

Melt Blown Dies: A Hot Innovation Spot

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Abstract

Melt blown (MB) technology requires precisely engineered and user-friendly equipment for successful new product development. Many significant efforts have been made to fully understand the technology and to improve the equipment by researchers and engineers around the world. The die assembly has always been the hot innovation spot in the history of melt blown technology developments. Among more than 210 U.S. patents related to melt blowing technology, approximately one-third of them are about hardware equipment and over 30 patents are on MB die assembly; the assembly consists of a polymer feed distribution system, a nose-piece and two adjustable air knives in many cases. Most of them are utility patents having the following three characteristics: novelty, utility and non-obviousness.

In this paper, I will discuss selected patents in the MB history chronologically and focus on their novelty.

Key words

melt blown, melt blown die, nonwoven, microfiber, thermoplastic, hot air, and die design.

Introduction

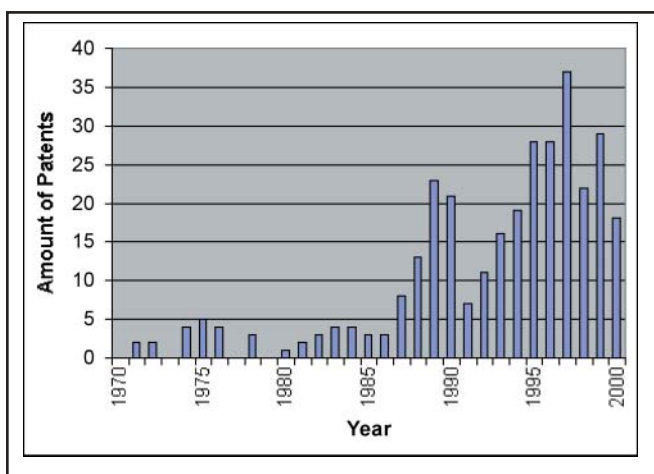
Melt blowing is one of the most popular processes to make super fine fibers on the micron or sub micron scale. It is a “one-step process in which high velocity fluid, normally air blows molten thermoplastic resin from an extruder die tip on a conveyor, or take-up screen, or substrate to form a fine fibered, self-bonded web” [1]. The concept of melt blowing thermoplastics was first introduced to the public in 1954 through a Naval Research Laboratory project initiated by Wentz [2]. Since then, the melt blowing process and a variety of melt blown products have been recognized, developed, and commercialized. Over 320 U.S. patents have been granted to the technologies and products related to melt blowing in the past 50 years. As shown in *Figure 1*, only 20 patents were

granted in the 70s; it increased to 64 patents in the 80s and jumped to 236 patents in the 90s. It is clear that the melt blown technology is finding its application in more and more fields, such as filtration, absorbency, hygiene and apparel.

Although there are many different designs of melt blown lines, the following basic components are quite common to almost all melt blowing process [2]

- A polymer feed system, generally a hopper fed screw extruder (two extruders for bicomponent MB system)
- A metering pump system to vary the polymer throughput rate (and/or ratio)
- A die assembly that consists of a polymer feed distribution system, such as a coat-hanger, to provide even polymer flow and residence time across the width of the MB die, a nose tip, and air manifolds.
- An air assembly to provide air streams with different temperatures and velocity.

Figure 1
THE PATENT PROFILE OF
MELT BLOWN TECHNOLOGY



- A collection device for collecting the attenuated filament streams thus forming a web with an almost random network of fibers, and

- A winding system to wind the formed MB web into a cylindrical package for easier subsequent handling.

These basic components of a melt blowing process are illustrated in *Figure 2*. McCulloch gave a brief history of melt blown technology development [3]. As noted, ExxonMobil, Accurate Products, Reifenhauer, Kimberly-Clark, Biax Fiberfilm and Nordson are among the biggest players in melt blown technology.

Melt blown technology requires precisely engineered and user-friendly equipment for successful new product development. Many significant efforts have been made to fully understand the technology and to improve the equipment by researchers and engineers around the world. The die assembly has always been the hot innovation spot in the history of melt blown technology developments. Among more than 210 U.S. Patents related to melt blowing technology, approximately one third are about hardware equipment and over 30 patents are on MB die assembly.

According to the definition, almost all of the above mentioned are utility patents. This type of patent is probably most familiar to the general public. It can be “any new, useful, and non-obvious process, machine, article of manufacture, composition of matter or any new, useful, and non-obvious improvement thereof” [4]. Novelty, utility and non-obviousness are the three basic characteristics of a utility patent. If a creation or innovation fails to show any one of them, it will lose its patentability.

Concept of Conventional Melt Blown Die

As mentioned above, a melt blown die is an assembly consisting of a polymer feed distribution system, a nosepiece and two adjustable air knives in many cases. There are basically two types of feed distribution systems that have been employed in MB die: T-type and coat hanger-type. Presently, the coat hanger-type distribution system is widely used because it provides both even polymer flow and even residence time across the full width of the die. The die nosepiece is a tapered hard metal piece with orifices or holes of high number density across the width. Its design and fabrication requires very close tolerances to produce high quality MB webs in terms of, but not limited to, fiber diameter and web uniformity. After extrusion from the die orifices, the polymer melt is attenuated to form the microfibers by the high velocity hot air streams from the air manifolds of the two sides of the nosepiece. The air manifolds normally can be adjusted to set desired air gaps and setbacks. Quite often, the nosepiece is referred to as the melt blown die. However, in this paper, melt blown die is used to describe the whole assembly. I will discuss the related patents in the history chronologically and focus on their novelty.

Innovations in MB Die

Drilled hole type MB die (1974)

Based on the formation of the orifices, a MB die is classified into two types: the drilled hole type and capillary type.

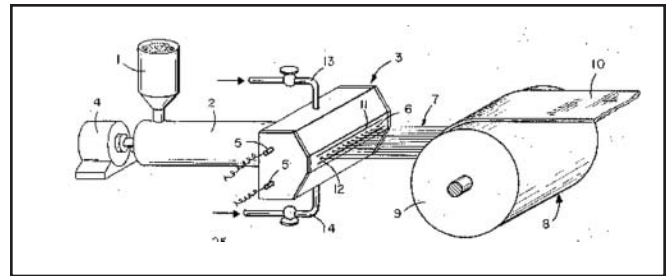


Figure 2
THE BASIC COMPONENTS OF A
MELT BLOWING PROCESS [6]

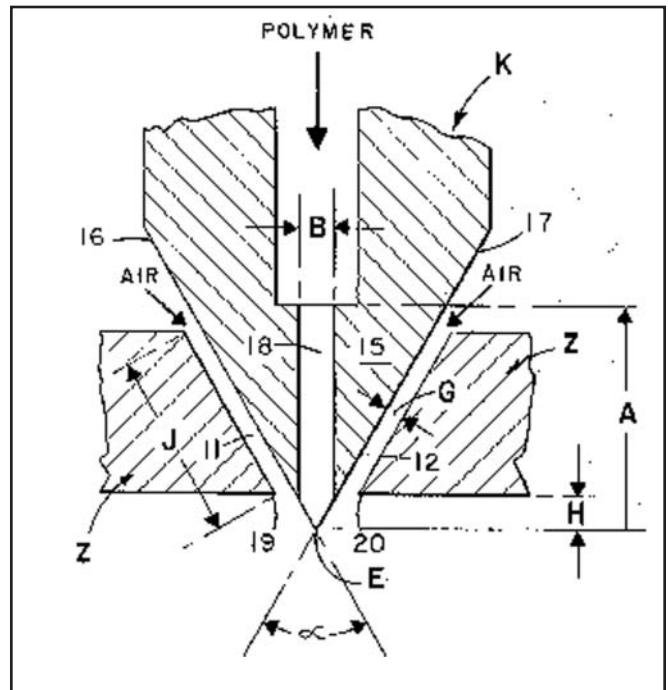


Figure 3
A DRAWING OF DRILLED HOLE TYPE
MELT BLOWN DIE [5]

On July 23, 1974, Exxon Research and Engineering Company was granted a patent on a drilled hole type MB die, as shown in *Figure 3* [5]. The cross-section of the die tip has a special triangular configuration with a plurality of orifices located in the edge-apex. These very small holes are drilled by mechanical drilling or electric discharge machining in a single block of hard metal, such as high quality steel. The precision in size, direction of the orifices and the distance between two adjacent orifices requires very close tolerances. Therefore, the fabrication of this type of die was very difficult and costly in the 1970s. Drilled hole type MB dies usually have a pair of air slots in each side of the nosepiece, which are connected to the air manifolds and can be adjusted to form different die settings.

In this patent, it claimed in detail that the die head comprises a die nosepiece and a pair of air slot adjustment devices. The shape and angles of the die nose piece, the cross

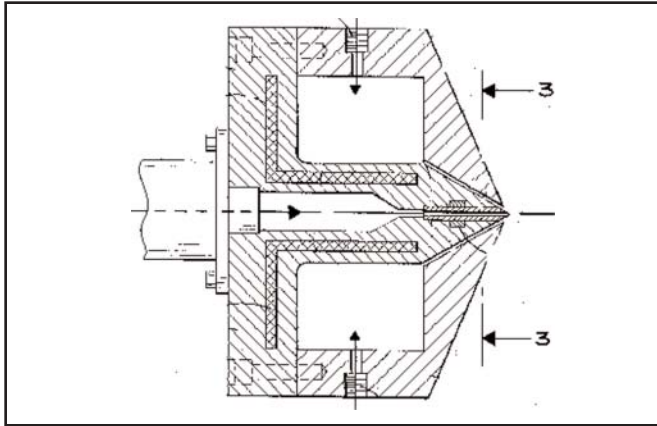


Figure 4
A DRAWING OF CAPILLARY TYPE
MELT BLOWN DIE [5]

section of the orifice, the connections of the channels, and the setting ranges of the setback and the air slot height were all specified. For example, it claimed the angle of the apex-edge is between 55° and 65°, and the height of the air slot is from 0.008 to 0.015 inch.

Capillary Type MB Die (1974)

On the same day (7/23/74), Exxon received another patent on a capillary type MB die [6]. As shown in *Figure 4*, the die is a two-piece assembly and the capillary tubes are included in the solder layer between the two pieces to form the die apparatus. In its 16 claims, included are the geometry of the die assembly, such as width of the die, angle of the die tip, and the sides of the capillary tubes, the alignment of the tubes and even the material of the capillary. It is noticed some of the claims are essentially the same as those in U.S. patent 3825380. Since they are about different types, these claims were still allowed by the examiner. Compared to the drilled hole type die, capillary type die has the advantages in achieving longer holes and more precise alignment of the orifice with great ease. Although melt channels have to be milled on the split halves, it can be done more easily as compared to drilling into a single piece assembly. Thus, the fabrication costs are greatly reduced. However, as the great advances in modern mechanical and electrical engineering, new and economic drilling technologies have made the fabrication of drilled hole type die much less costly. This may be one of the reasons that the drilled hole type die nosepiece is still widely used by some major manufacturers, such as Reifenhauer and Accurate Products Co.

Multi-row orifices in one die head (1980)

Productivity is a crucial factor for industry. After ensured product quality and safety, the highest productivity is always desired for a profitable product. For a melt blown die head, having a single row of small orifices, productivity may be improved by increasing the polymer throughput. However, the capability is very limited because the fiber diameter normally increases with throughput, which is a sacrifice of prod-

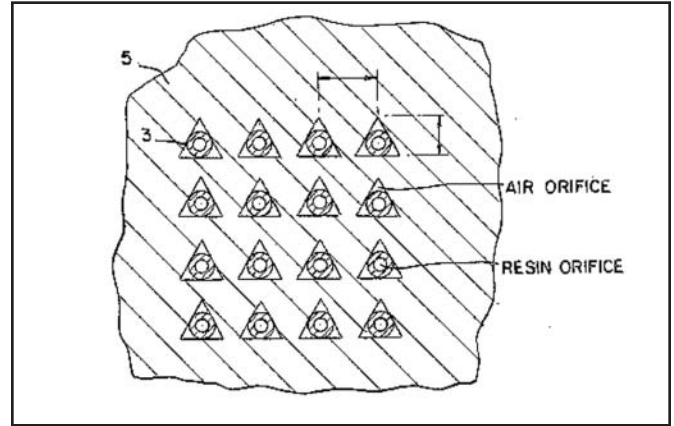


Figure 5
PART OF A MB DIE HEAD SHOWING RESIN
ORIFICES IN AIR NOZZLES [7]

uct quality for many applications, such as filtration. For a single row MB die head, the other way to increase productivity is combining more than one beam, parallel to one another, with a significant additional capital cost.

In 1980, Schwarz patented his discovery of melt blowing thermal plastic polymers [7], disclosing the apparatus and process to form fine fibers through orifices in nozzles.

According to this patent, fiber-forming polymer is heated up to low viscosity and accelerated quickly by nozzle blown air to near sonic velocity to produce fine fibers with little polymer degradation. This discovery broke the limitation of air from two sides of the tapered die tip. Therefore, a number of orifice rows can be arrayed in a single die head to achieve desirable productivity without a tremendous capital increase, as shown in *Figure 5*. Besides the innovation in the die head, the melt blowing process was also claimed in Schwarz's patent [7], including the temperature, polymer viscosity, molecular weight of MB fiber and the average fiber diameter. This is important considering the utility of the invention, because it may not function well under other processing conditions. The equipment of this technology is currently available in Biax-Filberfilm Corporation, which is showing great potential in nonwovens industry.

Innovation in Slot Die (1988)

It is well accepted that one of the important goals of the MB process is to produce super fine fibers; therefore, the diameter of the orifices must be small, normally around 0.3~0.5 mm. Filters are required between the extruder and the die orifices to remove the foreign particles, agglomerated particles, cross-linked polymers, slag, and carbon deposits. The small orifices in the die tip are still in danger of hole plug due to the formation of fine particles downstream of the filters.

The patent granted to Kimberly-Clark [8] disclosed a slot die for melt blowing to avoid the orifice geometry. The slot die has a single continuous slot opening running its length, instead of a number of individual orifices. In order to produce fiber instead of film, at least one of the inner sides of the slot has spaced grooves perpendicular to the apex line and one of

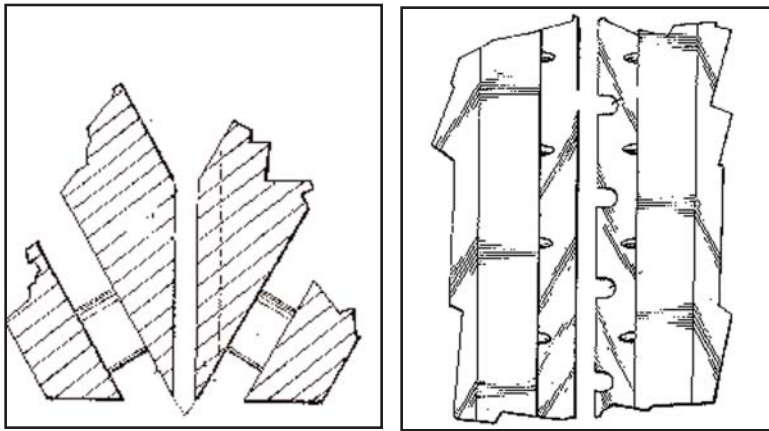


Figure 6
THE SLOTTED MB DIE HEAD WITH AT LEAST ONE SIDE HAVING SPACED GROOVES [8]

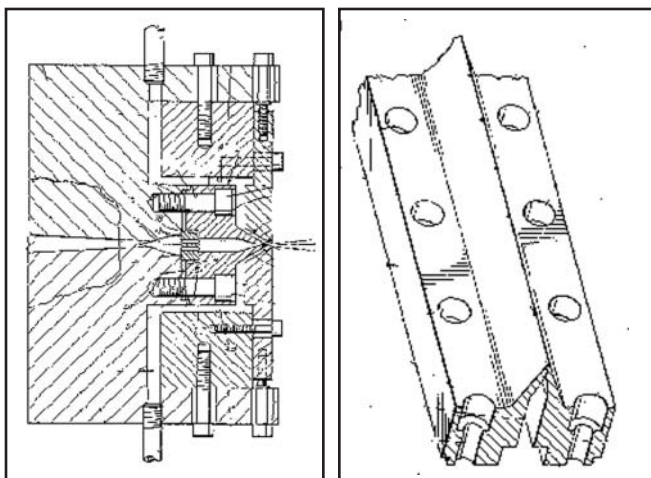
the sides extends below the other side to form a lip within the fluid stream, as shown in *Figure 6*.

This invention greatly minimizes the plugging problem, which saves production time and reduces the maintenance expenditures. It seems obvious that fabrication of a slot die like this requires much less capital cost.

Innovation in Die Nosepiece (1989)

As noticed, the earlier melt blowing die normally includes the die tip and the die body into the same piece of hard steel, although they are separately manufactured. This configuration has a strength weakness region at the triangular apex due to the high density of orifices. In 1989, Accurate Products Co. developed and patented a MB die where the die tip is mounted by bolting inwardly toward the orifices onto the die body [9]. Opposite and equal forces are applied on both sides of the orifice row to secure the die tip (*Figure 7*). The die tip in this invention is enforced by increasing its cross-sectional area to resist internal extrusion pressure. This invention also provides the advantage of easy die handling. Under a certain cir-

Figure 7
A DIE WITH AN ATTACHED NOSEPIECE [9]



cumstance, the orifices of the die need to be cleaned for removal of carbonized polymer residuals, which is very difficult to remove by regular purging. The mounted die tip can be then easily disassembled and cleaned by specialty techniques and equipment, such as high temperature ovens and ultrasonic cleaners. This type of die nosepiece is presently widely used in industry for the single row orifice die assembly.

Innovation of modular die (1997)

The width of a melt blown web is determined by the width of the die, which is normally fixed at the point of die design and/or manufacture. The invention of modular dies enables the users to vary the length of the die by merely adding modules or removing modules from the structure [10]. The modules are mounted in a side-by-side manner and

each includes an internal valve for controlling polymer flow. Each module consists of a body, a die tip assembly, and polymer and air flow passages for conducting hot melt and hot air from the manifold through each module.

One of the advantageous features of the modular die construction is its versatility. Based on the reference [10], the cost of modular die tip is approximately \$300/inch, which is relatively inexpensive comparing to \$1300/inch for regular single-row-orifice, single-metal long die tip. And the length of the die can economically be extended to lengths of 200 or more inches.

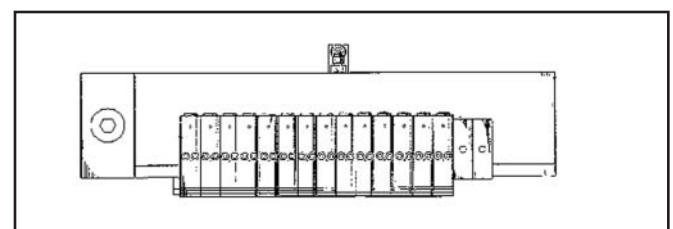
When damaged or plugged, instead of the whole die tip, only the related portions need to be repaired or replaced. Therefore, the modular die construction also offers the advantage of quick maintenance and reduced equipment and service costs.

Innovation of offset-hole MB die (2000)

Research has concluded that filament entanglement starts at approximately 1.5 inches from the die [11], in which the fine orifices are accurately machined to parallel one another with a typical tolerance of 0.0005 to 0.001 inches. The entanglement is a form of filament-to-filament interaction and becomes increasingly extensive as the filaments travel farther from the die. This interaction is responsible, at least partially, for the formation of "shot", an imperfection of MB web.

A patent has been recently granted to The University of

Figure 8
A MELT BLOWING MODULAR DIE ASSEMBLY [10]



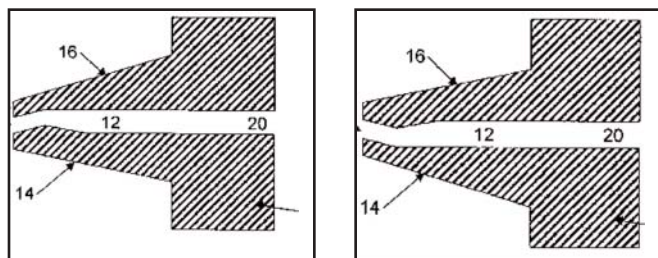


Figure 9

**MB DIE NOSEPIECE WITH ADJACENT HOLES
OFFSET TO EACH OTHER [12]**

Tennessee Research Corporation [12] for the innovation of a MB die nosepiece, which comprises a multiplicity of offset holes for hot melt extrusion. In each pair of adjacent holes, the first hole angled toward the upper face and a second hole angled toward the lower face, as shown in *Figure 9*. It is claimed that this nosepiece reduces the filament-to filament interaction, thus minimizing the “shot” formation.

Another advantageous feature of this innovation is the enhanced interaction between the extruded filaments and the air, thus improving filament attenuation.

Increasing air velocity is frequently used as a way to reduce fiber diameter, since the drag forces between the extruded filaments and the air are proportional to air velocity. There are two concerns associated with this method: acceptable limits and energy consumption. Because the operation window of hot air for MB process is not wide, increasing velocity is normally limited by the web quality, noise level, amount of fiber fly and the energy cost. This invention provides the possibility to produce finer fiber without increasing the air velocity to an expensive, high level.

Summary and conclusions

As indicated in the above examples, each patent has one or more clear objectives. That is where utility of an innovation goes. Behind the innovation, it normally involves the inventor’s extensive research, broad experience and knowledge accumulation. Most importantly, new ideas generate creatively, based on understanding, absorption and distillation of the prior arts. This is almost always true in utility innovations.

Melt blown technology is one of the most active fields in both academic and industrial sectors. It is expected that related innovations in process, equipment, instruments and manufactured articles would merge continuously. The current melt blown die tips are far from perfect, and improvement will remain the hot spot in innovation, as melt blowing processes continue to be elucidated.

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