**THE NEW GENERATION FIBERS: REVIEW OF HIGH PERFORMANCE AND SPECIALTY FIBERS**

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**Abstract:** The current situation of the textile fibres has been on a great deal for scientific applications and environmental concerned. Transformations have been taken place due to the need of improved properties in the new age group end requests. Textile fibres polymers will bring about a revolution as they have started replacing the metals and will make the Bright future due to the various Research & Development activities of the world. The main trust has been in nano- technologies applied to textiles and clothing to improve the properties and performance of existing materials. Overall, this review has covered the most prominent fibers in next generation especially biodegradable fibers, high performance application fibers and the nano fibers and its impact on the next generation fibers.

**Key Words:** Biodegradable Fibers, High performance, Nano Fibers, Specialty Fibers

# Introduction

Fiber knowledge and expertise has developed extremely over the last few decades, and the production of fibers, especially regenerated fibers has increased at a remarkable rate. By the end of 21st century, a lot of different specialty fibers and materials were produced worldwide; in the industrialized world fibrous materials are used at a high rate per year. Fibers have no equivalent in other materials in terms of weight, ease of fabrication, efficient utilization, and economics.

Following that the needs for ideas in fiber science and knowledge have increased speedily. To this end research about fiber science technology, logical understanding and up-to-date manufacturing techniques along with well-organized specialty fibers have been required, covering the all-inclusive field of fiber science, manufacturing, technology, and the profit-making aspect of the field. This aspiration has been achieved in different scholars and researcher through which different innovative fibers have been invented to this time; even future forecasts have been made in laboratory and industrial levels, but more on the Nano-scale high performance fibers [[1](#_ENREF_1), [2](#_ENREF_2)]. It has been extremely useful for studying fiber science within chemistry, chemical engineering, and material science, in different fiber perspective. In recent years our generation, fibers have been becoming the center of scientific and technological inventions, resulting from so many factors including better understanding of the science of fibers and availability of new and refined materials[[3](#_ENREF_3)], synthetic techniques, and analytical tools of a fundamental nature.

* 1. **Historical developments in fiber science and technology**

The development of fiber science and technology has become more prominent factor in all aspects of fiber formation, nature of fiber and end-user applications [[4](#_ENREF_4)]. The means of fiber development of natural, regenerated, man-made, high-modulus/high-tenacity, inorganic, high-quality and smart fibers have become the special attention of the world so that reflect a great impact on way of life[[5](#_ENREF_5)]. Historically, advancements have been customized in terms of development of ideas of fiber structure, polymer assembly, Means of investigating fiber structure, especially crystal structures in high performance fibers [[6](#_ENREF_6), [7](#_ENREF_7)] macromolecular hypothesis, fundamentals of polymer crystallization, relations between fiber structure and performance [[8](#_ENREF_8)].

These advancements have lead to the development of different smart fibers with smart application especially high interests towards

 Natural fibers with genetic evolution, breeding, reinforcements, genetic control of protein structures lead to intricate specificity in fiber shape constructions [[9](#_ENREF_9), [10](#_ENREF_10)].

 Regenerated fibers made to redevelop fibers from discarded cotton or forest pulp comprising chemical alteration of cellulose like Cellulose nitrate (nitrocellulose) extruded through fine holes (spinnerets) in Chardonnet process(*dry spinning*), *wet spinning and* development of melt spinning, Man-made polymer fibers including production of polyhexamethylene adipamide, nylon 66, nylon 6 and *polyester* produced in a sequence of steps *of* polymerization and assembly of polymer chip charted via spinning and solidification,

 High-modulus, high-tenacity (HM-HT) fibers[[11](#_ENREF_11)] have linear polymers with a degree of crystallinity no more than 50%, mean orientation angles no more than 20°, liquid-crystals in solutions of linear polymers with stiff molecules and almost perfect crystallinity, perfect orientation, fully extended chain molecules, like para-aramid *Kevlar, a*llow super-drawing, ultra-high molecular weight, and highest strength,

 Inorganic fibers used as a decorative material, insulation, fibre- reinforced composites. These fibers have been made by melt extrusion, cooling and wind-up operations to create un-oriented, and amorphous network structures.

 In the late twentieth-century; Carbon fibers were developed as high performance fibers for composites utilized as partially carbonized fiber with good thermal resistance and oriented structure of imperfect graphitic crystals.

 Ceramic fibers utilized f for high-temperature composites based on silicon carbide. They have been produced by melt-spinning of organo-silicon polymers or solution-spinning from a viscous liquid containing aluminum salts, micro-crystalline ceramic fibers and rigid materials

 Specialist and smart fibers having high chemical and thermal resistance for particular applications and/or properties good for medical applications for wound-healing or tissue engineering [[11](#_ENREF_11), [12](#_ENREF_12)], specific electrical or magnetic properties, hollow fibers, fibers with active constituents, can change color, act mechanically or electromechanically, generate latent heat, perform as sensors, or other actions for Wearable electronics and other forms of applications.

Recently special attention has given for specific application fibers like Biodegradable [[12](#_ENREF_12)]fibers and High performance fibers in the Nano-scale technology fibers. This review has mainly focused on the next generation fibers mainly in the Nano-based fibers [[13](#_ENREF_13)]with eco-friendly oriented techniques more emphasized on biodegradability[[14](#_ENREF_14)].

* 1. **The role of Nano-science and nanotechnology in the new generation fibers**

Nano fibers have been defined as fibers having a diameter less than 1000nm in textile applications with large surface area. So that Nano science plays a great role by reducing the size of particles which occupy more space, depend on on the properties of constituent materials at a very small scale sizes involving lots of complex concepts difficult to define and understand. Nano fibers have unique properties of size and surface area. Their very smaller size gives them; unique physical and chemical properties [[15](#_ENREF_15)] make the fibers to be utilized in very small places. More over their giant surface areas gives them lots of surface to work with, very suitable for new technologies requiring smaller and smaller environments for chemical reactions and speeds up of the chemical reaction. These fibers have been produced by Melting process, Interfacial polymerization and Electro-spinning techniques. The Nano fiber technology has four generations of time lines [[15](#_ENREF_15)].

* The 1st generation (~2000)Nano fibers were fibers of the form passive Nano structures with dispersed and contact Nano structures(like aerosols and colloids), products incorporating Nano structures(like coatings and nao particles), reinforced composites and Nano structure metals(polymers and ceramics).
* 2nd generation (~2500) nano fibers were fibers called active nano stracures of bio-actives focused on health effects like drugs and bio-devices, and physico-chemical actives like transistors, actuators, amplifiers, and adaptive structure fibers
* 3rd generation 2010 ) system of Nano-systems; including guided assembling, 3D networking and new categorized structural designs and evolutionary robotics systems
* 4th generation ((~2015 − 2020) molecular Nano-systems including molecular strategies of design, atomic design and emerging functions.

There are different features and Structures of Nano fiber Particles which impart particular properties for the fiber and can be grouped in to three systems of whiskers, net and wrap structures [[15](#_ENREF_15), [16](#_ENREF_16)]

In general the new generation of textile fibers most probably focused on High performance fibers and Biodegradable fibres. Biodegradable fibres include Lyocell fibres, Sea cell, Smartcel, Poly lactic acid (PLA), Bacterial cellulose, Bacterial polyester, Biosteel Soya protein fibre (SPF). High performance fibers like Dyneema Hygra and Goretex [[17](#_ENREF_17)].

The Biodegradable fibers [[18](#_ENREF_18)] are Cry of the time, improved properties with Research and development across the globe.

1. **The Next new generation fibers**
   1. **Biodegradable fibers**
      1. **LYOCELL (1st Manmade Biodegradable Fiber)**

It utilizes renewable resources as raw materials with High physical performance that makes it a universally applicable fibre even ideal for nonwovens and comfortable next to the skin. In most cases it can be manufactured through solution spinning methods with Principally Oak & eucalyptus trees from sustainably managed forests as a raw material. It has been used for all kinds of Fabrics, Non-woven, Technical textiles, Battery separators, Membranes and Paper [[19](#_ENREF_19)].

* + 1. **Sea cell Fibers**

They are produced from Seaweed available in abundant with lot of good properties it has been found lyocell-like cellulosic fiber with antimycotic and antibacterial properties, extracted from Seaweed combined with silver ions incorporated together in a modified lyo cell process[[20](#_ENREF_20)]. Its application has been restricted to improvements of blood supply in skin, activate metabolism, Sportswear, undergarments, socks, work clothes and household fabrics allergy sufferers and hygiene articles. It has been also utilized for anti-inflammatory and for the production of anti-microbial fabrics[[21](#_ENREF_21), [22](#_ENREF_22)].

* + 1. **Smart cell fiber**

Smart cell fiberis a Phase Change Material (PCM) micro composite of the latest manufacturing generation with thermo regulating features by which the temperature regulation is assured[[23](#_ENREF_23)]. It has been provided with extraordinary wearing comfort and excellent climate management[[24](#_ENREF_24)]. It has been manufactured from renewable sources[[25](#_ENREF_25)]. The combination of cellulose with zinc by lyocell process had made 100% biodegradable, mainly applied for Sportswear, Bed textiles, protection against heat or cold in a human body and Anti-inflammatory apparels [[26](#_ENREF_26)].

* + 1. **Poly lactic acid (PLA)**

Poly lactic acid (PLA) has been found linear aliphatic thermoplastic polyester derived from 100% renewable sources of corn, sugarcane[[27](#_ENREF_27), [28](#_ENREF_28)]. It has been manufactured as 100% compostable polymer and potentially reducing the Earth’s carbon dioxide level and highly sustainable than comparable polymers on the market today[[29](#_ENREF_29), [30](#_ENREF_30)]. It has been manufactured by direct condensation of lactic acid by means of the cyclic intermediate dimer (lactide), in a ring opening process and spun by melt spinning process [[30](#_ENREF_30)]. It has been utilized for apparels, home ware, nonwovens, filtration and separation, hygiene, industrial/household wipes, medical applications and as a plastic material[[31](#_ENREF_31)].

* + 1. **Bacterial cellulose**

**Bacterial cellulose** has been an organic compound produced from the genera Aceto-bacter, Sarcinaventriculi and agro bacterium[[32](#_ENREF_32)]. Bacterial microbial cellulose has been tailored to have specific desirable properties of versatile structures, allowing it to be shaped in a variety of ways to satisfy different uses[[33](#_ENREF_33)]. It has been produced from Cellulose found in many microorganisms like fungi, bacteria, and algae through Reactor based production or Fermentation production[[33](#_ENREF_33)]. The products are used for ultra-strength paper, filter membrane in hi- fidelity, loudspeakers and headphones, cosmetic industry, wound dressing, especially in burn cases, treat wounds from venous ulcers, internal treatments, such as bone grafts and other tissue engineering [[34](#_ENREF_34), [35](#_ENREF_35)].

* + 1. **Bacterial Polyesters**

Bacterial polyesters have been found fromlinear polyesters produced in nature by bacterial fermentation of sugar or lipids called Polyhydroxyalkanoates[[36](#_ENREF_36)]. These polymers have been produced by the bacteria to store carbon and energy. Polyesters were deposited in the form of highly refractive granules in the cells[[36](#_ENREF_36), [37](#_ENREF_37)]. They have been produced by a culture of a micro-organisms of Alcaligenes, eutrophus placed in a suitable medium having appropriate nutrients so that Polyester produced by microorganisms as raw material [[36-38](#_ENREF_36)].

The products have been used for sutures and suture fasteners, tacks, rivets, staples, and screws, bone plates and bone plating systems, surgical mesh, repair patches, and cardiovascular patches, bone graft substitutes, and wound dressings s, vein valves, bone marrow scaffolds skin substitutes[[39-41](#_ENREF_39)].

* + 1. **BIOSTEEL (manmade spider silk)**

BIOSTEEL (manmade spider silk) has been founda high-strength based fiber material made from the recombinant spider silk-like protein extracted from the milk of transgenic goats[[42](#_ENREF_42)]. The fiber has 7-10 times as strong as steel condition compared for the same weight, and can stretch up to 20 times its unaltered size without losing its strength properties. It has known by the novel fibre of the 21st Century produced with pronuclear microinjection and nuclear transfer technology in the goat’s system[[43](#_ENREF_43)]. The milk produced by the transgenic goats contains spider silk proteins applicable for bulletproof vests, artificial ligaments, improved car airbags and more reliable parachutes. It has been viewed as a resource of future biotechnologies[[43](#_ENREF_43), [44](#_ENREF_44)]. Further the fiber has been considered as one of the new generation Fibres[[45](#_ENREF_45)].

* + 1. **Soya Bean Protein Fiber**

Soya bean protein fiber has beena rapidly developing area with research being undertaken in several countries[[46](#_ENREF_46), [47](#_ENREF_47)]. Primarily America and China have being producing the fiber in biochemistry utilized in the production process to modify the structure of soya bean protein fiber[[48](#_ENREF_48)]. On the other hand, the strength of the fiber has been added by incorporating polyvinyl alcohol PVA that has the benefits of higher strength and modulus[[49](#_ENREF_49)]. The fiber has been wet spun and the protein was extracted from the soya meal from which oil has already been extracted[[50](#_ENREF_50)]. The fiber has been utilized for apparels, domestic textiles, winter wear and undergarments[[51](#_ENREF_51)].

* 1. **High Performance Fibers**

These fiber have been utilized for super end applications owing to the limitations of nature, demand of the time and improved properties[[52](#_ENREF_52), [53](#_ENREF_53)]. These fibers have been classified in to three major classes[[54](#_ENREF_54)].

* + 1. **DYNEEMA (UHMW-PE)**

This fiber has been found as one of the most high fiber having extremely long chains, high molecular mass usually between 2 and 6 million units by which UHMWPE has been synthesized from monomer of ethylene and spun in the gel spinning process[[55](#_ENREF_55)]. The process was used for the production of yarns required for special applications in bulletproof vest, personal armour, car armour, cut-resistant gloves, climbing equipment, suspension lines on sport parachutes and para gliders[[56](#_ENREF_56)]. Dyneema has been used for the 30-kilometre space tether and Engineers' Satellite technology[[57](#_ENREF_57)].

* + 1. **HYGRA (porous water absorptive polyester fiber)**

HYGRA has been found the other form of HP fiber. Inrecent years, **a** highly moisture absorptive & highly moisture releasing nylon has been developed, used for cloths[[58](#_ENREF_58)]. But it lack moisture absorbency caused stuffiness, stickiness & was Uncomfortable so that now it has been possible to manufacture a fiber from a highly water absorptive polymer having absorbency capacity up to 35 times the polymer weight, & developed an epoch-making fiber HYGRA[[59](#_ENREF_59)]. The Fiber has been produced by the skin-core structure[[60](#_ENREF_60)] consists of nylon skin part & hydrophilic core part through the melt spinning process for different applications of clothes (sportswear, socks, undergarments)[[61](#_ENREF_61)] and non-clothes (life materials, civil engineering, construction technology, interiors, industrial materials)[[62](#_ENREF_62)].

* + 1. **GORETEX (expanded-POLY TETRA FLUORO ETHYLENE)**

These fibers are fibrousmaterials typically based on thermo-mechanically expanded PTFE and other fluoro-polymer products[[63](#_ENREF_63)]. This membrane has about 9 billion pores per square inch (around 1.4 billion pores per square centimeter), each pore is approximately1/20,000 the size of a water droplet, making it impenetrable to liquid water[[64](#_ENREF_64)]. The membrane has a self-cleaning effect as the dirt molecules also can penetrate or enter the pores due to their extremely small Size. It has been prepared by using an emulsion polymerization process that utilizes the cover surfactant pfoa, mainly used for conservation of illuminated manuscripts, water repellent, used internally in medical applications like sutures, vascular grafts, heart patches, and synthetic knee ligaments[[64](#_ENREF_64), [65](#_ENREF_65)].

* 1. **Nano-fibers**

These fibers are manufactured through Nano technology by which atoms, molecules and Nano sized materials have been thereby manipulated in a systematic, precise and controlled manner to produce novel materials with innovative and different properties to those obtained by conventional material engineering at the micro-scale[[66](#_ENREF_66), [67](#_ENREF_67)].

Nano-technology has been termed a “bottom up” technology because of the use of such small scale building units in contrast to Conventional materials engineering at the macro-scale considered as a “top-down” approach. The use of nano-science and nano-technology to control the internal structure of a material at nano-scale is considered to lead to materials with fewer defects and hence of a higher quality[[68](#_ENREF_68)].

* + 1. **Application of Nano -technologies in the new generation fibers**

The application of Nano materials in fibers has been in three approaches

The 1st one has been for nano-materials that are nano-scale in one dimension, application of very thin surface coating (2nm-100nm) to textile materials whereas the 2nd approach has been for nano-fibers and nanotubes essentially nano-scale in two dimensions and their utilization in many forms of composite materials offers opportunities for improving the mechanical properties, altering electrical, optical or biological characteristics[[69](#_ENREF_69)]. The last approach would be involved in the use of Nano-particles (Nano-scale in three dimensions) for incorporation in fibers, coating, films to provide a myriad of possibilities such as imparting antimicrobial, flame retardant and chemical softening effects to textiles and clothing[[70](#_ENREF_70)].

Nano fibersare defined as fibers with diameters less than 100 nanometers. In the textile industry, this definition has been often extended to include fibers as large as 1000 nm diameter. Nano fibers range in diameter of 2-600 nanometers and are very difficult to see with the naked eye so they are studied using magnification and many researches have been done on spider dragline silks. The strength of a spider dragline is much stronger than a steel fiber of equivalent size[[71](#_ENREF_71)].

* + 1. **Advance application areas of Nano- based fibers**

Various applications of nanofibers have been found with their encouraging recent research in healthcare for regenerative medicine, wound treatment, drug delivery systems. They are also utilized for environmental engineering applications in Water filtration, dust filtration, face mask manufacturing sectors. Nano fibers have been also utilized for the production of functional goods like functional clothes, functional food, and electronic materials like battery materials, high conductivity materials, and transparent conductive films. In general the applications of nano based fibers has been summarized in **Figure 2** 1.

1. **Advanced production systems of the new generation fibers**

Most prominent manufacturing techniques have been revolved in advanced polymerization techniques[[72](#_ENREF_72)] like interfacial polymerization[[73](#_ENREF_73)] followed by melt processing[[74](#_ENREF_74)], electro spinning[[75](#_ENREF_75)], anti-solvent induced polymer precipitation and electrostatic spinning[[76](#_ENREF_76)] or catalytic synthesis as in the case of carbon nano-fibers production systems.

* 1. **Melt Processing**

The melt processing has been involved “Melting” Fibers: Nano fibers can be made by melting polymers and spinning or shooting them through very small holes. As the fiber spins out it stretches smaller and smaller.

* 1. **Electro-spinning Nano-fibers**

Nano-fibers produced from synthetic fiber materials can be formed with a high surface area to volume ratio and small pores sizes in fabric form. The potential end uses for such nanowires are in filtration, wound dressings, tissue engineering, Nano composites, drug delivery devices and sensors.

Nano-composite fibers consist of Nano fibers containing particles with one dimension in the Nano- meter range. The particles may be spheres, fibrils and by varying the amounts, their alignment, and distribution within the Nano fiber improvements in the mechanical, electrical, optical or biological properties may be obtained whereas the carbon Nano-tubes essentially consist of tiny shells of graphite rolled up into cylinders, either as single tubes or multiple tubes joined together [[16](#_bookmark44)]. In Electro spinning process, a polymer solution is injected at a constant feed rate though a nozzle or needle which is charged to a high voltage (10kv to 30kv). The applied voltage is sufficiently high, the surface of the fluid elongates and a Taylor cone is established. On increasing the applied voltage further, a charged liquid jet is ejected from the Taylor cone and attracted to the earthed collector, which is positioned at a fixed distance from the needle. During this process the solvent evaporates from the polymer solution, leaving dry polymer fibers on the collector as shown in Figure 2.

Effect of process parameters on fiber diameter

1. Nano fiber properties depend on distance between needle and collector

2. At present the production rate of this process is measured in grams per hour

Different fibers have been used for this purpose of spinning including like Polyglycolic acid (PGA) Polylactic acid (PLA), PGA – PLA, Polydioxanone (PDO), Polycaprolactone (PCL), PGA – PDO, PLA – PCL and PDO – PCL

More than 30 polymers, including polyethylene oxide, DNA, polyaramids, and polyaniline, have been electro spun. These fibers can be made of variety organic (nylon, polyester, acryl) or biological polymers (proteins, collagens).

* 1. **Carbon nanotubes**

Carbon Nano tubes are allotropes of carbon with a cylindrical nanostructure with length-to- diameter ratio of upto132, 000,000:1; highest strength to weight ratio, helps in creating light weight space crafts, easily penetrates membranes such as cell walls, Electrical resistance changes significantly when other molecules attach themselves to the carbon atoms and in developing sensors that can detect chemical vapors in cancer treatment. In recent years, commercial applications of CNT in making bicycle component, manufacturing of light weight boats, replacing transistors from the silicon chips as they are small and emits less heat, electric cables and wires, solar cells and fabrics[[77](#_ENREF_77)].

The carbon Nano-tubes exhibit remarkable properties of a tensile strength some one hundred times that of steel at one sixth of the weight, A thermal conductivity superior to all but the purest diamond; Electrical conductivity similar to copper but with an ability to carry much higher electrical currents[[78](#_ENREF_78)].

On the other hand Nano-coating the surfaces of textiles, clothing and textiles is one approach to the production of highly effective anti-microbial treatments for killing the bacteria that can lead to malodor formation. The Nano-coating is held on the fiber surface by strong electrostatic and hydrogen bonds and punctures the bacterial wall, killing bacteria that can accumulate in textiles and clothing through the retention of human respiration exuded through physical activity and wear. Nano-coating of textile fabrics, complete finished garments or can be obtained by plasma polymer treatment. Plasma is the fourth state of matter (after solid, liquids and gases) which was proposed by Sir William Croakers, as a result of experiments in the passage of electricity through gases[[79](#_ENREF_79)]. Additionally plasma generated by electrical discharge through gas consists of a mixture of positive and negative ions, electrons, free radicals, ultraviolet radiation, and many different electronically excited molecules[[80](#_ENREF_80)]. By vary the conditions of the plasma treatment and the nature of the specific gas presents, a variety of surface treatments can be produced that change the chemical or physical nature of the fibre surface, thereby radically altering all treatments that depend upon fibre adhesion like for example coating, lamination and bonding.

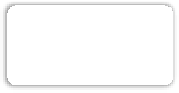
It has been possible detection of virus and improved the immune system by finding and disabling unwanted bacteria and viruses.

1. **Conclusion**

The present scenario of the textile fibers has been on a great deal for specific applications and environmental to the atmosphere. Changes have been taken place due to the need of improved properties in the new generation end applications. Exponential growth of the textile industry, which has been primarily, runs on textile fibers polymers will bringing about a revolution as they have started replacing the metals will make the Bright future due to the various Research & Development activities worldwide. The main trust in Nano-technologies applied to textiles, clothing and will be to: Improve the properties and performance of existing materials; Develop smart and intelligent textiles with novel functions; greatly increase the use of fibers in technical textiles, biomedical and healthcare options; and Open up new opportunities for fibers as sensors. Overall, Nano-technologies offer great potential for the future and could radically change consumer perception of what constitutes a “standard” apparel fabric.

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Sport apparel,

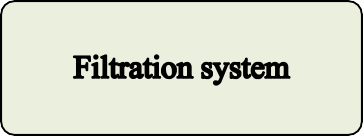
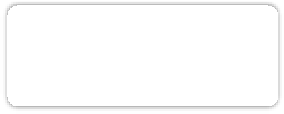
Sport shoes,

Climbing,

Rainwear,

Outerwear garments,

Baby diapers



(Heating, Ventilation, and Air-Conditioning)



HVAC system filter

ULPA filters (Ultra Low Penetration Air)

HEPA (high- efficiency particulate arresting)

Air, oil, fuel filters for automotive,

Filters for beverage, pharmacy, medical applications,

Filter media for new air and liquid filtration

Applications, such as vacuum cleaners.

Figure 1: Advance application areas of Nano- based fibers

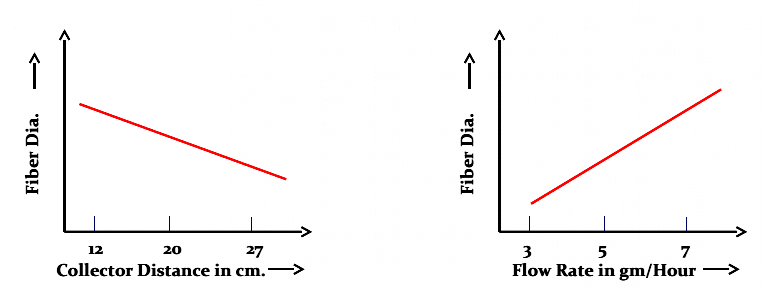


Figure 2: Effect of process parameters on fiber diameter