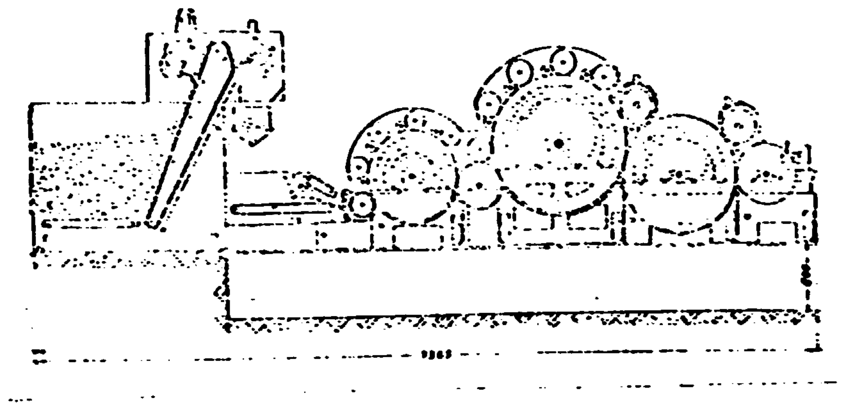


Figure 2. Carding machine

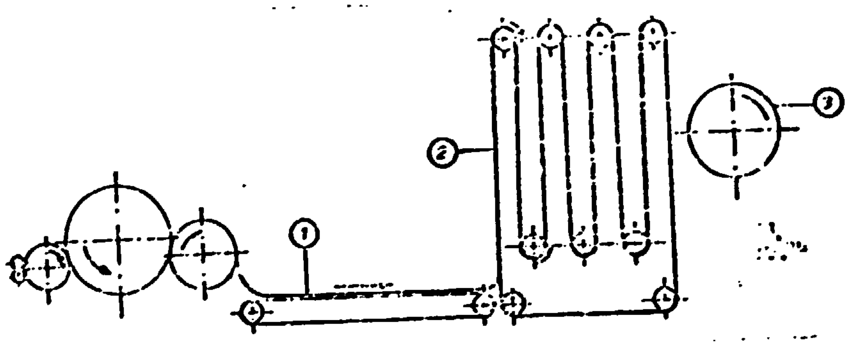


Figure 3. Lapping of web on a continuous belt.

1-conveyor
2-lapping belt
3-reel-up

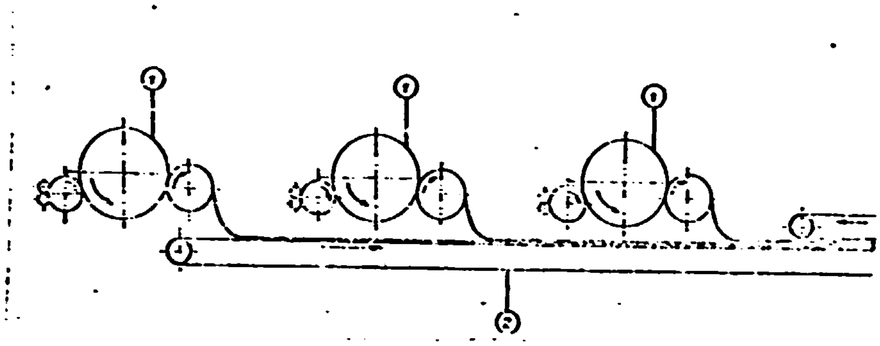


Figure 4. Lapping of webs from different cards.
1-carding machines   2-conveyor

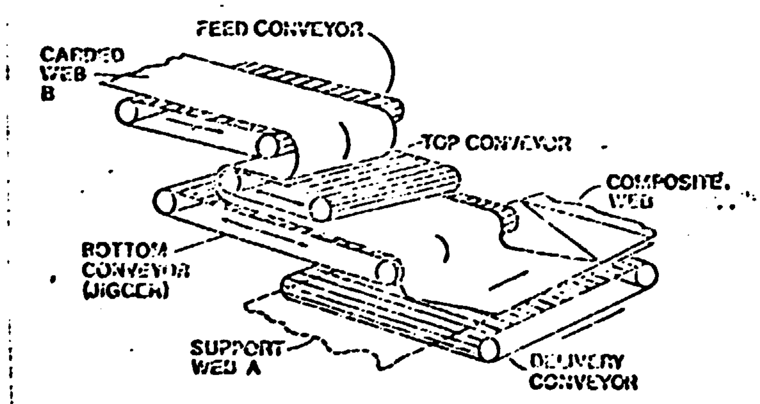


Figure 5. Schematic presentation of cross-lapping two webs on a conveyor.

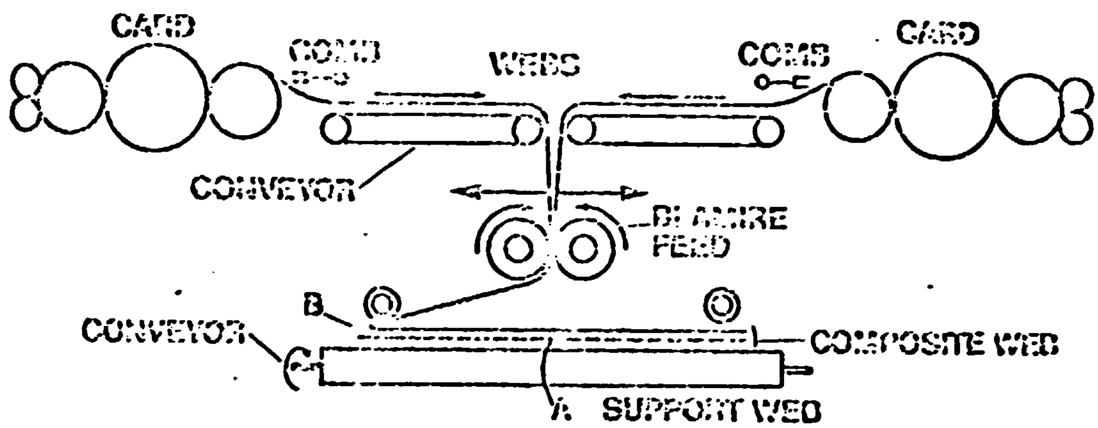
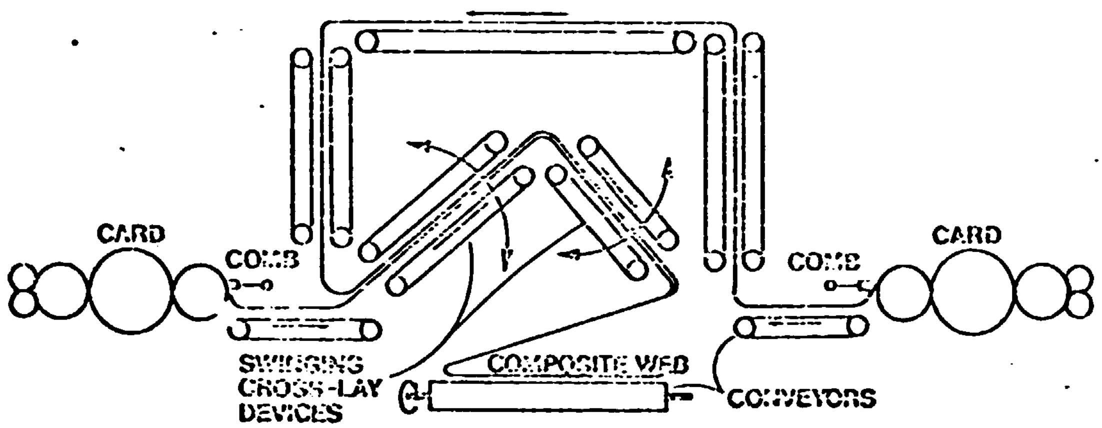
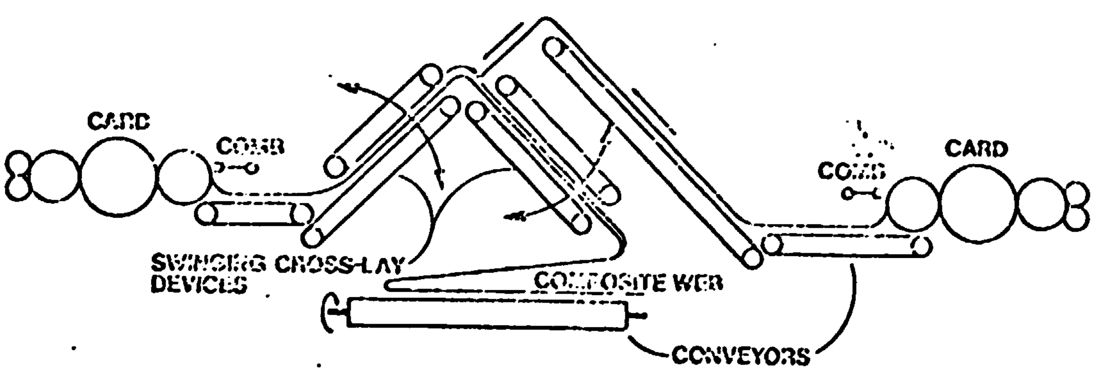


Figure 6. Web feeding from two cards facing each other.





Figures 7 and 8. Cross-lapping with swinging apron.

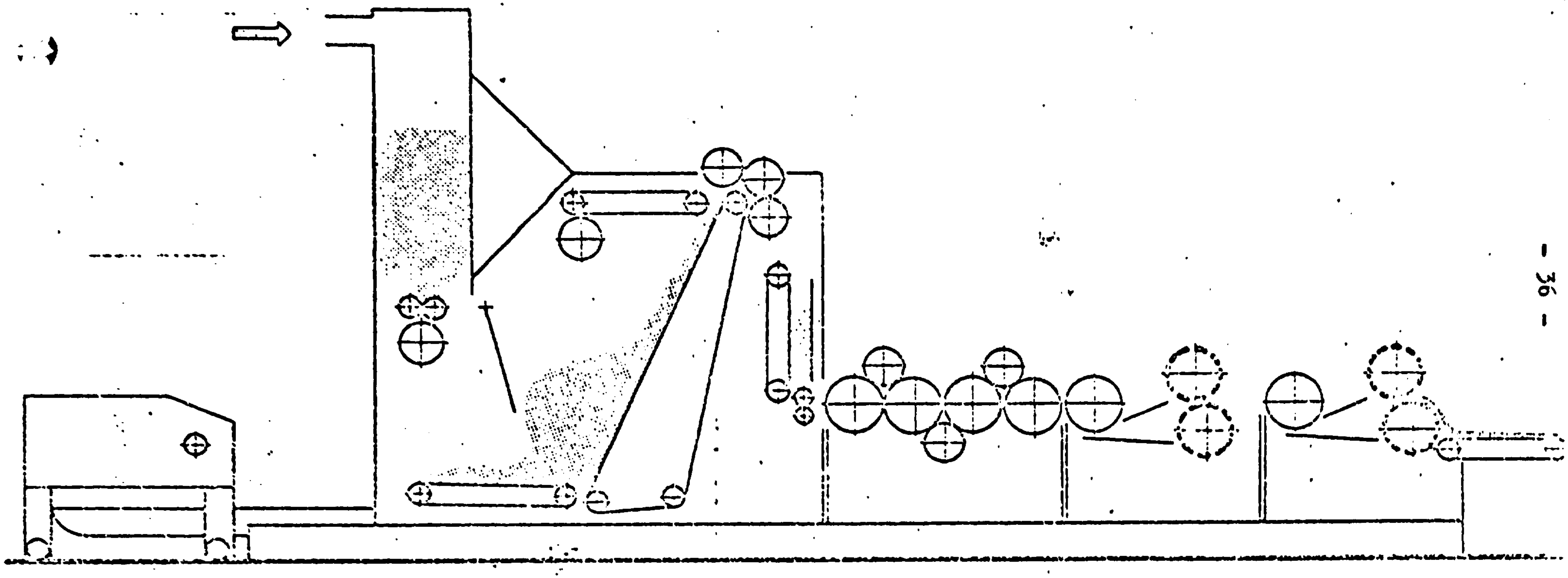


Figure 9. DOA nonwoven machine 1112 + TS + D

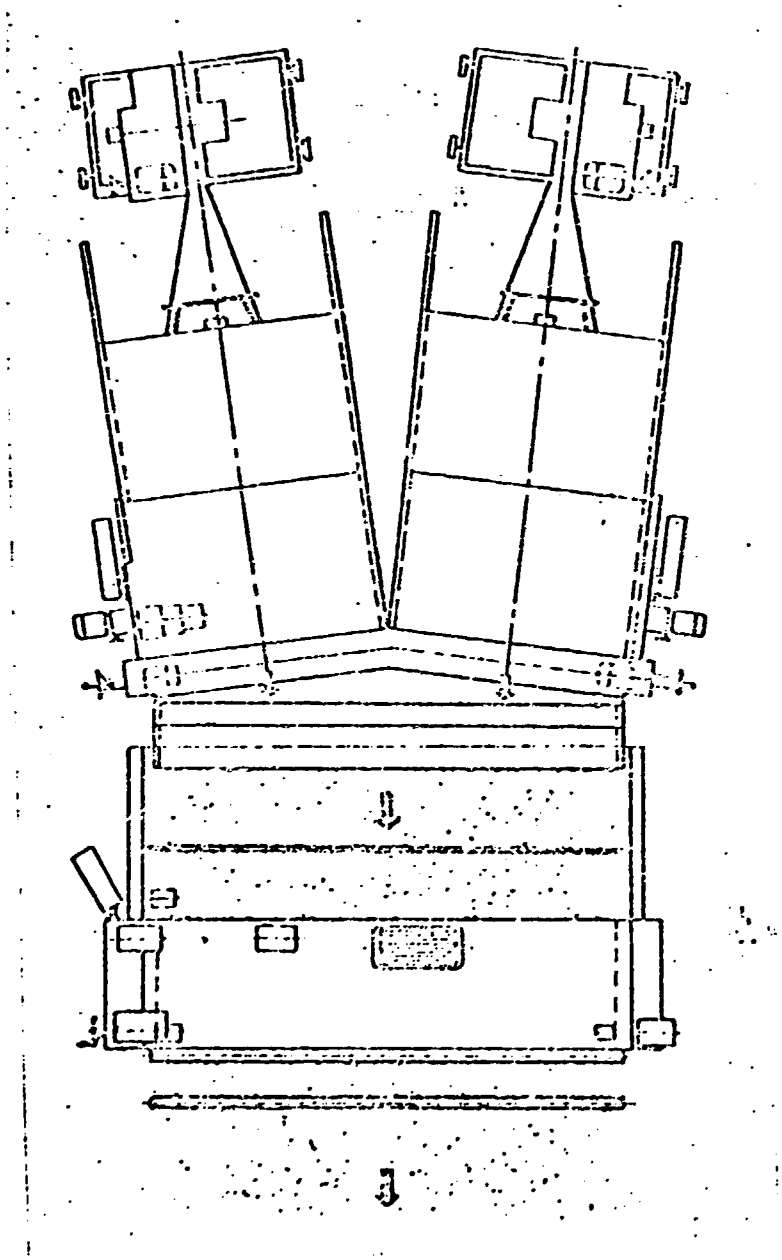


Figure10. DOA nonwoven machine with doubled width.

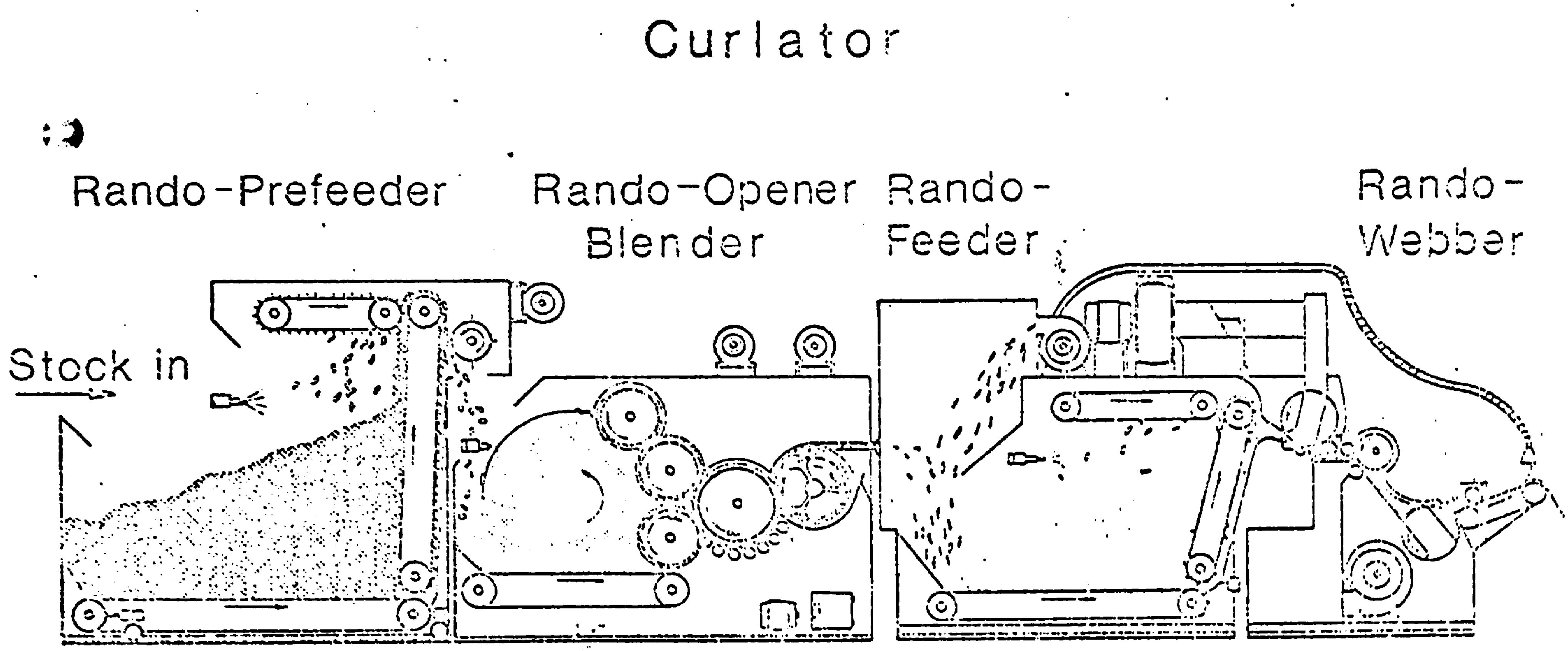


Figure 11. Curlator nonwoven line.

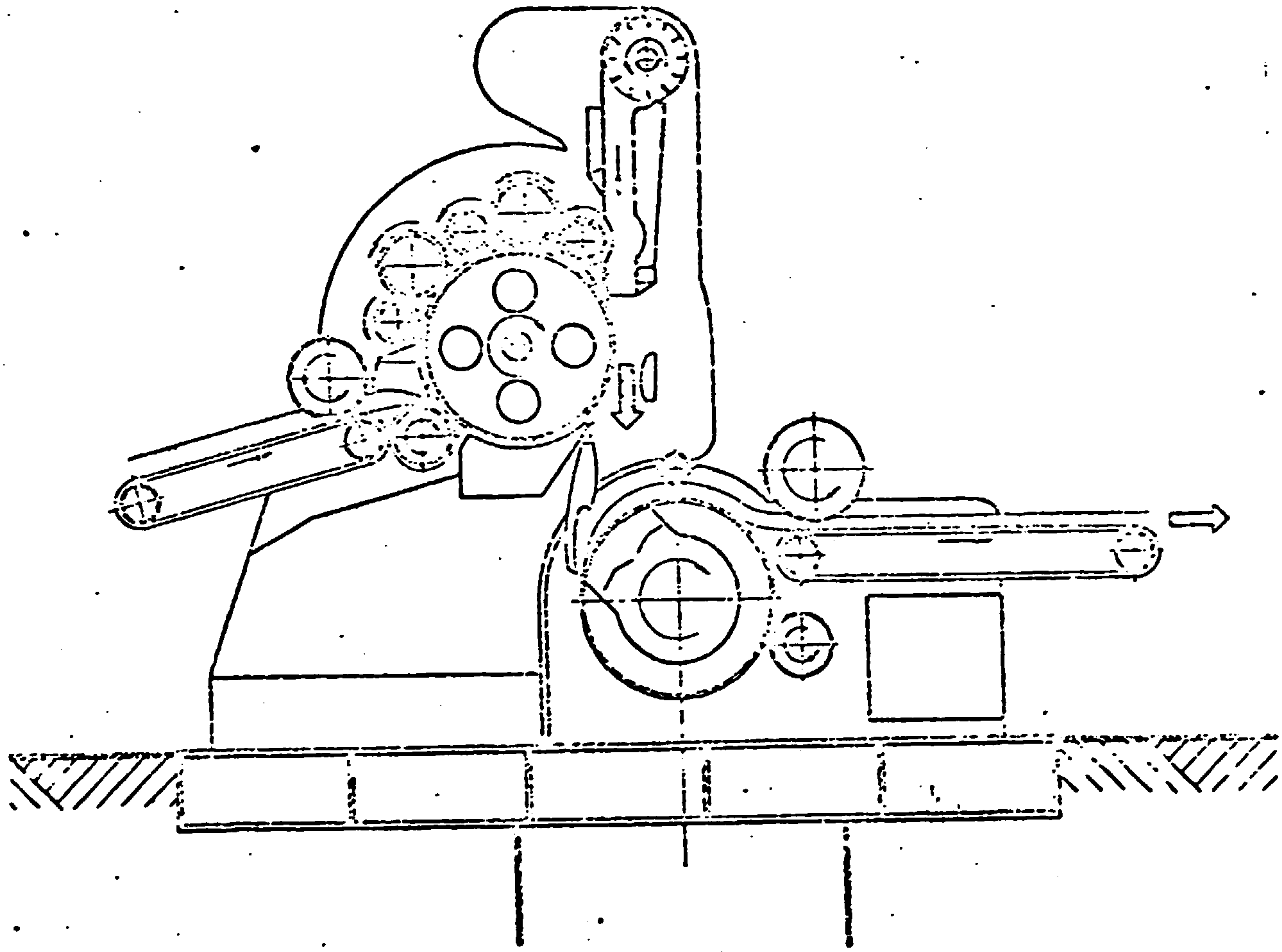


Figure 12. Fehrer random card K12

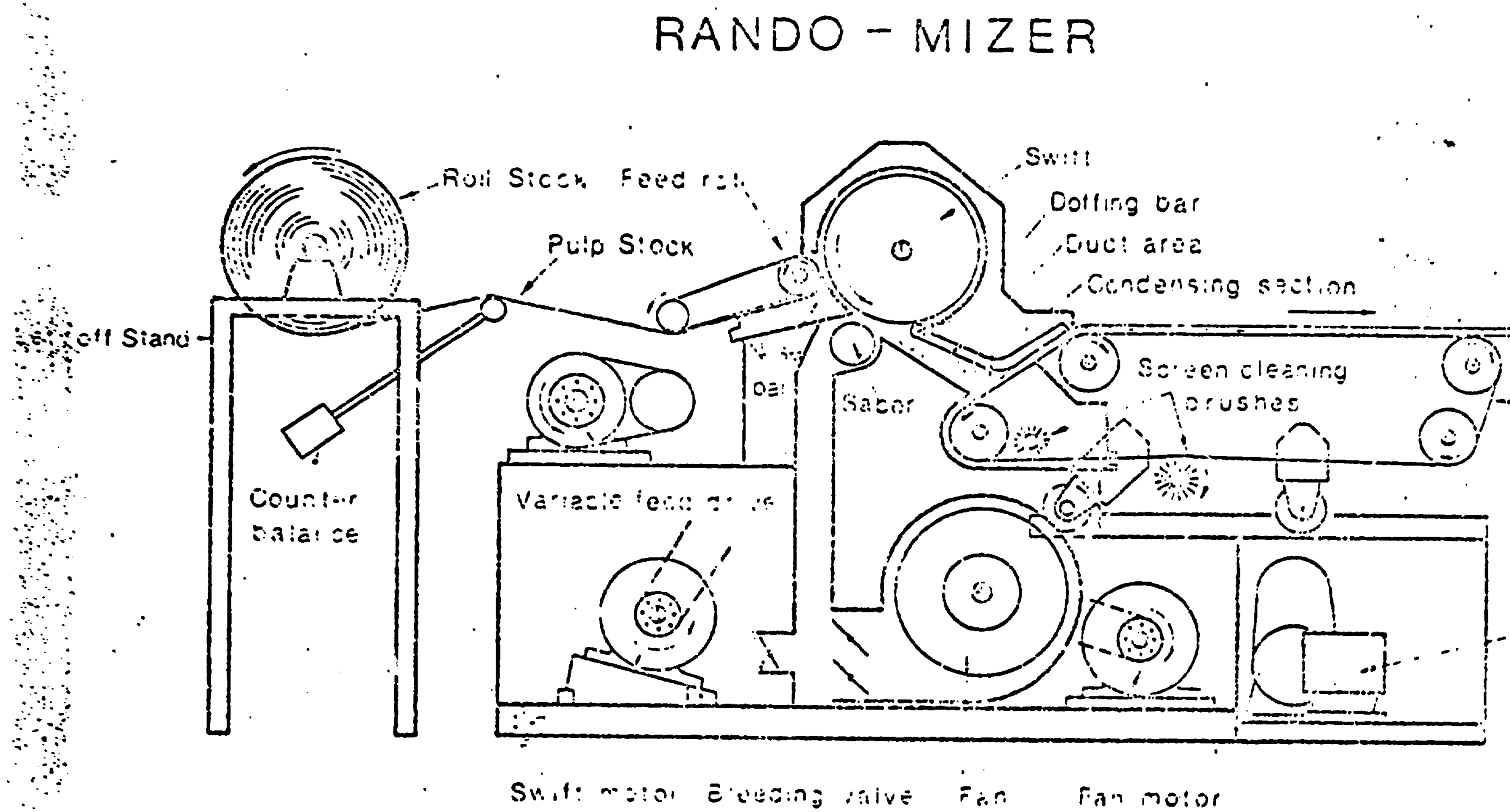
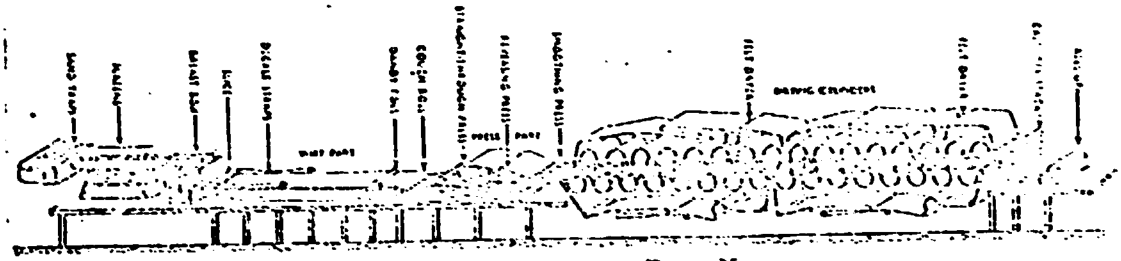


Figure 13. Nonwoven formation by air deposition of pulp.



TYPICAL FOURDRINIER PAPER MACHINE.

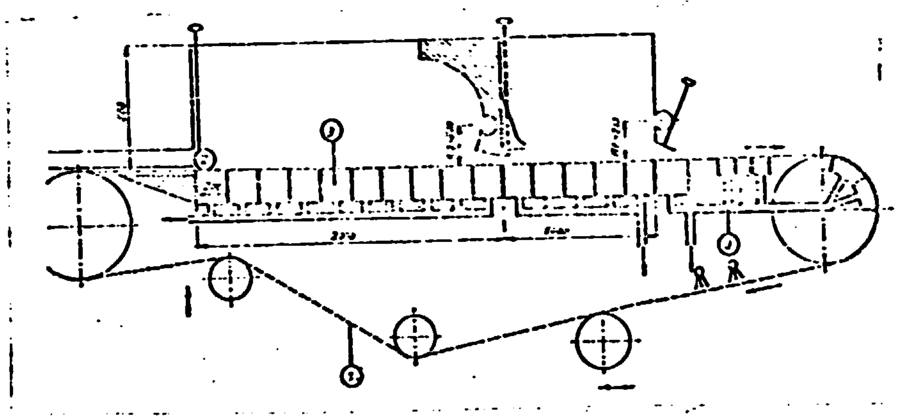


Figure 15. Views of paper machines.

1-wire belt,2supply of fiber (stock) suspension,3foils

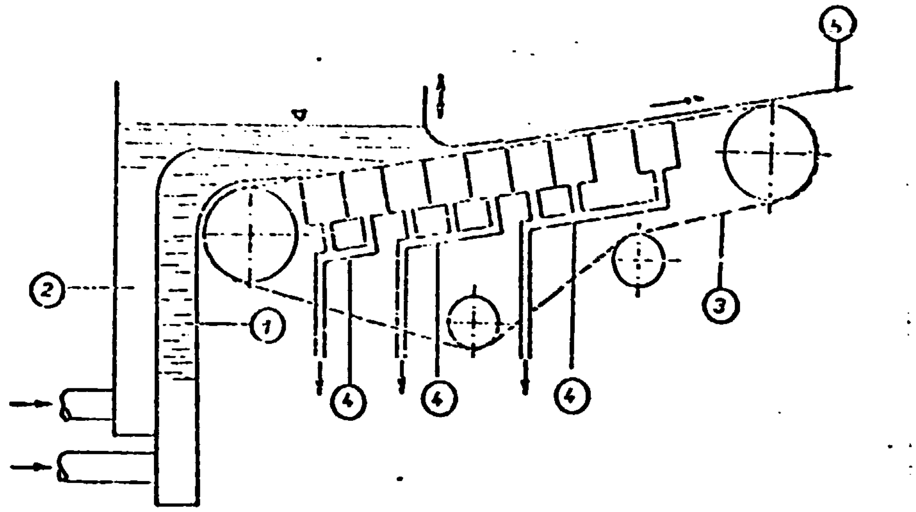


Figure 16. View of headbox of Voith Hydroformer

1-Formation zone 1, 2-formation zone 2, 3-wire belt
4-suction boxes, 5- web

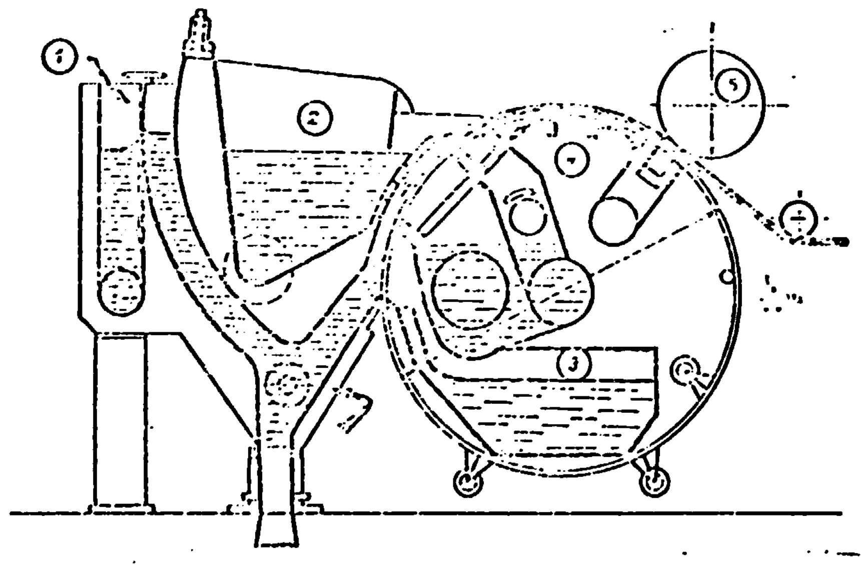


Figure 17. View of headbox of Rotoformer produced by the Sandy Hill Corporation

1-Supplying piping of suspension of fibers, 2-regulating pond for height of suspension, 3-water collection from free flow, 4-suction boxes, 5-web pick up roll.

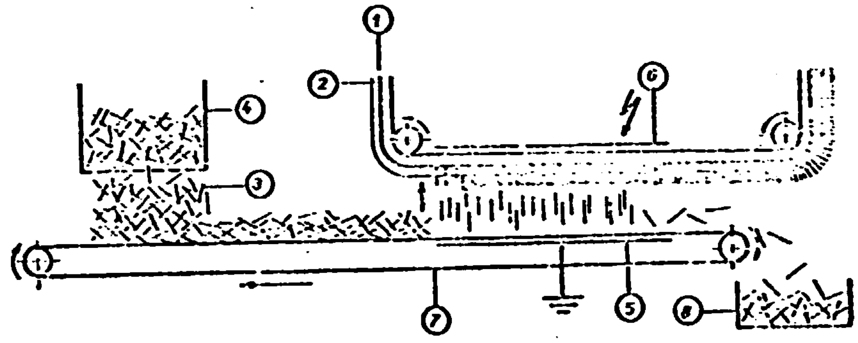


Figure 14. Electrostatic flocking

1-carrier, 2-adhesive, 3-flock, 4-fiber metering, 5-electrode, 6-counter electrode, 7-conveyor, 8-excess flocking fibers.

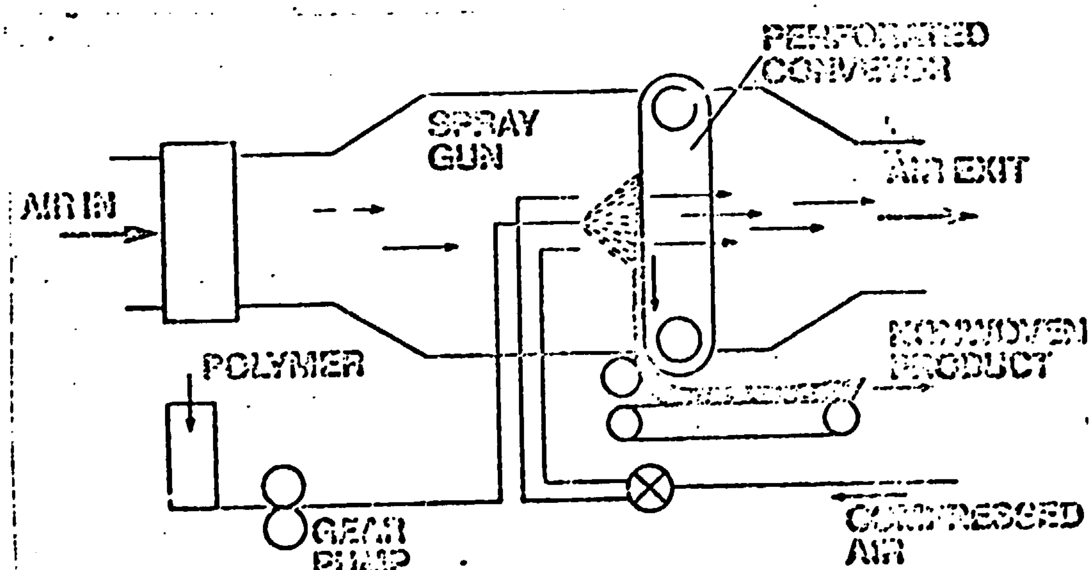


Figure 18. Schematic arrangment for spray web formation.

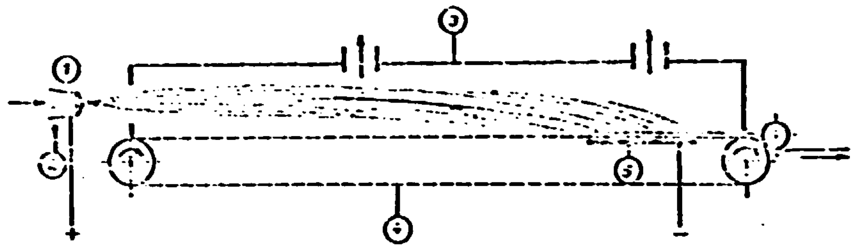


Figure 19. Web formation by fiber spraying in an electro= static field.

1- spray nozzle, 2- air supply, 3- drying chamber,4-conveyor, 5- counter electrode.

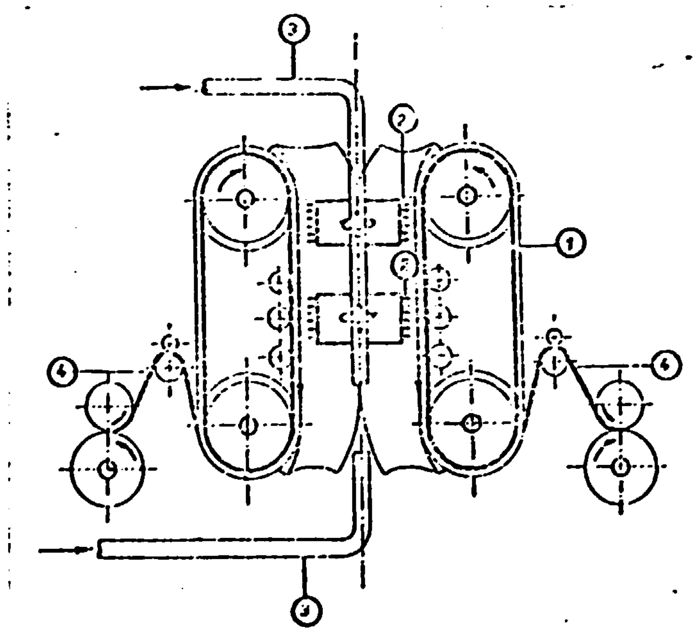


Figure 20. Web formation from a polymer by centrifugal forces.

1-circular arrangement of six conveyors,2-rotating spinnerets 3-polymer supply, 4- web reel-up.

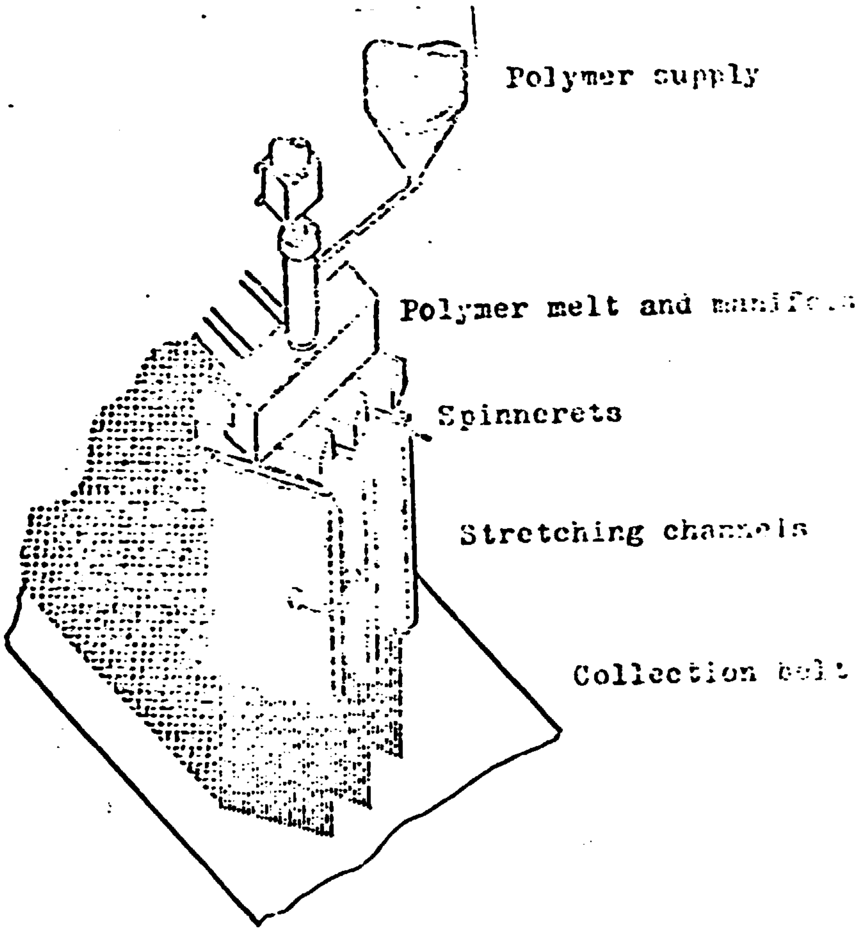


Figure 21. Web formation from a polymer by spin extrusion [illegible] air stretching.

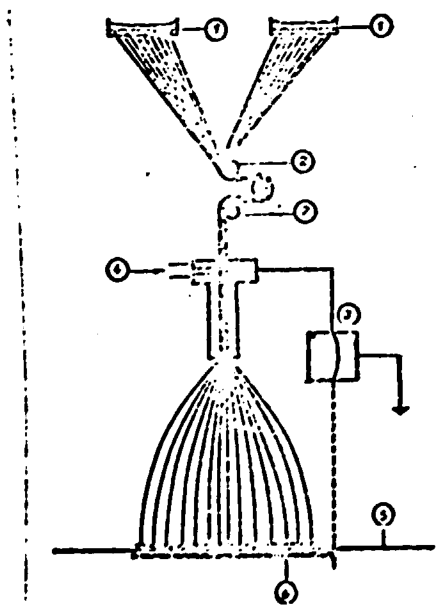


Figure 22. Spin [illegible] electrostatic fiber [illegible]. 1-spinnerets, 2-st[illegible], 3-charging, 4-air [illegible], 5-con- veyor, 6- counter [illegible].

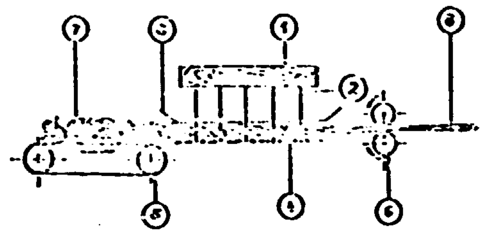


Figure 24. Needle loom arrangement.

1-needle board
2-needle
3-perforated screen
4-support
5-conveyor
6-rolls
7-basic web
8-needled web

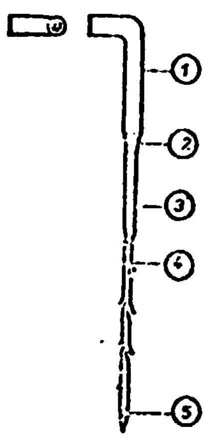


Figure 23. Barbed needle for needle punching

1-stem of needle
4-barbs

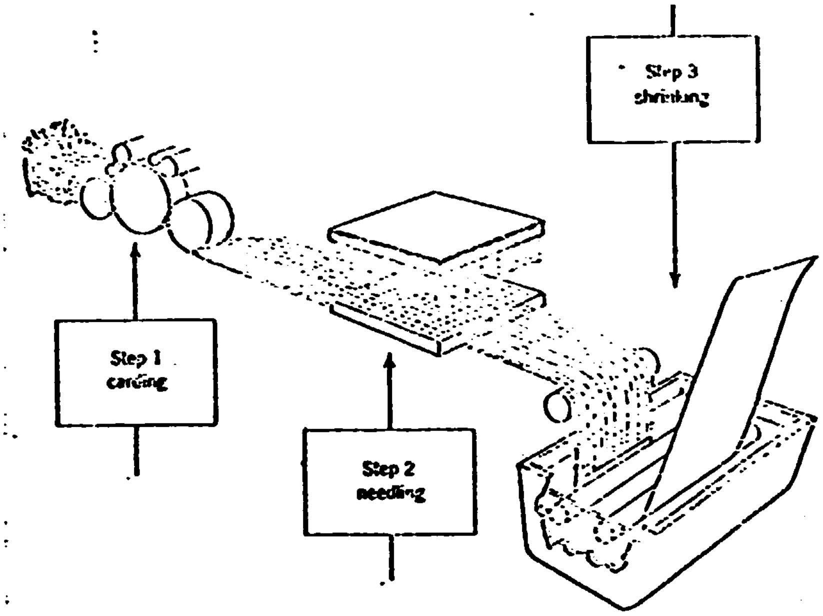


Figure 25. Needle loom in a card line.

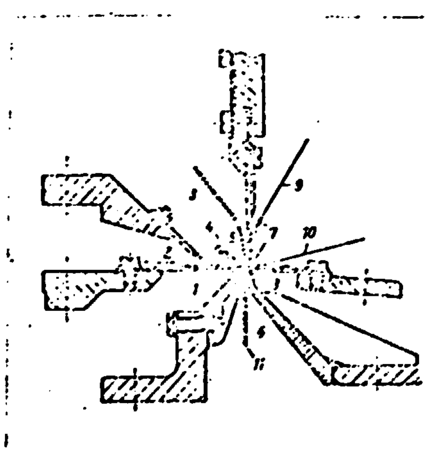


Figure 26. Stitch bonding by the Arachne technique

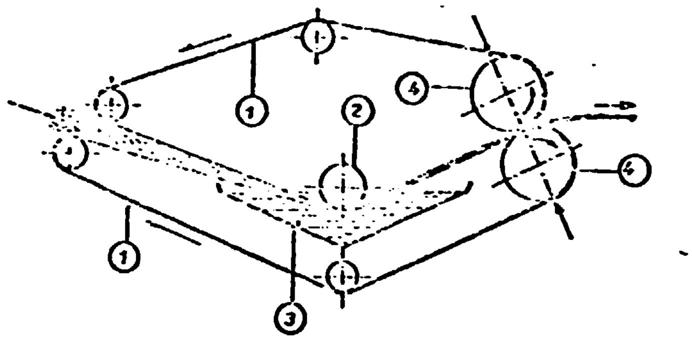


Figure 27. Web impregnation by dipping between two conveyors.

1-conveyor

2-press roll(metering)

3-trough with binder dispersion

4-squeeze rolls

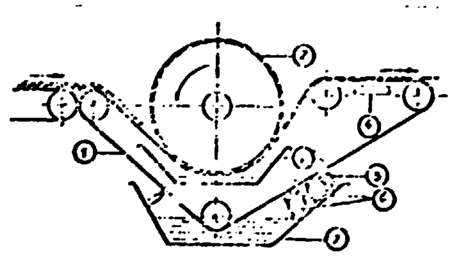


Figure 28. Web impregnation by dipping between screen and roll.

1-perforated screen
2-perforated drum(roll)
3-trough with binder dispersion
4-removal of excess binder
5-water spray for screen cleaning
6-rotating brushes
7-waste water

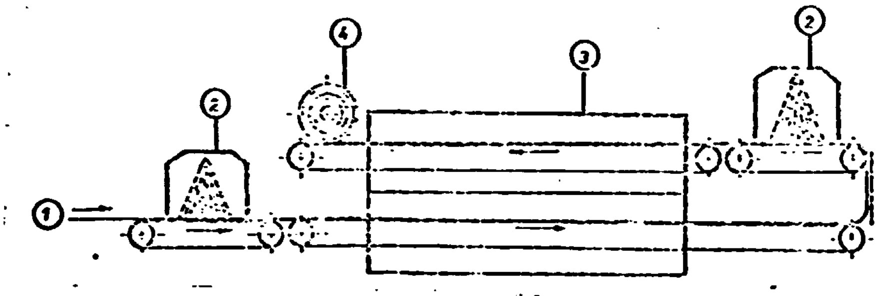


Figure 29.Spray application of binder dispersion.

1- from web formation

2- spray chamber

3- drying oven

4- reel-up

Figure 30.(below) Printing techniques for print bonding

1- Relief printing
2- Rotary screen printing
3- Intaglio printing
4- Flexo printing

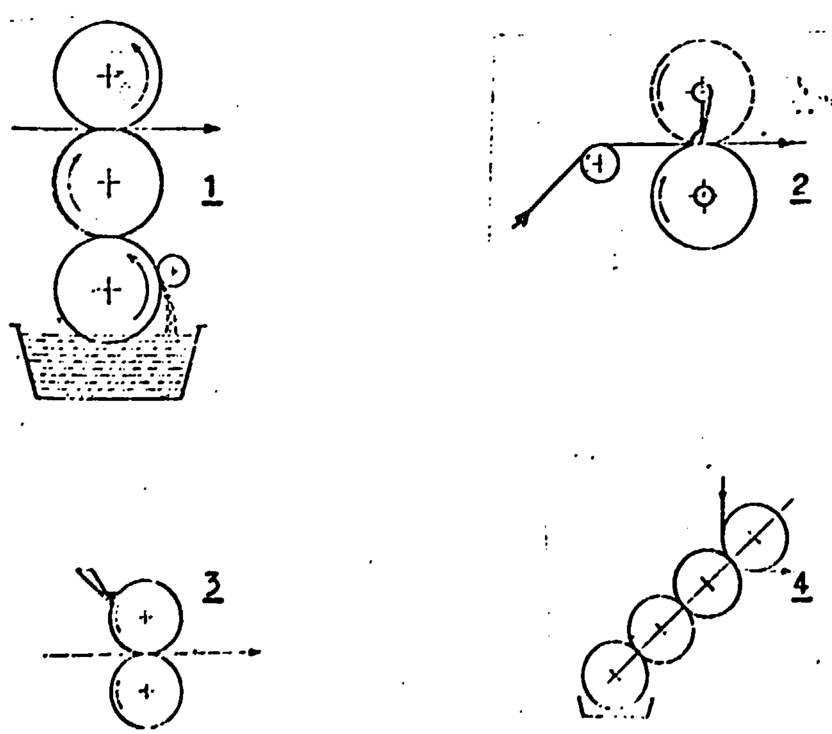
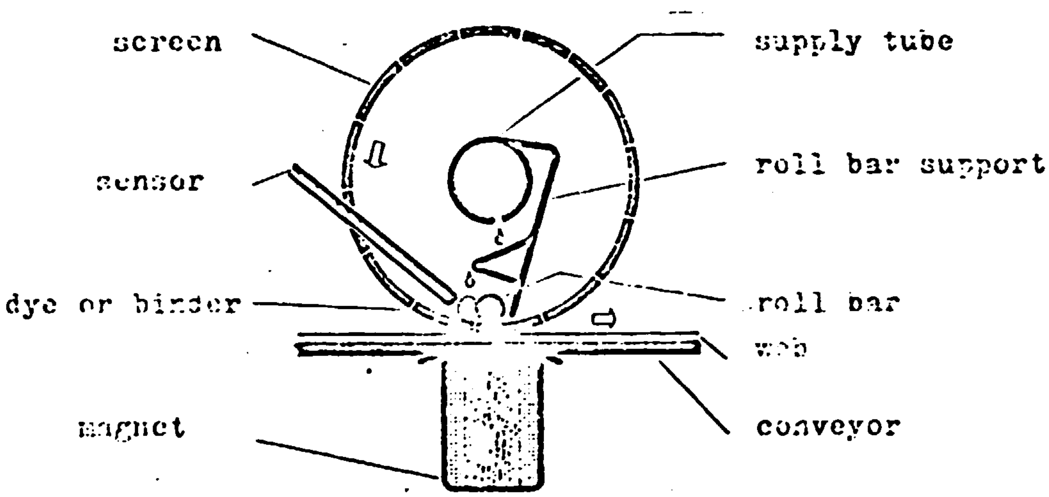


Figure 31. Detailed view of rotascreen-printing installation.



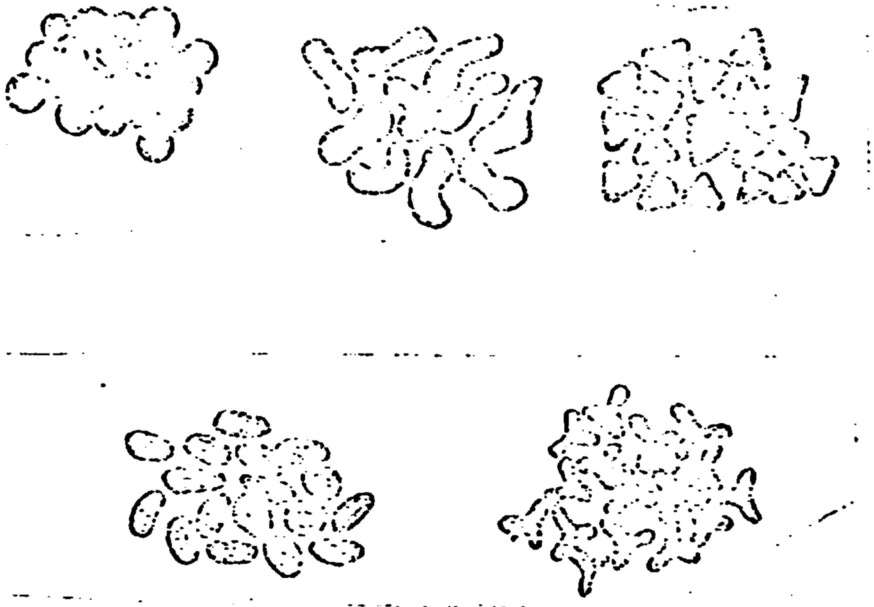


Figure 36. Cross-sections of synthetic fibers engineered for nonwovens.

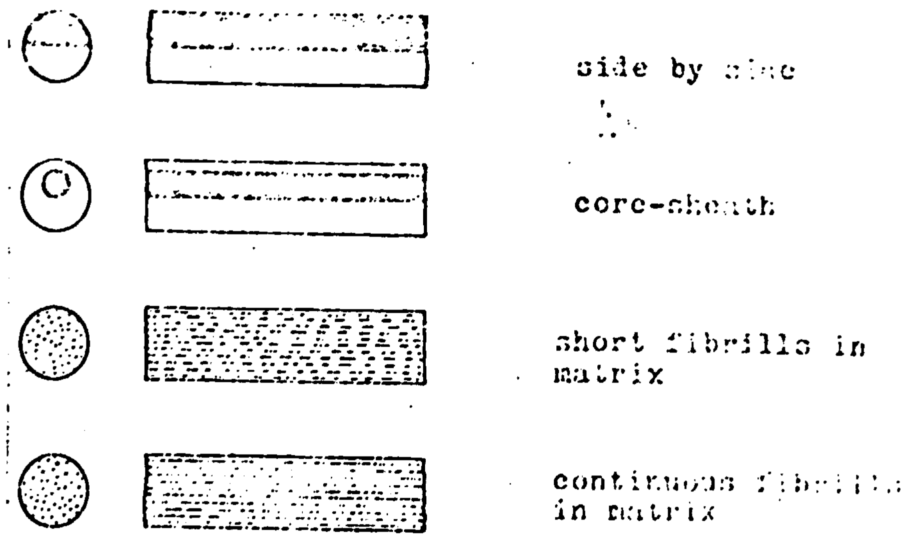


Figure 37. Bicomponent fibers

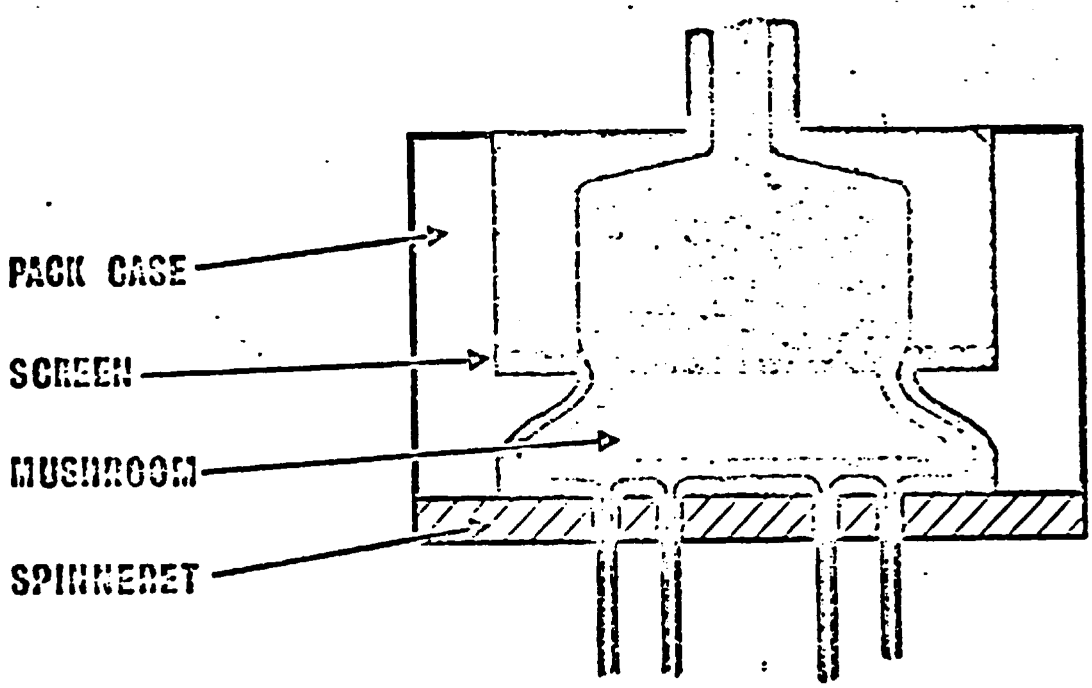


Figure 38. Spinning of a bicomponent fiber with sheath-core structure.

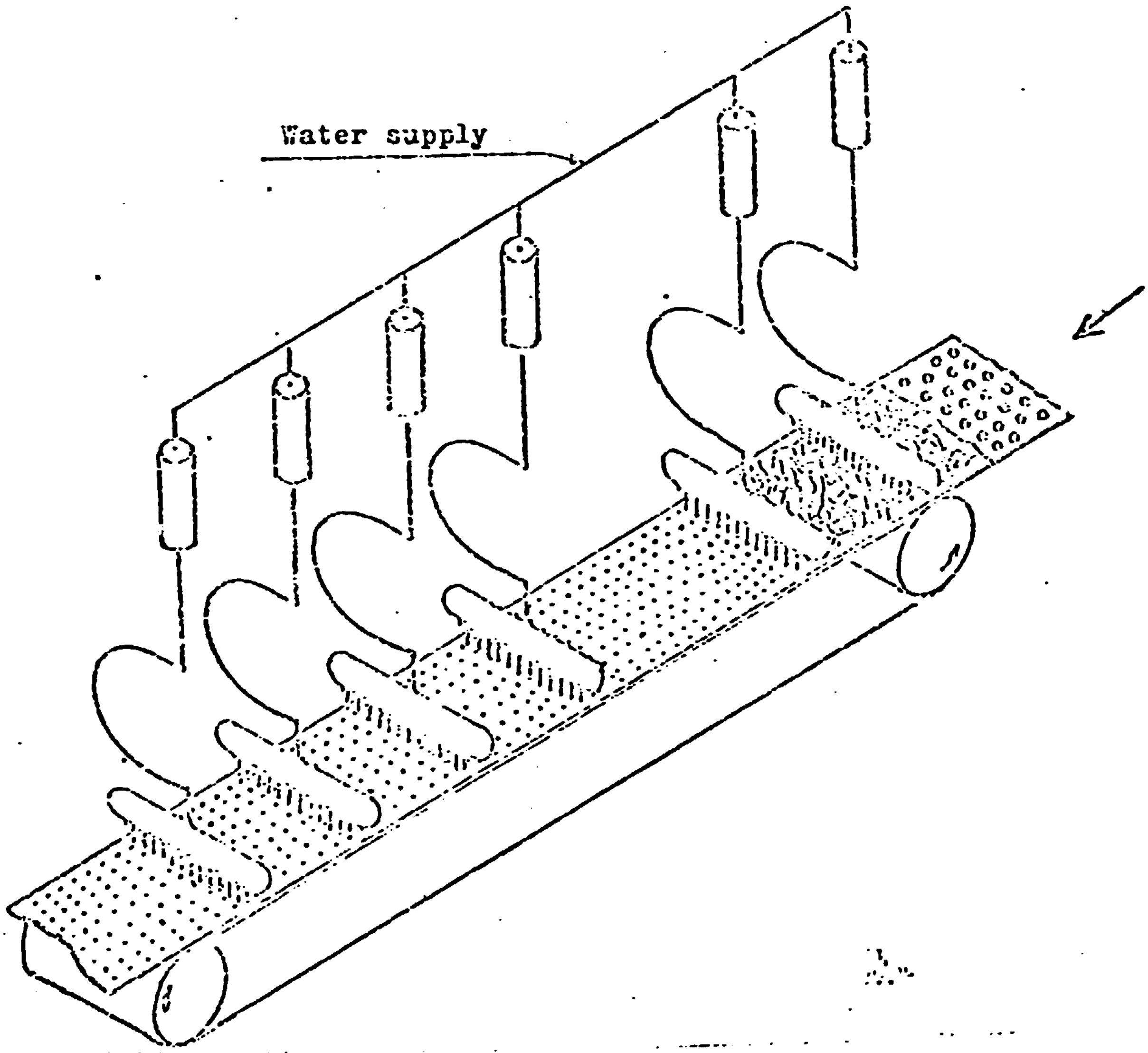


Figure 39. Spun laced process

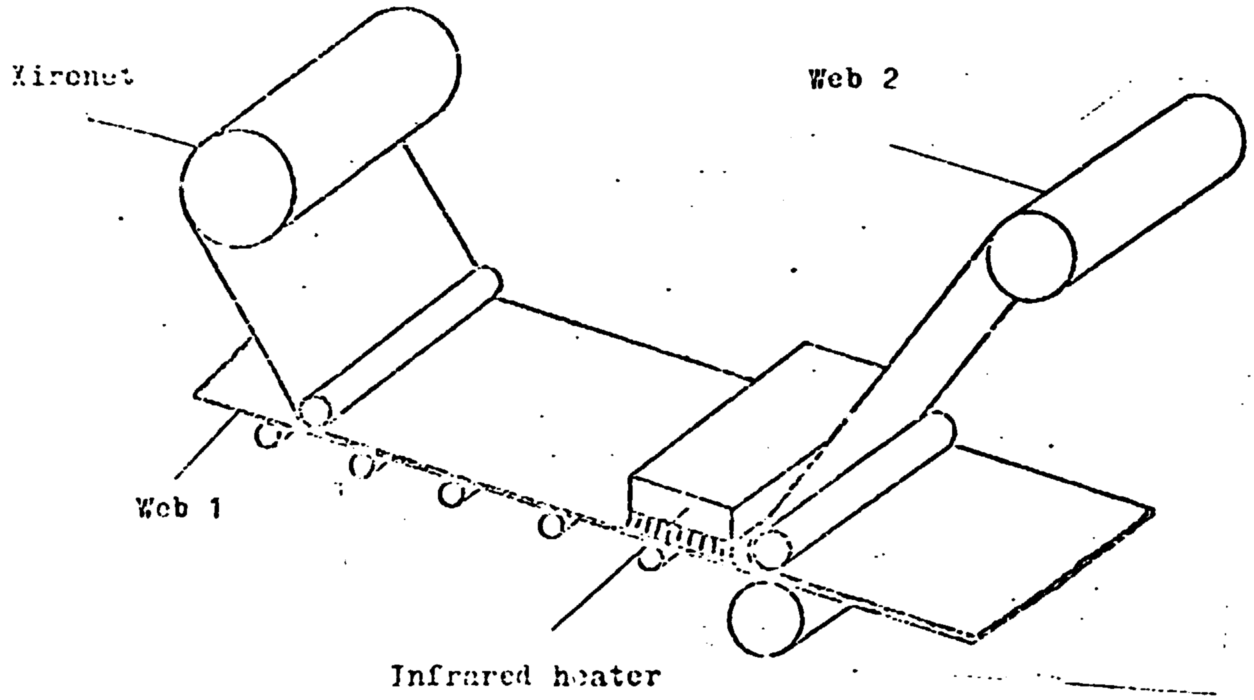


Figure 40. Xironet bonding

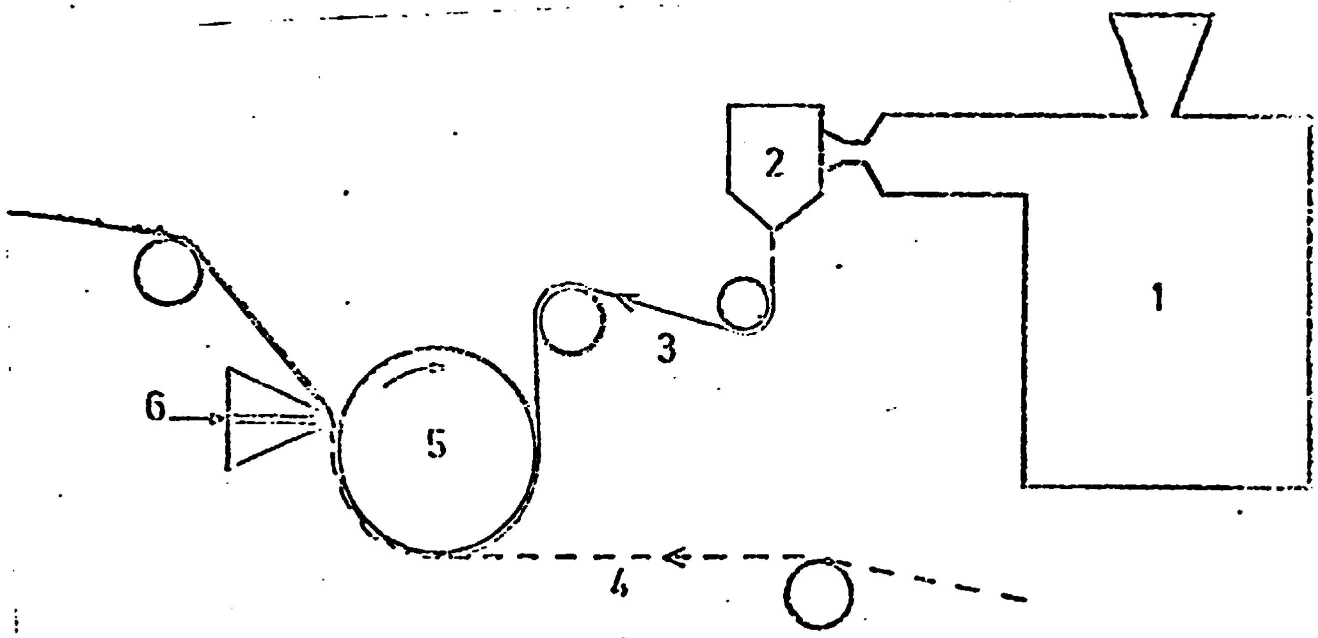


Figure 41. METZ-O-LAN process

1-extruder,2-slot,3- thermoplastic polymer film,4-carr...
5-melting roll,6-cooling air stream.

<u>[illegible]:</u>

A. Krcma, Manual of nonwovens
The Textile Trade Press, 1971 , Manchester, England

P. Lennox-Kerr, Nonwovens '71
The Textile Trade Press, 1971 , Manchester, England

Rationalisierungskuratorium der Deutschen Wirtschaft,
Vliesstoffe
Deutscher Fachverlag GmbH, 1971 , Frankfurt/M.

Rationalisierungskuratorium der Deutschen Wirtschaft;
Unterlagen zu den Vorträgen des 52.Weiterbildungsseminar 1974

<u>Recommended Journals:</u>

Allgemeiner Vliesstoffreport
Disposables&Nonwovens
Disposables International
Disposables Newsletters
Nonwoven Materials Newsletter
Nonwoven Report